Soil Survey Interpretation, Land Evaluation and Land Resource Management

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Abstract *: The present land evaluation methodology has historically grown from former systems which have gradually been improved and updated. The main concern hereby is to come to an accurate and objective assessment system based on clear definitions and sound assumptions.*

The most recent evaluation procedure has been introduced since the mid-seventies by FAO. It is a crop-specific suitability system that is based on the comparison of plant growth and production requirements with prevailing environmental conditions. Five phases can hereby be distinguished: (1) identification of the land utilization type, (2) definition of its growth requirements, (3) compilation of basic climatic, soils and physiographic data of the study area, (4) matching of those field data with the crop requirements, and (5) determination of the suitability classes on the basis of the nature and degree of crop-growth constraints.

The ever increasing progress in technical know-how for reclamation and improvement of land provides good prospects for an appropriate land resource management in the future, both in the developing and in the industrialized countries.

Soil constitutes an important medium through which crops are grown, food is produced, water is filtered and sewage is dumped. This explains why mankind has always given good care to the soil and to its agricultural and other potentials.

In many parts of Europe, where, for obvious socio-historical reasons the family farms had almost continuously been split into very small plots. The introduction of a more efficient, modern and mechanized agriculture required a reallotment of the land. This regrouping of land and the reassignment of the property of one farmer to another could only be achieved after a thorough assessment of the land value.

During the war period the paramount role of the intertropical belt as a food supplier had also been emphasized, and as such a whole series of large development schemes were conceived in former virgin tropical and subtropical regions. The establishment of extensive rubber, oil palm or coffee estates promoted by the ruling colonial power, or of smallholders settlements in zones which were inexplored before, urged obviously for systematic investigations of the soil and its natural potential. The failure of large-scale agricultural schemes in zones where no such preliminary studies had been made —as was the case in the famous groundnut scheme in East Africa, illustrate the importance of such investigations.

Except for some scattered research projects, present-day soil studies are generally part of a commissioned integrated land resource programme, the major aim of which is often to increase the crop production and/or to improve proper land use. In those are as of the world where, due to the increasing population, a higher food production is needed. Soil surveys should in the first place, locate and determine the extension of highly productive land with a description of the inherent soil properties. They may as well define the so-called unproductive wastelands, and even indicate the appropriate technologies and costs for the reclamation.

A typical example of such a situation occurs in India where current projections show that, with an assumed annual demographic growth rate of 1.9 per cent the nation's population will attend the mark of 1 billion by the end of the century, asking for an increase in the annual food production (cereals and pulses) from the present 175 million tonnes to an anticipated 239 million tonnes. This goal can only be achieved through an increse of the per hectare yields and through a better exploration of marginally suitable lands or wastelands (Bhumbla & Khare, 1986; Khanna and Gupta, 1989; Khanna & Pavate, 1989). In this context it is logical that India's new Five Year Plan 1990-95 gives a major priority to the inventorization of natural resources including soil resources the reclamation of both saline-alkaline and acid soils and the proper exploitation of water resources (Planning Commission, 1989). If it is considered that in many parts of Bihar and Uttar Pradesh, rice yields on alkaline lands attend hardly 1 tonne/ha while after reclamation easily 3-4 times more could be obtained. Thus an intensive soil study programme may well pay off under those circumstances.

The problem is completely different in the industrialized world where, as a result of the air and water pollution, soils become enriched with various types of harmful components. Under conditions of a growing concern about the protection of the environment, the spectrum for soil interpretative research has tremendously been enlarged, mainly in view of the chemical treatment of polluted areas. Hence, the former classical soil studies or more recent land evaluation work is no more exclusively dealing with agricultural potentials, but has also to consider alternative uses imposed by nature protection laws and broad-scale town and country planning as a whole. The restoration of the original landform and vegetation cover in mining areas, such as in the immediate neighbourhood of rock phosophate and pyrite mines in the Dehra Dun region, in Bihar or in many other parts of India (Mathur *et al.* 1985; Soni & Vasistha, 1986) is an example of such an environment-oriented pedology.

Evolutionary Trends

From these introductory considerations it is clear that the initial study of the soil and the interpretation of its properties has tremendously changed. In the early approaches, with the limited knowledge on soils, interpretations and evaluations were easy and simple, and this work could well be achieved by one or two experienced persons.

With the development of soil science as an indepenent and more complex discipline, the role of the soil properties in crop growth and environmental behaviours has become better understood and therefore evaluation procedures had to take into account a much larger number of factors and conditions.

Even to-date important disparities persist in the approach towards land use and soil management planning, and those go often back to historical events or are directly linked to the scientific background of the investigators. The mainly pedogenetic approach, as followed by the French school, is challenged by the more agrogeological viewpoints in Germany, the pedogeography as promoted by some Russian scientists or the landform and geomorphological survey system developed by the Australian school (Christian and Stewart, 1953). In the past decades one may moreover note the growing emphasis on a soil chemistry and soil physics based land evaluation approaches, obviously linked to the increasing demand for fertilizers and/or soil structure stabilizers. An excellent historical review on soil science approaches is given in this context by Boulaine (1989).

In India, soil investigations at the present moment are often associated to agrochemistry, and are therefore strongly promoted by the fertilizer industry. The excellent book on 'Soils of India and their management', compiled and edited by Biswas *et al.* (1985) is a publication of the Fertilizer Association of India. Many private or public sector fertilizer companies sponsor extensive soil research programmes. The approach of the National Bureau of Soil Survey and Land Use Planning has, on the other hand, a more pedogenetic inspiration to introduce the current international trends in associating pedogenetic and classification criteria with soil behaviours and requirements for crop production and other land use alternatives.

In the most recent approaches at world level, advantage has been taken from the shortcomings experienced in the past. Soils are now interpreted in a broader context, whereby not only soil parameters are taken into account, but also consideration has been given to other environmental factors that have an impact on the potential of the land. These other factors refer mainly to climatic, topographic and water resources.

New approaches find generally their explanation in former experiences. Hence, it is obvious that for a better understanding of the actual trends in soil survey interpretations and land evaluation, a short historical review of concepts and methods of earlier systems may constitute a useful exercise. In this respect 3 fundamental trends can be distinguished, following a logical time sequence.

The Simple Soil Survey - Interpretation Approach

From the early start of soil zonality investigations and up till approximately the Early Sixties, soil mapping and interpretation was mainly based on a few individual profile characteristics like texture, drainage, soil depth and slope/erosion hazards. In this period, a major attention was paid to directly observable morphological and physical properties, and this attitude was fully reflected in the concepts used in the current classification systems. As such, in the USA the soils were differnetiated at a high level between Pedocals and Pedalfers, depending essentially on colour characteristics and on the eventual presence of free time in the profile. The mapping and classification of cocoa soils in the Gold Coast (Brammer, 1956) was also based on colour criteria, linked to the soil nutrient status. In the former American classifications of Kellogg (1949) and Thorp and Smith (1949), Latosols and Podzolics were merely identified on the basis of morphological criteria like colour and textural differentiations, although in the light of the present knowledge many of those great groups turn out to include a wide range in natural fertility and agricultural potentials.

Soil survey interpretations under those circumstances followed no systematic methodology with respect to the tyupe and number of the criteria to be considered. Hence, relative appreciations were mainly left to the personnal interpretation of the soil scientist. In cultivated areas, this soil appraisal was often based on the extrapolation and evaluation of crop yields obtained on similar, well-known soils. In virgin lands, where no such references could be made, the interpretative work was mainly based on the observation and evaluation of the native vegetation, which is a good expression of the natural fertility status of the soil. The appearance of a particular grass or tree species often reflects the chemical or nutritional nature of the soil profile. Hence, the presence of Imperata cylindrica is a good indicator for the occurrence and extension of the poor Oxiosols in Africa and the Far East. Various types of the Borassus palm in the Tanzanian coastal belt (Verheye, 1980) can be associated with patches of seasonally waterlogged soils.

The optimal benefit of this soil-plant relationship was achieved in the former Belgian Congo, where the systematic soil survey as part of the former INEAC studies was carried out by a multidisciplinary team, including a soil scientist and a botanist or phytosociologist.

The Complex Agropedological Approach

After the Second World War, the increasing demand for soil inventories and their agricultural applications made clear that a more systematic approach was needed, whereby the former somewhat personalized way of appraisals should be replaced by a more objective system based on a range of parameters to which a specific rating could be given.

A typical example of such an approach is the Capability System of the USDA Soil Conservation Service, published by Klingebiel and Montgommery (1966). This evaluation method lists a number of criteria that are essentially related to permanent physical or other characteristics that either limit land use or that impose risks to yields or to management potentials. The criteria considered and rated in terms of limitations to land use refer to particular to: (1) slope and erosion hazards for wind and water,(2) soil depth,(3) drainage, (4) workability, (5) stoniness and rockiness, (6) waterholding capacity, (7) permeability, (8) nutrient availability, (9) fertility status, (10) salinity and alkalinity hazards, and (11) climate.

Based on these parameters an interpretative evaluation is then achieved into 8 capability classes, indicating the potential to produce crops and pasture over a long period of time. The risk of soil damage or limitations in use becomes hereby progressively greater from class I to class VIII. Soils without major limitations and/or having the widest range of alternative uses (in terms of crops, pasture, woodland...) are assigned to class I; those that have important constraints and/or have the least number of alternative uses are grouped under class VIII. Because agriculture is considered to be of the highest priority, classes I to IV are mainly reserved for agricultural uses, while classes V to VIII refer essentially to non-agricultural purposes (forestry, pasture, wildlife...).

This capability system has been designed to assist farmers and various planners in the USA for interpreting soil maps and to enable broad generalizations in terms of soil potentialities, limitations in use and specific management problems. This system presents some inconveniences which are probably less important when applied by a small group at national level, but which may become very relevant when used at a wider scale. The major question marks left in this context may be summarized under the following three headings:

First: The system leads to a general appraisal, but does not deal with the growth and production of specific crops; each having particular requirements. This approach may therefore be very useful for broad planning purposes at regional and national level or for large-scale projects that ask for rapid, preliminary results at prefeasibility levels. It gives, however, no accurate answer to specific agricultural uses, because one and the same soil units may be very suitable for one crop, but unsuitable for another because of the various growth requirements for each of them. Wetland rice, for example, will produce best yields on lands which are too poorly drained, too frequently flooded, too impermeable or too difficult to work for other crops.

Second: The parameters which are taken into consideration are almost exclusively soil characteristics, and do not pay enough attention to climatic growth requirements. The system can therefore be considered as a crop-specific evaluation approach, but corresponds more to a key for soil survey interpretations, whereby the prime concern is given to a sustainable agriculture and to the risk of erosion and soil losses under a given management level. The capability ratings hereby obtained give indeed not a productivity scale for crops, but constitute a general appraisal for broad land use planning.

Third: The definition of the criteria is not always accurate enough so as to avoid different interpretations by different people. While, for example, the ratings for drainage, soil depth or moisture holding capacity are rather well defined. This is not the case for the climate, the fertility, can hardly be evaluated by one single value because the role of moisture and temeprature insolation, daylength,... covers a very wide spectrum.

Agropedological capability evaluations, based on similar principles, are currently applied by most French soil survey institutes and groups. This yields a so-called "carte des resources en sols (soil resources maps)" or a "carte des constraintes (map of limitations)", which indicate for each soil map unit the major limitations for land use, followed by a qualitative appreciation for crop growth. As this approach makes no direct link with the current agroclimatic conditions of the region, no quantitative appraisal can be achieved. Table 1 gives an extract of the map legend of such a "carte des resources en sols" for Togo (scale 1/200,000), established by Leveque (1978) and describing the agronomic units as derived from the soil map.

The Integrated Land Evaluation Approach

The factors that influence crop growth, have a direct impact on the production. Land use potential has led to a completely new approach, whereby a prime concern has been given to the plant and its specific growth requirements. This approach is mainly based on an initial listing of the crop production factors, followed by the evaluation of the degrees by which these factors decrese the yield.

In this concept, it is assumed that the capability of a land to produce crops is determined by the combined effect of

TABLE 1. Extract from the map legend of the soil Resources Map of Togo (scale 1/200,000)

Agron. unit	Soil map unit		Depth (cm)	Coarse fragm. %	Texture S=Sandy C=Clay	Drainage	Moisture reserve	Fertility
	Dom.	Assoc.						
1	11	8,9,10 11,12,16 20, 21,22	60-100	0-20	SC to C	Good	Very poor	Very good
2	36	5,12,13	130+	50-60	SC to C	Very good	Moderate	Medium
3	37	5,13	100+	55-65	S over C	Very good	Moderate	Medium
4	19	6,7,12 13	110+	60-70	S over SC	Good	Rather poor	Medium
5	38 39 42	2,3,4 6,7,12 13,19	120+	50-60	S over C	Very good	Rather poor	Medium to low
6	22	23,4 5,12,13	120+	55-65	S over SC	Good	Poor	Medium to low
7	8,16, 20,21,23	4,6,12 13	100+	60-70	S over SC	Rather good	Rather poor	Very poor
8	15	9,20	70-90	10-30	S to SC	Good	Moderate	Poor

By A.Leveque (1978), translated by Verheye

physical, human and capital resources of an area.The physical resources refer mainly to climatic characteristics, landform pattern, soil and moisture conditions. Human resources deal with the availability of farmers and to their ability for farming, i.e. mangement practices, land tenure conditions and social structures. Capital resources include the availability of funds.

While physical resources can be considered as relatively constant, human and capital resources are of a much less stable nature, as they may be affected by short-term options, political decisions or even by natural demographic evolutions. The evaluation of the physical resources can therefore be considered as a single operation which requires relatively few updating. The socio-economic context, however, is much more variable and needs regular reconsideration as a function of the changes which have taken place and which affect the productivity or potential of the land.

Basic principles and Assumptions

The basic concept and the principles of this new approach have been outlined *in extenso* in the FAO Framework for Land Evaluation (FAO, 1976). This document compiles also the five fundamental assumptions of land evaluation approach:

First: Land suitability can only be properly evaluated for a specific kind of use. This embodies the preliminary recognition of the fact that different kinds of land use have different requirements. The latter is a direct reply on the weakness felt while using the USDA Capability Classification (Klingebiel and Montgommery, 1966). From this assumption it is evident that a preliminary decision has to be taken with respect to the required land use before the evaluation procedure can be initiated.

Second: The evaluation requires a comparison of the benefits obtained and the inputs needed on differnt types of the land. In other words, the suitability for each use is assessed by comparing the required inputs with the yields or other benefits. This means also that highly productive land is not necessarily giving the highest benefits.

Third: The evaluation has to be made in terms which are relevant to the physical, economical and social context of the area concerned, and in this respect a multidisciplinary approach is necessary. This principle refers to the specific growth requirements on one hand and on their marketing value on the other hand. If it is clear that potatoes can not be grown in the humid tropics due to evident climatic and soil constraints, a similar limitation may occur when the production of a good cash crop is considered to be less relevant and thus not economical in areas which are too far away from the main markets.

Fourth: The suitability assessment must refer to the use of the land on a sustained basis. It is evident that short-term profitability must be disconsidered if this leads to environmental degradation or to other changes in the land properties, which cause a permanent depreciation of the area under study. Evaluation studies must therefore include in their assessments the probable consequences for the environment and for a long-term productivity.

Fifth: Evaluation exercises include the comparison of more than one single kind of use. This means that an evaluation is only reliable if the benefits and imputs from any given kind of use can be compared with at least one, and usually several different alternatives. Those may include the comparison of different crops within one mangement type, or may relate to differnt farming systems and even come up with a choice between agriculture, forestry, ranching or other uses. This principle is in full agreement with the approach by Klingebiel and Montgommery (1966).

It is clear that soil is not the only medium for such growth. Indeed, the ability of the land to grow crops is not only determined by the individual soil properties, but also by other environmental factors. In that respect a differentiation had to be made between the (limited) concept of a soil and the (broader) concept of land. Land has therefore been defined as a specific area of the earth's surface, with characteristics that embrace all reasonably stable or predictrable, cyclic attributes of the biosphere, including those of the atmosphere (climatic resources), the soil (soil resources), geology and hydrology, topography and biology; those attributes include also the results of past and present human activities to the extent that those exert a significant influence on present and future uses of the land by Man (socio-economic resources).

Land covers thus a much broader concept that soil. If the physical resources for land evaluation are investigated, attention should be paid not only to soil properties but also to climatic, topogrpahic and hydrological factors.

When growth conditions and production capacities have to be investigated, it is necessary to take into consideration the particular crop growth and production requirements, and those may well differ between one land use type and another. This has led to the introduction of the concept of the 'land utilization type', which is defined as a specific subdivision of a major kind of land use determined in terms of both the crop and the management type. Maize production under a modern industrialized cultivation type depends indeed not only on the specific soil and climatic requirements for the crop as such, but also on the landform and on other conditions which allow the economic use of machines and/or any other modern tools.

Evaluation Procedure

The procedure for the physical land evaluation is schematically represented in Figure 1. The socio-economic aspects can hereby be considered as a series of alternative scenarios which take into account the momental conditions available within the frame of the overall natural potentials of the area.

This step-by-step methodology follows the prinicples and guidelines as explained in the FAO Framework (FAO, 1976) and the FAO Agro-ecological Zone approach (FAO, 1978) but uses in addition the experiences acquired in the follow-up studies by other workers (Sys, 1978; Sys **et al.** 1977; Verheye, 1978, 1980 and 1987; FAO, 1989). The system refers basically to a definition of the crop growth requirements expressed in terms of climatic, soils and physiographic criteria, followed by the matching of those with the corresponding environmental parameters.

The methodology is scale-independent, and its principles and procedures can be applied in any area and at almost any given scale. The precision of the input data varies, however, with the scale, and so does accordingly, the accuracy and reliability of the output. For an evaluation at national scale, where the main soil data base is an association map, one can thus not expect that suitabilities are defined with the same precision level as is the case for a village study which delineates homogeneous soil units.

The approach includes five phases (Figure 1).

Phase 1 refers to the identification of the land utilization type, which means that one should consider at the same time the type of crop or crop variety as well as the mangement type under which the

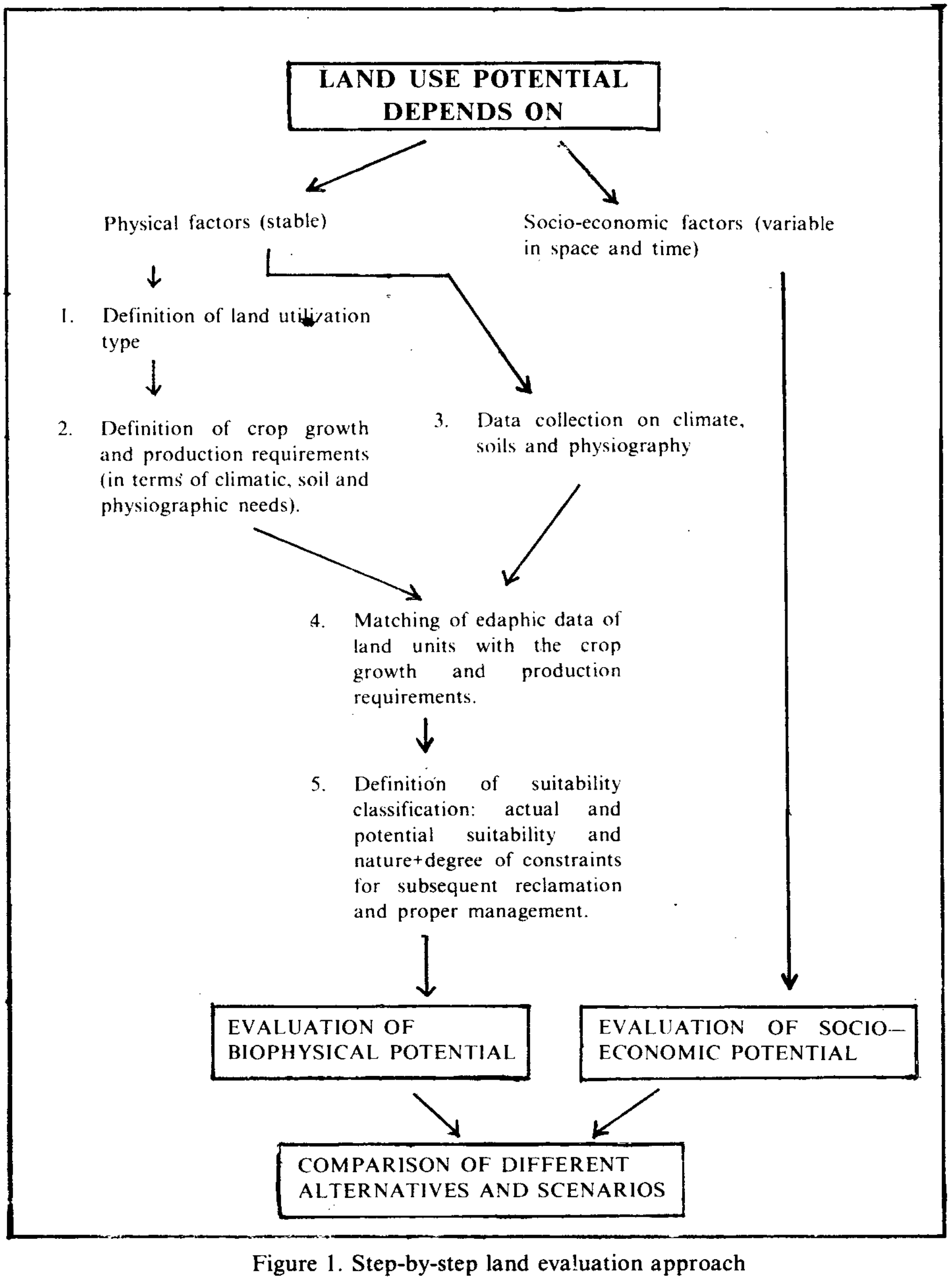

Figure 1. Step-by-step land evaluation approach

production will take place. This dual definition is needed, because it affects both the biophysical growth conditions and the workability situations for field preparation, harvesting, transport to markets, etc.

Phase 2 deals directly with those growth and production conditions. Plant growth requires a reasonable moisture and nutrient supply, linked to a sufficient rooting depth and a good energy regime for photosynthesis and biomass production.Those requirements may therefore be expressed through a series of so-called qualities related respectively to the moisture and energy or temperature regimes in the growing period, the rooting and aeration conditions and the fertility status of the soil, including the eventual sensitivity to toxic elements. Moreover, because productivity and profitability of agriculture are largely determined by field preparation and harvesting conditions, a workability-trafficability component may also be considered for some land utilization types.

The growing period can be simulated from a simple water balance using climatological and evapotranspiration data (FAO, 1978). Its moisture regime depends on the rainfall amount and distribution, the situation of the groundwater table and related capillary rise, the soil moisture retention capacity and the evapotranspirative demands. Its thermic or energy regime is determined by the current temeprature, insolation and day-length data. Secondary climatic conditions may affect plant growth over the total growing period or during part of it, and need therefore to be considered as such.

Rooting and aeration conditions affect the penetration and development of the plant root system in search for water and nutrients. They are mainly influenced by the soil depth, the texture and/or the eventual presence of coarse fragments in the profile.

The crop nutrient supply is determined by the cation exchange capacity and the base status. The organic material content of the topsoil, as a source for organically-held nutrients, also plays a role.

The susceptibility or sensitivity to specific chemical components in the rootzone can directed be quantified by the introduction of threshold figures for $CaCO_3$ or gypsum contents (in arid zone soils), electrical conductivity and ESP (in coastal or inland saline-alkaline regions), or exchangeable aluminium level (in poor tropical soils). The presence of heavy metals in the soils around industrialized centres may constitute a heavy burden for crop production in those areas.

Additional requirements related to seedbed preparation and harvesting procedures refer to workability, trafficability and erosion hazards. These depend largely on the combined effects of the soil mositure status (rainfall, groundwater depth, internal drainage, lateral water movement), slope and soil surface characteristics. In terms of management practices, slope and surface properties (stoniness, rockiness) may have an influence on the potential use of machinery for tillage and harvesting and, hence, determine the appropriate management system.

Because various crops (maize, sorghum, sesame, pasture...) have different growth requirements, and because a traditional agriculture (manual labour force, no use of fertilizers, no water control...) may well be operational under conditions that allow no industrialized cultivation practices (for example: use of machines on heavy slopes) a requirement table needs to be established for each land utilization type. As an example to such an exercise table 2 summarizes the crop growth requirements for rainfed sorghum production in a traditional agricultural system and for crop cultivars adapted to Sahelian condition in Africa. In this table, the left column lists the parameters which have an impact on the growth and production, while in the columns to the right the specific values are given which correspond to respectively the optimal (= no constraints) and progressively more marginal conditions (= slight, moderate and severe constraints). The nature of those constraints can broadly be defined as follows:

No limitations: the specific characteristic is optimal for plant growth.

Slight limitations: the characteristic is nearly optimal for the given land utilization type and affects productivity for not more than 20% with regard to optimal yields;

Moderate limitations: the characteristic has a moderate influence on the yield decrease, which may reach up to 50%; nevertheless, benefits can still be made and the use of the land remains profitable.

Severe limitations: the characteristic has such an influence on the productivity of the land that the use becomes very marginal and/or yields decrease below the profitability level.

Phase 3 deals with the collection of environmental data which affect directly the crop production. These refer mainly to the standard climatic, soils and physiographic data as available from soils and land evaluation reports. It is obvious that, in view of the subsequent matching exercise (see below) all such edapic data need to cover the requirements for crop growth and production, as defined in phase 2.

Phase 4 makes up the key operation of the evaluation procedure. It deals with the matching of the environmental conditions of the area with the specific crop and production criteria as defined earlier. This exercise leads to the evaluation for each individual soil and climatic unit of the nature and degree of limitations as compared to the optimal conditions.

Phase 5 indicates the criteria of suitability classification. Based on the number and degree of limitations a scale can then be established and suitable and unsuitable lands can be demarcated.

TABLE 2 . Production requirements for rainfed sorghum cultivation at a traditional management level.

Crop parameters	Degree of constraints			
	No	Slight	Moderate	Severe
Length- growing period (in days)	140+	110-140	90-110	90-
Moisture regime				
Rainfall (mm)	600+	500-600	350-500	350-
P/PET Humid period	1.3+	1.1-1.3	1.1-	
Thermic regime				
Mean temperature (°C)				
Rooting conditions				
Soil depth (cm)	80+	50-80	30-50	30-
Texture 0-50 cm	Medium Fine	Me. Coarse Fine	Very Fine Coarse	
Coarse fragments (%)	0-15	15-35	35-50	50+
Aeration conditions				
External drainage	Good	Moderate Imperfect	Poor	
Flooding risk	None	Except. Short	Rare Short	Frequent Long
Response of nutrients				
CEC (meq/100 g soil)	8+	5-8	2-5	2-
Sum of bases (meq/100g)	8+	5-8	5-	
pH (water)	6-7.5	7.5-8 5.5-6	8-8.5 5-5.5	8.5+ 5-
Org. matter-topsoil (%)	1.5+	0.8-1.5	0.8-	
Sensitivity of toxic elements				
electr. Cond: (mmhos/cm)	0-8	8-12	12-16	16+
ESP				
Workability and erosion hazards				
Slope (%)	0-8	8-15	15-30	30+
Rock outcrops (%)	0-3	3-15	15-30	30+
Coarse fragm. topsoil	0-3	3-15	15-30	30+

Suitable land (order S) corresponds to land on which sustained use of the land under consideration is expected to yield benefits which justify the imputs without unacceptable risk of damage to land resources. It can be subdivided into three classes which reflect the degree of suitability:

S1: highly suitable land having not more than 3/4 slight limitations; yields are expected to be between 90 and 100 % of the optimal production;

S2: moderately suitable land, with more than 3/4 slight limitations and/or no more than 3/4 moderate limitations; yields will range between 70 and 90 % of the expected optimal production;

S3: marginally suitable land with more than 4 moderate limitations and/or no more than two severe limitation which, however, can technically be reclaimed, and which, obviously, do not exclude the justified use of the land.

Unsuitable land (order N) may be defined as that land which has qualities that appear to preclude the sustained use of the land utilization type under considerfation.

For areas which have no optimal suitability it may be worthwhile to know and to indicate the nature of the limitations, because this information may help to identify the main kind of improvement measures required with their eventual cost. Such information is then supplied at subclass level by the addition of a lower-case letter in third position behind the order and class symbols. The following subclass subdivisions are suggested:

c: climatic limitations (rainfall, temperature, growing sea son,...);

t: topographic limitations (slope, relief, erosion, ...);

w: wetness limitations (drainage, flooding....);

s: limitations related to physical soil properties (soil depth, stoniness, texture, ...);

f: limitations related to natural fertility deficiencies which can not immediately be corrected (organic matter content, cation exchange capacity, base status, ...);

a: salinity and alkalinity limitations.

Land Resource Management

The suitability classification obtained through this method results in the first place in the evaluation of the actual fitness of the land to produce a given crop. By indicating the nature of the constraints the attention may be focussed to land reclamation activities and to potential improvements of yields and profitabilities.

It is evident that, if a land is unsuitable for a given land utilization type because it has 3 or 4 severe constraints, there is little scope for improvement. If however, there is only one moderate or even severe limitation it may be worthwhile to study the possibility for land reclamation and improved productivity. The result of this study will hereby largely be determined by both technical and financial considerations.

A low suitability classification because of a severe textural constraints or due to a limited profile depth and/or the presence of high amounts of coarse fragments may leave litle prospects for improvements because those constraints are neither technically nor economically feasible to improve. The same holds true for most climatological constraints, except for moisture shortages which can technically be overcome by irrigation.

As a rule it can be assumed that unfavourable moisture conditions, either due to water shortages or excesses, can technically be reclaimed. Their economic feasibility remains, however, a problem, as both irrigation and drainage schemes are expensive and can only be profitable for crops which provide a high financial return. Horticulture, flowers and a few excluding fruits, grown in the off-season may be considered as relevant examples of such situations.

Constraints related to root development are generally difficult to reclaim, and under such situations it may therefore be more interesting to search for alternative land use types, and even to shift completely to non-agricultural uses.

The fertility status of the rootzone is rather easy to improve through the application of proper fertilizer and/or the amelioration of the organic matter contents. Economic aspects may, however, be determining in this case, because the higher inputs have to be recovered by a corresponding increase in yields. The reclamation of large surfaces of alkaline soils in Indo-Gangetic plain is a typical example of a situation, where, the technical know-how for application of gympsum is well available, but where the socio-economic aspects, and in particular the initial costs for field preparation, land levelling, bunding and purchase of the gypsum by the local farmers constitute a serious bottleneck for an appropriate improved land management.

Under marginal conditions for crop production in the Third World or for soil pollution in the industrialized areas the ever increasing technological progress in proper resource management and in reclamation techinques provides good prospects for a more appropriate and optimilized utilization of the land, at least under the condition that also the socio-economic aspects have been properly considered.

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