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SOIL SURVEY PROCEDURES
FOR DEVELOPMENT
PURPOSES

by

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Note: This paper represents the views of its author only, and except where specified these should not be taken as necessarily representing standard practice within the Land Resources Division.

INTRODUCTION

This paper is intended primarily for those administrators, agriculturists, and planners who have occasion to request, commission, advise on the need for, or subsequently to evaluate, interpret and apply the results of, soil surveys. Implicit in it is the application of such surveys to the problems of the under developed countries, and to predominantly tropical and sub tropical environments. It should also be noted that the comments that follow are based primarily upon British and Commonwealth experience, particularly in Africa.

The paper starts from the premise that despite the large number of soil surveys carried out since 1945, they have not influenced agricultural development, or contributed to increased productivity to the degree which might be expected from the amount of work; and that agricultural development has occurred regardless of, rather than as a result of, soil surveys.

This assumption is based upon the lack of examples in the professional literature of cases where the prior availability of soil survey findings substantially influenced agricultural policy and decision - taking, either in avoiding mistakes, or in indicating the form and location of new or improved agricultural land use. There is a similar apparent scarcity of examples in which agricultural research has been influenced by, or initiated as a result of, soil surveys and there are few references to correlations between the results of research and units shown in soil maps. This might be termed the "comprehension gap" represented in Figure 1.

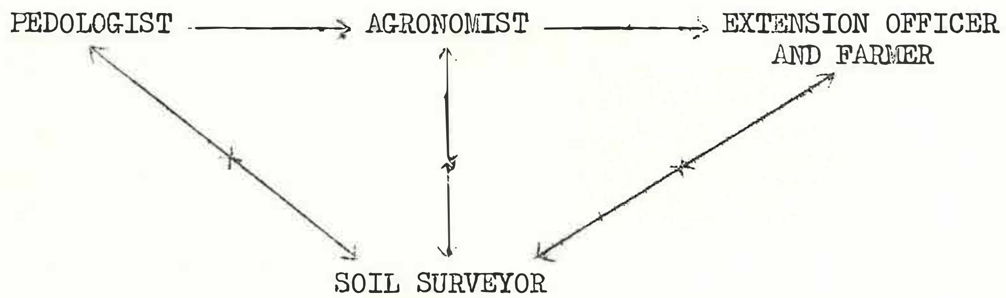


FIG. 1. THE COMPREHENSION GAP

It expresses the failure of soil surveys in one of their most important functions, namely to act as the vehicle for the transference of knowledge, both between various branches of agricultural research (through helping where appropriate, to delimit the applicability of research results), and between agricultural research as a whole and planning and extension work.

The significance of this is not difficult to appreciate. Out of 100 papers (randomly chosen) reporting research into the chemical and physical processes within the soil body or soil fertility studies, none quoted references to, or descriptions of, soils, in taxomomic units appropriate to soil mapping at any level below that of great soil groups.

Not once was a precise reference made to a soil map as being indicative to the reader of the precise area and range of soil types to which the research would be applicable.

Where surveys exist this suggests either that the chosen mapping units are inappropriate; or there is too wide a difference between the mapping units and those described in the report; or that the type of data collected by surveys is insufficiently relevant to research and extension work. Alternatively agriculturalists may not sufficiently understand the limitations and possibilities of soil surveys, thus resulting in there being no policy for surveys, or surveys being requested which are inappropriate to their objective.

What can be achieved is illustrated in a paper by Higgins (1964), which sets out a detailed summarisation of rice growing soils in certain parts of Northern

Nigeria. This precise summary is based upon properly planned and carefully executed soil survey programmes. The data quoted are related to management by reporting the results of agronomic experiments carried out upon the specified soil types. As a result the soil maps of these areas may be immediately re-interpretated as a land classification map for rice growing. Such work is of great value, but is confined almost entirely to those countries which have had soil survey units, able to pursue a coherent programme for a substantial period of time (Murdoch, 1963; Brammer, 1960; Klinkenberg and Higgins, 1968). Such work also indicates that despite positive criticisms of soil surveys (Gibbons, 1961), they can respond effectively to the requirement that the results can be usefully correlated with agricultural productivity.

To this end we need to examine the different forms of soil survey in relation to various agricultural objectives, to consider the methods and organisation of work to achieve such ends, and the extent to which modern technology may assist.

Table

TYPES OF S

TYPE INTEGRATED OR SINGLE ASPECT	OBJECTIVE	MAP SCALE	PHOTO SCALE	SOIL SAMPLING DENSITY (Avg. per sq.ml.) (=2.6 km^2)	TYPICAL AREA COVERED (sq.mls)	METHOD
RECONNAISSANCE (usually integrated)	National or regional inventory	1:250 000 and smaller 1/	1:25 000 to 1:80 000	<1 (often< .05 i.e. <1:20 sq ml.)	>2 000 (usually >10 000)	Physiographic + free traversing
EXTENSIVE (usually integrated but may be single aspect)	Detailed inventory: broad agric. potential	1:100 000 to 1:250 000	1:25 000 to 1:50 000	± 1	1 000 to 10 000	Physiographic + irregular grid to give reasonable average spacing
INTENSIVE (either)	Location and definition of projects	1:25 000 to 1:100 000	1:25 000 to 1:50 000	1 - 10	500 to 5 000	Physiographic + (usually irregular) grid + interlining
DEVELOPMENT STUDY (usually single aspect)	Project execution and farm planning	1:25 000 or larger (Irrigation projects usually >1:10 000)	Preferably larger than 1:25 000	Minimum about 10; no upper limit	Usually <50	Regular grid + interlining
MANAGEMENT PROBLEM STUDY (single aspect)	To characterise experimental environment, assist solution of agronomic problems	1:10 000 or larger	1:10 000 or larger	As reqd.	Small	Regular grid + interlining

1/ 1:250 000 is a "smaller" scale than 1:25 000

2/ Routine studies: Mechanical analysis, pH, C.E.C., total exchangeable bases, base s
Genesis and Classification studies: Clay minerals, Silica/sesquioxide ratio, thin
Fertility studies: Av. P and K, reserves of P,K,N,Fe,Al, trace elements
Irrigation studies: Conductivity, soluble salts, E.S.P., av. water capacity, permea

Table 1

TYPES OF SURVEY

METHOD	SUBJECT MAPPING UNITS					SOIL ANALYSES REQD. 2/
	INTEGRATED	SOIL	GEOMORPHOLOGY	VEGT.	LAND USE	
ysiographic free raversing	Land system or higher categories	Order, sub order, or great soil group depending on complexity	Major relief units	Topo/ Climatic	Topo/ Climatic	Routine: all lab samples Genesis and classification: selected samples. Fertility studies: to characterise major series.
ysiographic irregular rid to give easonable verage pacing	Land system	Great soil groups, or topographic or genetic associations of series	Relief units or major landforms.	Communities	Farming systems or cultivation density	Routine: all lab samples Genesis and classification: on selected samples. Fertility studies: to characterise major series.
ysiographic (usually regular) rid + terlining	Land system and facets (usually the latter)	Series, or associations of series in complex areas.	Individual landforms.	Associations	Crop dist. or field patterns or cult. density	Routine: all lab samples Fertility: to characterise all significant series. Irrigation: mostly by undisturbed cores.
egular rid + terlining	-	Phases of series &/or selected parameters	Landform elements or slope units	Species distribution (e.g. tree counts)	Existing crop/cult. distribution &/or proposed layout.	Routine: all lab samples Fertility/Irrigation studies: in sufficient nos. to assess unit variability and provide adequate basis for management (Irrigation mainly be means of field studies.)
egular rid + terlining	-	Parametric units may be desirable	Slope units	Indicator species	Problem distribution, e.g. pests, or disease, or water table level and quality	As reqd.

bases, base saturation, O.M.
ratio, thin section studies, mineralogical analysis of sand fraction.
s
acity, permeability (field and undisturbed cores).

TABLE 2. TYPES OF SOIL SURVEY (after Smith, G. D., 1965)

TYPE		MAP UNITS	SCALE[1]	PURPOSE
EXPLORATORY		Associations of phases of great soil groups.	1:1 000 000 and smaller (schematic maps)	1. To locate areas of substantial soil difference (inventory) 2. Locate more detailed work. 3. Test legend.
RECONNAISSANCE		Associations of phases of soil series or higher categories (great soil groups or families)	1:62 500 to 1:500 000	1. To survey areas suited only to extensive use. 2. Pre-detailed survey to locate and define such work.
DETAILED	LOW INTENSITY	Phases of associations of series.	1:30 000 and smaller.	For forestry and grazing development areas.
	MEDIUM INTENSITY	Phases of soil series	1:10 000 to 1:30 000	For arable development areas.
	HIGH INTENSITY	Phases of soil series specified on a denser sampling pattern.	1:7 920 and larger.	For very intensive development areas e.g. irrigation, urban expansion

[1] Details of scale derived from other sources, principally, U.S. Department of Agric. Handb.18, Soil Survey Manual.

TYPES OF SOIL SURVEY

Three groups of people are concerned with soil surveys. Those who request such surveys; those who conduct the surveys; and those who have to interpret and apply the results of the surveys. Perhaps one important reason for the rather negative interest in soil maps of many workers in the agricultural field, is the fact that those who request and those who apply the results of soil surveys are rarely the same people. This can result in unsuitable specifications being issued for surveys. Two questions must be answered in drawing up a brief: What purpose is the survey to serve? Who is going to use the results? Table 1 sets out in summary form the main distinctive groups of soil survey, although it must be understood that the divisions between them and the scales and taxonomic units suggested must not be regarded too inflexibly. Within these broad categories any survey must be specified on its own merits to meet its own particular circumstances.

Many authors recognise some similar sub-division amongst soil surveys. For example Beckett (1968), groups soil surveys into three types; "One-stage" soil surveys in which the maps show the boundaries of the defined sub divisions; "Two-stage" soil surveys in which the maps portray groupings of the units defined and described in the accompanying text; and "Three-stage" soil surveys in which the units shown on the maps are so complex that they have little value in terms of presenting information about the distribution of the basic units of description. Carbonnell (1966), divides surveys up into 4 categories which he characterises by selecting what he describes as a median map scale for each, as follows :-

reconnaissance surveys with a map scale of 1:200,000;
semi-detailed surveys with a scale of 1:50,000;
detailed surveys with a scale of 1:10,000;
and very large scale surveys with a factor of 1:500/5,000.

It is clear from his comments that these respectively equate with the purposes of general inventory, project definition, project execution, and special purposes such as urban planning or engineering works. Smith, (1965), divides his soil surveys respectively into exploratory, reconnaissance, and detailed; the latter being in turn sub-divided into low, medium, and high intensity surveys, and he characterises each type of survey by the type of soil unit used on the accompanying maps with consequent implied distinctions of publication scale. (See table 2).

Before considering each type of survey set out in table 1 in more detail, the relationship between soil surveys and other forms of environmental survey must be considered. "Integrated" has two quite different aspects in relation to a survey programme. Firstly it may be applied in the sense of a single coherent programme for a given area, which, within itself, leads to progressively more intensive examination of successively more limited areas in a sequence of surveys designed to lead from the first appraisal of an hitherto underscribed environment, to a final stage of successful project execution. This is integration on a long-term basis and is rarely encountered as a conscious policy applied from the start. "Integration" is more commonly used to refer to the combination, within one survey, of a team of environmental scientists dealing with several, or all, co-varying and mutually influencing aspects of the physical environment and it is in this sense that the term is used in Table 1. It must be stressed that whilst it is generally preferable to have the whole team working together simultaneously, it is not always necessary; and considerations of seasonality, personnel availability, and transport logistics may in practice disperse the activities of the team in time or space, or both. As Table 1 indicates, there is a rough general rule that the more intensive and detailed the survey required, the more likely it is that such a survey will have to concentrate upon one aspect of the environment. The pre-eminent aspect is most commonly soil as the medium of cultivation, although not necessarily always so. For example when dealing with semi-arid lands, grassland ecology might become the prime consideration.

I. RECONNAISSANCE SURVEYS

Type of Survey: Normally an integrated survey, presenting its results in a series of small scale maps, one map for each aspect of the environment, often with a map at somewhat larger scale summarising these results in terms of "integrated" map units given such titles as "Land Systems" of "Natural Regions".

Objective: National or regional inventory. Such a survey should present a coherent account of the whole of the physical environment, stressing the interrelationships of the several aspects. It should establish the taxonomic units for each aspect, using high level categories, but providing some description of the detailed composition of each of those categories. It is likely to indicate development potential only in broad and rather subjective terms, governed primarily by climate and topography. It rarely makes qualitative or quantitative assessments of the potential relevant to project planning or the selection of management techniques. However the initation of such detailed work does not necessarily have to await the ultimate completion of the whole reconnaissance survey, provided that it is sufficiently far advanced to indicate the most promising areas for the next phase of investigation.

Survey Methods: Heavy reliance is placed upon remote sensing techniques, particularly air photo interpretation, for establishing mapping units and marking boundaries accurately. Such techniques also assist the planning of field traverses in order to provide adequate confirmation of the boundaries, plus description of the units based on sufficiently widespread sampling to ensure that no important area has been left uninspected. Representative blocks may be examined in greater detail to help characterise the major units. The siting and frequency of such "sample strips" depends upon a number of factors, especially the anticipated complexity of the patterns within the landscape and the amount of time and manpower which can be devoted to examining them without detracting from the main programme of the survey. As a broad general rule it may be taken that not more than one per cent of the total area should be examined in sample strips, aligned if possible from interfluve to interfluve at right angles to the contours and separate maps on a suitable (large) scale should be prepared for the results of each survey, if they are to provide full value.

In reconnaissnace work, field work should be kept to the minimum considered acceptable for the nature of the terrain, and consequently the success of such surveys largely depends upon the experience of the team, both as photo interpreters and as field workers, most especially of the team leader. from a minimum basis of fact they will have to erect an elaborate structure of inference and interpretation. The pattern of field traverses should make the maximum use of motorable roads and trails and also of footpaths, avoiding as far as possible any regular traverse grid which may require time and labour to lay down.

Typical Area; From about 2,000 sq. miles (5200 km^2) upwards, most commonly between about 10,000/100,000 sq. miles (26,000-260,000 km^2). Below 10,000 sq. miles (26,000 km^2) there is an increasing tendency for the usefulness of a reconnaissance survey to decline, because for the effort involved in mounting an integrated survey with its several specialists, there is an as yet undefined minimum area and as this is approached there is de facto a tendency to intensify the survey, which then assumes the form of a second stage survey. At the other extreme, above 100,000 sq. miles (260,000 km^2) there is a tendency for the opposite to occur, even in a comparatively uniform and featureless region. Data collection may become too sparse and the survey consequently amorphous, unless the period allowed is adequate. In such cases it becomes increasingly desirable to divide the survey into several smaller surveys in the interests of providing results at regular, not too long-delayed intervals.

Photo Scale: 1:25,000 to 1:80,000. Individual prints may be assembled into mosaics or print laydowns varying from contact scale to 1:1,000,000, or even, occasionally, smaller scales in order to present entire regions in a single, or manageable number, of sheets. With the largest surveys conducted at the smallest scales, satellite photography may be helpful in delimiting the largest regional patterns. If suitable panchromatic black and white photography exists, it will usually suffice. If new photography has to be requested other forms of photography may be justified (see p. [illegible]).

Map Publication Scale: 1:250,000, or smaller. If a larger scale is considered necessary it implies that the survey has not been, or ought not to have been, a reconnaissance survey. The principal map usually displays integrated units selected from the "land system" hierarchy. Individual subject maps are also presented in most cases, usually at a smaller, common, scale. Apart from these maps and any maps associated with sample strip work, it can be useful to show areas of particular interest or importance at a larger scale, if possible as blocks within the text and if necessary only to sketch map standards. In addition it should be mentioned that block diagrams and profile cross-sections are useful methods of showing the relationships between and within map units. This work taken in toto, implies substantial cartographic surpport for reconnaissance surveys.

Typical Subject Map Categories:

1. Integrated: land system, or higher category (province, region, etc.)
2. Soil: order, sub-order, or great soil group.
3. Vegetation: generally topo-climatic units, or physiognomic units, e.g. "montane grassland", or "tree savanna".
4. Geomorphology: major relief units, such as "high altitude plateaux", or "alluvial outwash plain".
5. Land use: topo-climatic units and/or cultivation density or crop distributional units.

Background Data: Data under this heading is normally taken from existing sources, either because collecting ab initio usually involves a period of years to be meaningful, or because the specialisation involved is not normally represented within the team of specialists.

1. Hydrology: regional or national water resources in terms of major river flow, or catchment area run-off.
2. Climate: apart from tabulated data for selected stations, climatic data at this level are normally presented in terms of regions of a topo-latitudinal nature, principally based upon rainfall and temperature. Filling-in the climatic map using interpolations based upon theoretical equations relevant to topography and latitude is a common necessity at this level.
3. Geology: usually age/stratigraphic units. The most useful units for soil definition would be lithological, particularly if these were associated with mineralogical or chemical description.

General Remarks: At this level soil is usually only one amongst several physical parameters being studied and described simultaneously. The density of full soil profile descriptions is low, rarely exceeding one per 10 sq. mls. (26 km^2), overall. Consequently heavy reliance is placed upon indirect evidence, including where available, analogous area data of a type which could be readily derived via a data bank.

Smith (1965), differentiates "exploratory" from reconnaissance surveys by a heavier reliance upon inferential evidence concerning soil forming factors, climate, vegetation, geology, and geomorphology. In this context he mentions the use of existing "published and unpublished soil data, checked if possible by traverses". This type of survey can be useful in circumstances where, although there has been no national reconnaissance, there is already a substantial amount of uncoordinated data on various aspects of the environment. Such a body of data, synthesised by a necessary minimum of field work, can produce a satisfactory alternative to a full, integrated, reconnaissance survey. This allows resources to be concentrated more quickly upon the next, more detailed, phase of survey work. The objectives which he allots to exploratory survey (see table 2) are the same, by and large, which one can set for reconnaissance survey. Authoritative advice should be sought where such a survey is contemplated in lieu of a reconnaissance, but generally the amount of uncoordinated data on agriculture and the physical environment extant in diverse files in headquarters, regional, and district offices makes this method more commonly feasible than is generally realised. Where feasible it should usually be cheaper and quicker.

II. EXTENSIVE SURVEY

Type of Survey: Usually integrated, but often with soil of pre-eminent importance.

Objective: Assessment of a single, or small group of, units defined by a reconnaissance survey. This may take two forms, separately or in combination. Either it may present a more detailed inventory of the selected areas without being too specific about recommendations; or it may present an outline of development project possibilities in terms of the range of scientifically feasible options, from which a choice of the most economically viable can be made for detailed examination in the context of current economic, social, and political circumstances.

Method of Survey: At this level there is still a heavy reliance upon remote sensing techniques especially air photo interpretation, but a denser network of field traverses will be used to establish an adequate body of fundamental data. For convenience and speed such traverses form an irregular network following existing roads and paths as far as may be consistent with maintaining the requisite smapling density (see p.) and the general desirability of traversing at right angles to the grain of the country. A reasonable average spacing should be aimed at in choosing the routes for field traverses, in the range 1 - 10 miles (1.6 - 16 km). Where air photographs are of limited use as in tropical rain forest, a closer spacing of ground inspection will be necessary both to locate boundaries and characterise mapping units. Sample strips may again be used, amounting to as much as 5% of the most important map units, for the same purpose as in reconnaissance surveys.

Typical Area: Not more than about 10,000 sq. miles, (26,000 sq. km.) and more usually of the order of 2,000/8,000 sq. miles (5,2000-20,800 km^2).

Photo Scale: 1:25,000/1:50,000. Prints may be assembled into mosaics and print laydowns, varying from contact scale to half degree sheets at 1:125,000. For soil associations where, for example, colour catenas are predominant, colour photography can be useful, and other imaging sensors in particular conditions (see pp.).

Map Publication Scale: 1:100,000/1:250,000. Individual subject maps will be at a smaller scale than the map of integrated units, though on occasions it may be more appropriate to make a subject map, e.g. soils, the principal map.

Typical Subject Map Categories:

1. Integrated: land system, or, occasionally in relatively featureless terrain, land facet.
2. Soil: association, the component units of which may be displayed on the separate sample strip maps.
3. Vegetation: communities.
4. Geomorphology: dependant upon complexity, either relief units, or individual major landforms, e.g. gently undulating plain; escarpment.
5. Land use: farming systems, e.g. intensive or extensive, with major crop patterns, such as "...cotton - tobacco - Groundnunts".

Background Data:

1. Hydrology: catchment area run-off, and river flow.
2. Climate: more detailed subdivisions of climatic regions based upon rainfall and temperature.
3. Geology: generally as for reconnaissance surveys.

General Remarks: It is rarely necessary to carry out both extensive and reconnaissance surveys and they tend to be mutually exclusive. If an exploratory survey in the sense of Smith (1965), has provided the first stage of land resource assessment, then extensive surveys may be a useful stage on the way to more intensive work, cutting out the reconnaissance stage altogether. Surveys at this level are primarily valuable for providing a moderately detailed basis appropriate to planning broadly applicable general improvements in farming practice, defining the geographical range for crops and for preparing a comprehensive list of possible development projects.

III. INTENSIVE, OR SEMI-DETAILED SURVEYS

Type of Survey: Integrated or Single Aspect Surveys, usually the latter.

Objective: Having completed an inventory and outlined the development possibilities, the intensive survey is intended to locate and define potential projects. To attempt to go straight to this kind of survey without the necessary preliminary stages is to reduce the soil surveyor to what Charter (1954), described as a "pedological procureur". In other words it would be using land resource appraisal to pick the eyes out of a country's natural resources for short-term benefit, without due consideration being given to coherent long-term agricultural evolution. Surveys at this level should provide a basis on which to lay down in fairly precise terms the possible crops, and the probable form of management. Given that the agricultural potential is of a primarily arable character, it is at this level that the soil map is most likely to displace the integrated unit map as the principle product of the survey.

Method of Survey: Although the advantages gained from using remote sensing techniques continue, there is likely to be a sharp increawe in the relative importance and amount of, field work. Where soil is the dominant aspect, it will often be desirable to have a basic framework in the form of a traverse grid, which may incorporate suitable roads and paths. It should aim at an average spacing, dependent upon the complexity, not closer than about 1 mile (1.6 km.). This is likely to be reinforced by interlining on a free survey basis (see Field Work p.). The grid survey having established the necessary overall basic minimum coverage, the free survey will locally intensify the sampling density sufficiently to ensure that the mapping units conform to a specified minimum purity. Judgment of this must rest with the survey leader. Depending upon the nature of the soil pattern and the purpose of the survey, there is quite a high possibility that at this level specialised forms of photography, e.g. true colour, false colour, infra-red, may be useful. Again the survey leader is likely to be best judge of this, particularly if he was past experience of the area or an analogous area.

Typical Area: Not more than about 5,000 sq. miles (13,000 km^2), and more usually of the order of 500-2,000 sq. miles (1300-5200 km^2).

Photo Scale: Preferably larger than 1:40,000, especially if the mapping scale is larger than that. Mosaics or print laydowns may be used, usually made at contact scale, unless the scale of available photography is larger than 1:25,000 while the proposed mapping scale is smaller than 1:50,000, when a scale smaller than contact scale may be adopted. For soil survey, if true colour photography is available for conditions in which boundaries may be identified largely by colour changes, then smaller scale photography may be acceptable than would be the case with panchromatic black and white photography.

Map Publication Scale: 1:25,000 to 1:100,000. If more than one aspect of the physical environment is presented on maps, then at this level or survey it is probable that they can all be usefully presented at the same scale, thereby economising on cartographic man-hours by making one base map suffice. Generally, at about this level, environmental surveys match the scale of the standard topographic series for the country, in a manner more typical of geological surveys. This, for cartographic reasons, makes it sensible, whenever possible, to make survey and map boundaries coincide.

Typical Subject Map Categories:

1. Integrated: land system, or in featureless country, land facet.
2. Soil: soil series, except in areas of complexity when associations may be necessary.
3. Vegetation: association.
4. Geomorphology: individual landforms.
5. Land use: units based upon crop patterns, cultivation densities, or particular photo-visual patterns of field shapes, sizes, and alignments.

Background Data:

1. Hydrology: detailed flow records of rivers and possibly sedimentation data.
2. Climate: detailed rainfall and temperature records, plus available data on wind strengths and directions, humidity levels, sunshine records, frost records etc. It may be necessary at this level to introduce a suitable density of automatic climatic recording stations. With modern statistical and computer techniques it is possible to make good use of short-term and even single season records obtained by such methods, provided there is an appropriate key station within the climatic region or sub-region, with which the records can be compared.

General Remarks: The intensive or semi-detailed survey is an essential stage in the vertical integration of land resource studies. It may, rarely, be excluded, if an extensive survey with adequate sample strip coverage has recently been conducted. In many areas where there is not, in the immediate future, any likelihood of development involving the adoption of techniques representing a considerable advance in farming sophistication, (e.g. intensive irrigation schemes in what has hitherto been semi-arid pasture land,) an intensive survey will represent the limit of what is presently needed. The well conducted survey at this level should provide all the data required for extension work and the kind of research and experimental programme usual in the Departments of Agriculture in most underdeveloped countries.

IV. DEVELOPMENT STUDY

Type of Survey: Usually single aspect.

Objective: Project execution. Surveys at this level are intended to assess the suitability of the soils of a limited area for a specific project. The soils have to be defined and described in considerable detail. By their nature some projects will require more than one aspect, for example an irrigation survey will require a detailed topographic map in addition to a detailed soil map. The detail provided by the survey must be adequate as a basis for elaborating the initial management proposals. It must also provide an adequate basis for agronomic trials. Costs per unit area surveyed are higher for this kind of survey than for the others.

Method of Survey: Fundamentally, development studies are grid surveys and although air photographs are still of very considerable importance, especially in assisting with the demarcation of boundaries, the sampling density on the ground must be sufficient not merely to characterise the soil units mapped, but to prove the required level of purity beyond doubt. As a guide the purity of mapping units must be of the order of 85% or better where the proposed development involves the introduction of exotic and sophisticated forms of agriculture. Rather lower standards may be accepted where the development involves only extension or intensification of the existing form of agriculture. In certain conditions, particularly those associated with a depositional soil pattern, in which the successive layers within the profile may not be genetically related and in which, therefore, the nature of the soil profile at a given point depends upon non-predicatable variables, such surveys will involve an extremely high density of sampling. As an example of this a recent survey conducted by the author covered an area of just under 1 sq. mile (2.6 km^2), selected as the pilot project for an irrigation development scheme. To give the necessary definition of soil units to an adequate level of purity 401 soil profiles were examined to a minimum depth of 5 feet. At this level of survey there is also a strong influence frequently apparent in favour of a parametric approach to the definition of the soil units. Where the objective is precisely defined, the presentation of soil data in terms of selected parameters of anticipated significance, instead of, or in addition to, a map showing more orthodox units can be of great value. This is particularly so in the case of layered depositional soils, which present marked difficulties in terms of orthodox profile - based mapping units.

Typical Area: Usually quite small. If a particularly large development area in envisaged it may be more practical to arrange a phased series of surveys to suit the planned progress of development. In terms of one soil surveyor plus a small staff of local field assistants and labourers, there is a definite limit to the area covered in a single annual survey. This obviously depends upon soil complexity, accessibility, ease of "going within the area and survey specification, but in practice it often seems to fall around a median figure of about 50 square miles (130 km^2), ± 25 sq. miles.

Photo Scale: 1:25,000 or larger and preferably near to the chosen mapping scale. Prints may be assembled into mosaics at contact scale, and individual enlargements of prints may be useful in the field for locational purposes during mapping. It is with surveys at this level of intensity that specialised forms of air photography are potentially most useful. Since most experimental evidence about them so far refers to large scale work it enables a better judgement to be made on their potential value than is the case with smaller scale surveys. Since the areas are small the cost per unit area of a photo contract is relatively high. Nevertheless, with development schemes, which usually involve a high level of capital investment, the cost of purpose-designed photography is likely to be justified by the potential advantages. It is difficult to decide whether there is a sensible maximum scale for such photography. Probably, given standard 9" x 9" prints, a scale of 1:2500, or even 1:5000 represents a maximum beyond which the relevant photo patterns, especially if separated by rather diffuse areas of transition, may not be conveniently recognisable within one or two prints, thus hampering boundary identification.

Map Publication Scale: This will depend to a large extent upon the complexity of the soil pattern and the overall size of the project, and therefore the number of sheets it is considered desirable to have. It will usually be larger than 1:25,000 and possibly larger than 1:10,000, especially if irrigation works or farm planning are involved. With the emergence of a parametric approach to soil mapping the presentation of maps for such a project may conveniently take the form of a single base map, perhaps showing the basic physiographic data, with transparent overlays to present the rest of the data in whatever combination may be momentarily required during the course of project planning and implementation.

Typical Subject Map Categories:

1. Integrated: not used.
2. Soil: phases of soil series, or specific parameters, e.g. the top-soil texture, or the sub soil pH.
3. Vegetation: species distribution, tree counts, etc.
4. Geomorphology: landform elements, or slope units, e.g. levee, river terrace, or slopes of <2%, 2-5% etc.
5. Landuse: detailed map of crops, and/or field distribution at the time of the survey (i.e. not from old photography). Alternatively or additionally, a map of the proposed land use and/or field layout.

Background Data:

1. Hydrology: (relevant to irrigation and erosion control projects) detailed stream flows, sedimentation loads, seasonal and regional water-tables, water quality.
2. Climate: detailed local climatic records, if necessary obtained ab initio; also initiation of micro-climatic studies.

Remarks: Development studies represent the greatest test for soil surveys. It is most commonly at this level that the soil map and report form a basis for critical investment decisions and operational planning. Work at this level should, therefore clearly show by means of reliability diagrams, the surveyor's assessment of the purity of the mapping units. He should also describe the nature and degree of variance from his modal descriptions. This is not a criticism of soil surveyors. It is not uncommon, for purely physical resons such as accessibility, available base maps and photography, time, and so on, for surveys to be qualitatively uneven. Where this is so, it should be clearly specified so that engineers and planners know the basis upon which they are working, and authorities may decide whether to commit further resources, and allow more time, perhaps at a later stage of the project, to survey.

V. MANAGEMENT PROBLEM STUDIES

Type of Survey: Parametric, single aspect studies

Objective: Follow-up studies, to answer immediate agronomic problems. Such studies may become desirable in relation, for example, to variable crop performance. It should be appreciated that whilst they may not in themselves provide an answer, they can make a vital contribution to the precise definition of the enviroment for experimental work concerned with the solution of particular problems and the establishment of medium and long term research for improved management. A growing collection of such records may have a significant contribution to make to agronomic knowledge.

Method of Survey: Predominantly detailed field surveys, based upon very high sampling densities for profile inspection, related to the appearances or performance of the crop/s. In the case of crop diseases, specialised photography such as false colour and infre-red may have a particularly relevant part to play.

Typical Area: Unspecified but rarely more than a few acres or hectares.

Photo Scale: Rarely smaller than 1:10,000 and often larger than 1:5,000, usually with photography being taken for the purpose.

Map Publication Scale: Published map are not always necessary. For the agronomic records, a very large scale map showing the distribution of significant soil factors in relation to the problem may be extremely valuable.

Typical Subject Map Categories: Each case has to be decided on its merits; often using *ad hoc* parametric units, e.g. salinity categories or bulk density of specified horizons, provided initial examination can suggest possible significant parameters.

Background Data: As required for each case.

General Remarks: Such surveys are rare to date, but potentially they have a very valuable contribution to make to tropical agronomy. As land use in the under-developed countries becomes increasingly intensive in the future, management planning will increasingly require work of this kind, associated with pedological research in depth, if increasingly fine profitability margins are to be sustained. In this context the remarks of Collis-George and Davey (1960), about the adequate instrumention of the experimental environmental environment, (especially where sensitive inter-actions may exist between micro-climatic or pedological factors and plant behaviour) are especially relevant.

ORGANISATION OF SOIL SURVEYS

From the foregoing it will be clear that modern soils surveys are becoming increasingly complex and frequently conducted in association with a much more elaborate appraisal of the whole physical environment. Where it is necessary to assemble a substantial team of overseas officers and local personnel, to obtain, possibly even fly new, photography; where transport and equipment and accommodation have to be assembled and supplies arranged; where arrangement must be made for cartographic support, laboratory support, and such aspects as data retrieval and finally publication, all to a time schedule, which itself may be governed by seasonality in the survey area, a Land Resource survey can become a very complex piece of planning itself.

TIME, COST, SAMPLING DENSITY

Comparatively little is available in the literature relating cost to sampling density, or the latter to the scale of survey. Tavernier and Sys (1965), quote the following data for the Republic of Congo-Kinshasa: 1:50 000 maps based upon 3-5 profiles per 10 ha. were produced by pedobotanical missions for 1.5% of the country; general surveys based upon 1 profile per km^2 were completed for 15% of the territory and these surveys include a limited amount of semi-detailed sample areas with 3-5 profiles per 10 ha. Vink (1963), gives a table listing 10 levels of survey, quoting sampling densities for each. Steur (1961), also quotes sampling densities for various scales of survey, but these, as with many others, refer to work primarily carried out in Europe and North America. They indicate densities ranging from 20 observations per hectare (2.5 acres) to 1 observation per 3 hectares (7.5 acres) for scales ranging from 1:5 000 or greater to 1:25 000, (Beckett, 1968). At larger scales, Vink's table suggests 1-3 observations per km^2 (0.4 sq. ml.) at 1:50 000, and <1 observation per km^2 at scales smaller than 1:200 000. O.R.S.T.O.M. use 1-2 observations per cm^2 of the soil map.

This reflects the fact that sampling density is controlled by two inter-related factors: The complexity of the soil pattern and the purity of the mapping units as stipulated in the survey specification.

It is difficult however to find a suitable basis for presenting costs, if one accepts that cash values quite quickly lose meaning through rising costs. Veenenbos (1957) and Vink (1963) use only relative terms, giving the % time saved by the use of air photo interpretation, or the area mapped per unit time at different scales, using air photographs.

Smith (1965), mentions costs of $2 per hectare for high intensity and $1.25 for low intensity detailed surveys. Francis (1962), in discussing pre-investment surveys quotes costs of resource appraisal, presumably within the experience of F.A.O., as being from 2-5% of the estimated capital investment involved in implementing a promising project. Beckett and Bie (1970) and Beckett (1968), as part of the Oxford Group's interesting and informative investigations into the efficacy of soil surveys have reviewed the available literature on costs relative to the scale of the survey and the survey procedures, further attempting to relate these to the precision and adequacy of the results. Beckett summarises costs in the general statement of principle that cartographic and clerical costs are approximately constant per unit area of map, thus decreasing in proportion to the square of the map scale when expressed as costs per unit area mapped, whilst the field costs tend to be proportional to the number of soil observations made and the number of observations per unit area mapped is proportional to the square of the map scale. A survey made by the author (Stobbs, 1963) was completed and the maps and results published for a cost of approximately £8 per sq. mile, for a mapping scale of 1:50 000. This figure however makes no provision for a proportion of the administrative overheads of the Department and Ministry under which the survey was carried out.

WORK SEQUENCE

The tasks involved in a survey, of whatever scale, can be broadly sub-divided into pre-field work, field work and post-field work. For small and intermediate-scale surveys of reconnaissance or extensive type the sub-division of working time between these phases is about one-third each. For an exploratory survey, especially one wherein the mapping units display a strong relationship to the physiography, the pre-field work stage may be proportionately greater, roughly up to one half of the total, the additional time being mostly at the expense of field work. The emphasis shifts towards field work as survey scale increases. At the development study level there is usually a very marked increase in the proportion of field work to more than half the total project time, and as much as 75% of the total scientific man hours because it becomes necessary to prove that the soil units mapped are of the requisite purity and to prove that the boundaries are placed in he position of "best fit". This emphasis upon proof becomes necessary because of the possible capital investment that may be decided upon the basis of the survey.

Where the soil surveyor is a member of an integrated team, it is highly probable that the overall pace of field work will be dictated by the soil survey requirement. The soil surveyor must dig for his data and consequently can take least advantage of air photographs - by definition he should also be last to carry out his air photo interpretation because of the inferential evidence provided for him by the equivalent work of the geomorphologist and ecologist.

<u>Pre-field Work:</u> This phase of the work comprises chiefly air photo interpretation and the collection of background and analogous area data. At the end of this phase it is commonly useful to have the results of the photo interpretation compiled into a provisional map supported by a proposed mapping legend and a set of notes summarising available environmental knowledge. The phase may start, where necessary, by defining the requirements for additional air photography and it will include the assemblage of photo mosaics, particularly if these are required in lieu of inadequate or non-existent topographic base maps. The scale of available photography will strongly influence the amount of time required for interpretation. For example, if a small scale reconnaissance survey of a large area has to utilize 1:20 000 photography, a much greater number of photographs will have to be handled and annotated than if the photography had been available at 1:50 000. In such circumstances it may be necessary to annotate the photo details and demarcate many more boundaries than may ultimately be required for the published map, because the restricted area of a stereo pair limits the ability to make running decisions on what detail and which boundaries will ultimately prove to be significant for the chosen mapping scale. In this context photo mosaics produced at such reduced scales from contact prints can be invaluable in helping to make such appraisals. Initial decisions will be required at this stage with regard to final map scale and approximate sampling densities in the light of evidence

collected during the pre-field phase. Photo interpretation may well be the longest single task, particularly in exploratory work. For example, Bawden and Stobbs (1963), spent approximately 8 man months on photo interpretation compared with less than 6 man months on field work. If new base maps may be required to present the data, or modifications of existing available maps may be required, initiation, at this stage, of a procurement programme, can save considerable time later.

Field Work: This is based upon three basic survey procedures, used separately or in combination. These are free survey, grid survey, and physiographic survey as defined by Beckett (1968). Physiographic survey is the form most commonly encountered in under-developed areas, at least down to the development study level. Remote censors are used, usually air photographs of various kinds, and with their help the boundaries of the units are plotted. The field work is then designed primarily to characterise the soil content within the boundaries, which are only likely to be checked in the event of a uniform and comparatively featureless landscape which provides few clear physiographic boundaries. One of the commonest difficulties in this kind of survey procedure is a lack of correlation between the photo patterns and soil units of a constant taxonomic level. The surveyor is then faced with establishing an artificial but meaningful local classification to describe the content of his units and must be able to make some statement about their purity. The selection of sampling densities to achieve this objective have in the past been mainly subjective but statistical theory is being increasingly applied to such problems and a current major survey by the Land Resources Division involving an area of some 60 000 sq. miles is testing a method of statistically adjusting the sampling density and its spatial distribution, to enumerate the soil units within each defined land system and test the validity of the system boundaries in a very uniform landscape (Lang, in preparation).

Free survey means essentially that the sampling is not fixed along any form of pre-determined line such as a formal traverse or a footpath, but, having by preliminary inspection outlined the properties and variability of the units to be mapped, proceeds to concentrate field sampling on locating the boundaries of these units with some precision. Free surveys tend in our context to grade into the physiographic type of survey where mapping so frequently depends upon the recognition of landscape features, true examples of free survey being rare.

Grid surveys may utilize either regular or irregular grids, the former normally taking a form of a compass controlled cut-line, the latter making at least partial use of roads and footpaths, although with the general intention of ensuring a reasonably even spread of traverse line per unit area. Irregular grids were common with reconnaissance level surveys before the widespread availability of air photographs. Regularly spaced traverse grids become increasingly common in development studies with increasing map scale, and greater concentration upon the single aspect approach. Sampling along the grids may be regularly spaced, or selectively intensified according to the visual complexities encountered. At the most sophisticated levels of development study, for example in planning the layout of an irrigation scheme, a basis of grid traverses will be supported by substantial interline sampling (a modified form of free survey). With the sampling density being progressively intensified until a fully proven satisfactory answer is obtained in terms of the precision of the boundaries the purity of selected soil units.

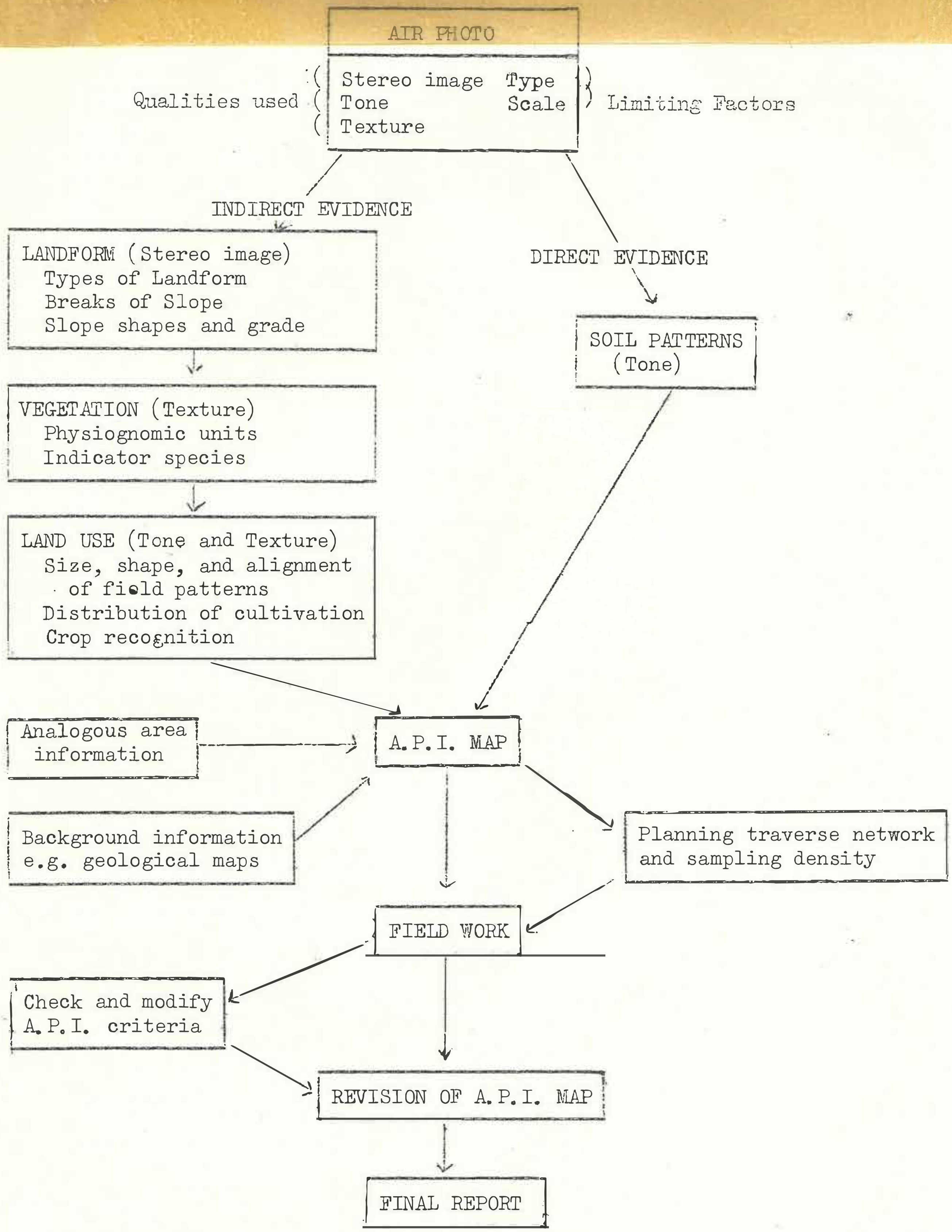
Much interesting research has been conducted in recent years by the Oxford Group led by Beckett into the definition of soil units, the location of boundaries, the assessment of surveys conducted by different methods, and the application of statistical techniques in refining the approach to such problems (Beckett and Bie, 1970, Webster and Beckett, 1964, 1968, Webster and Wong, 1969, Burrough, 1968, Beckett, 1967). From their work evidence is available relating to the adoption of particular survey procedures in given circumstances. As the survey scale becomes larger, for example, a grid survey appears to be relatively more efficient than a free survey. They also investigated the relative efficiency of different levels of expenditure on staff, by conducting surveys on both a free and grid basis by a scientific officer and scientific assistant respectively. The general conclusions to this work indicate that the grid survey can be more readily conducted than the free survey by the less sophisticated assistant, who will be able to achieve a high relative proportion of the scientific officer results in about the same time, but of course at less cost. This has important implications for survey work in under-developed countries where the availability of highly trained graduate personnel is extremely limited, but it is possible to obtain and train intelligent but less highly qualified local assistants.

Their series of experiments also suggested that it is possible in some conditions for a few well chosen critical parameters to provide as good and more cost-effective an answer in terms of soil maps than the use of some traditional unit such as the soil series. Webster and Wong (1969), demonstrate the potential value of Principal Component Analysis in reducing several soil properties to a single variate expressing a large proportion of available information. By using this principal component as a quantitative measure at sampling points, and plotting the result against distance they found it possible, except in flat terrain, to use this procedure to site soil boundaries. This seems to favour a parameteric approach to soil mapping. An interesting corollary to this work, on soil mapping units and their purity, is that the experienced soil surveyor is still potentially capable of making the best fit of profiles into classes on a subjective basis compared with computer selection based upon a number of parameters. This presumably must reflect the difficulty of selecting parameters with a high degree of correlation. On this latter point Burrough (1968) made interesting studies of the changing contribution of individual parameters to total variance, which shows quite separate groups within which there is a high degree of inter-dependence, but between which there is a much lower correlation.

Though these conclusions and inferences seem to be most applicable at the large scale, detailed, development study level they should prove of practical value in helping to define procedures for future surveys. For example it suggests that a useful distinction can be made between surveys dealing respectively with depositional and erosional landforms. The former, because of the high degree of non-predictable variability due to successive, frequently

FIG 3.   AIR PHOTO INTERPRETATION IN SOIL SURVEY

The type and scale of air photography determines the amount of detail which can be identified and interpreteted by means of the stereoscopic image, tone and texture of the photo patterns. The diagram below refers to the use of panchromatic black and white photography.



genetically unrelated, depositional layers, is best approached on a high intensity formal grid survey basis. On the other hand erosional areas, especially those associated with peneplains and extensive pediments on which there is a greater tendency to a regular spatial distributional rhythm, lend themselves to free and physiographic surveys, to which statistically controlled random sampling procedures may be applied (Lang, in preparation).

Air Photo Interpretation: The role of air photo interpretation in soil survey is now well understood and can be conveniently summarised in diagrammatic form in Fig.3. Few areas now lack air photograph coverage, and the advantages to be gained by using air photos in terms of time, detail, and precision have been set out many times (Buringh, 1960; Vink, 1963; Soil Survey Staff, U.S.D.A., 1966, Goosen, 1967, to mention a few of the more prominent).

Fig 3

Remote sensors for Soil Survey

It is in the field of remote sensors that some of the potentially most important technological developments are occurring. Since they involve some form of airborne or space platform, and the sensing and processing equipment is complex, it follows that they are expensive to obtain and the conditions under which they are worth obtaining should be precisely spelled out. Unfortunately, probably because of expense and complexity, few field tests have been undertaken outside North America and Europe. Most work so far published refers to work using large scales (> 1:25 000, and as large as 1:500) and little of it refers to soils. Frey (1967) tabulates a number of prominent experiments of which only three mention soils. It is thus possible to draw few conclusions relating to the kind of surveys being discussed here.

Because of scale, space photography is unlikely to be of much value in the immediate future, save in verification of macro-patterns concerned with the smallest-scale reconnaissance and exploratory work.

More can be hoped for at larger scales from photographic and non-photographic sensors of the electromagnetic spectrum. From 0.3-1.2 /u conventional cameras and photographic techniques can be used to produce panchromatic black and white, true colour, false colour infra-red, and infra-red photography. From 1.5-14.0 /u the 'thermal' infra-red spectrum is recorded by optical-mechanical scanners transmitting a signal to magnetic tape or cathode ray tube for direct film recording. Radar sensors (chiefly side-scan radar) operate on wavelengths between 0.5 cm - 100 cm.

The sensing capabilities of these various wavelengths may be mobilised in various combinations referred to as multiband[2] and multispectral[3] sensing.

FOOTNOTES:

1. "Remote sensing" refers to the use of devices, mounted on airborne or space platforms, sensitive to visible or invisible radiation, which record physical phenomena by measurement of the emitted or reflected radiant energy. The devices may be photographic, or other forms of imaging or non-imaging equipment.

2. Frey (1967) defines "multiband" as "referring to images formed, usually simultaneously, in more than one portion of the photographic region of the electromagnetic spectrum and analysed jointly".

   This commonly means obtaining panchromatic, true colour, false colour infra-red and infra-red photography by special multiband cameras, using films and filters in combinations to suit the expected photometric analytical requirements for objects examined. This includes the process known as "colour enhancements".

3. "Multispectral" in this sense refers to non-photographic imagery obtained simultaneously from more than one part of the electromagnetic spectrum, for joint analysis. It can also include the data derived from non-imaging sensors. Research in this field is much concerned with identifying spectral "signatures" for physical objects.

Colwell, (1968) and Simonett, (1968) recently reviewed the state of Land Evaluation studies in relation to both the photographic and non-photographic regions of the spectrum. Colwell points out the advantages obtainable from false colour. It distinguishes healthy vegetation by reversing the green to red, whilst the reddish hues in soil are reversed to green. In conditions where tonal contrast on black and white film (panchromatic) might be hard to attribute correctly to fine herbaceous cover or direct soil reflectance, this can be a useful advantage. It would not necessarily be any better than true colour films for the surveyor however, and the reversal of colours would make it rather more difficult for inexperienced personnel to use. Colwell also points out that false colour has the ability to penetrate haze due to its sensitivity to long wavelengths and the exclusion of short wavelengths, and where late dry season photography is required in areas characterised by seasonal burning, this might suggest its possible value. Simonett's comments concerning the thermal infra-red region and the use of emission spectroscopy to examine it, seem to point to a possible future value to soil surveys in conditions in which mineralogy may be significant in identifying soil types. He also draws attention to the capability of such a system to detect, by means of a succession of flights over an area in the course of a day, useful information concerning such soil factors as bulk density and moisture content, by examining the daily cycle of thermal response. He stresses however that such work is still very much in the experimental stage, and geometric distortions and limited resolution leave present thermal infra-red imaging systems inferior to cameras.

Myers and Heilman (1969), in a later paper claim to have used thermal infra-red sensing to obtain a qualitative indication of soil water to a depth of about 50 cm in bare soil. De Loor (1968) clearly spells out the circumstances influencing the use of thermal infra-red scanning systems and confirms their potential relevance to such properties as permeability and soil moisture content.

Simakova (1959) compares photography taken on panchromatic, infra-red, three-layer colour, and two-layer colour and claims interpretative superiority for three layer colour, and two layer colour taken through light-yellow or orange filters. Parry et al (1969), more recently concerned themselves with attempts at soil identification by comparing true colour photos with the hue, value and chroma of the soil in the field. They concluded that it helped to distinguish types within a series and distinguish changes dependent upon differences in soil moisture or organic matter content. Andronikov (1967), refers to Russian studies of the spectral reflectance capacity of soils leading to a characterization of the brightness of soils in both the visible and "invisible" regions of the spectrum. A relationship is claimed between spectral brightness and humus content, texture, moisture content, nature of the surface, degree of podsolisation and other factors. This data is used to decide the best spectral zone in connection with aerial photography for soil purposes.

From these and many other similar papers few firm conclusions can be drawn, by reason of the scale of the photography used, their dissimilar experimental environment and the generally vague nature of the statements concerning superiority. This accords with the results (unpublished) of a trial conducted in the Land Resources Division by Blair Rains, using panchromatic, true colour and false colour. Assessed in terms of time saved in photo-interpretation, or length of boundary defined, the superiority of either colour form over panchromatic film was at best marginal, given experienced interpreters.

The conclusions may be summarised thus:

1. Work on the thermal infra-red region is still in the experimental stage and is inconclusive, though promising.

2. False colour infra-red may have advantages in particular situations as indicated above.

3. True colour photography has a definite advantage where the soil surface is visible and colour distinctions are significant mapping factors - there are 20 000 variations of hue, and chroma reportedly visible to the human eye compared with no more than 200 shades of grey (Parry et al, 1969). Colwell (1968) discusses the technical attributes of the colour films commonly available.

4. Forms of photography other than panchromatic can frequently be useful through providing the soil surveyor with additional indirect evidence from better definition of other aspects such as vegetation. In this case integrated surveys would seem to have a stronger claim to special photography than most soil surveys.

Multiband and multispectral techniques reportedly improve object detection and recognition by increased image contrast (Malila, 1968). Frey (1967), reviews research recently proceeding into this method of applying remote sensing and Colwell (1968) discusses the theory of tonal and spectral "signatures" implicit in it. Colwell also mentions, as do Myers and Heilman (1969), the possibility of this approach lending itself to automation via a variety of scanning devices. Again, though interesting, this work still lies largely in the experimental arena and no soil surveys have been reported as having made extensive use of such techniques.

Simonett (1968), discusses radar remote sensing (chiefly side-scan radar) and concludes, as does De Loor (1969), that its chief advantage is its all-weather capability. Both agree it is best suited to reconnaissance work at 1:100 000 - 1:500 000 and it offers more specific possibilities at this stage to forestry and geomorphology than to soils.

Post Field Work: There are two aspects of post field work which are of relevance to the context of this paper: laboratory analysis of soil samples, and preparation of the soil maps. Both are initiated in the course of field work and particularly where the soil map may require a non-standard base, forward planning is necessary (Fig.2).

Soil Analysis: Laboratory resources are very limited in many of the areas with which this paper is concerned. To make the best use of available resources and/or to minimise overseas transport of samples it is desirable to have a clear policy for analysis. The Land Resources Division has established the following four categories:

1. Routine analysis
2. Fertility studies
3. Irrigation studies
4. Studies for purposes of classification and pedogenetical studies

The needs of each survey can be discussed in terms of possible requirement in each of these categories, having regard to the objective of the survey (Table 1).

Interpreting analytical results arising therefrom, in the sense of defining their significance for agronomic purposes is a sphere which lends itself more readily to the immediate application of statistical techniques than most parts of soil survey. Papers by Holland (1968), Hanotiaux (1966), Dzubay (1965) and Skene (1960), for example, have discussed the application of such techniques to calculating the number of samples required to achieve specified standards of characterisation, to determining degrees of error attributable to such variables as sampling depth and to analysing the laboratory results themselves by such techniques as component analysis.

Soil Maps and Illustrative Material: From the point of view of the soil surveyor, three separate activities are of concern; preparation of a suitable base map; compilation of his field data onto the base map; and preparation of illustrative material such as block diagrams and profiles.

For base maps, photo mosaics and orthophotographic maps can offer alternatives to orthodox maps, but are used normally only in the absence of suitable orthodox maps. Rhody (1966) set forth the advantages of orthophotography for forestry, but for soil work they do not appear to hold any present advantage, other than possibly facilitating the alignment of the field annotated air photographs with the relevant physiographic features. Base maps, block diagrams and cross-sections can nowadays be compiled by automated processes. In the case of illustrative material this can be done directly from the photograph if desired. If the survey data are collected on a referenced point sampling basis (Stobbs, 1968), usually utilising air photographs, they can be prepared for computer processing, and diagrammatic print outs can be obtained which serve a useful, though usually interim, purpose.

The present lack of examples of these applications in soil surveys of underdeveloped areas reflects more the fact that the necessary equipment is not yet in widespread use among cartographic organisations, than any unwillingness on the part of soil surveyors. It is the cartographers who stand to gain in efficiency in due course - the soil map will still be qualitatively the same.

CONCLUSIONS

The past decade has not seen the emergence of any new techniques representing a radical departure from existing practice, which are ready for full scale objective, but technological improvements, particularly in the remote sensing sphere, have yet to be thoroughly tested in the conditions with which this paper is concerned. When this has been done it will be possible to lay down guidelines governing their use.

In the underdeveloped world this reflects the scarcity of funds to devote to purely experimental projects, and above all of time, staff and equipment to carry them out, while there is so much of an urgent and practical nature awaiting attention.

This paper has attempted to clarify the relationship between soil survey and national development with a view to defining those activities in which it may now be feasible to consider introducing advances in technique.

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