development, (5) payment capacity, (6) irrigation benefits, (7) irrigation and drainage systems, (8) land appraisal, (9) irrigation assessments, (10) environmental assessments, (11) return flow water quality, and (12) social impacts.

The fundamental requirement of the classification system addressed in this report is to define, for the time, place, and economic and social setting, what is to constitute a finding of irrigability and then to establish principles and procedures for land classification that permit a critical selection of the irrigable lands. Irrigation presents a unique capability with great promise for the future of many people. Planners have a moral duty and a technical responsibility to apply skillful planning techniques founded upon sound concepts of land and water use.

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Evaluation of Soil Resources by ORSTOM

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Since 1946, Office de la Recherche Scientifique et Technique Outre-Mer scientific workers have drawn up more than a thousand soil maps, from moist tropical forest to Sahelian regions, from Black Africa to the Mediterranean areas, the West Indies and French Guiana, and the Pacific islands. The primary aim between 1946 and 1956 was to catalogue types of soils, often unknown to begin with, and map them on a medium scale (1:200,000). Subsequently, four other types of maps were prepared: two large-scale types for development schemes (1:50,000 and 1:20,000); and two small-scale types for regional planning purposes (1:500,000 and 1:1,000,000). For various reasons, government departments in the countries involved differed considerably in the use they made of these maps. Certain technical services had considerable difficulty interpreting, in development terms, maps and reports written by soil scientists. Aware of this difficulty, ORSTOM prepared new documents to supplement soil maps to provide a clearer definition of soil capabilities. As time has gone by, various methods of presentation have been used. It is the experience of ORSTOM in this area that is described in the following report.

USERS' NEEDS AND DIFFICULTIES IN RESOURCE EVALUATION

The land user's ideal would be to have documents giving, for each soil type, all possible forms of crops and optimum conditions of usage to ensure maximum yield, while preserving natural fertility. For many reasons it is extremely difficult to achieve this objective in most tropical regions.

To begin with, the state of soils knowledge varies widely depending on world regions; but in general, agricultural research does not yet provide all the factors needed to define all the opportunities of use for each type of soil.

Next, assuming that this objective can be achieved, another very important problem involves the wide range of possible farming methods, from the most intensive to the most extensive. Between drip irrigation, drought-animal tilling and the extensive stockbreeding of the Sahelian nomads, there exists a whole series of possible farming methods, which depend mainly on local social and economic factors as time passes. This is impractical, at any rate for soil scientists.

Finally, there is the problem of map scale. There are three scales to be considered: for soil distribution on the ground, for land use by man, and for soil maps. Soil distribution on the land is closely related to topography and parent material variations. Soil types succeed one another in a toposequence over variable distances: some tens-of-meters in some cases; a few hundreds in others; and thousands of meters are occasionally found. In these circumstances, maps show pure soil units only when they are large-scale or very large-scale. When medium or small-scale, soil units become complex, regardless of the method of classification or taxonomy.

By soil-utilization scale is meant the size of farming units. This factor can vary considerably, from a few acres for the family holding for market gardening, to several thousand hectares for the stock ranch. The method of utilization of soil maps will differ considerably depending on such factors.

Finally, the soil map scale is rarely determined by ground truth, in other words, by the soil-distribution scale. It is sometimes determined by the objective, for example an irrigation scheme or regional planning. But it is usually governed by financial requirements, and in most cases the map scale is much smaller than the soil distribution scale. Consequently, most maps represent complex units, usually soil associations.

An association is a combination of soil types consisting of one dominant soil and its associated soils, which when grouped together often corresponds to a geomorphological unit. An association may comprise soils with very different capabilities, sometimes incompatible with one another. And that is what frequently makes soil maps difficult to use. The concept of capabilities is a complex one: the capabilities of the various soils in an association differ from one another increasingly as agriculture intensifies. On the other hand, for unmechanized agriculture in Sudan regions, involving very little or no fertilizer use, many types of soils could be grouped together. This can be done even if they are labelled differently by soil scientists in order to conform to classification or taxonomic rules, provided that they allow the same range of crops. Differences among these soils will involve the level of yield of the various plants grown, in relation to inputs or farming techniques.

These remarks suggest the separation of two types of factors affecting capability: one factor concerns the suitability or unsuitability of soils for a specific use; and the other factor concerns soil fertility levels in relation to different cultivation methods, and depends on intensiveness and on complexity. The case of suitability or unsuitability involves the concept of limiting factors or utilization constraints. The second case must take into account, for each particular use, soil capabilities in relation to likely inputs and social and economic conditions.

This analysis of users' needs and the difficulties of meeting them in tropical regions explains the decision by French scientists to use different methods of cartographical representation.

SOLUTIONS ADOPTED

Various technical solutions have been adopted; they vary depending on the climatic environment, as well as on map scale. In most cases, however, maps have been drawn on the basis of a conventional soil map. A few examples may be given to illustrate this. A very great number of large-scale soil suitability maps (1:10,000 or 1:20,000) have been produced, for Cameroon, Madagascar, the West Indies, etc. This is the most straightforward case, in which soil units represent a single type, and in which the caption indicates possible uses. Two categories of maps have been established in Tunisia, one showing suitability for dry farming, and the other suitability for irrigated farming. Together with the soil map, users accordingly have three maps with different legends.

Another method is at present being tried in French Guiana, where soil variability is very high. Soil cover is not characterized by specific contours but by isodifferentiation curves. Toposequences are represented in cross sections or diagram blocks. Agricultural engineering units categorize all soils with the same type of drainage. In view of the major effect of lateral circulation of water in upper horizons, for example on plant rooting and on soil erodibility, this is the characteristic method to categorize soils with a morphology that changes quickly on slopes.

Not many examples exist of medium-scale soil suitability maps based on conventional soil maps. There is, however, the case of a soil-resource map taken from a 1:200,000 soil map, with an agricultural engineering unit key. The method, performed on a small scale (1:500,000), will be described later. On the other hand, maps exist combining geomorphological and soil data and defining wide farming suitability groups. Two systems are being worked out. One of these, produced by Institut Recherches Agronomie Tropicale (Paris), first defines morpho-soil units on the basis of an interpretation of links between morphogenesis and pedogenesis. It then assesses the capabilities of the physical environment, allowing constraint maps and land-allocation recommendation maps to be drawn. The second system, at present being developed by ORSTOM in the Ivory Coast, concerns morphological and soil landscapes to the scale of 1:200,000. Internal drainage, water-holding capacity, percentage of coarse components, and rock depth are given for each unit. Information on agricultural suitabilities is supplied in the text accompanying each map.

For small-scale maps (1:500,000 and 1:1,000,000), it is difficult to define soil-utilization possibilities in a key, because the map includes complex soil units or soil associations. However, planners are interested in such soil maps insofar as they make a useful contribution to the choice if not of crops, at least to possible systems of exploitation. This is why authors of the various maps that have been drawn confine themselves to showing either a wide classification of agricultural qualities (rich, fair, poor), or very general farming possibilities, such as dry farming, irrigated farming, or grazing. A typical example is the 1:1,000,000 map of New Caledonia.

Another method has been tested in Sahelian regions, notably in Upper Volta: the "soil resource map." It is based on dividing soil cover into units suitable for the same type of traditional or extensive farming. Anything is possible in intensive farming, where the soil may be no more than a physical support. For example, let us consider the sand dunes, found over wide areas of the Sahel. It is not recommended that the dunes should be used to grow millet, since this traditional crop results in movement of the dunes by wind erosion. But it would be possible to recommend drip irrigation with the use of fertilizer and manure to grow strawberries, as is done near Dakar. Given the social and economic situation in the Sahel, a 1:500,000-scale map provides only for low-intensive or medium-intensive cultivation, with an emphasis on utilization constraints. These constraints comprise those which cannot be altered by human intervention, and those which can be changed more or less easily. The former constraints include soil depths and textural classes, which govern suitability or unsuitability for a given purpose. The latter include chemical richness, which can be altered by the use of fertilizers; soil water resources, which can be improved by irrigation; and the upper horizon structure, which can be altered by working the soil.

From a practical viewpoint, the method is based on prior establishment of a fertility factor table. Eight soil characteristics have been selected as governing farming capabilities. The order in which they are given is based mainly on the degree of constraint: the first two, depth and texture, are immutable, as mentioned above; the others can be altered by human intervention. Fertility factors are as follows:

1. Available depth: *this is not the depth of the soil but the depth that can be reached* easily by roots (cf. presence of gravel in many tropical soils).
2. Textural type: this is represented by two textures: the upper horizon and the B horizon (importance of textural variation is for rooting and water dynamics).
3. Existing water economy: this is the available water and its variation in relation to climatic season, namely soil moisture characteristics.
4. Chemical features: these consist of the sum of cation exchanges and base saturation.
5. Deficiencies (e.g. phosphate).
6. Presence of adverse chemical elements (e.g. free aluminum, sulphides).
7. Organic matter: quantity and quality.
8. Adverse physical properties (e.g. sealing).

The fertility factor table was composed by analyzing the references on 1:500,000 soil maps. Next, units were categorized on the basis of soil types ("dominant" types) in the same class for soil depth and textural type (in other words the two inalterable units) on the basis that they represent fairly homogeneous groups for agricultural purposes. It is understood, of course, that the types of "associated" soils that they contain may vary, with different capabilities or at least fertility levels.

This initial soil classification for defining agronomic units is inadequate for planning purposes, since small-scale maps are involved. Soil classified within the same unit—regardless of the method of classification used – may be distributed widely over different climatic zones from an agricultural viewpoint. This is why comparable agronomic units (according to average depth and textural type) have been subdivided on the basis of a third criterion, climatic zonality. The different zones take into account the length of rainy season or seasons, and also average rainfalls. Because of the insufficiency of such data in many regions and the year-to-year variability in Sahelian regions, zone boundaries are somewhat vague.

Ultimately, one obtains a key of agronomic units. Opposite each of the units of this key, there are details of constraints (erodability) and recommendations for land use (fertilizer requirements, working of soil, etc.). In practice, land use planners find out quickly from the map about comparable agronomic units. They then examine the table, which details the eight essential characteristics for each of them, representing fertility factors on the basis of which choice of specific uses may be made. Finally, land users refer to another table, which shows correspondence with soil map units. The reader should consult this soil map and the report accompanying it, first to find out about soil distribution in the landscape (toposequences, associations), and partly to discover the morphological and physico-chemical properties of each of the soils in the association.

Initial reactions from government departments are encouraging. Technicians seem to be less discouraged than in the past by the complexity of soil maps and soil scientist's jargon because of the preliminary reading of soil resource maps. They have therefore been found to meet a need.

CONCLUSIONS

Beek (1978) emphasized the high number of map systems aimed at evaluating soil utilization possibilities. The ORSTOM experiment does not allow any conclusions to be drawn about the advantage of one system over another. The choice must depend first on the scale adopted, second on the accuracy of available data, and finally on the local social and economic framework. Maps are easier to produce on a large scale. But planners often call for small-scale maps, wanting all farming possibilities to be defined for each type of soil, with an indication of the potential fertility level for various hypotheses of extensive or intensive cultivation. This objective cannot be achieved by soil scientists alone; but it would be reached if soil scientists, agricultural experts and economists combined their resources. Unfortunately, the state of agronomic knowledge of the average depth of profiles could involve the elimination of certain crops or their acceptance; the recommendation that mechanized methods should not be used; or accepting the methods with the risk of insufficient yields on a local and economic level—this last factor can vary in time. In addition, the idea of depth is sometimes counterbalanced by the concept of chemical richness, and advances in the development of new varieties further complicate the situation.

The state of affairs and regional planning needs in new African states have led ORSTOM to produce small-scale "soil resource" maps. These supplemental soil maps still have to be drawn. It is not their purpose to propose precise forms of soil utilization, but to stipulate constraints on use. In other words they list limiting or favorable soil factors, with quantitative details of soil erodability and the level of chemical fertility. Definitions of farming methods, which involve technical, social and economic factors, is at a later stage, which for the moment lies in the field of agricultural experts, planners and decision-makers.

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PART TWO

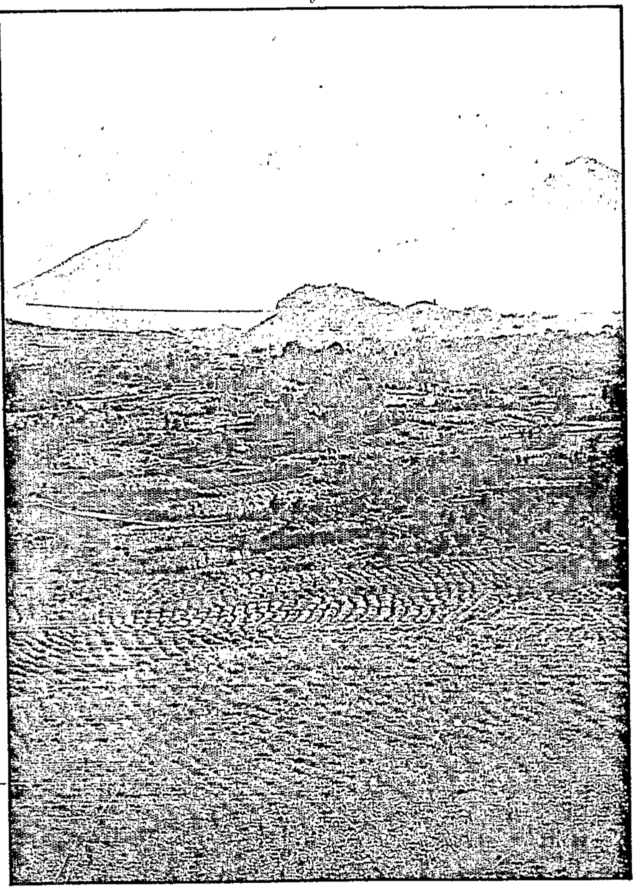
ADEQUACY OF SOIL RESOURCE INVENTORIES

Section I

Criteria for Appraising Soil Surveys

Soil Resource Inventories and Development Planning

Proceedings of Workshops at Cornell University 1977-1978



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