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Soil Surveys and Their Application in Tropical Agriculture

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In a recent paper on soil surveys Kellogg (1962) stated ' I am persuaded that the failure of the British Groundnut Scheme in East Africa did more to get soil surveys accelerated in that continent than anything else'. Undoubtedly there is now a greater appreciation of the value of soil surveys for developing countries and the provision of aerial photographs and improved maps has made surveying quicker and more accurate. On the other hand greatly increased funds from national and international agencies and the fact that soil surveys have become fashionable have led to a much greater interest in this type of work. Soil surveys have the added attraction to aid-giving agencies of having a beginning and an end and the end—the brightly coloured soil maps—can be exhibited as a measure of achievement.

In many territories the impetus for soil surveys has arisen from the necessity to introduce new crops, to expand established ones or to define areas for new settlements. Quite frequently, areas for detailed soil mapping have been chosen by administrators or politicians and the soil surveyor has then been expected to find suitable soils within the boundaries defined by them. This has been termed 'turning soil scientists into pedological procurers' by Charter (1957). In recent years this situation has been improving as a result of the greatly increased tempo of soil surveys. This has relieved the soil surveyors from pressure for ad hoc surveys and has allowed them to spend more time on reconnaissance surveys. Thus the roles are being reversed and the position is being reached where the surveyor can outline areas of potential agricultural value for the administrator.

In view of the fact that soil surveys are covering increasing areas of tropical countries and that the demand for surveys continues to increase there is need for a critical appraisal of their role in improving tropical agriculture. In this paper attention is drawn to some aspects of soil surveys and their use which need further investigation in order that such surveys may realize their full potential in contributing to the improvement of tropical agriculture.

OBJECTIVES OF SOIL SURVEYS

When funds were severely restricted most soil surveys were undertaken for limited objectives such as those outlined above. Now that there is generally more money available there is a greater tendency for work to be undertaken for ill-defined objectives or to fulfil the purpose, often vaguely expressed, of making an inventory of the country's resources. There is, of course, no objection to making such an inventory since soil maps have many applications outside agriculture. Nevertheless some of the considerable sums of money being spent on soil surveys could be spent better on other aspects of soil research as, for example, in follow-up agronomic work. Often it would be of immense value, both to the donors and the recipients of soil survey funds, if both parties were to spend some time considering just how a soil survey could advance the development of agriculture in the particular country over say the next 20 years. As science is continuously adding to our knowledge of soils, particularly tropical soils, there can be no 'complete' or 'final' soil map. Thus whilst a soil survey must aim at bringing forth all the basic information possible about the soils in the area, it should also be oriented towards well-defined objectives. If the objectives are clearly defined then it is possible to make a logical decision on whether 'reconnaissance' or 'detailed' soil mapping will be the more appropriate.

Most tropical countries have a genuine need for a reconnaissance soil survey, on at least a broad scale, over the whole country. Such a survey is invaluable in an area where there is little agricultural development for it enables the experienced soil surveyor to delineate those areas, which are the most promising or the most

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easily developed, for the range of crops to which the environment is suited. A reconnaissance soil survey is also very valuable for providing a framework into which subsequent detail can be fitted. On the other hand a reconnaissance soil survey is really of little value as a basis for improving agriculture in a long-settled agricultural area since the farmers themselves have already accumulated a large amount of information from their own experience. Although it might be suggested that such a survey could define the problems confronting agricultural improvement, the agricultural advisory service, if one exists, can define them much better. Thus detailed work will be required to provide soil knowledge of value under conditions of long-settled agriculture.

There is not always a clear distinction between reconnaissance surveys and detailed surveys, but perhaps the most suitable distinction is that given by Johnson (1962) for the U.S.A. There, detailed mapping involves the direct observation of all soil boundaries throughout their course whilst, in reconnaissance mapping, some of the lines are drawn on the basis of photo-interpretation or inference. In the U.S.A. three levels of intensity of detailed surveys are employed: high intensity surveys are made at mapping scales of 1:7 920 or 1:15 840; medium intensity surveys, in which the map entities tend to embrace somewhat broader ranges of slope, soil depth etc., are usually made at a mapping scale of 1:15840; low intensity surveys, for areas of relatively extensive soil use, are at mapping scales of 1:15 840 to 1:31 680. The scales of mapping for detailed soil surveys are not always indicated by other countries. In England detailed surveying is carried out on maps at a scale of 1:10 560 whilst in New Zealand detailed soil surveys are published at 1:31 680 (Pohlen 1962).

Ideally, tropical areas with dense agricultural settlement would require soil maps at least at the medium intensity level of the U.S.A. Achieving this degree of detail and accuracy, even in settled areas with limited roads, would be extremely time-consuming and often quite beyond the resources available. To achieve a similar degree of detail and accuracy in unsettled areas, particularly those under forest, is almost completely out of the question. That these factors are operative is shown by the fact that even the more detailed soil surveys in the tropics are really made by detailed reconnaissance methods.

It would be very useful to know the type of detail which should be aimed at when mapping at the larger scales. Obviously very detailed separations can be made on the basis of profile morphology and laboratory data but there are many instances where, under present management conditions, the various units have virtually the same fertility. In fact, many separations are possible which, from the point of view of soil fertility, are virtually meaningless in the present state of knowledge of tropical soils. This is not confined to tropical soils for Grissom (1961) has drawn attention to the general difficulty of selecting valid criteria for differentiating soils relative to land use. Exceptions to the above are found in the volcanic soils of the West Indies where relatively sharp boundaries, between soils of markedly different fertility, can occur.

A further point which should have bearing on decisions about undertaking detailed soil surveys is the state of development of the country. In terms of both their services and their resources virtually all tropical territories are underdeveloped though there are exceptions in the West Indies, for example, where some of the islands are relatively well developed in their resources, such as they are, but poorly developed in their services. The state of development of a country's services is a very important consideration, when deciding on the scope of detailed soil surveys, for there is little point in doing a detailed survey of a million acres if the country has the services to develop only 100 000 acres in the next 20 years.

The foregoing consideration thus suggests that whilst reconnaissance soil surveys in tropical countries can nearly always be justified, detailed surveys require close examination as to their purpose and their necessity. They are obviously valuable and indeed essential for irrigation schemes where their value rests on the fact that the major soil factors influencing irrigation agriculture are both known and mappable. They are possibly of value also in areas of intensive mono-culture, for example, of sugar-cane, but they have yet to prove their value for the general run of tropical agriculture, particularly, peasant agriculture.

SOIL CLASSIFICATION IN SOIL SURVEYS

It is of course possible to carry out a soil survey without classifying the mapped soils either in relation to one another or to soils in different areas. However, the value of the work is increased immeasurably if the soils can be placed in groups showing their interrelationships. Not only is the subsequent value of the soil map enhanced but the surveyor is given the opportunity to contribute to an understanding of the soils in the region. However, a soil classification, to be really valuable, requires considerable comprehension of the soils involved and at the present time mapping of tropical soils is well ahead or the knowledge of their genesis and properties. Normally the type of classification adopted will depend on the amount and kind of information available but it is obvious that a classification based on the results of detailed mapping would be virtually useless in extensive reconnaissance surveys unless the amount of detailed mapping is very great.

Usually, in the tropics, the surveyor will use recognized principles for his classification since he is unlikely to have the time or the facilities to work out new ones. The most comprehensive soil classification is the '7th Approximation' (Soil Survey Staff 1960) but unfortunately the orders covering the tropical soils, particularly that on latosols, are the least comprehensive. At the lower categories the 7th Approximation is more detailed than most other systems of classification so that its use at the lower levels even in tropical soils, is possible. However, the principles governing the choice of the differentiae are defined only in rather general terms and whilst these differentiae may have appropriate significance under conditions in the U.S.A., they need not have the same significance in all tropical soils. There does not, in fact, appear to be any fully satisfactory method for classifying tropical soils at the lower levels at present. It might also be questioned whether the soil type, as presently defined, is the most appropriate basic unit for classification in tropical soils. There does not appear to be anything better in view at present but subsequent research may show that the parameters now defining soil types should be modified for tropical soils.

Padi soils are a special group of soils which, because of their intensive agriculture, require detailed mapping but which have received little attention from the classification point of view. For this reason the recent paper by Kanno (1962) on their classification is of interest. He points out that rice soils are the result of a combination of both natural and artificial soil forming factors; they not only inherit some of the characteristics of the soils from which they have been developed but waterlogging and complicated cultivation practices bring about chemical and physical changes in the profile which have to be taken into account in their classification. It is of interest that Kanno uses an ecological definition, i.e. growth of one or two crops per year, as the initial separation of rice soils. Subsequent divisions are made on the basis of gleying, drainage, type of clay mineral and texture. This classification would appear to have considerable value for fertility work on rice soils since most of the criteria used for differentiae are known to influence crop responses.

The soil surveyor in the tropics needs a classification at the higher categories when carrying out reconnaissance soil surveys and in these conditions some form of descending system only is possible since accurate data on the soils will not be available in large amounts. Such a system may be based on genetic factors as in the Russian classification (Ivanova 1956) or on pedogenetic processes as in those of Aubert and Duchaufour (1956), D'Hoore (1960) and Pohlen (1962). The latter states that, in New Zealand, the genetic classification is an attempt to interpret the soil in terms of soil processes as indicated by morphological, chemical, biological and other soil properties.

The descending type of classification has been used in the early days of soil survey and classification in many parts of the world and the U.S.A., Russia and Australia have all used a genetic approach. Both the U.S.A. and Australia have moved away from the emphasis on genetic criteria and in Russia, though the genetic approach is still regarded as the only approach to soil classification, there is considerable emphasis on the use to be made of soil profile data (Basinski 1959). Thus in the tropics, where soil studies are relatively limited, a genetic approach forms an excellent working hypothesis for studies of soil processes. In the future, when there is much more information from detailed field and laboratory studies, an ascending type of classification may become necessary.

In tropical areas there would appear to be considerable scope for the use of landscape analyses as a basis for reconnaissance mapping. Perhaps the best known landscape unit is the catena as defined by Milne (1935). This is a repeating unit formed on similar parent material and under the same climate, the pattern of soil development being the result of differential drainage as influenced by topography. The unit is in fact part of a toposequence.

An entirely different kind of toposequence is that on steep land where there is a pattern of eroding and accumulating phases in the landscape. Such a pattern is common in the volcanic soils of the West Indies and being very important from the fertility point of view, should be recognized in soil mapping.

In the volcanic islands of the West Indies and indeed elsewhere another sequence is found which is the result of the effect of increasing rainfall on the same parent material under similar drainage conditions. The resulting soils form a characteristic sequence from lower to higher elevations, of regosols through immature soils to kandoid and finally allophanoid latosolics.

This sequence, which might be regarded as another sort of catena and was in fact suggested as such by Milne, resembles the soil suite of New Zealand (Taylor and Pohlen 1962). It could be regarded as a pluviasequence.

Different parent materials will of course give different sequences but the pattern remains the same.

In older landscapes in the humid tropics, where the soils are thoroughly weathered and leached, the parent material exerts a profound influence and in granite country in Malaya, for example, a repeating pattern due to the different types of granite is found. The more basic rocks give soils with a higher clay content, the more acid, sandy soils. Although the pattern is not nearly so regular as in the toposequence and pluviasequence landscapes, a pattern which might be termed a geosequence can certainly be found.

In many parts of the world soils have formed under environments which are very different from those of the present day. In these, cycles of erosion and deposition can be distinguished and the term ‘K cycle’ has been introduced by Butler (1959) to describe the sequences which result from periodic phenomena. He points out that the difference in age of the surface in any locality is a prime cause for soil differences. In terms of ground surface relationships the periodic phenomena lead to the development of characteristic sequences which might be termed chronosequences.

These suggestions for the recognition of landscape units, with soils which appear to be dominated by one or other of the soil-forming processes, are merely put forward as an illustration of a way in which landscape analyses might be used for an understanding of the soil pattern and thus lead to more meaningful soil maps. A form of landscape analysis has, in fact, been used for the broad scale reconnaissance surveys by the Land Research and Regional Survey organization in Australia (Christian and Stewart 1953). They use ‘land systems’ as the unit of mapping and they define a land system, which is a composite of related units, as an area throughout which there is a recurring pattern of topography, soils and vegetation.

LAND USE CLASSIFICATION

In developing countries, a soil survey is a means to a very practical end, the end being some form of interpretative soil classification. Sometimes it is suggested that this should be left to the agriculturist or horticulturist but in fact, soil surveyors are in the better position to carry out land capability classification and interpretative soil groupings, since they have studied the soils in the field and have seen their variations and observed their management and fertility problems. Nevertheless in interpretative soil classification the soil surveyor in the tropics is often at a serious disadvantage for he is frequently relatively inexperienced or, if experienced, is so in a different environment. In addition, far less is known about the soils; and the difficulties in the tropics are summarized by Riecken and Smith’s statement (1949) that ‘The greater the body of knowledge about soil profiles of an area and the more complete the understanding of the functional relationship of the important soil properties to the soil-forming factors, the easier will be the task of establishing the basic soil profile units of the area. Moreover the decisions will be more satisfactory if the management requirements are known through research and experience’.

An interpretative soil classification may include the formulation of some kind of productivity rating, which is a prediction of the behaviour of the soil under a particular system of land management. The rating may be expressed as a percentage of the potential production of a particular crop growing on the soils recognized as best suited to it and under better than average management conditions. In the tropics it is extremely difficult to apply this type of approach, especially in peasant agriculture, since the management levels are generally so low that it is, in fact, almost impossible to get an accurate estimate of the potential yield of any particular crop. Thus in the West Indies it is very difficult to form an accurate estimate of the yield potential of most of the soils for food crops. With cash crops, for example, bananas and sugar-cane, it is easier since these are grown by a number of estates with high standards of management.

An alternative method is to use a rating such as the Store (1933) index whereby the soil is interpreted on the basis of its profile, texture and modifying factors. This approach can lead to difficulties also since the emphasis given to any one factor should vary from region to region. In temperate lands, with the necessity for mechanization, steep slopes are given a low rating whereas level soils, low in chemical fertility, are given a higher rating. In the tropics, however, steep slopes are quite suitable for many tree crops but the infertile level soils may be too expensive, in terms of fertilizers, to utilize for peasant agriculture. Moreover the limited knowledge of tropical soils makes it more difficult to apply such inductive methods.

Factors affecting productivity of tropical soils vary greatly from region to region. In the older weathered and leached soils, for example, detailed relationships in terms of soil fertility appear rather obscure and may perhaps depend on rather fine differences in the small amount of weatherable minerals. It would also appear that the amount of clay, even though the predominant clay mineral remains the same, is of great importance. In Malaya, soils formed on different types of granites show quite marked differences in their ability to grow crops even though all the soils appear equally weathered and leached. The more basic members give rise to soils with a higher clay content and possibly their ability to hold more moisture and retain more nutrients makes them more productive soils. Perhaps in such soils a good correlation between a single factor and overall soil fertility may be found. Soils with differing kinds of clay, differing base saturation and differing amounts of silts may present a much more complicated problem when correlating classification with fertility.

Figure 1. Influence of management standards on productivity ratings

In an attempt at interpretative soil classification soils cannot be considered in isolation, for good soils can 'carry' poor soils, i.e. make it worthwhile developing them in terms of services like roads etc. The 'good' soils alone may not justify developing an area but the 'good' soils together with the potential of the 'poor' soils may make it profitable.

In setting up land capability classifications in the tropics more attention should be given to management as a factor in calculating productivity ratings. The latter can vary very greatly depending on the type of management which is adopted. Soils under well-managed, adequately financed estate agriculture have the greatest potential. Soils with peasants organized into groups and working under close supervision, as for instance in some land development schemes, will have a lower potential and those under ordinary peasant agriculture will have the lowest potential of all.

The influence of any particular limiting factor will vary with the class of management. Steep slopes and rockiness, 'permanent' limiting factors, operate more or less equally against estates and peasants but low fertility, lack of drainage, or need for irrigation, 'temporary' limiting factors, reduce the potential productivity more for peasants than for estates. Figure 1 demonstrates these interactions in graphical form. 'Permanent' limiting factors, in increasing severity, are set out along AB. These comprise the seven land capability classes of Steele, Vernon and Hewitt (1954), running from Class I (A and B slopes of good soils) to Class VII (rock out-crops, river wash etc.). 'Temporary' limiting factors are set out along AC and increase in severity from low fertility through poor drainage to poor water supply. Management factors are set out along AD with the standard of management increasing from A to D, from peasant farmers to well managed highly capitalized estates. The slope of BD would vary with the kind of crop; it will be steepest for crops which have the highest response, to good management.

In illustrating the interactions controlling productivity, Figure 1 is of course highly stylized but there may be sufficient information on a number of the major crops on at least some soils to be able to give more precise meaning to the limits illustrated by the diagram.

It is unfortunate that the material for calculation of productivity ratings in tropical soils is generally extremely scanty, for soundly based ratings could be of immense advantage to countries which have very limited capital for development and which will or should wish to use it where it can produce the most benefit. In some ways the approach described by Visser (1952) in Holland, where increased productivity is estimated in terms of additional land, might be useful. Thus an increase in production of 25 per cent on an existing acre of agricultural land is equivalent to bringing into production a quarter of an acre of new land. It would appear that this approach would be particularly useful for such projects as rice irrigation schemes where improvement of the drainage and irrigation of existing land would often bring a bigger return on investment than the reclamation of new land. However, political considerations may be overriding and it may be considered better to have two farmers, both farming poorly, than to have one farming well and the other not at all.

Single factor soil maps are sometimes used as a method of interpretative classification. Such maps are usually based on a more complete survey of the area and their value depends on the particular factor and the extent of its dominance in the soil productivity. Certain single factor maps, such as those showing depth of peat or levels of salts, may be made in a primary survey; these are valuable, since they show a factor which is overwhelmingly dominant in the use of the land and they can be made more quickly.

In spite of the inherent difficulties in making land use recommendations for tropical soils, force of circumstances has led to many such recommendations by soil surveyors. However, large numbers of surveys are of such recent date, mostly post-1946, that generally there has not been time to test out the value of their assessments and, where the surveyed land has been developed, the soil surveyor has often long since gone elsewhere. Appraisal of these surveys in the light of subsequent agricultural development would be of great value.

SOIL SURVEYS AND SOIL FERTILITY

Although the past decade has seen very considerable development in soil surveys in the tropics, there has not been the same emphasis on the second or follow-up stage—studies on the fertility of the soils which have been mapped. This is, in fact, a more difficult and time-consuming phase than soil survey. It must be recognized that the final measure of soil fertility is the field experiment and that properly conducted field experiments form the soundest basis for productivity ratings and for studies on the chemical and physical factors controlling productivity. Furthermore fertilizer trials should be carried out even where there are no prospects, at present, of using fertilizers.

In the past much of the field experimental programme was carried out in experiment stations, where neither the fertility nor the management was representative of farmers' land. Only in recent years have field experiments on farmers' land become a recognized part of the research programme on soil fertility. Examples of such work are the experiments by Nye (1951) in West Africa and by Mukerjee (1960) in India. The approach to field experiments can take several forms. Where there is very little detailed information on the soil then probably the best technique is one such as that used by Mukerjee. In this, simple trials are laid down on sites selected at random, with one replicate per site, in an area of fairly homogeneous soils. The results can be analysed as replicates of one trial or split up into regions and analysed as groups. This type of experiment gives information on the overall fertilizer requirements of the region but gives little information on individual soils or on individual farmers' fields. Thus it might show that the use of fertilizers is profitable from the national standpoint but not necessarily so for the individual farmer. Furthermore this type of experiment is not suitable as a basis for material for plant and soil analyses. The advantage of this approach is that it is a fairly quick method of getting an overall picture of the fertilizer needs of a country and is thus of value when such a country is embarking on a fertilizer manufacture or subsidy policy. However, it is of limited value in regions where areas of homogeneous soils are small and changes in fertility abrupt.

Instead of selecting sites entirely at random they can be selected on the basis of some observation on the soil. Thus the sites for the large series of trials on phosphate responses of various crops carried out in the U.K. in 1941-46 and 1951-53 (Cooke 1956) were generally chosen on the basis of soil phosphate levels as determined by soil analyses. There are obvious advantages in such an approach but it is of limited application in the tropics since soil analysis is generally of little value for predicting fertilizer responses.

If soil maps are available the more useful approach is to use factorial experiments, carefully selecting the sites on the basis of an examination of the soil and its relation to the modal profile. The ability of the agronomist to recognize the soils is therefore very important. This is the approach now being used in the West Indies (Twvford and Coulter 1962). Factorial experiments are certainly the most useful, particularly if treatments are carried out at three levels, for it is thus possible to obtain response curves. Although primary attention will probably be given to nitrogen, phosphate and potash, there is very good reason to extend the factorial treatments to other factors amongst which plant density is probably one of the most important. Presented thus, experiments on farmers' fields appear deceptively simple but the very fact that they are difficult to arrange and manage has been the main reason preventing their much wider adoption. In the tropics there are all the difficulties inherent in dealing with poor farmers, small fields, poor protection against humans and stock, and the fact that the farmer cannot really spare land from which he may get no return. Perhaps the most important factor of all is management, and many experiments are useless because the standards of management are such that poor management completely overshadows any fertilizer effect. In order to have a justified basis of comparison of the productivity and responses of different soils it is essential that all trials have near uniformity of management in terms of cultivation, plant density, weed control, pest control, time of planting etc. Though such standards may be quite far removed from those of the farmer it is still essential to have them.

The number of experiments which can be carried out depends on a host of factors and there will never be enough experiments to take care of all the soils involved. Some of the trials will inevitably be lost so that extra trials need to be put down. However, if too many come to fruition the agronomist will be unable to deal with them and it is only after considerable experience of the particular conditions that he will be in a position to judge accurately the appropriate number of field trials to use in the area.

Yates (1952) discusses the returns to be expected from experimentation and points out that there may be a case for not carrying out the full amount of experimentation on one particular line that can be justified on economic grounds since the returns on the last few incremental steps are relatively small and it may be possible to use such experimental resources more effectively on other problems. He goes on to point out the advantages to be gained from coordinated series of modern well-designed factorial experiments, quoting sugar beet as an example. The issues raised in his paper are very important for experimentation in the tropics but they appear often to be ignored. The literature suggests that there are far too many experiments, mostly carried out on experimental stations, which are designed to take care of the last few incremental steps which he mentions. If his suggestions were accepted it could mean that experimental stations in the tropics would have a limited life for experimental work on soil fertility.

The information to be gained from a well-planned series of field experiments goes far beyond the results on fertilizer response for the particular crop and the particular soil. The experiments can supply the material for the study of correlations of nutrient uptake, soil analyses and fertilizer response. By carrying out pot experiments on the same soils, correlations between pot results and field results can be obtained. Spurious results in the field, important elements left out of the trial or the presence of toxic substances may be shown up by pot trials. Fertilizer trials are also the basis for correlations between soil classification and soil fertility. These considerations suggest then that the maximum amount of information from field experiments can only be obtained by a team approach and it is this which is so often lacking in the tropics. It scarcely needs emphasizing that one of the greatest advantages to be obtained by this approach will be the accumulation of a mass of background information essential for a better understanding of tropical soils.

Such basic information provides a possibility of extrapolating the results for a particular crop on a particular soil to other soils for the same crop. However, it would also be of great value if the results from a particular crop on one soil could be extrapolated to other crops on the same soil. The knowledge of the physiology of nutrition of tropical crops is at the moment too scanty for this to have much promise. Obviously tropical crops have greatly different requirements for individual nutrients but it is difficult to answer the question as to whether nutrients available to one species are unavailable to another. Information on this point is very limited but the paper by Nye and Foster (1956) on the uptake of ^{32}P suggests that there are no differences in the availability of soil phosphorus for the different species. If this is generally true then the ability of one species to take up much more of a particular nutrient from a given soil than another species may be due to root distribution and the volume of soil explored by the roots and the rate of uptake at a given activity.

In conclusion therefore it may be stated that, in the tropics, progress in soil mapping is already far ahead of the progress in gathering knowledge of soil fertility. The gap is likely to widen, since for any particular area soil mapping can be a short term project whereas fertility studies are essentially long term. Thus soil surveys should not be carried out in isolation in the tropics; they should be regarded as a part of the whole project for studying fertility of tropical soils.

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