From soil survey interpretation to land evaluation

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History

The increasing and competitive demand for land, both for agricultural production and for other purposes requires that decisions be made on the most beneficial use of limited land resources, whilst at the same time conserving these resources for the future. The function of land evaluation is to bring about an understanding of the relationships between the condition of the land and the uses to which it is put, and to present planners with comparisons and promising alternative options.

Since time immemorial, man has evaluated land for his own, mainly rural, purposes. The men that Moses sent to spy out the land of Canaan (Numbers 13:21) reported having found a land flowing with milk and honey. Apparently they considered this land very suitable for the types of land use they had in mind: camel-grazing on the semi-arid plains and date-growing at the oases. The Bible also reports that it took Moses's land evaluators four months to reach their conclusions and report back to headquarters.

Since then the techniques of land evaluation have evolved substantially; the duration of the process has grown too. The evaluation in biblical times required four months; it took Brazilian land evaluators all of the 1970's to explore and report on the Amazon Basin. (Admittedly, the Amazon Basin is 4 million km^2). The Brazilians had at their disposal aerial photographs at a scale of 1:400,000 – photographs that were totally unaffected by the persistent cloud cover, being taken with side-looking radar from high altitude aircraft. When helicoptered into remote places, sometimes populated by hitherto undiscovered Indian tribes, the land evaluators could make use of LANDSAT satellite imagery, colour and infrared photographs at a scale of 1:130,000, multispectral photographs at a scale of 1:70,000, and black-and-white video tapes at a scale of 1:23,000. To analyse their soil samples, they had atomic adsorption spectrophotometers available at the local laboratory. For climatic analyses, they could resort to data from hundreds of meteorological stations.

Apart from this development in techniques, there has also been a development in the approach to land evaluation.

Soil science was given a great opportunity to develop during the 1930's when the sudden uncontrolled intensification of settlement and agricultural land use threatened the very foundation of human existence: its food production. But with the rapid development of soil science and the unavoidable proliferation of its technical jargon, it was gradually realized that a wall was being raised between the soil scientists and those who needed the results of their work – from planners and engineers to extension workers and subsistence farmers. Soil survey reports were put

aside because their potential users could not interpret the too technical information. Soil scientists were challenged to broaden their vision or, as Professor Cline of Cornell University put it: 'They should attempt to look at soils the way the farmer does'. Renowned soil scientists such as EDELMAN (1963) and KELLOGG (1961) advocated in clear writing the need for a closer association with the users of their information. Their vision paved the way for a relatively small number of soil scientists to dedicate their efforts to the full and effective application of the knowledge available about soils.
Before World War II, in response to the suddenly realized need for a convenient interpretation of land characteristics in planning and applying soil conservation measures on farms, the USDA-SCS Land Capability System was developed. The postwar years saw the development of other systematic applications of soil information, which were concerned with yield prediction and soil and water management. The Land Classification System for Irrigated Agriculture, as developed by the U.S. Bureau of Reclamation, is an example of this. The systematic synthesis and presentation of information on the characteristics and behaviour of soil, as classified and outlined on maps, became known as 'soil survey interpretation' (BARTELLI et al. 1966).

Recent developments

Soil survey interpretations are predictions of performance, not recommendations for the use of soils. Agricultural land use requires not only that crops and/or livestock grow, but also that the land is conditioned for optimal productivity: that the seedbed is prepared, the crop is sown, protected against hazards, pests, diseases, weeds, that it is harvested, transported and processed. Depending on the kind of land use these agricultural practices make specific demands on the manageability of the land. In the industrialized countries a more or less uniform, high level of management has prevailed, which has encouraged a nation-wide standardized land evaluation system, either for general land use purposes or specific crops. But in developing countries, very different levels of management exist side by side. In such countries one must be very careful when introducing these alien systems! Here, the land use assumptions underlying land capability grouping must be more differentiated. One of the aims of today's land evaluation is to provide land use planners with information based on a methodology that uses the same concepts and procedures for any kind of land use so that comparisons and cross references are facilitated. Such a methodology is best served by a systematic approach to the kinds of land use considered, and by explicit mention of the assumptions that have led to their selection.
Aware of the need for precisely defined kinds of land use in systematic land evaluation, FAO undertook the task of developing a world-wide standardized methodology. Two multidisciplinary commissions, one in The Netherlands and one within FAO, prepared a joint paper that was discussed at an FAO Expert Consultation in Wageningen (BRINKMAN and SMYTH, eds. 1973). After another meeting in Rome the FAO Framework for Land Evaluation was published (FAO 1976; ILRI 1977). This Framework tries to incorporate the advantages of existing systems and, by a careful definition of land utilization types and land assessment factors, to avoid some of the pitfalls that inevitably occur when a system that was developed in one country is applied in another country with different land use conditions.
Since the USDA Land Capability System and the USBR Land Classification System for Irrigated Agriculture are probably the best known approaches to land evaluation, I shall discuss them first. Both systems have been modified for use in different countries; in particular the modified systems of soil survey interpretation developed during the 1960's in Brazil and Iran served as major references for the new FAO Framework. This Framework is not in itself an evaluation system but rather a set of concepts, principles and procedures on the basis of which local, regional or national

evaluation systems can be constructed. The study of present and potential land use is important when applying the Framework which represents the climax of this quarter century of international methodological reassessment.

USDA Land Capability System

At first, land capability mapping and soil survey tended to be undertaken as separate exercises serving different purposes. But with the advance of soil survey techniques, today's land capability maps are a product of systematic soil survey interpretation.

The earliest and best known system of land capability mapping, dating back to the early 1930's, is that of the Soil Conservation Service of the U.S. Department of Agriculture KLINGEBIEL and MONTGOMERY 1961). This System is based on permanent physical land characteristics that limit land use or impose risks of erosion or other damage that can easily be identified. Important characteristics for interpretation are slope, soil texture, soil depth, permeability, water holding capacity and type of clay. The System groups soil mapping units in eight capability classes on the basis of their capability to produce common cultivated crops and pasture plants over a long period of time. The risk of soil damage or limitations in use become progressively greater from Class I to Class VIII. The most general step of the Capability System is the separation of land suited for cultivation (Classes I–IV) from land not suited for cultivation (Classes V–VIII). Soils having the greatest alternative uses (cultivated crops, pasture, range, woodland, wildlife) are assigned to Class I; soils with the least number of alternative uses (only wildlife, recreation, or watershed protection) are assigned to Class VIII. The Capability System is designed (1) to help farmers and others use and interpret the soil maps and (2) to enable broad generalizations to be made on the basis of soil potentialities, permanent limitations in use, and management problems.

Nowadays land use planning sometimes needs to protect prime agricultural land against competing non-agricultural uses. The Land Capability System provides essential information for this type of planning. For example, in British Columbia, Canada, where arable land represents less than

Table 1.
Slope limits and soil losses within capability classes on three groups of uneroded soils (KLINGEBIEL 1958).

Capability Class	Soil group A[1]		Soil group B[2]		Soil group[3]	
	Slope %	Soil loss[4] tons/acre	Slope %	Soil loss tons/acre	Slope %	Soil loss tons/acre
I	0–2	0–5	0–1	0–4	–	–
II	2–7	5–23	1–5	4–15	0–1	<0.2
III	7–12	23–53	5–9	15–38	1–5	2–15
IV	12–18	53–98	9–14	38–74	5–9	15–38
VI	18–30	98–189	14–24	74–142	9–14	38–74
VII	30+	189+	24+	142+	14+	74+

[1] Soil having favourable characteristics and qualities throughout 4-feet depth for growth of common agricultural plants. Maximum tolerated soil loss: 5 tons/acre per year.
[2] Soils having moderately favourable characteristics and qualities for growth of common agricultural plants. Maximum tolerated soil loss: 3–4 tons/acre per year.
[3] Soils having unfavourable characteristics at shallow to moderate depths for growth of common agricultural plants. Maximum tolerated soil loss: < 2 tons/acre per year.
[4] Estimated soil loss based on continuous up-and-down cultivation-200 feet slope length.

10% of the total land area, land in the Frazer Valley corresponding to Classes I, II, and III may not be taken out of production to provide space for urban or industrial development.
It must be emphasized that the prime concern of the classification is the risk of erosion, and not productivity. This is why in the classification grazing is given preference over agriculture with increasing hazards of land degradation, while woodland is given preference over grazing. The capability system is not a productivity rating for specific crops; this is nicely illustrated in Northern Portugal, where the best land in the country for producing the world famous port wine is classified as Class VI and VII land.
A major disadvantage of the system is that capability classes are related to soil losses (Table 1) on the assumption of a moderately high level of management (i.e. one that is within the ability of the majority of the farmers in the U.S.A.) whereas in the developing countries very different levels and systems of management occur.
More specific studies of soil erosion will relate expected soil losses not only to the soil but also to the type of crop and the type of soil management. Of all the factors influencing erodibility the crop and management factors are more difficult to assess than the actual physical features of the soil. The differences in erosion caused by different kinds of land use and management practices may be much greater than the differences in erosion from different soils given the same management. When referring to soil loss from two identical experimental plots, HUDSON (1971) reported losses 15 times greater from the plot with a badly managed crop of maize than from the plot with a good maize crop.
The effects of soil and crop management on soil loss from a highly weathered red tropical soil are also relevant here (Table 2).
It may be concluded that general purpose land evaluations such as the USDA Land Capability Classification are useful for broad planning purposes at regional and national levels, provided that their underlying assumptions about management level and land use practices reflect the true situation in the area. For more detailed land use planning decisions, such groupings are of little significance and need to be complemented by separate land evaluations for precisely defined land use purposes.

USBR Land Classification for Irrigated Agriculture

The Land Classification System of the Bureau of Reclamation of the U.S. Department of the In-

Table 2.
Effect of soil and crop management on soil loss (LAL 1976).

Slope %	First season					Second season				
	Bare-fallow	Maize-maize (mulch)	Maize-maize	Maize-cowpeas (no till.)	Cowpeas-maize	Bare-fallow	Maize-maize (mulch)	Maize-maize	Maize-cowpeas (no till.)	Cowpeas maize
1	1.00[1]	0.00	0.20	0.00	0.06	1.00	0.00	0.11	0.00	0.19
5	1.00	0.00	0.10	0.00	0.06	1.00	0.00	0.04	0.00	0.08
10	1.00	0.00	0.08	0.00	0.04	1.00	0.00	0.04	0.00	0.06
15	1.00	0.00	0.14	0.00	0.04	1.00	0.01	0.16	0.03	0.39

[1] cumulative soil-loss factors

terior (USBR 1953) is an interesting example of multidisciplinary land evaluation. It is used for formulating and planning irrigation projects. The system enables the prediction of crop production inputs and yield outputs as a function of physical factors (soil, topography, drainage, climate, water quality) *and* socio-economic factors (technological levels, economic conditions, social organization, resourcefulness of the people, and the development goals).
The planners of irrigation projects are well served by this land classification system because it integrates all these plan-determining elements. Whereas the USDA Land Capability System is based in the first place on a physical principle, 'No soil erosion should occur', this system is based on an economic principle for distinguishing between different (four or six) land classes. Land class is defined as a category of lands with similar physical and economic attributes that affect the suitability of land for irrigation; it is an expression of the relative level of payment capacity. The amount of money remaining for the farm operator after all costs, except water charges, have been met and after an allowance has been made for family living, is identified as the payment capacity. The economic and physical factors are correlated through the relationship between soil, topographic, and drainage factors and productive capacity, production cost, and land development costs for a given project setting. Class 1 has the highest level of irrigation suitability, hence the highest payment capacity. Class 2 has intermediate suitability and payment capacity. Class 3 has the lowest suitability and payment capacity. Class 4 designates special use classes such as 4F fruit, or it is used to designate land with excessive deficiencies but which has nevertheless been shown to be irrigable by special engineering and economic studies. Class 5 is used as a temporary designation for lands requiring special studies before a final land class designation can be made, and Class 6 is land not suitable for irrigation development.
To separate the different land classes in a given project area specific limits of soil properties and other physical parameters are set up. The selected limits underlying such 'land classification specifications' are site-specific, depending on climate and economic setting, and must be prepared anew for each project area. An example is given in Table 3.
Results of the land classification are used for: (1) selection of irrigable lands, (2) determination of water requirements, (3) selection of land use and size of farm, (4) selection of the land development methods, (5) determination of payment capacity, (6) determination of irrigation benefits, (7) development of layouts for irrigation and drainage systems. At present the land classes in the USBR System are defined for 'irrigated farming', without specifying the type of crops, or the type of farming. Sometimes, separate land classes are created for special crops (e.g. paddy) with unusual land requirements. This acknowledged need to be more explicit about the kind of crops to be grown under irrigation indicates that different types of land use (crops, farming systems) can affect the economic and financial feasibility of the same parcel of land.
Originally the USBR methodology of land classification proceeded directly to the survey and mapping of the land classes. All pertinent diagnostic factors of the environment were studied and interpreted simultaneously. This approach can save time and money when the nature of the planned development, including the choice of crops and management practices, is clearly de-

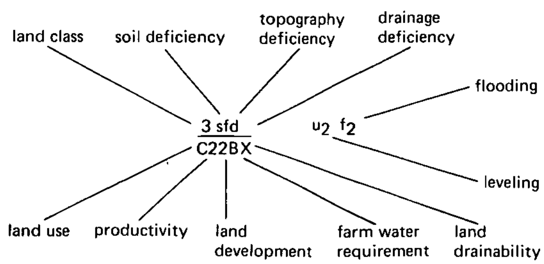


Figure 1.
Example of the mapping symbols used in the Irrigation Suitability Classification (USBR 1953).

Table 3.
Land classification specifications for irrigation (FAO 1979).

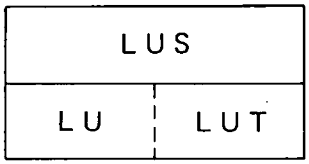
				Climate Zones D and E
	Class 1	Class 2	Class 3	Class 4
SOILS				
Texture (Surface 30 cm)	FSL–CL	LFS–C	Peat & Muck LS–C	LH–C
Moisture Retention (AWHC–120 cm)	> 12.5	10–12.5	7.5–10	7.5–10
Effective Depth (cm)	> 100	75–100	50–75	30–50
Salinity ($EC_e \times 10^3$ at equilibrium)	<4	4–8	8–12	12–16
Surface sodic conditions (Slick spots) Per cent of area affected (may be higher with favourable soil minerals)	0–10%	10–25%	25–40%	40–50%
Sodicity (exch. Na meq/100 g soil with irrigation equilibrium) (may be higher with favourable soil minerals)	<1	1–2	2–3	3–4
Permeability of least permeable layer in soil (in place measurement) cm/hr	0.5–5	0.157–15.75	0.157–15.75	0.157–15.75
Permissible cobble %	10	10–25	25–50	same as
Permissible gravel %	15	15–20	50–70	Class 3
Rockiness (small outcrops)	None	0–2% of surface covered	2–10% of surface	10–20% of surface
Soil Erosion				
TOPOGRAPHY (or land development item)				
Stone for removal (m^3/ha)	<20	20–45	45–95	95–130
Slope (per cent)	0–2	2–5	5–15	15–20
Surface levelling	Light	Medium	Medium heavy	Medium heavy
Tree removal (amount of cover)	Light	Medium	Medium heavy	Medium heavy
DRAINAGE – Soil Wetness				
Air Drainage		Not applicable to this climate zone		
Depth to Drainage Barrier cm	250	200	175	120
Surface Drain	No problem	Minor problem	Restricted	Restricted

fined and when sufficient is known about the effect of the selected diagnostic factors on irrigated land use. But the increasing need to assess the possibilities of irrigation for a variety of alternative uses, management systems and projects made it desirable to base irrigation studies on systematic soil surveys that could provide the information needed to predict the performance of all relevant land use alternatives (FAO 1979). Especially in climatic zones with pronounced dry and wet seasons, such as the Mediterranean and Monsoon climates, land evaluation must assess the prospects of irrigated agriculture, rain-fed agriculture and the combination of the two.

FAO Framework for Land Evaluation

General

In this Framework (FAO 1976) an attempt is made to treat the process of land evaluation systematically against the background of a land use system (LUS), which has been subdivided into a physical land constituent mostly described by land evaluators in terms of land (mapping) units (LU), and a land utilization type (LUT):



In this way it should become possible to predict the performance of present and alternative land use systems representing different land units/ land utilization type combinations, taking full account of the differences and similarities between the land units identified during the land resources studies.

The Framework describes land evaluation as a process of comparing or 'matching' the land with the use. This is an iterative procedure: knowledge of the land leads to conclusions about which uses may be expected to suit the land in question, while at the same time, in view of physical land limitations, the land uses may be modified or adapted to the land limitations. The matching exercise includes consideration of physical inputs for improving and conserving the land.

From land units to land qualities

Land resources are usually described and presented on maps in terms of land mapping units, which may be more or less heterogeneous. This degree of heterogeneity will also affect the reliability of the land evaluation. Land resources mapping involves an enormous amount of data about soil, climate, hydrology, vegetation etc. But because the data are collected according to discipline, important relations and interactions between different land attributes are often overlooked, particularly those between soil and climate. In many existing systems of land evaluation, single or minor compound land characteristics, such as texture or drainage, are used as a basis for diagnosis and for establishing class-determining specifications (GIBBONS and HAANS 1976). If land characteristics are employed directly in evaluation, problems arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not by slope angle alone but by the interaction between slope angle, slope length, permeability, soil structure, rainfall intensity and other characteristics.

In the FAO Framework, combinations of land characteristics relevant to specified uses are used as assessment factors reflecting limitations to land suitability and are called land qualities (LQ).

Table 4
Land characteristics and land qualities

Land characteristics	Land qualities		
	Risk of water-logging	Work-ability	Drain-ability
Soil texture		x	
Soil permeability			x
Watertable	x	x	x
Infiltration rate	x		x
Topographical level			x
Micro-relief	x	x	x
Precipitation/ Evaporation		x	

Table 5.
Definition of the land quality 'Workability' (BEEK et al. 1980).

Degrees of workability Wk	Potential evapotranspiration (Thornthwaite) during critical months						
	Oct. 64 mm	Nov. 35 mm	Dec. 21 mm	Jan. 22 mm	Feb. 25 mm	Mar. 38 mm	Apr. 52 mm
Number of rainless days after soil saturation							
1	6	9	13	13	13	9	6
2	7	10–11	14–17	14–17	14–17	10–11	7
3	8	12–15	18–23	18–23	18–23	12–15	8
4	9–11	16–18	24–27	24–27	24–27	16–18	9–11
5	12+ days	19+ days	28+ days	28+ days	28+ days	19+ days	12+ days

Table 6.
Measurable properties of workability (BEEK et al. 1980)

Texture of suface soil	micro relief	depth of the watertable (winter)			
		> 80 cm	50–80 cm	30–50 cm	<30 cm
Sand	levelled	Wk 1	Wk 1	Wk 1	–
Sandy loam Loamy sand	uneven	Wk 1	Wk 1	Wk 1	Wk 2
Silty loam	levelled	Wk 1	Wk 1	WK 2	WK 3
Loam	uneven	WK 2	Wk 2	Wk 3	Wk 3
Silty clay	levelled	Wk 2	Wk 3	Wk 3	Wk 4
Loam	uneven	Wk 3	Wk 4	Wk 4	Wk 5
Scl/cl	levelled	Wk 3	Wk 4	Wk 4	Wk 5
Clay loam	uneven	Wk 4	Wk 4	Wk 5	Wk 5

Land qualities are described in terms of measurable land characteristics derived from the land mapping units. Within each land quality a number of constituent single, or minor compound land characteristics would have to be distinguished for rating the land qualities they belong to (Table 4).
Land quality ratings must be significant, given the land use requirements. For instance, workability of the soil can be rated in number of days without rain that are required after the soil becomes saturated, to permit field operations with specified equipment (Table 5).
The degrees of workability have been related to measurable component properties (Table 6).

Yield predictions

An important criterion for grouping land for specific land use purposes is the expected yield (output). The level of expected yield is related to land qualities and inputs. Figure 2 gives an example of input-output relationships, indicating that a land quality, original level of available phosphorus, can be improved and what the consequences are for the yield.

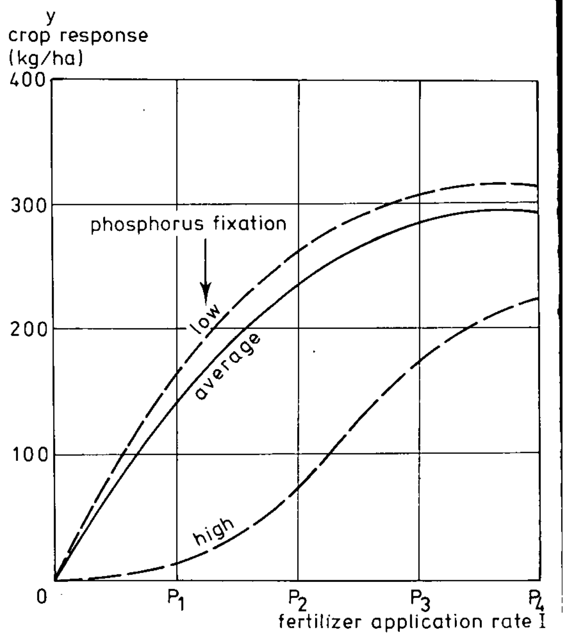


Figure 2.
Hypothetical partitioning of low phosphorus soil test population in two sub-populations with different P-application efficiencies based on different P-fixation levels (BEEK 1978).

However, these relationships are not always available, certainly not for every LUT-LU combination that is considered to be important in the study area. Therefore other approaches for obtaining this vital information are needed, the most obvious one being the transfer of knowledge from analogous situations that are better known, or even the use of simulation models.
There is a tendency to make the analysis of productivity more fundamental by identifying and quantifying the ecological components, e.g. of the water regime (SLABBERS et al.1979), responsible for limiting the maximum yield that could be expected given the available radiant energy and the genetic build-up of the plant in question. One (very big) step towards such sophistication is the construction of models based on fundamental plant growth and production processes, which include land factors in their equations for calculating theoretical yields (de WIT et al. 1978; FEDDES et al. 1978).
In 1968 NIX presented broad proposals for describing primary biological production as the result of dynamic interactions between genotype and physical environment, taking into account the energy, water, gas and biotic regimes. The CSIRO Symposium on Land Evaluation in Adelaide, Australia, where Nix presented his paper, probably marks the beginning of a more integral approach to the survey and interpretation of land resources. Encouraged by the FAO studies and meetings, 'land evaluation' became a specific area of interest.
One of the results was the FAO Agro-Ecological Zones Project (FAO 1978) which aimed at the assessment of crop productivity on a world wide basis and the preparation of maps indicating zones of similar yield potential for selected crops. This project uses a mathematical model that relates yields of 11 selected important rain-fed annual crops to photosynthesis and respiration losses. Soil factors derived from the FAO/UNESCO Soil Map of the World have also been considered, as qualitative reduction factors. But climate is of course the principal variable. Water availability is computer-calculated in terms of period in days (30-day-intervals) when available water and temperature regime permit crop growth: 'the length of growing period'. A computer programme for matching the crop's climatic and soil requirements with the climate/soil inventory is the basis of the final productivity rating and of the area calculations of the different land classes.

From land utilization types to land use requirements

The characterization of land utilization types may include a variety of factors according to the detail and purpose of the land evaluation study. Depending on the phase of the development planning process and the corresponding intensity of the study, separate alternatives could represent broad differences in agricultural use (irrigated arable farming; rain-fed arable farming; rangeland, etc.), specific aspects of such use (e.g. gravity irrigation; sprinkler irrigation), or even specific crops. Fundamental references for the selection of relevant land utilization types includes:

- overall development situation
- attributes of the land

The overall development situation provides the socio-economic, demographic, legal, institutional and political setting of land evaluation and represents a valuable yardstick for the kind of development to which land evaluation is expected to contribute. In regard to the attributes of the land, a distinction should be made between the socio-economic and the physical attributes of land. Socio-economic attributes such as land tenure, land value, etc. represent an important reference for the selection of pertinent land utilization types; they constitute the context of physical land evaluation, whereas the physical land conditions are the main object in land evaluation. Figure 3 presents a more detailed diagram of the process of synthesis of land utilization types. From the descriptions of the land utilization types, the land use requirements (LR) that each of them poses on the land should be derived. These land use requirements are the most fundamental aspects of the land utilization types for purposes of land evaluation. The land use requirements of a LUT determine to a great extent

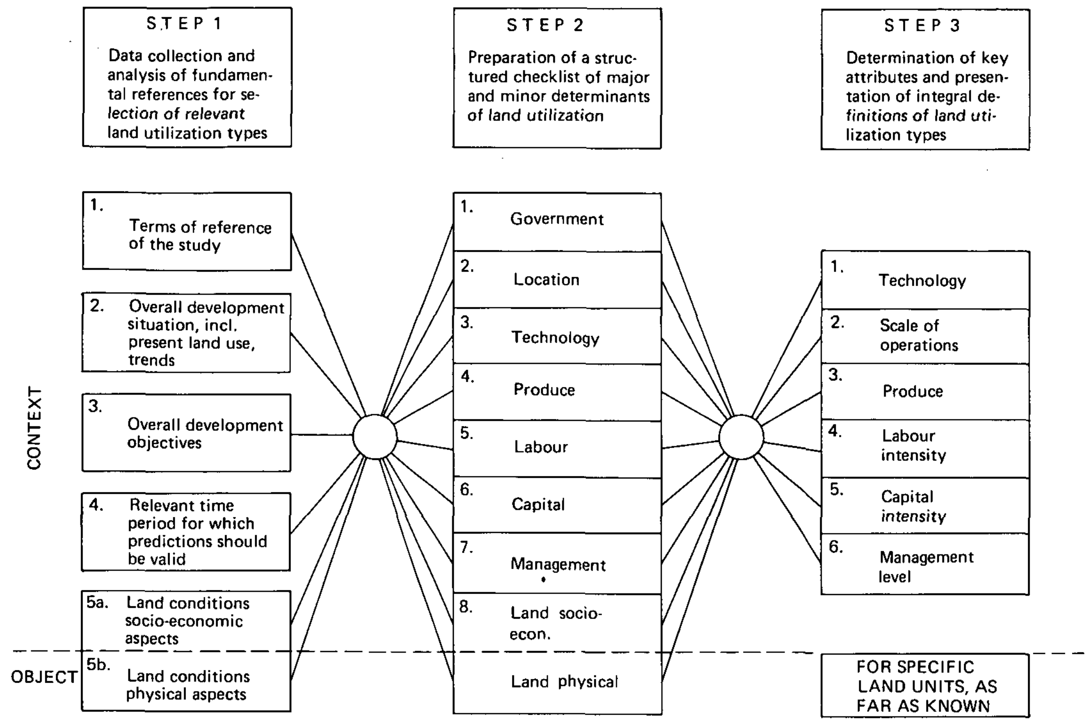


Figure 3.
The process of synthesizing land utilization types (BEEK 1978).

which land resources data need to be studied and in how much detail. In agronomy the term 'requirement' is commonly used when speaking of the specific land conditions required for the proper functioning of a certain crop (or agricultural implement). Examples of requirements include: water requirements, nutrient requirements and seedbed requirements of a certain crop, and the soil moisture and workability requirements needed by certain types of machinery during specific time periods of the year. Because the land use process is continuous and dynamic, in order to facilitate data measurement it will be necessary to disaggregate the land use process into a number of component processes and activities that take place during defined time periods. Each process or activity should be characterized by its own land use requirements. Once the continuous land use process has been disaggregated into a kind of land utilization calendar that specifies in chronological order each pertinent land use process/activity and the corresponding land use requirements, it should become possible to make a problem-oriented analysis of the status of the time-variable land qualities that should meet these land use requirements. Much is already known about the value of LR as far as the land use requirements of specific crops are concerned, e.g. the nutrient and water requirements, resistance to toxic elements such as alkalinity and salinity (Table 7).

Such relationships are useful to determine whether a particular land use requirement, absence of soil salinity, is met by the land quality, actual level of soil salinity, and if not, how much this land quality is limiting the yield (MOORMANN and van BREEMEN 1978).

A very critical aspect of land evaluation is the availability of information about these land use requirements, especially in developing countries. This information is often very difficult to obtain, and may be incomplete or vague. It is not unusual to find that handbooks on the cultivation of tropical crops give the ideal land conditions, which bear little resemblance to the actual land conditions prevailing in the project area where the suitability needs to be evaluated (VINK 1975).

Land use requirements versus land qualities

Matching the land use requirements with the land qualities for a specific combination of land utilization types and land units (LUT-LU combination) indicates how suitable a given tract of land is for a certain use. Diagnosis of suitability entails the prediction of expected outputs, physical inputs, and of changes in the status of the land qualities, e.g. in the sustained productive capacity of the land. Input-output analysis should include in the first place the study of the relation between land qualities and the outputs, and the relation between inputs and outputs. These relations are interrelated and depend on the land utilization type under consideration, because each land utilization type can be different in its requirement for a certain land quality. These

Table 7.
Crop salt tolerance levels for different crops (adapted from AYERS and WESTCOTT 1976).

	Yield potential								Max. ECe
Crop	100%		90%		75%		50%		
	ECe[1]	ECw[2]	ECe	ECw	ECe	ECw	ECe	ECw	
Barley	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28
Cotton	7.7	5.1	9.6	6.4	13.0	8.4	17.0	12.0	27
Rice (paddy)	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	12
Sorghum	4.0	2.7	5.1	3.4	7.2	4.8	11.0	7.2	18
Wheat	6.0	4.0	7.4	4.9	9.5	6.4	13.0	8.7	20

[1] Electrical conductivity of the saturation extract of the soil in millimhos per cm at 25 °C.
[2] Electrical conductivity of the irrigation water in millimhos per cm at 25 °C.

two relations and the input/land-quality relation together represent the relation structure of the land use system (LUS):
- land-quality/output relations (LQ/Y)
- input/output relations (I/Y)
- input/land-quality relations (I/LQ)

For defining land suitability classes, attention should be given to the selection of land suitability criteria for land evaluation. Examples of land suitability criterion variables could be:
- yield level
- performance reliability
- flexibility for timing of field operations
- flexibility in choice of equipment for field operations
- levels of physical inputs required
- sustained production

The land suitability classes stand for different values of each criterion variable corresponding with the different degrees to which the land use objectives are expected to be met. In the absence of a common denominator for criterion variables of different dimensions, the land suitability classes are mostly verbal descriptions of the degree to which the land use objectives are met.
To reach the desired goal of land evaluation, i.e. the optimal utilization of land, the 'best' combination of LQ, LR, I and Y must be found, based on explicit land suitability criteria. The systematic breakdown of the land use system into measurable land qualities, land requirements, inputs and outputs is the foundation of a systems approach to land evaluation (see Figure 4).
In Figure 4 a distinction is made between descriptive and prescriptive land use systems analysis.
During the descriptive analysis, physical inputs for manipulating constraining land qualities are compared with their effects on these land qualities and on the outputs, e.g. yield projections. This analysis provides the decision maker with information about alternative land use possibilities. During the prescriptive analysis or land suitability classification, for each LU-LUT combination the input/land-quality output combination that places the land unit in the highest possible land suitability class is selected: these combinations are the soil and water management recommendations.
Reconnaissance type land evaluations often have to rely on a limited data base and a rather qualitative descriptive input/output analysis. But the recent investigations conducted by the FAO Agro-Ecological Zones Project and the Centre for World Food Studies in Wageningen are now developing more quantitative methods. This is important for pinpointing high potential areas where detailed investigations are justified, and for regional planning purposes in general.
Detailed land evaluations should always be as quantitative as possible in their descriptive input-output analysis. Such analyses underlie important planning decisions concerning land improvement and the introduction of new farming systems.
The descriptive analysis may satisfy most, if not

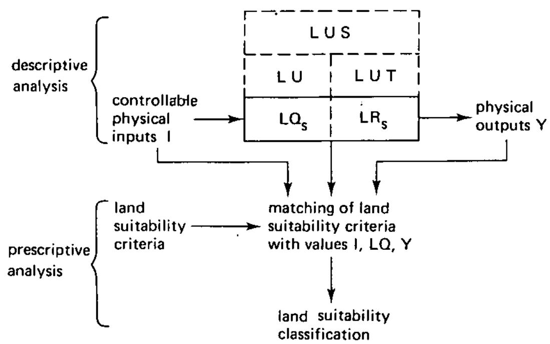


Figure 4.
A diagrammatic representation of systems analysis in land evaluation (adapted from BEEK 1978).

all data needs of the land use planner for establishing optimal crop rotations or farm sizes and in selecting the most economic project alternative. Land evaluation should not assume *a priori* that the 'best' alternative will always be implemented, but should present its conclusions on land suitability as separate classifications for carefully planned alternative options. This gives the planner more flexibility in making his planning decisions, as it provides him with a deeper insight into the development possibilities in the project area.

Expected developments

Whereas the FAO Framework for Land Evaluation represents a milestone in the evolution of a realistic approach to land evaluation, it still relies heavily on data collection, and for practical reasons there is a limit to the number of observations of natural phenomena and experiments that can be made relating to one specific site (VELDKAMP 1979). The ideal of sufficient reliable data from the project site is defeated by time and money. Therefore there is an obvious need for additional techniques to generate information about the expected effect of physical inputs on outputs and on the land itself. Making analogies with other areas has been the most common technique for obtaining such additional data (BENNEMA 1978). But one cannot always rely on the correlation with analogous areas, since many development situations are characterized by a unique combination of socio-economic and physical constraints and very specific development objectives. As the analysis of physical input/output relations also tends to become more and more complex, systems analysis and simulation will need to be increasingly relied upon. Mathematical and analogue models will probably become valuable tools for the study of specific land qualities and land use processes. The models will relate foremost to specific partial land evaluation problems, e.g. of water movement in the soil, soil tillage, the behaviour of plant nutrients and chemical fertilizers and the prediction of potential yield (WIND 1979; FEDDES and van WIJK 1977). The use of mathematical models solely for simulating all input/output relations influencing the performance of a land use system will probably remain too complex to satisfy practical land evaluation entirely in the immediate future. Since the task of modelling and simulation is likely to be beyond the scope of routine land evaluation, specialized institutes should be asked to carry out the more detailed problem analyses. For a better characterization of the environmental regimes (i.e. land qualities), modifications may be required in the data-collecting stage of land evaluation, the methods and density of sampling, the techniques of making land resources maps and the classification of land attributes. More attention should be paid to the study of 'land' and 'landscape', rather than to the study of components only, such as soil, climate, vegetation, hydrology (ZONNEVELD 1979).

Land evaluation must compromise between scientific ideals and the limitations set by the availability and reliability of data and the means available for handling these data. Furthermore, land evaluation is concerned with prediction, which signifies that its results cannot exceed certain limits of probability because of the variation in weather conditions and human behaviour. Recent investigations in the field of ecosystems and theoretical plant production are increasing our understanding of fundamental biological processes. Such contributions are of great conceptual significance for land evaluation. In addition, soil scientists and agricultural engineers are increasing our understanding of mechanisms underlying the various soil and water management and engineering practices. Meanwhile, land evaluation is likely to continue making its predictions of land use performance by interpreting site-specific data and relying on the transfer of knowledge by roving specialists with a 'good eye' for the land. This human capacity, which must have already been Moses's concern when he had to select his men for spying out the land of Canaan, is nowadays often found amongst soil surveyors and physical geographers, who have the opportunity to develop singular skills for observing and correlating multiple natural phenomena, so important to land evaluation. How to translate the rather intuitive knowledge of these modern-day prophets into workable manuals is probably the greatest challenge facing land evaluators in the immediate future.

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