ASSESSMENT OF LAND RESOURCES FOR RAINFED CROP PRODUCTION IN MOZAMBIQUE

LAND UTILIZATION TYPES AND ECOLOGICAL ADAPTABILITY OF CROPS

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This report is the first of a series of six reports prepared to record the activities and results of the study entitled "Assessment of land resources for rainfed crop production in Mozambique". The work plan of the study is given in the Consultants' Report of Kassam and Van Velthuizen (1981), and the six reports of the series are:

1. Land utilization types and ecological adaptability of crops.

2. Climatic data bank and length of growing period analysis.

3. Climatic resources inventory of Mozambique.

4. Land resources inventory of Mozambique.

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6. Land suitability assessment:

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ABSTRACT

The report describes the land utilization types of the study, stating the circumstances under which the crops are to be produced. The eight crops selected for the study are: maize, sorghum, pearl millet, wheat, soybean, groundnut, cassava and cotton. Each crop is considered at two levels of inputs, a low and a high.

The report also describes the ecological adaptability of crops from which the crop climatic and edaphic requirements relevant to land evaluation are derived.

AVALIACAO DOS RECURSOS DA TERRA
PARA PRODUCAO EM SEQUIRO DAS CULTURAS
EM MOCAMBIQUE

TIPOS DE UTILIZACAO DA TERRA E CAPACIDADE DE ADAPTACAO DE CULTURAS

SUMÁRIO

O relatório apresenta os tipos da utilizaçao da terra do estudo, estabelecendo as circunstâncias sob as quais as culturas estao para ser produzidas. As oito culturas seleccionadas para o estudo sao : milho, mapira, mexoeira, trigo, soja, amendoim, mandioca e algodao. Cada cultura é avaliada em duas condiçoes de entradas de factores de produçao, uma baixa e uma alta.

O relatório também descreve a capacidade de adaptaçao de culturas das quais as exigências climáticos e edáficas referente à avaliaçao de aptidao da terra sao derivadas.

1. INTRODUCTION

This is the first report in the series. It describes the land utilization types of the study and ecological adaptability of rainfed crops.

The eight crops selected for the study are:

1. Maize (Zea mays)
2. Sorghum (Sorghum bicolor)
3. Pearl millet (Pennisetum americana)
4. Wheat (Triticum aestivum)
5. Soybean (Glycine max)
6. Groundnut (Arachis hypogaea)
7. Cassava (Manihot esculenta)
8. Cotton (Gossypium hirsutum)

Of these crops, wheat and soybean do not as yet occupy a significant area in Mozambique, but there are Government plans to considerably expand their area in the future.

Having selected the crops, it is necessary to define the conditions under which they are to be grown (Land Utilization Types). Without such a definition, the evaluation is not valid, because land suitability for a crop varies very considerably according to the circumstances under which it is produced. Two simple examples serve to illustrate: (a) lands with slopes of more than 14 percent, or of a very stony nature, are not normally suited to mechanical cultivation, but can be cultivated with hand tools, and (b) very heavy soils, such as Vertisols, cannot be cultivated with hand tools, but are suited to mechanized cultivation. Thus, a description of the circumstances of cultivation is vital to any sound evaluation of land.

Further, the usefulness of climatic and soil inventories for predicting land suitabilities is dependent on how far the climatic and soil requirements of crops/land utilization types can be matched with the climatic and soil parameters used in the inventories. It is therefore essential to understand climatic and edaphic requirements and responses of rainfed crops in order to define the parameters that are to be inventoried for land suitability assessment.

This report describes the details of the land utilization types of the study, and climatic and edaphic adaptability of rainfed crops. The concepts and principles of crop ecological adaptability relevant to land evaluation are described in FAO (1978).

2. LAND UTILIZATION TYPES

Combined descriptions of crops, produce, inputs, technical know-how, etc., form the basis of the definition of the land utilization types employed in the assessment.

Detailed definition of land utilization types applicable to a national land evaluation is difficult, because of the wide variation in economic, social and management factors across the country. However, for an adequate description of land utilization types involving crop production, information on the following is desirable:

- crop and produce (e.g. maize for dry grain or green cobs or silage),
- cropping pattern (e.g. sole cropping, intercropping),
- market orientation, including whether towards subsistence or commercial production,
- capital intensity,
- labour intensity,
- power sources (e.g. hand labour, draught animal, fuel using machinery),
- technical knowledge and attitudes of land users,
- technology employed (e.g. crop cultivars, weed, pest and disease control, fertilizers, implement and machinery, farm transport),
- infrastructure requirements (e.g. extension services, processing plants),
- size and configuration of land holdings, including whether consolidated or fragmented.

For the purpose of this study, generalized land utilization types have been considered. These are based on single crops and are to be evaluated at two levels of inputs, a low and a high. The former corresponds to a low technological level and involves hand cultivation. The high input level involves mechanical cultivation under capital intensive management practices. The two input levels can be visualized as representing two points on a production/input curve, corresponding to no on-farm capital inputs and a high level of capital inputs.

The assumed conditions under which the crops are to be produced for the two input levels are presented in Table 1. Thus a total of 16

Table 1 ATTRIBUTES OF THE LAND UTILIZATION TYPES CONSIDERED

Attribute	Low Inputs	High Inputs
Crop and produce	The eight rainfed crops described	
Production method	Rainfed production, no irrigation or water importation. Sole cropping only, no multiple cropping	
Market orientation	Subsistence production	Commercial production
Capital intensity	Low	High
Labour intensity	High, including uncosted family labour	Low, family labour costed, if used
Power source	Manual labour with hand tools	Complete mechanization including harvesting operations
Technology employed	Local cultivars. No (or markedly insufficient) fertilizer, no chemical pest, disease and weed control, fallow periods for both water and nutrient accumulation	High yielding cultivars. Adequate fertilizer application, chemical pest, disease and weed control, fallow periods for water accumulation only where necessary
Infrastructure requirement	Market accessibility not essential; no or inadequate advisory services	Communications and market accessibility essential; high level of advisory services
Land holding	Small, fragmented	Large, consolidated

alternative land utilization types are considered in the assessment, i.e. two input levels for each of the eight crops.

Pertinent in the definition of the land utilization types are the facts that:

a. the cereal and leguminous grain crops are produced for dry grain only (e.g. they do not include green cob production of maize, or production of soybean as vegetable);

b. sorghum with white or yellow grains are considered in the evaluation; sorghum with red or brown bitter grains, normally used for brewing beer, are not explicitly considered in the assessment;

c. the crops comprise readily available local cultivars (low inputs) and high yielding cultivars (high inputs) of the following ranges in lengths of growth cycles:

Wheat	100-130 days	(spring cultivars)
Maize	90-120 days	(mean temperature $>20^{o}$)
	>120 days	(mean temperature $>20^{o}$)
Sorghum	90-120 days	(mean temperature $>20^{o}$)
	>120 days	(mean temperature $<20^{o}$)
Pearl millet	70-90 days	
Soybean	90-120 days	
Groundnut	90-120 days	
Cassava	180-330 days	
Cotton	170-180 days	

d. storage facilities as an on-farm production input are not considered in the study; consequently, post-harvest storage losses are not considered in the assessment.

3. CROP CLIMATIC ADAPTABILITY

This section deals with the interrelationships between climatic factors and crop characteristics, in terms of climatic adaptability of crops and productivity for agriculture.

Photosynthesis produces the source of assimilates which plants use for growth, and the rate of photosynthesis is influenced by both radiation and temperature. However, plants also have an obligatory developmental pattern in time (and space) which must be met if the photosynthetic assimilates are to be converted into economically useful yields of satisfactory quantity and quality. The developmental sequence of crop growth in relation to the calendar (i.e. crop phenology) is influenced by climatic factors.

In general, temperature determines the rate of growth and development; but in some crops temperature may also determine whether a particular developmental process will begin or not (e.g. chilling requirement for initiating flower buds in pyrethrum), the time when it will begin, the subsequent rate of development, and the time when the process stops. In some crops both day-length and temperature may determine the time when the plant will flower, e.g. photoperiodic winter cereals which require vernalization. In other crops, at a given temperature, day-length alone may determine the time of flowering (e.g. photoperiodic tropical cereals), while low temperature can cause problems through delay in flowering and maturation and poor seed set (e.g. maize and sorghum in high altitude areas in the tropics). In some perennial crops, when there is no 'genetic' check on growth, unimpeded growth and development can be harmful to yield. Therefore, a temperature and/or dry season check on excessive growth is required to avoid overbearing and crop exhaustion (e.g. arabica coffee) so that subsequent yields are obtained on a regular and sustained basis.

Futher, in some crops the quality of the economically useful yield is influenced by temperature (e.g. pineapple, tea), while in other crops (e.g. rainfed cotton, sorghum and wheat), yield formation must take place under appropriate climatic conditions in order to obtain an acceptable quality. Wet conditions during the yield formation period and maturation lead to poor quality lint in cotton, attack from sucking bugs and grain mould in sorghum, and grain germination in the panicle in wheat. In addition, other agronomic problems associated with crop harvest and storage occur in such conditions.

Accordingly, in the study, consideration has been given to the specific climatic requirements for yield quality (described above) in addition to the climatic requirements for photosynthesis (growth) and phenology.

3.1 Photosynthesis and Phenological Characteristics

Within any suitable length of growing period, the temperature regime (and photoperiodic regime when the available cultivars are photosensitive to day-length) governs which crop can be grown. When the climatic phenological requirements are met, then both the temperature and radiation regimes set a limit to crop productivity. This is because natural selection and breeding has forced the physiological processes of crops to operate at optimum rates only within a certain range in temperature. In particular, the evolutionary changes that have occurred in the biochemical and physical characteristics of photosynthesis have led to a large variation between crops both in the optimum temperature requirement for photosynthesis and the response of photosynthesis to changes in temperature and radiation.

Consequently, when the climate of a region is phenologically suitable for a given crop, it is possible to relate the temperature and radiation regimes to crop productivity from knowledge of the temperature and radiation responses of photosynthesis. Because the temperture and radiation responses of photosynthesis depend on the nature of the photosynthesis pathway, it is possible to group crop species with similar assimilation pathways and of more or less equal photosynthesis ability.

Provided temperature requirements are met, for a rainfed crop to be successful, it is necessary that its growth cycle (from germination to crop maturity in annuals, or the period of new growth in any year in established perennials) should be of such a length that it is comfortably contained within the growing period as determined by environmental conditions. In some crops, climatic factors may control when a particular development process begins, while in other crops climatic factors have to be agronomically utilized to stop certain developmental processes. Once these 'requirements' have been met, then whatever the climate may have to offer during the growing period, different crops are obliged to follow a certain developmental pattern in time, and accumulate yield at different stages in their life cycle. The rate at which plant parts are formed in time and space, although influenced by temperature, imposes a limitation on the use of time available during the growing period for growth and yield forming activities. Therefore, if a crop is to produce satisfactory yields, it must be allowed to meet its phenological obligation of proceeding unimpeded through the various developmental events in time. Consequently, when the length of the growing period is limited, then the days to maturity of crop cultivars must match the growing period accordingly. Failure to do so does not completely exclude cultivation of the crop but does result in reductions of yield and quality because the time available for yield forming activities is curtailed.

Further, although a crop species may offer cultivars of different life-span, the agronomically optimum length of growth cycle (for a growing period of a given length) is obtained when the developmental timetable is of such a length that it allows the crop to produce sufficient vegetative growth to support concurrently (e.g. grain legume crops, root and tuber crops) or subsequently (e.g. cereal crops), the necessary yield forming activities within the ecologically determined start and end of the growing period. In practice, it is often necessary to locate the yield forming activities of some crops during a particular part of the growing period in order to meet the conditions necessary for harvest, storage and social use.

Consequently, the optimum physiological length of growth cycle of a crop that is also agronomically optimum, and the location of the crop's life-span within the growing period, is influenced by location-specific constraints in addition to phenological constraints.

3.2 Crop Climatic Adaptability Inventory

To assess crop species for their climatic suitability, it is convenient to prepare an inventory of crops based on their climatic requirements for both photosynthesis and phenology which bear a relationship to yield in quantity, and where necessary to yield in quality. The rate of crop photosynthesis, growth and yield are directly related to the assimilation pathway and its response to temperature and radiation. However, the phenological climatic requirements, which must be met, are not specific to a photosynthesis pathway.

Consequently, crop species have been classified into four groups (Table 2) according to their fairly distinct photosynthesis characteristics. Further, the time required to form yield depends on both the phenological constraints on the use of time available in the growing season and the location of yield (e.g. seed, leaf, stem, root). This information is also given (Table 3) so that additional characteristics of crops may be used to match crops and their cultivars to prevailing climatic conditions.

3.2.1 Characteristics related to photosynthesis

The division of crops into four groups (Table 2) is based on the differences between crop species and their photosynthesis pathways and the response of photosynthesis to temperature and radiation, because these differences determine productivity potential when climatic phenological requirements are met.

The two major pathways of photosynthesis are the C_3 pathway and the C_4 pathway. In the former, the first product of photosynthesis is a 3-carbon organic acid (3-phosphoglyceric acid), while in the latter the first products are 4-carbon organic acids (malate and aspartate). In general crop species with C_3 assimilation pathways have relatively lower rates of CO_2 exchange at a given radiation level than C_4-species. Further, C_4-species have maximum rates of photosynthesis in the range of 70–100 mg CO_2 dm^{-2} h^{-1} with light saturation at 1.0-1.4 cal cm^{-2} min^{-1} total radiation, while C_3-species have maximum rates of photosynthesis in the range of 15–30 mg CO_2 dm^{-2} h^{-1} with light saturation at 0.2–0.6 cal cm^{-2} min^{-1}.

However, both the C_3 and C_4 assimilation pathways are adapted to operate at optimum rates over a range of temperatures. In the case of C_3-species, one group is adapted to operate under conditions of moderately cool and cool temperatures (10-20°C) (e.g. wheat, white potato), and the other group is adapted to operate under conditions of

Table 2 AVERAGE PHOTOSYNTHESIS RESPONSE OF INDIVIDUAL LEAVES OF FOUR GROUPS OF CROPS TO RADIATION AND TEMPERATURE

Characteristics	Crop adaptability group			
	I	II	III	IV
Photosynthesis pathway	C_3	C_3	C_4	C_4
Rate of photosynthesis at light saturation at optimum temperature ($mg\ CO_2\ dm^{-2}\ h^{-1}$)	20-30	40-50	> 70	> 70
Optimum temperature (°C) for maximum photosynthesis Operative range range (°C)	15-20 5-30	25-30 15-35	30-35 15-45	20-30 10-35
Radiation intensity at maximum photosynthesis ($cal\ cm^{-2}\ min^{-1}$)	0.2-0.6	0.3-0.8	1.0	1.0
Crops of the assessment	Spring wheat	Groundnut Soybean Cotton Cassava	Pearl millet Lowland/tropical maize Lowland/tropical sorghum	Highland/temperate maize Highland/temperate sorghum

Table 3 CLIMATIC ADAPTABILITY ATTRIBUTES OF CROPS

Attributes	Spring wheat	Soybean	Cotton	Cassava
Species	*Triticum aestivum*	*Glycine max*	*Gossypium hirsutum*	*Manihot esculenta*
Photosynthesis pathway	C_3	C_3	C_3	C_3
Crop adaptability group	I	II	II	II
Length of growth cycle	100-130	90-120	170-180	180-330
Harvested part	Seed	Seed	Seed cotton	Tuber
Main production/use	Grain (C)	Grain (L)	Fibre	Carbohydrate
Growth habit	Determinate	Indeterminate	Indeterminate	Indeterminate
Life-span: Natural	Annual	Annual	Perennial	Perennial
Life-span: Cultivated	Annual	Annual	Annual	Annual
Yield: Location	TI	LI	LI	R
Yield: Formation period	LT	ME	ME	TT
Suitable thermal climates for rainfed production	MC, C	W	W	W

C - Cereal
L - Legume
TI - Terminal inflorescence
LI - Lateral inflorescence
R - Root

LT - Last one-third of growth cycle
ME - Middle to end period of growth cycle
TT - Two-thirds of growth cycle
W - Warm (>20°C)
MC - Moderately cool (15-20°C)
C - Cool (5-15°C)

Table 3 (Cont'd)

Attributes	Pearl millet	Tropical sorghum	Tropical maize	Temperate sorghum	Temperate maize
Species	*Pennisetum americana*	*Sorghum bicolor*	*Zea mays*	*Sorghum bicolor*	*Zea mays*
Photosynthesis pathway	C_4	C_4	C_4	C_4	C_4
Crop adaptability group	III	III	III	IV	IV
Length of growth cycle	70-90	90-120	90-120	> 120	> 120
Harvested part	Seed	Seed	Seed	Seed	Seed
Main product	Grain (C)	Grain (C)	Grain (C)	Grain (C)	Grain (C)
Growth habit	Determinate	Determinate	Determinate	Determinate	Determinate
Life-span: Natural Cultivated	Annual Annual	Annual Annual	Annual Annual	Annual Annual	Annual Annual
Yield: Location Formation period	TI LT	TI LT	TI LT	TI LT	TI LT
Suitable thermal climates for rainfed production	W	W	W	MC	MC

moderately warm to warm temperatures (25-30°C) (e.g. cotton, groundnut). These C_3-species constitute Groups I and II respectively.

In the case of C_4-species, one group is adapted to operate under conditions of warm to very warm temperatures (25-35°C) (e.g. tropical maize, tropical sorghum), and the other group is adapted to operate under conditions of moderately cool to moderately warm temperatures (15-25°C) (e.g. temperate maize, temperate sorghum). These C_4-groups of crops constitute Groups III and IV respectively.

One further group of species has evolved and adapted to operate under xerophytic conditions. These species have the Crassulacean Acid Metabolism (CAM). Although the biochemistry of photosynthesis in the CAM-species has several features in common with C_4-species, particularly the synthesis of 4-carbon organic acids, CAM-species have some unique features which are not observed in C_3- and C_4-species. These include capturing the light energy during the day-time and fixing CO_2 during the night-time, with consequently very high water use efficiencies. CAM-species are adapted to operate under warm temperature conditions (20-30°C). There are two CAM-species of agricultural importance (i.e. pineapple and sisal), and these constitute a separate group not considered in the present study.

3.2.2 Characteristics related to phenology and yield

In the sequence of events in the developmental pattern of crop growth, yield formation and senescence, organs are differentiated in which assimilates for growth are made and accumulated. Some of these organs become the yield forming organs where the harvestable assimilates (e.g. starch or other carbohydrates, protein, oil, fibres) are stored.

Botanically the growth habit of a crop may be determinate (where no more leaves are formed once the apical bud of the vegetative shoot has become reproductive, and fruits and seeds are borne on terminal inflorescences) or indeterminate[1] (where the apical bud remains vegetative and fruits and seeds are borne on lateral inflorescences). Further, whether a crop's natural life-span is annual, biennial or perennial, the time required to form yield, and the cultivated life-span, depend on the portion of the plant that is economically useful.

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[1] Crops with monopodial and sympodial branching habit (e.g. cotton) are regarded as having an indeterminate growth habit. In such crops the apical meristem on sympodial branches produces an inflorescence, and axillary buds below it grow into branches which in turn produce apical inflorescences and subterminal branches.

When it is a reproductive part (e.g. fruit, seed), yield may be formed either in the last phase of the crop's life in terminal inflorescence of annual crops (e.g. cereals) and annual shoots of perennial crops (e.g. banana), or during a greater or smaller fraction of the crop's life in fruits and seeds borne on early or late-formed lateral inflorescences of annual crops (e.g. leguminous pulses and oil seeds, tomato) and perennial crops (e.g. fruit tree crops).

When the economically useful portion is a vegetative part (e.g. leaf, root), yield may be formed throughout much or all the period in which growth is possible in a sufficiently long-lived annual (e.g. tobacco, potato), biennial (e.g. sugarbeet) or perennial (e.g. yam, sugarcane) crop.

In some biennials (e.g. sugarbeet, onion) and perennials (e.g. sugarcane), because yield is formed in vegetative parts, flowering lowers the yield. Consequently, the former crops are grown as annuals under conditions which will not favour flowering (or bolting). In the case of sugarcane, it is grown either as a biennial when non-flowering cultivars are available, or on an annual basis (i.e. plant and ratoon crop or plant crop only) when non-flowering cultivars are not available.

In Table 3, information is given on days to maturity for crops and the main products obtained from them. In respect of their life-span and the proportion of their growth cycle which can be used to form yield, information is also given on growth habit, natural and cultivated life-span, location of yield, and approximate yield formation period.

Generally, annual and biennial crops have a range of cultivars of different life-spans, and in perennial crops the period of new growth in any year also varies between cultivars and regions due to both genetic and ecological reasons. However, the genetic yield potential of cultivars is related to the number of days to maturity, or the period of new growth. This is because when the developmental timetable is severely telescoped and phenological events occur too rapidly (as in very early maturing cultivars of annual crops, or perennial crops with a very short period of new growth), there is generally a drop in yield potential even when the crop is allowed to reach normal maturity. Similarly, there can often be a drop in yield potential when the developmental timetable is severely stretched and phenological events occur too slowly. This is because the continuous or concurrent growth of non-economically useful parts may compete for assimilates with the growth of economically useful parts and thereby interfere with the yield forming activities, or the continuous growth may exhaust the crop in the case of some perennials so that subsequent yields are lower. There is, therefore, an optimum physiological length of growth in a crop species related to the highest genetic yield potential the species can offer. However, within the environmentally determined length of growing period, the particular cultivar of a crop species, found to be most suitable agronomically, may not necessarily be the one with the highest genetic yield potential but may still allow satisfactory yields to be obtained within a particular set of agronomic circumstances (land utilization type).

An indication is also given in Table 3 of the thermal climate within which the most suitable areas of adaptability for rainfed production may be found when the agronomic consequences of the climatic requirements for photosynthesis, phenology, yield formation and quality are considered along with other production factors in matching rainfed crops to a particular set of climatic conditions prevailing in a specific area of interest.

4. CROP EDAPHIC ADAPTABILITY

As a medium in which roots grow and as a reservoir for water and nutrients on which crops continuously draw during their life cycle, soils have long been recognized as an important natural resource and valuable economic asset requiring protection, conservation and improvement through good husbandry.

The adequate agricultural exploitation of the climatic potential or sustained maintenance of productivity largely depends on soil fertility and using soil on an ecologically sound basis. Soil fertility is concerned with the ability of the soil to supply nutrients and water to enable crops to maximize the climatic resources of a given location. The fertility of a soil is determined by its both physical and chemical properties. An understanding of these factors is essential to the effective utilization of climate and crop resources for optimum production.

In order to assess suitability of soils for crop production, soil requirements of crops must be known. Further, these requirements must be understood within the context of limitations imposed by landform and other features which do not form a part of soil composition but may have a significant influence on the use that can be made of the soil.

Many soils are a result of climatic action and, as a result, climate and soil in many instances have relationships which may have a mutual enhancing effect (negative or positive) on crop productivity. The close interrelation of climate and (zonal) soil and natural plant community, to some extent, aids assessment of land suitability.

4.1 Basic Soil Requirements of Crops

The basic soil requirements of crop plants may be summarized under the following headings, related to internal and external soil properties:

a. Internal requirements:

- the soil temperature regime, as a function of the heat balance of soils as related to annual or seasonal and/or daily temperature fluctuations;

- the soil moisture regime, as a function of the water balance of soils as related to the soil's capacity to store, retain, transport and release moisture for crop growth, and/or to the soil's permeability and drainage characteristics;

- the soil aeration regime, as a function of the soil air balance as related to its capacity to supply and transport oxygen to the root zone and to remove carbon dioxide;

- the natural soil fertility regime, as related to the soil's capacity to store, retain and release plant nutrients in such kinds and proportions as required by crops during growth;

- the effective soil depth available for root development and foothold of the crop;

- soil texture and stoniness, at the surface and within the whole depth of soil required for normal crop development;

- the absence of soil salinity and of specific toxic substance or ions deleterious to crop growth;

- other specific properties, e.g. soil tilth as required for germination and early growth.

b. External requirements: in addition to the above internal soil requirements of crops, a number of external soil requirements are of importance, e.g.:

- slope, topography and characteristics determined by micro- and macrorelief of the land;

- occurrence of flooding as related to crop susceptibility to flooding during the growing period (e.g. potato, maize very susceptible), or, inversely, to flooding requirements (e.g. rice). The incidence, regularity (irregularity) and depth of flooding are possibly the most important factors determining the potential use of extensive river flood plain soils;

- soil accessibility and trafficability under certain management systems.

4.2 Crop Edaphic Adaptability Inventory

From the basic soil requirements of crops, a number of crop response related soil characteristics can be derived at least for the most important crops and existing cultivars. One of these characteristics is, for instance, soil pH. For most crops and cultivars, optimal soil pH is known and can be quantified by a range within which it is not limiting to growth. Outside the optimal range, there is a critical range within which the crop can be grown successfully but with diminished yield. Beyond the critical range, the crop cannot be expected to yield satisfactorily unless special precautionary management measures are taken.

The same holds for other soil requirements of plants related to soil characteristics. Many soil characteristics can be defined in a range that is optimal for a given crop, a range that is critical or marginal, and a range that is unsuitable under present technology.

Table 4 presents, for each of the crops of the study, optimal and critical ranges of the following soil characteristics: soil slope, soil depth, soil drainage, flooding, texture and clay type, natural fertility (including cation exchange capacity, percent base saturation and organic matter), salinity, pH, free calcium carbonate content and gypsum content. Seven drainage classes and 14 texture classes, subdivided by clay type, are used in the ranges (FAO/UNFPA 1980).

Difficulty was experienced in rating crop requirements with regard to inherent (natural) soil fertility, this attribute being a combination of many individual soil characteristics. To a large extent, however, inherent fertility is related to total exchangeable bases which can be determined through the cation exchange capacity of the soil and the relative degree of saturation of the organic and mineral exchange complex. Both of these characteristics, i.e. CEC and base saturation, are used as the basis for estimating crop fertility requirements as low, medium or high.

Table 4 CROP EDAPHIC ADAPTABILITY INVENTORY

Crops	SLOPE (PERCENT)				DRAINAGE	
	High inputs		Low inputs		All inputs	
	Optimum	Marginal	Optimum	Marginal	Optimum	Range
Wheat	0 - 8	8 - 16	0 - 8	8 - 24	MW-W	I-SE
Pearl millet	0 - 8	8 - 16	0 - 8	8 - 24	MW-SE	I-E
Sorghum	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE
Maize	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE
Cassava	0 - 8	8 - 16	0 - 4	4 - 16	W	MW-SE
Soybean	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE
Groundnut	0 - 8	8 - 16	0 - 8	8 - 20	W-SE	MW-E
Cotton	0 - 8	8 - 16	0 - 8	8 - 20	W	MW-SE

Crops	FLOODING		TEXTURE			
	All inputs		High inputs		Low inputs	
	Optimum	Marginal	Optimum	Marginal	Optimum	Range
Wheat	F_o	F_1	L-MCs	SL-MCs	L-SC	SL-KC
Pearl millet	F_o	F_1	L-CL	LS-KC	L-CL	LS-KC
Sorghum	F_o	F_1	L-C	LS-MCs	L-SC	LS-KC
Maize	F_o	F_1	L-C	SL-MCs	L-SC	LS-KC
Cassava	F_o	F_1	L-SiCL	SL-KC	L-SiCL	LS-KC
Soybean	F_o	F_1	L-SC	SL-KC	L-SC	LS-KC
Groundnut	F_o	F_1	SL-SCL	LS-KC	SL-SCL	MS-KC
Cotton	F_o	F_1	L-MCs	SL-MCs	L-SC	SL-KC

Table 4 (Cont'd)

Crops	DEPTH (cm)		$CaCO_3$ (PERCENT)		GYPSUM (PERCENT)	
	All inputs		All inputs		All inputs	
	Optimum	Marginal	Optimum	Marginal	Optimum	Marginal
Wheat	> 50	25-50	0 - 30	30 - 60	0 - 5	5 - 20
Pearl millet	> 50	25-50	0 - 25	25 - 50	0 - 3	3 - 15
Sorghum	> 50	25-50	0 - 30	30 - 75	0 - 5	5 - 20
Maize	> 50	25-50	0 - 15	15 - 30	0 - 3	3 - 15
Cassava	>100	75-100	0 - 1	1 - 10	0 - 0.5	0.5 - 3
Soybean	> 75	50-75	0 - 20	20 - 35	0 - 3	3 - 15
Groundnut	> 50	20-50	0 - 25	25 - 50	0 - 3	3 - 15
Cotton	>100	75-100	0 - 25	25 - 40	0 - 3	3 - 15

Crops	pH		FERTILITY REQUIREMENT	SALINITY (mmhos)	
	All inputs		All inputs	All inputs	
	Optimum	Range		Optimum	Marginal
Wheat	6.0-8.2	5.2-8.5	moderate/high	0 - 5	5 - 10
Pearl millet	5.5-7.5	5.2-8.2	low	0 - 4	4 - 6
Sorghum	5.5-8.2	5.2-8.5	low/moderate	0 - 5	5 - 10
Maize	5.5-8.2	5.2-8.2	moderate	0 - 4	4 - 6
Cassava	5.2-7.0	4.5-8.2	low	0 - 2	2 - 4
Soybean	5.5-7.5	5.2-8.2	moderate	0 - 3	3 - 6
Groundnut	6.0-7.5	5.5-8.2	moderate	0 - 3	3 - 6
Cotton	6.0-7.5	5.5-8.2	moderate/high	0 - 8	8 - 12

Table 4 (Cont'd)

Crops	ALKALINITY (ESP)	
	All inputs	
	Optimum	Marginal
Wheat	0 - 30	30 - 45
Pearl millet	0 - 30	30 - 45
Sorghum	0 - 20	20 - 35
Maize	0 - 15	15 - 25
Cassava		
Soybean	0 - 8	8 - 15
Groundnut		
Cotton	0 - 20	20 - 35

Drainage classes

I = imperfectly drained
MW = moderately well drained
W = well drained
SE = somewhat excessively drained
E = excessively drained

Textural sequence

MCs = montmorillonitic clay, structured
C = clay (mixed unspecified)
KC = kaolinitic clay
SC = sandy clay
SiCL = silty clay loam
CL = clay loam
SCL = sandy clay loam
L = loam
SL = sandy loam
LS = loamy sand
MS = medium sand

Flooding classes

F_o = no floods
F_1 = occasional floods

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