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LAND RESOURCES EVALUATION PROJECT

MALAWI

METHODOLOGY FOR LAND RESOURCES SURVEY AND LAND SUITABILITY APPRAISAL

by

J.A. Eschweiler, S. Paris, J.H. Venema, A,J.M. Lorkeers and R.I. Green

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SUMMARY

This document describes the methods which have been used by the Land Resources Evaluation Project to assess land suitability at reconnaissance (1:250,000 scale) level of the eight Agricultural Development Divisions in Malawi. The methods have been designed to follow the principles set out in the FAO Framework for Land Evaluation (FAO, 1976). These principles are described.

The way in which the land resources survey was carried out is discussed. The physical environment is described and mapped in terms of agro-climate, soils and physiography and these aspects are combined to defined land units. Present land use and vegetation cover are also described and mapped, and all information is stored in the computerised Land Resources Data Base.

An Automated Land Evaluation System interfaced with the Data Base is used to classify land in term of its suitability for a range of crops under both traditional and improved traditional management. Suitability is also determined for a number of useful tree species.

The presentation of results in the form of reports, maps and the computerised data storage and retrieval system is described.

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LIST OF ABBREVIATIONS AND SYMBOLS

ADD	-	Agricultural Development Division
ALES	-	Automated Land Evaluation System
APT	-	Agricultural Planning Toolkit (FAO, 1988)
ASA	-	Annual Survey of Agriculture
CDA	-	Climatic Data Analysis
CEC	-	Cation Exchange Capacity
DAR	-	Department of Agricultural Research
DM	-	mean number of dry months/year (i.e., months with <50 mm of rainfall)
EPA	-	Extension Planning Area
EC	-	electrical conductivity
FAO	-	Food and Agriculture Organization of the United Nations
itm	-	improved traditional management
K	-	Potassium
LGP	-	length of growing period
LHB	-	Land Husbandry Branch (Dept. of Agriculture, Min. of Agric.)
LRDB	-	Land Resources Data Base
LREP	-	Land Resources Evaluation Project
LQ	-	land quality
LUT	-	land utilization type
m asl	-	meters above sea level
me/100 g	-	milli-equivalent per 100 grams
MLW/85/011	-	symbol for Land Resources Evaluation Project
N	-	Nitrogen
P	-	Phosphorus or Precipitation
P-an	-	mean annual precipitation
PET	-	potential evapotranspiration
RDP	-	Rural Development Project
SMS	-	Subject Matter Specialist
T-an	-	mean annual temperature
T-EGP	-	mean temperature during the end of the growing period
T-GP	-	mean temperature during the growing period
T-min	-	mean minimum temperature of the coolest month
tm	-	traditional management
UNDP	-	United Nations Development Programme
USDA	-	United States Department of Agriculture

CHAPTER 1

INTRODUCTION

In the past, land use changes often came about by gradual evolution as the result of many separate decisions taken by individuals. Nowadays the aim is to bring them about by the process of land use planning. The function of land use planning is to guide decisions on land use in such a way that land resources are put to the most beneficial use for man, whilst at the same time conserving those resources for the future. This type of planning must be based on an understanding both of the natural environment and of the kinds of land use envisaged. It is the function of land evaluation to bring about such understanding and to present land use planners with comparisons of the most promising kinds of land use.

The required information to carry out land evaluation is collected during land resources surveys - the collection of data related to the physical environment. Land resources surveys are usually geared towards the collection of data related to soils, physiography, climate, land use and natural vegetation and include the presentation of their spatial distribution and variability. These surveys are carried out according to certain principles and prior to field operations a survey methodology is established.

In the past a modified Land Capability Classification System, developed originally by the USDA (Klingebiel and Montgomery, 1961), as described in the Land Husbandry Manual for Malawi (Shaxson, 1977) has enjoyed wide acceptance in Malawi. The system was designed to appraise land, in a rather general way, such as for rainfed cropping, forestry etc. It has been used mainly for farm planning at large scales. In 1976 a new approach to land resources appraisal was introduced, published in FAO´s Framework for Land Evaluation (FAO, 1976), followed by a series of guidelines for land evaluation for specific major kinds of land use, such as rainfed cropping, irrigated cropping, forestry, and extensive grazing (FAO, 1983, 1984, 1985, 1987b).

In some cases the principles outlined in the framework and the subsequent guidelines were followed in Malawi, for example, in Dedza District (Young and Goldsmith, 1977) and in the Salima Lakeshore Project (Hunting Technical Services Ltd., 1983). The principles advocated by FAO have been further elaborated by the Land Resources Evaluation Project (LREP) and were applied in land resources appraisals for all ADD´s in Malawi at reconnaissance level. A few areas were also studied at semi-detailed level by the same method.

It should be noted that the guidelines presented in this report only relate to the physical properties of the land. Economic and social analysis should be carried out as a second stage on the land use alternatives which appear most promising on the basis of physical evaluation - the so-called "two-stage approach" in land evaluation. The advantage of this approach is that first-stage land evaluation results have a relatively long time validity, whereas economic evaluations are usually short-lived due to changes in economic conditions.

1.1 OBJECTIVES

The present report is a technical background document. It gives a detailed account of the land resources survey and land evaluation methodology applied in the land resources appraisals carried out by LREP at ADD level within Malawi. It provides a methodology for land resources survey and land suitability appraisal following an approach based on the FAO "Framework for Land Evaluation". Although it is primarily intended for professional Land Husbandry Officers and Soil Surveyors, it may also serve others concerned with land evaluation in Malawi, and it is hoped that the application of the methodology outlined in this report will ensure consistency and compatibility of future exercises.

The methodology of land resources survey and land suitability appraisal presented in this report was designed for studies at reconnaissance to semi-detailed level. Obviously, the models will need refinement and adjustment when applied at detailed level.

1.2 ARRANGEMENT OF THE REPORT

In Chapter 2 an introduction to the FAO approach to land evaluation is presented and the methodology to obtain the basic information required to carry out land evaluation, i.e. land resources data, is discussed in Chapter 3.

The methodology for land evaluation of four major kinds of land use is presented in Chapter 4: "Land suitability appraisal" and Chapter 5 "Computerized land evaluation". These chapters explain the land evaluation models developed for Malawi.

Chapter 6 explains the Land Resources Data Base (LRDB). The LRDB contains all information on the physical environment collected by the surveys, grouped according to ADD. All automated land evaluation models developed by LREP draw their data directly from this data base.

The last chapter (Chapter 7) deals with the presentation of the results of the land evaluation through tables, maps and descriptions showing the spatial distribution of various degrees of suitability for any particular type of land use.

A glossary is provided to facilitate the understanding of the terms frequently used in connection with land evaluation. The appendices contain, among other things, a listing of crop requirements for 22 crops and 16 forestry species in terms of agro-climatic and edaphic characteristics.

CHAPTER 2

LAND EVALUATION: THE FAO APPROACH TO LAND SUITABILITY ASSESSMENT

2.1 INTRODUCTION

The FAO methodology for land evaluation is a system which assesses the suitability of a certain tract of land for a given use. It goes a step further than older general-purpose land capability assessment systems: it enables the planner not only to compare two different tracts of land but also to compare the merits and constraints of different land-uses (down to the level of individual crops) on one and the same land unit. The FAO methodology can be seen as one answer to a complicated problem: how to create a rational, complete and workable basis for providing land-based recommendations for the increase and diversification of agricultural production on a sustained basis, which is geared in particular to the needs of developing countries.

The FAO methodology for land evaluation was first published in 'A Framework for Land Evaluation' (FAO, 1976). This document was followed up by a set of documents comprising guidelines for major kinds of land-use such as rainfed agriculture (FAO, 1983), forestry (FAO, 1984), irrigated agriculture (FAO, 1985) and extensive grazing (FAO, 1987b).

This chapter provides a summary of the concepts of the FAO land evaluation system, and is essentially an extract of the Framework and the documents mentioned above.

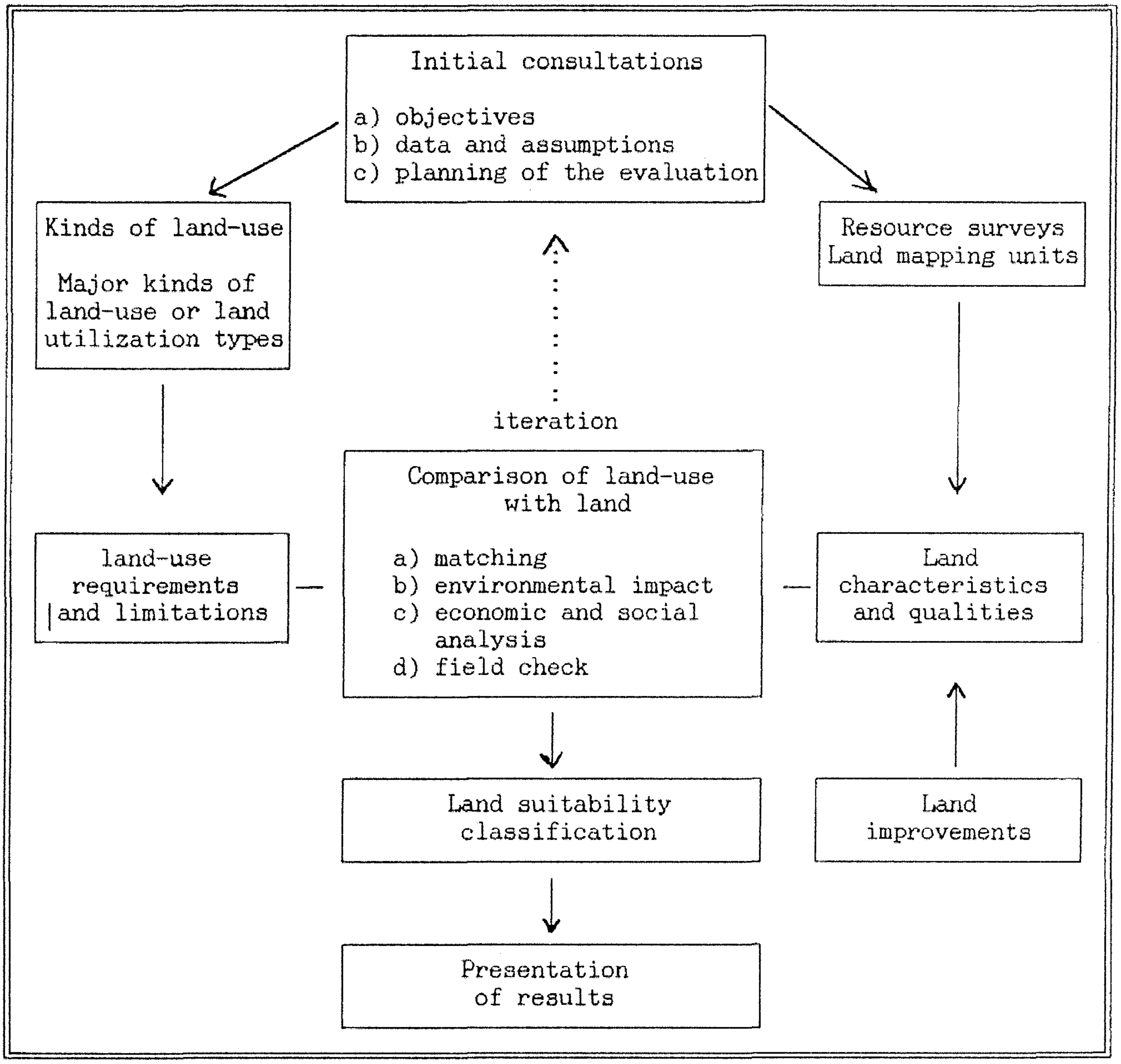
2.2 OBJECTIVES AND PRINCIPLES OF LAND EVALUATION

Land evaluation is the assessment of land performance when used for specified purposes. It is based on analyses of relations between land-use and land. It provides a rational basis for taking land-use decisions and gives estimates of required inputs and projected outputs. In Figure 1 a schematic representation of activities in land evaluation is given.

2.2.1 Objectives

The principle objective of land evaluation is to select the optimum land use for each defined land unit, taking into account both physical and socioeconomic considerations and the conservation of environmental resources for future use. Detailed objectives vary considerably according to the purpose and scale of the land evaluation.

FIGURE 1. SCHEMATIC REPRESENTATION OF ACTIVITIES IN LAND SUITABILITY ASSESSMENT (From: Dent and Young, 1981; p. 146).



The evaluation process does not in itself determine the land use changes that are to be carried out. It provides data and recommendations on the basis of which the users can base their decisions with respect to planning, development or management. To be effective in this role, the output from an evaluation should give information on several potential forms of use for each area of land, including the consequences of each.

2.2.2 Principles of land evaluation

The Framework was formulated specifically to satisfy the objectives stated above. It is dynamic in concept and aims to predict the effects of changes in land use through an understanding of relationships. The relationships concerened are both physical and socioeconomic and exist between a given tract of land and its use.

The Framework is based on six principles:

1. Land suitability is assessed and classified with respect to specified kinds of use. It may be defined in broad terms (rainfed agriculture) or more exactly (a tobacco crop under improved traditional management).

2. Evaluation requires a comparison of the outputs obtained and the inputs needed on different types of land. For example, the cost of fertilizer may be compared with the income obtained from additional yield.

3. An interdisciplinary approach is required. The disciplines needed depend on the type of evaluation. For rainfed agriculture they are likely to include soil survey, agro-climatology, soil conservation, agronomy and socioeconomics. Evaluation for other major kinds of land-use may require inputs in forestry or livestock grazing. These disciplines may be covered by separate subject matter specialists or, to a certain extent, be combined in a small number of individuals.

4. Evaluation is made in terms relevant to the physical, economic and social context of the area concerned. Land which is suitable for a given crop in one area will not always be suitable in another although the quality of the land is similar. This is due to differences in technical knowledge of the farmers, in food preference, in capital availability, in transport costs etc.

5. Suitability refers to use on a sustained basis. The main implication of this principle is that suitability assessment should take account of soil erosion hazard and depletion of plant nutrients.

6. Evaluation involves comparison of more than one kind of use. Evaluation is carried out for a number of land-use types of which

inputs and outputs can be compared.

2.3 LAND

The activities in land evaluation that are specifically concerned with the land comprise two elements: land resource surveys and description of land units, and assessment of the land qualities and land characteristics.

2.3.1 Land resource surveys and land units

Several types of natural resource surveys form the basis of the land component of the land evaluation system. The types of survey which are normally used in land evaluation, are inventories of agro-climate and landform and soils.

The inventories should be geared to the needs of the land evaluation purpose at hand. Emphasis must be on those aspects of the land which play a role in the definition of land qualities and these aspects need to be surveyed in adequate detail. The inventory of agro-climate consists mainly of an analysis of historic meteorological records in the office, while the landform/soils inventory requires considerable fieldwork.

The inventory of agro-climate is ususally done at 1:250,000 scale or smaller since the density of rainfall or meteorological stations does not justify presentation in greater detail. For landform and soil inventories three levels of intensity may be distinguished:

- Reconnaissance surveys; broad inventory of resources for regional studies; typical scale 1:250,000; mapping units are often compound and provide only estimates of the conditions of the land pertaining to land suitability.

- Semi-detailed surveys; for more detailed planning; typical scale :50,000; mapping units are both compound and homogeneous; observation ensity is such that conditions of the land pertaining to land uitability are at least reliable estimates.

- Detailed surveys; for planning and design of projects; typical scales 1:10,000 to 1:25,000; mapping units are usually homogeneous and conditions of the land pertaining to land suitability can usually be reliably quantified.

A <u>land unit</u> is a mapped area of land with specified characteristics and is the basic unit of evaluation. Land units usually combine different types of resource information, such as soils and agro-climate, and are mapped by superimposing of the various resource maps. Land units and land mapping units are further elaborated in Chapter 3.5. The basic aim of land units is that they should be of maximum relevance to the range of land uses envisaged by the evaluation. In theory, land units should approximate to land management units with uniform suitabilities for particular kinds of use and similar management requirements. In practise however this can never be fully achieved due to limitations imposed by mapping, particularly at smaller mapping scales.

2.3.2 Land qualities and land characteristics

A land quality (LQ) is an attribute of land which acts in a distinct manner in its influence on the suitability of the land for a specific kind of use. Examples of LQs are moisture availability, rooting conditions and erosion hazard. See Table 1 for a list of LQs for rainfed agriculture.

TABLE 1. LAND QUALITIES FOR RAINFED AGRICULTURE (Source: FAO, 1983, p.176)

LAND QUALITY	Letter suffix
1. Radiation regime (sunshine)	u
2. Temperature regime	c
3. Moisture availability	m
4. Oxygen availability to roots	w
5. Nutrient availability	n
6. Nutrient retention capacity	t
7. Rooting conditions	r
8. Conditions affecting germination or establishment	g
9. Air humidity as affecting growth	h
10. Conditions for ripening	i
11. Flood hazard	f
12. Climatic hazards (e.g. frost, storm)	c
13. Excess of salts (salinity, sodicity)	z
14. Soil toxicities	x
15. Pests and diseases	p
16. Soil workability	k
17. Potential for mechanization	q
18. Conditions for land preparation or clearance	v
19. Conditions for storage and processing	j
20. Conditions affecting timing of production	y
21. Access within the production unit	a
22. Size of potential management units	b
23. Location (accessibility)	l
24. Erosion hazard	e
25. Soil degradation hazard	d

A land characteristic (LC) is an attribute of land which can be measured or estimated; LCs are used as a means of describing LQs and distinguishing between land units. LCs are grouped according to climate, landform and soil; examples are mean monthly rainfall, slope angle, soil depth, pH and salinity. There is an almost infinite number of LCs and therefore no attempt is being made here to present them in a list.

An essential feature of LQs is that they influence land suitability in a particular manner. Many LCs however do not by themselves influence land suitability in such a manner, but combine to describe LQs. (e.g. texture influences both moisture availability and erosion hazard). LQs are composed of a limited number of LCs (e.g. rooting conditions is composed of soil depth, stoniness of the profile and textural characteristics). In some instances only one land characteristic is needed for describing a LQ; in such cases a LC acts as a LQ (e.g. oxygen availability is composed of soil drainage only).

In practice only a limited number of LQs has to be used. Those LQs should be selected which are known to have a marked influence on the output from, or the required inputs of, a certain crop or kind of land use, and of which critical values to the performance of the crop occur in the study area; these are diagnostic land qualities. Each diagnostic LQ must be rated into classes and a critical value must be assigned to each class limit. The classes used must coincide with the suitability classes of the land-use requirements (see Section 2.4).

2.4 LAND USE

The activities in land evaluation that are specifically concerned with land use comprise two parts: description of the kind of land use, and assessment of the land use requirements.

2.4.1 Kinds of land use

One of the principles of the Frmaework states that land suitability is assessed and classified with respect to specified kinds of use. It follows that types of land-use for which the land is being evaluated must be clearly defined.

Land-use can be defined at two levels of detail. A major kind of land use is a major subdivision of rural land use such as rainfed agriculture, irrigated agriculture, forestry etc. A land utilization type (LUT) is a kind of land use defined in more detail, according to a set of technical specifications in a given socioeconomic setting. In Table 2 a checklist is given of the factors used in descriptions of LUTs.

TABLE 2. CHECKLIST OF FACTORS USED FOR DESCRIPTION OF LAND UTILIZATION TYPES (Source: FAO, 1983; p.30).

Crops grown	Infrastructure requirements
Market orientation	Cropping characteristics
Capital intensity	Material inputs
Labour intensity	Cultivation practises
Technical knowledge and attitudes	Livestock
Power	Forestry
Mechanization	Other non-crop outputs
Size and shape of farms	Yields and production
Land tenure	Economic information

A LUT is described at the level of detail required and the concept of a LUT is flexible and its description can range beteen a summary of a few words to a precise description of more than a page. As a minimum requirement, both the nature of produce (e.g. a single crop) and the socioeconomic setting (e.g. improved smallholder) must be specified.

2.4.2 Land use requirements

Land use requirements (LURs) are the conditions of the land necessary or desirable for the successful and sustained practise of a given LUT. LURs can be subdivided into crop requirements, management requirements and conservation requirements.

LURs must be described in a parametric way, each parameter corresponding with a LQ (e.g. LUR - rooting requirements versus LQ - rooting conditions). In addition, the subdivision in classes of each parameter needs to correspond - as a prerequisite to a meaningful matching procedure (see Section 2.5) - with the classes used in the LQ descriptions. The implication is that, notably in the case of crop requirements, each parameter must be rated in a number of classes for each crop in terms of its suitability; these are called factor ratings. Critical values must be assigned to the suitability class-limits, which at least in theory correlate with yield levels. Classes are denoted with lower case letters ´s´ and ´n´ as follows: s1 (highly suitable), s2 (moderately suitable), s3 (marginally suitable) or n (not suitable).

Reliable quantitative information on LURs is limited in the literature. In particular, information on the disaggregated requirements or tolerances of individual crops with respect to specific parameters is scarce. Only the influence of a few LCs on crop yield is properly verified, for example the influence of pH. Usually only general trends or cut-off points are known for the influence of specific environmental parameters on crop performance. In addition, considerable variation exists in the requirements of different cultivars of a crop. A reliable set of crop requirements is therefore hard to compile.

2.5 MATCHING OF LAND USE REQUIREMENTS WITH LAND QUALITIES

Matching is the process of comparing LURs with diagnostic LQs of land units. Matching results in an assessment of land suitability for each LUT/land unit combination.

Matching is a step by step procedure in which all diagnostic LQs of each land unit are being considered for a given LUT. If the requirement for optimum performance of a given LUT is equal to or less demanding than a LQ of a given land unit, no limitation for this LUT occurs for this land unit with respect to that particular quality. A partial land suitability rating of s1 (highly suitable) results. If the particular LQ is more severe than the requirement of the LUT, a suitability rating results which is in accordance with the previously defined factor ratings for the given LUT - s2, s3 or n. An example is presented in Figure 2.

After comparison of the LURs of the given LUT with all diagnostic LQs of the given land unit, a list of partial land suitability ratings results. The lowest partial land suitability rating determines the final land suitability class for the LUT/land unit combination.

For a given LUT this procedure is followed for all land units.

2.6 LAND SUITABILITY CLASSIFICATION

The matching procedure, described in the previous section, leads to a land suitability classification for each LUT.

The Framework prescribes that consideration must be given to possible land improvements, and that an environmental impact analysis and socioeconomic analysis must be carried out, before the suitability classification is finalized. LREP has carried out these procedures only to a limited extent as follows:

1. Land improvements can be subdivided into minor and major improvements. In the present LREP studies minor improvements, such as fertilizer application and simple soil conservation measures, are part of the specifications of the LUTs. Major land improvements, such as the installation of drainage systems or land levelling, are not considered at the present evaluation stage, as more detailed assessments would be necessary.

2. An environmental impact analysis is mainly concerned with the effect on land and soil degradation of the recommended LUTs. These considerations have already been incorporated in the LQs for erosion hazard and nutrient availability.

3. A socioeconomic analysis is beyond the scope of the present project, but socioeconomics have been considered in general terms in determining the management levels for evaluation of LUTs.

Thus, essentially only the first stage is carried out of the two-stage approach in land evaluation, in which land suitability is determined on the basis of physical criteria, and subsequently analysed with respect to socioeconomic considerations. The second stage has to be carried out before the results of the present land evaluation are used for planning purposes.

The land suitability classification system consists of three levels of generalization:

- Land suitability orders. At the highest level, subdivision is made into tracts of land which are suitable (denoted with "S") or not suitable (denoted with "N").

- Land suitability classes. At the second level a subdivision is made into seven classes which are described in Table 3.

- Land suitability subclasses. At the third level, lower-case letter suffixes are added to the suitability classes. They indicate the type of limitation to the given LUT. If more than three limitations occur, only the three most important ones are indicated. The suffixes used for a particular limitation are explained in Table 1.

The overall land suitability class is determined by the law of the minimum, i.e. the land quality(ies) posing the severest limitation determine(s) the overall land suitability.

FIGURE 2. EXAMPLE OF MATCHING PROCEDURE (SIMPLIFIED)

LAND UTILIZATION TYPE:
Tobacco at improved smallholder level

LAND UNITS:

A, B

CROP REQUIREMENTS:

1) Temperature regime (Mean temperature growing period, °C):

15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	25.0-27.5	>27.5
n	s3/s2	s1	s1	s2	s3

2) Moisture availability (Length of growing period, days):

90-120	120-150	150-180	180-210	210-240	240-270
n	s3/s2	s1	s1	s2	s3

3) Oxygen availability (drainage class):

excessive	well	moderately well	imperfect	poor
s1	s1	s2	n	n

LAND QUALITIES:

A: 1) Temperature regime: 20.0-22.5 °C
2) Moisture availability: 150-180 days
3) Oxygen availability: mod.well drained

B: 1) Temperature regime: 25.0-27.5 °C
2) Moisture availability: 120-150 days
3) Oxygen availability: well drained

MATCHING:

A: 1) Temperature regime (c): s1
2) Moisture availability (m): s1
3) Oxygen availability (w): s2

B: 1) Temperature regime (c): s2
2) Moisture availability (m): s2/s3
3) Oxygen availability (w): s1

LAND SUITABILITY CLASSIFICATION:

Tobacco at improved smallholder level, land unit A: S2w

Tobacco at improved smallholder level, land unit B: S2/3m

TABLE 3. DEFINITIONS OF LAND SUITABILITY CLASSES

SYMBOL	SUITABILITY CLASS	DESCRIPTION	POTENTIAL YIELD as percentage of the maximum attainable yield
S1	Highly suitable	Land having no significant limitations to the sustained application of the given LUT.	100-80 percent
S2	Moderately suitable	Land having limitations which in aggregate are small to substantial to the sustained application of the given LUT; production levels will be reduced and/or costs will be increased when compared with S1.	80-50 percent
S3	Marginally suitable	Land having limitations which in aggregate are severe to the sustained application of the given LUT; production levels will be reduced and/or costs will be increased such that it is often impracticable or uneconomic for the defined use.	50-20 percent
N	Not suitable	Land having limitations which preclude any possibility of successful sustained application of the given LUT. In some cases the land could be made suitable by major changes, e.g. the use of intensive soil conservation measures	<20 percent
S1/2 S2/3 S3/N	intermediate classes	Land having intermediate land suitability, or land of which the suitability is divided among two classes.	

Note: The maximum attainable yield is defined as the maximum yield that can be obtained for a certain crop at a particular management level, - traditional or improved traditional.

The results of the land suitability appraisal take the form of tables in which the land suitability classes are listed for each LUT/land unit combination. The results can also be presented on maps using land unit maps as a base, one map for each LUT.

2.7 LAND EVALUATION VERSUS LAND CAPABILITY CLASSIFICATION

For many years a land capability classification system has been in use in Malawi (Shaxson et al, 1977). It is based on the system developed by the Soil Conservation Service of the United States Department of Agriculture.

The land capability classification system is a qualitative, general-purpose system. The version used in Malawi subdivides the land into nine classes: land suited to cultivation (classes 1 to 5), land suited to grazing (classes 6, 7 and 9), treecrops or forestry (classes 6 and 7) and finally land suited to wildlife or tourism (class 8). Class limits are defined in terms of limitations, of which erosion hazard plays a leading role. The system was originally meant for farm planning. It is relatively simple to use and easy to present.

Although the land capability classification system is well established and has proved its merits in Malawi, it has a number of disadvantages:

1. It evaluates the land for generalized types of use.

2. It produces only qualitative evaluation results.

3. It assumes a decreasing order of value of the land from best to worst. It assumes that land which is best suited for arable use is also best for other uses.

4. It is primarily for soil conservation purposes. Although this is a commendable aim in itself, it tends to overlook other limitations.

5. It is primarily suited for planning at the farm level.

Land suitability evaluation, however, is more dynamic in concept and is not fixed to a limited set of conditions or applications. Land suitability evaluation is able to overcome the above mentioned disadvantages to land capability classification, as follows:

1. It evaluates the land for specific types of use at a specified management level. This can be done at the generalized level of a major kind of land use down to the specific level of individual crops. Attmepts are made to quantify inputs and outputs.

2. It does not classify the land irrespective of its use.

3. Although it often uses limitations in assessing land suitability for a given use, the final suitability is in terms of positive potential.

4. Soil erosion hazard is treated as a subsystem along with several others. After the suitability evaluation an environmental impact analysis may be carried out.

5. It is able to provide essential background information for all levels of planning at all scales from generalized regional down to detailed farm planning.

Land suitability evaluation, however, has one disadvantage of its own: it is complex and relatively time consuming in its use. Therefore, much time and effort has been spent on computerization of the system.

"From a viewpoint of practical utility in land use planning and management, suitability evaluation is far superior to land capability classification for most purposes; land capability classification is effective only to farm planning, and then at a rather elementary scale. Suitability evaluation puts forward alternative possibilities for changes in land-use, whether major new uses or changes in detail, presents the consequences of such changes for each part of the surveyed area, and so provides evidence contributing to planning, management and investment decisions." (Quoted from Dent and Young, 1981; p. 186).

CHAPTER 3

LAND RESOURCES SURVEY

3.1 INTRODUCTION

The resources evaluation is carried out separately for each of the eight Agricultural Development Divisions. The study of an ADD consists of a first phase of land resources inventory and a second phase of land suitability evaluation. The resources inventory phase mainly consists of surveys of soils, physiography, agro-climate, vegetation and present land use. The results of the surveys are presented on maps at a scale of 1:250,000 with the following themes:

- Soils and Physiography

- Agro-climatic Resources Inventory (iso-line maps)

- Agro-climatic Zones (derived from the Agro-climatic Resources Inventory, see Section 3.3)

- Present Land Use and Vegetation (see Section 3.4)

For land suitability evaluation land units are used, which are defined by characteristics of soil, physiography and agro-climate. The definition and mapping of land units is done as follows:

1. The Agro-climatic Zones Map is superimposed on the Soils and Physiography Map and an inventory is made of all significant combinations of units of both maps

2. Land units are defined as a combination of the characteristics of soil units and agro-climatic zones (see Section 3.5)

3. Land units are mapped; the land unit map showing all original soil boundaries with addition of a few extra lines to split up soil mapping units which continue through more than one agro-climatic zone

All information on the land units is stored in a computerised Land Resources Data Base (LRDB, see Chapter 6). This database also includes information on present land-use and vegetation, which is described for each soil unit. The LRDB is the central repository of land resources information and is also used to provide the necessary information for a computerised land suitability evaluation programme (ALES, see Chapter 5).

3.2 SOILS AND PHYSIOGRAPHY

3.2.1 Survey method and relevant land characteristics

The phase of data collection includes the following activities:

a) Literature and map study to collect existing information on geology, physiography and soils.

b) Preliminary study of aerial photographs and satellite images to delineate obvious soil/physiography boundaries and to plan fieldwork.

The use of remote sensing techniques is essential in all surveys. A stereoscopic (i.e. three-dimensional) view of the terrain will save time and money, as well as improve accuracy.

c) Fieldwork. The main purposes of fieldwork are: the verification of the boundaries established through remote sensing, the search for additional boundaries, the description of representative soil profiles and the collection of samples.

The most important land characteristics studied in the field are listed below.

physiographic and general characteristics:

- parent material
- rockiness
- surface stoniness
- topography: dominant slope and slope range
- landform and topo-location: particularly the distinction between water receiving sites and water shedding sites is of importance
- altitude (meters above mean sea level)
- present erosion
- occurrence and frequency of flooding
- drainage, including frequency of ponding
- vegetation and land use (see Section 3.4)

soil profile characteristics:

- effective rooting depth and depth limiting factor
- colour
- particle size: texture and content of coarse mineral fragments
- structure
- consistence
- cracks
- cementation

- porosity

- roots

- presence of free calcium carbonate

In detailed surveys observations are usually made according to a grid system. In semi-detailed and reconnaissance surveys, however, the surveyor often uses his own judgement to select observation points. This is the so-called free survey method. With this method it is extremely important that records of soil and physiography are made at points which are typical for large areas otherwise they have little value. The site selection of soil pits and other observation points is one of the most difficult tasks of a reconnaissance survey. For this purpose a study of aerial photographs of the area is essential. Care should be taken in the field to avoid sites which are not typical, such as termite mounds, gullies and rills, roadsides, areas with excessive compost or manure, etc. Samples are taken either from each soil horizon or, if there are no distinct horizons, from the topsoil (approx. 0-20 cm), the upper subsoil (approx. 30-50 cm) and the lower subsoil (approx. 80-100 cm). For routine analyses each sample should weigh at least 1 kg. The samples should be properly labeled and their identification number and depth entered on the soil profile description form. Soil augers can be used to observe a limited number of important soil characteristics, such as texture, depth and drainage.

Apart from the study of soil pits at selected sites, extensive travel is needed to obtain information on dominant characteristics of a mapping unit which is not easily derived from aerial photographs. Generally the inventory of dominant or average values of characteristics within established mapping units is more important than the precise and detailed study of individual observation points. For example, it is much more important to establish the most common slope class and the range of slopes within a mapping unit than to know the exact gradient of the slope on which a soil profile is sited.

For the recording of field observations a field sheet has been designed. A copy of this field sheet, together with an explanation of the entries, is given in Appendices 1 and 2. Some characteristics mentioned on the field sheet may never be used for land evaluation, but are included to get a complete picture of the soil profile and the site, or are needed for soil classification and correlation.

It is important that all surveyors in the country use the same terminology and symbols. For the description of most characteristics the Guidelines for Soil Profile Description (FAO, 1977) is recommended. Necessary additions are given in Appendix I.

d) Laboratory analysis of soil samples.

For a general soil inventory the following analyses are recommended:

- texture: with separation of sand fraction for coarse textures

- pH (in water)

- electrical conductivity (EC) for samples with pH 6.5 or more

- free calcium carbonate for samples with pH 6.5 or more

- exchangeable bases (K, Na, Ca and Mg)

- exchangeable aluminium (Al) for samples with pH of 4.5 or less

- cation exchange capacity (CEC)

- organic carbon percentage (C) (samples from upper 50 cm only)

- total or available nitrogen percentage (N) (samples from upper 50 cm only)

- available phosphorus (P) (samples from upper 50 cm only)

- micro nutrients copper (Cu), Zinc (Zn), Boron (B) and sulphur (S) (samples from upper 50 cm only)

For methods used by the Dept. of Agricultural Research (Bvumbwe, Chitedze), see Appendix II.

3.2.2 Soil classification and correlation

3.2.2.1 General

Soils have been classified in two ways: firstly through a system designed by LREP of soil groups and soil families, and secondly through a system designed by FAO for the FAO-Unesco Soil Map of the World (FAO, 1988). The system designed by the Project is valid for Malawi only and is fully explained in Field Document No. 3 (Venema, 1990). The classification according to the FAO system should be considered as additional and has been used for the sake of soil correlation.

3.2.2.2 LREP soil classification: soil groups and soil families

Soils are classified at three levels of generalisation:

1. soil parent material

2. soil group

3. soil family

Soil groups or soil families should not be confused with the units of the Soils and Physiography Map ("soil units") which are defined by additional physiographic characteristics (see Section 3.2.3.3).

- Soil parent material

Some important characteristics of physiography and soils closely relate to differences in superficial geological strata. Soil parent material has therefore been selected as the diagnostic characteristic at first level for reconnaissance survey. Soil parent materials have been grouped in six classes, symbolised by one capital letter each. Soil parent material classes are listed in Table 4.

TABLE 4: SOIL PARENT MATERIAL CLASSES

symbol	description
A	Fluvial, colluvial and/or lacustrine sediments
B	Mafic* igneous and metamorphic rocks
D	Medium- to fine-grained or mixed coarse- to fine-grained sedimentary rocks
S	Coarse-grained sedimentary rocks
X	Felsic* and intermediate igneous and metamorphic rocks
Z	Aeolian deposits

* Note: mafic = rocks with dark-coloured (ferromagnesian) minerals
felsic = rocks with light-coloured minerals such as feldspar and quartz

- Soil group

For the description and classification of the soil groups quantitative criteria have been used similar to those described in the Legend for the Soil Map of the World (FAO, 1988). For the purpose of the present survey some of the Soil Units defined in the FAO Legend have been grouped together. The reason for this is that some of the distinctions are thought to be not very relevant for land suitability evaluation (e.g. distinction between Luvisol and Nitisol or between Cambisol and Regosol) and also to facilitate the re-interpretation of previous soil surveys.

The differentiating criteria for the soil groups incorporate soil characteristics which are most relevant for land suitability evaluation for arable farming and forestry. Such characteristics are soil depth, occurrence of flooding, salinity, drainage, texture, topsoil consistence, presence of free lime and inherent chemical fertility of the upper 50 cm of the soil.

For Malawi a total of 13 soil groups have been distinguished. The key and the definitions of these groups are given below. A simplified key and the correlation of the soil groups with FAO Soil Units (FAO, 1988)is given in Appendix III.

<u>u - lithic soil group</u>

Lithic soils have a depth of 30-50 cm over hard rock or other hard material not penetrable by roots and more than 20% fine earth (soil materials with a diameter of 2 mm or less). Characteristics other than depth may vary widely.

v - vertic soil group

Vertic soils have more than 30% clay in the upper 18 cm and develop wide cracks up to a depth of at least 50 cm when dry. They are mostly very deep. Cracking is caused by the presence of montmorillonitic clay minerals which shrink when dry and swell when moist. Seasonal shrinking and swelling causes a slow but continuous mixing of soil material in at least the upper 50 cm of the soil.

f - fluvic soil group

Fluvic soils are soils which are continuously rejuvenated through the deposition on the surface of sediments transported by water. They are derived from alluvium and are mostly very deep. There may be a considerable variation in particle size, both vertically in the profile (stratification) and horizontally. Gravelly layers can be observed in a minority of the profiles.

s - salic soil group

Salic soils have high salinity (> 4 mmho/cm) in most of the upper 100 cm. They are at least moderately deep.

g - gleyic soil group

Gleyic soils are very poorly to poorly drained. They have a water-saturated topsoil or a high groundwater table during at least part of the year.

a - arenic soil group

Arenic soils have a sand or loamy sand texture throughout the upper 100 cm (or less if soil depth is less).

m - mopanic soil group

Mopanic soils have within the upper 50 cm a horizon with high bulk density and low porosity, resulting in a very hard consistence when dry and very low permeability. The mopane tree (Colophospermum mopane) is one of the few trees in Malawi tolerant of the compact and dry nature of this group of soils.

c - calcaric soil group

Calcaric soils are calcareous in most of the upper 100 cm, or less if soil depth is less. (Soil material shows strong effervescence with diluted (10%) hydrochloric acid or contains > 2% calcium carbonate equivalent).

<u>p - paralithic soil group</u>

Paralithic soils have highly weathered rock which starts within a depth of 75 cm from the surface and continues to a depth of at least 150 cm. The soil above the weathered rock is often skeletal (> 35% coarse mineral fragments). The weathered rock provides foothold for roots, but only holds limited available moisture and nutrients.

<u>r - dystric-ferralic soil group</u>

Dystric-ferralic soils have a low CEC-clay (< 24 me/100 g) in most of the upper 100 cm and a low base saturation (< 50%) in at least part of the upper 50 cm. They are strongly weathered and heavily leached. They are usually very deep (> 150 cm), well drained with a red colour and clay texture throughout the profile.

<u>x - eutric-ferralic soil group</u>

Eutric-ferralic soils have a low CEC-clay (< 24 me/100 g) in most of the upper 100 cm and a high base saturation (> 50%) throughout the upper 50 cm.

<u>d - dystric-fersialic soil group</u>

Dystric-fersialic soils have a medium to high CEC-clay (> 24 me/100 g) in most of the upper 100 cm and a low base saturation (< 50%) in at least part of the upper 50 cm.

<u>e - eutric-fersialic soil group</u>

Eutric-fersialic soils have a medium to high CEC-clay (> 24 me/100 g) in most of the upper 100 cm and a moderate to high base saturation (> 50%) throughout the upper 50 cm. The relatively high CEC-clay indicates only a limited advance of the ferrallitization process and the presence of considerable amounts of weatherable minerals. The moderate to high base saturation indicates a low degree of leaching and the presence of exchangeable bases, particularly calcium, magnesium and potassium.

- soil family

Within a soil group one or more soil families are distinguished. These soil families are defined at a level of detail similar to those of the Soil Series described previously for Northern and Central Malawi (Young & Brown, 1962; Brown & Young, 1965). Criteria used for the distinction of soil families are (in order of importance):

- parent material class (see above)

- soil group (see above)

- soil depth (one of the following classes: 30-50 cm, 50-100 cm, 100-150 cm, > 150 cm)

- drainage class (one or two of the following classes: very poor, poor, imperfect, moderately well, well, somewhat excessive, excessive)

- particle size topsoil (0-30 cm) (one or two of the following classes: coarse, coarse-skeletal*, medium, medium-skeletal, fine, fine-skeletal)

- particle size subsoil (> 30 cm) (same criteria as for topsoil)

- pH class (a range of not more than 1.5 units: e.g. 5.0-6.0, or 6.0-7.5)

- CEC class (one of the following classes (me/100 g): <5, 5-10, >10)

Soil families may also be described in terms other than those given above (e.g. nutrient status, colour), but they do not form part of the definition.

Soil families are named after a place or river near which the family was first found. The same family, however, may also occur far away from this place. The list of soil families needs to be updated continuously, but efforts should be made to keep it as short as possible. The key to the soil families and their descriptions are given in Field Document 29 (Venema, 1990). An example of the list of soil families is given in Appendix IV.

3.2.2.3 Correlation with Units of the Soil Map of the World (FAO, 1988)

- Introduction

To make the soil information more accessible, all soil families distinguished in the present survey have been classified according to the FAO classification.

In the FAO classification Soil Units** are defined on the basis of the occurrence of quantitatively defined soil characteristics which relate to soil formation. In addition, phases are distinguished which refer to additional limiting factors of the land. The FAO system distinguishes between 28 major soil groupings, subdivided at second level into 153 Soil Units. About 17 first-level Units are common in Malawi. A simplified key to the 17 relevant Soil Units is given in Appendix V. This key does not replace the one given in the Revised Legend (FAO, 1988), but is meant to

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* skeletal = >35 % mineral fragments with diameter of >2 mm.

** The FAO Soil Units should not be confused with the units of the Soils and Physiography Map of the present study which are also called "soil units" (lower case letters).

give a quick reference to the major soils. For any serious classification effort the Revised Legend should be consulted.

3.2.3 The Soils and Physiography Map

3.2.3.1 Introduction

Soils and physiography are described in terms of "miscellaneous land units" and of "soil units". Miscellaneous land units are types of land defined by one outstanding characteristic which severely limits its use for agriculture and forestry. Miscellaneous land includes marshes, rock outcrops, very steep slopes and open water. Other land is described in terms of soil units which are defined by a large number of characteristics related to soil and physiography. Miscellaneous land units and soil units are shown on the Soils and Physiography Map at scale 1:250,000. This map shows single miscellaneous land units and soil units or a combination (complex) of one miscellaneous land unit with one soil unit or a combination of two soil units. The map is accompanied by a separate legend sheet which can be found in the back pocket of each ADD report.

3.2.3.2 Miscellaneous land units

Five miscellaneous land units have been distinguished, each symbolised by one single capital letter:

- E Very severely eroded land (badlands)
- M perennial marshes
- R land with predominantly very shallow soils (soils with an effective depth of < 30 cm) or with extremely gravelly or stony soils (soils which have < 20% fine earth in the upper 75 cm) or rock outcrops.
- V land with very steep slopes (> 55%)
- W open water

3.2.3.3 Soil units

The term "soil unit" is an abbreviation of "soil and physiography unit". Soil units are defined by characteristics related to both soil and physiography. There are four levels of generalisation:

- soil parent material

The first and highest level of generalisation is soil parent material. Classes of parent material are symbolised by a capital letter. Six classes have been distinguished, as shown in Table 4.

- slope class

The second level of generalisation is dominant slope inclination.

This means that the various parent materials found in the survey area will be sub-divided according to dominant slope. There are five slope classes covering the range from 0 to 55% slope and symbolised by the numbers 1 to 5 as indicated in Table 5. Areas with dominant slopes of more than 55% are mapped as one of the miscellaneous land units.

TABLE 5: SLOPE CLASSES

class	slope range (%)
1	0 - 2%
2	2 - 6%
3	6 -13%
4	13 -25%
5	25 -55%

- soil group

Sub-division at third level is according to soil group. Soil groups are soil types defined at a high level of generalisation using some of the most relevant criteria mentioned in the FAO-Unesco Legend for the Soil Map of the World. The symbol for a soil group is a lower-case letter. Thirteen soil groups have been distinguished, which are defined in Section 3.2.2.1. A simplified key to the soil groups is given in Appendix V.

- soil units

At the fourth and lowest level the soil family and a number of additional land characteristics are used to sub-divide units of the third level. Soil families are defined by depth, drainage, particle size, soil reaction (pH) and cation exchange capacity (CEC); the additional land characteristics are: surface stoniness and rockiness, present erosion and flooding. Fourth-level units are called soil units, the term "soil unit" being used as an abbreviation for "soil and physiography unit". The symbol for a soil unit consists of four elements, starting with the symbols for the three higher levels of generalisation and ending with a serial number, e.g. A1f4. The number of soil units per ADD at reconnaissance level varies from approximately 35 to 80; the total number of soil units for the country at the same level is 270.

3.2.3.4 Legend

The legend shows the four levels of generalisation - parent material, slope, soil group and soil unit - as explained above. An example of the legend is shown in Appendix VI. The information given for each of the soil units can be sub-divided as follows:

I. diagnostic characteristics

- parent material
- slope
- soil group
- soil family
  - depth
  - drainage
  - particle size topsoil
  - particle size subsoil
  - pH (0-50 cm)
  - CEC (0-50 cm)
- surface stoniness and rockiness
- present erosion
- flooding

II. additional information

- hectarage
- classification (FAO, 1988)
- nutrient status (NPK) (0-50 cm)
- colour subsoil
- landform

The diagnostic characteristics of a soil unit are the same throughout the country and cannot be changed. The additional information is only valid for a particular survey area (e.g. hectarage, landform), or may be modified if more information becomes available (e.g. nutrient status). The classes used for the description of each of the characteristics are given in Appendix VII.

3.2.3.5 Soil mapping units

Soil mapping units are areas on the Soils and Physiography Map defined by one soil unit in the case of a homogeneous soil mapping unit and by two soil units or one soil unit and one miscellaneous land unit in the case of a complex soil mapping unit. The symbol for a soil mapping unit is made up of the symbols of the relevant soil units and miscellaneous land units, for example A1v3, A1f1/A1g2 or X5p2/R. In the case of a complex soil mapping unit it is assumed that the first soil unit takes up 70% of the area and the second soil unit or miscellaneous land unit 30%.

3.3 AGRO-CLIMATE

3.3.1 Introduction

Climate plays an important role in the evaluation of all of the four major kinds of land use considered in this study (see Chapter 4). Data gathering on climate is separated from other survey activities and is limited to a desk exercise on the basis of historical records from Malawi´s Meteorological Services.

Following the concept of agro-climatic zonation (FAO, 1978, 1981, and Kassam et al. 1981, 1982), Eschweiler and Nanthambwe (1988, 1990) and Nanthambwe (1990) have carried out (agro-) climatic resources inventories for the Southern, Northern and Central Regions of Malawi. Their reports provide a comprehensive overview of relevant climatic parameters together with their spatial distribution, based on a computerised analysis of historical records. The study undertaken by them was specifically carried out to provide the required climatic data for land suitability appraisals.

In the following sections a brief description is given of the climatic parameters that have been used in compiling Agro-climatic Zones Maps for each Region in Malawi. The maps themselves and the accompanying legend is discussed in Section 3.3.3

3.3.2 Agro-climatic Resources Inventory

A climatic data bank, arranged by Region and District has been installed within LREP/LHB in Lilongwe were detailed records from 18 meteorological stations and 318 rainfall stations in Malawi are kept. These records cover the period between 1955 and 1985. The Climatic Data Analysis Programme of FAO´s Agricultural Planning Toolkit (FAO, 1987a) and an IBM compatible microcomputer were used for the calculation of, among others, the reference length of growing period (LGP), pattern of the growing period, P/PET ratios, mean temperature during the growing period and the average starting date of the growing period. The processed data, i.e. the Agro-climatic Resources Inventory, has been published in the above mentioned reports, one for each Region in Malawi, and forms part of the data bank.

The Agro-climatic Resources Inventory quantifies the prevailing moisture and temperature regimes in Malawi and presents their spatial distribution on a scale of 1 : 250,000.

3.3.2.1 Length of growing period

The climatic aspect of moisture availability is expressed through the LGP, which is defined as the period when rainfall (P) exceeds half potential evapotranspiration (PET, modified Penman (Frere, 1979) based on multiple linear regression analyses) plus the period required to evapotranspire an assumed 100 mm of stored soil moisture. The LGP is therefore the period of the year when moisture supply and temperature permit crop growth and was calculated on the basis of a water balance model, comparing rainfall (monthly data of individual years of records) and stored soil moisture with PET. The LGP of each rainfall station and meteorological station was calculated and the resulting LGP is expressed in days and its spatial distribution has been indicated on a map, using 15 day intervals, and represents the average LGP during years with a unimodal rainfall pattern (no dry spells affecting plant growth during the rainy period). The LGP is of importance to annual cropping, its length determines the choice of crops and crop cultivars, for example, short-cycle varieties versus long-cycle varieties.

The longest LGP in Malawi is found on the Lichenya Plateau of Mt. Mulanje with a LGP of over 300 days. The shortest LGP occurs along the lower Shire River and the Elephant Marsh in Chikwawa District were the LGP is about 110 days.

3.3.2.2 Pattern of the growing period

To determine the year-to-year variation in the number of lengths of growing periods per year, a historical profile was compiled showing groups of years each with a different number of growing periods per year. The proportional representation of each group in the total historical series was then computed. There may be more than one growing period in a single year due to the occurrence of one or more dry spells. The relative occurrence of years with one, two or even three LGPs is expressed as the "pattern of the growing period". A total of 5 patterns have been recognized within Malawi, as indicated in Table 6.

The pattern with the highest risk of having dry spells during the rainy season, pattern 1-2-3, is found only in the Southern Region and,

TABLE 6: PATTERN OF THE GROWING PERIOD

code	proportion (%)	description
1	100	Occurence of one growing period per year in all years.
1-2a	90:10	Occurence of one growing period per year in 90% of the years (dominant lenght number) with two growing periods per year in 10% of the years (associated length number).
1-2b	75:25	Occurence of one growing period per year in 75% of all years with two growing periods per year in 25% of the years.
1-2c	60:40	Occurence of one growing period per year in 60% of all years with two growing periods per year in 40% of the years.
1-2-3	70:25:5	Occurence of one growing period per year in 75% of all years with two growing periods per year in 25% of the years and three growing periods per year in 5% of the years.

covers most of Chikwawa and Nsanje Districts, and around Lake Chirwa in Mulanje, Zomba and Machinga Districts.

3.3.2.3 Quality of moisture supply

The quality of moisture supply is defined as the ratio P/PET during the growing period. Three classes have been used: <1.0, 1.0-1.3, and >1.3. When the ratio is less than 1.0 it means that P is less than PET for most of the time during the growing period. Crops are likely to suffer from water stress and soil moisture storage is usually very low. With the ratio between 1.0 and 1.3 there is still a chance of crops suffering from water stress for short periods, but this is far less pronounced than in the first case. Soil moisture storage to the assumed maximum of 100 mm may not be completely achieved. With a ratio of over 1.3, crops are unlikely to suffer from water stress during the growing period and a maximum soil moisture storage is achieved.

Areas having a P/PET ratio of less than 1.0 are found only in Nsanje, Chikwawa and the eastern part of Mwanza District.

3.3.2.4 Mean temperature during the growing period

Most farmers in Malawi grow annual crops. It is therefore important to know what the mean temperature is during the LGP. The mean monthly temperature was calculated for each month of the year and for each 100 m interval in altitude, using a linear regression formula (Lancaster, 1980). The mean temperature during the growing period was then calculated using FAO's software (FAO, 1987a). The spatial variation in temperature is expressed through the concept of "thermal zones". Within Malawi seven thermal zones have been identified. Their characteristics are presented in Table 7.

TABLE 7: DESCRIPTION OF THERMAL ZONES.

code	description	T-mean GP [1]
Wv	Very warm	>27.5
W	Warm	27.5-25.0
W-Wm	Warm to moderately warm	25.0-22.5
Wm-W	Moderately warm to warm	20.0-22.5
Wm-Cm	Moderately warm to moderately cool	20.0-17.5
Cm-Wm	Moderately cool to moderately warm	15.0-17.5
Cm	Moderately cool	12.5-15.0

[1] Mean temperature during the growing period in °C.

The highest mean temperature during the growing period is found along the lower Shire River in Nsanje and Chikwawa Districts. The lowest are found on Mt. Mulanje (Lichenya Plateau) and on Nyika Plateau.

3.3.2.5 Mean temperature towards the end of the growing period

Some annual crops require lower temperatures in order to achieve optimum growth rates, e.g. wheat. With a growth cycle of about 120 days it could be fitted into the cooler part of the longer LGPs, as mean monthly temperature decreases towards the end of the growing period.

3.3.2.6 Average starting dates of the growing period

The computed average starting date of the growing period determines the point in time when field preparations, and all activities prior to planting, should have been completed. The average starting date of the growing period in Malawi falls in most areas within the second half of November, except in the lower and higher altitude areas where it usually starts later or earlier, respectively. Standard deviations vary, but indicate a fairly reliable onset of the growing period.

3.3.2.7 Mean annual rainfall

The mean annual rainfall is of importance for perennials and was obtained directly from the records of rainfall and meteorological stations. The mean annual rainfall in Malawi varies from about 610 mm (rainfall station Kafukule in Mzimba District) to about 3,300 mm (rainfall station Mwangulukulu in Karonga District).

3.3.2.8 Mean number of dry months per year

The mean number of dry months per year is of importance for perennials. A dry month has been defined as having less than 50 mm of precipitation. This data was also obtained directly from the records of rainfall and meteorological stations. The mean number of dry months in Malawi varies from a maximum of eight in various parts of the country to a minimum of one on the Lichenya Plateau of Mt. Mulanje.

3.3.2.9 Mean annual temperature

The mean annual temperature is closely related to altitude and is of importance for perennials. The mean annual temperature was derived from the mean monthly temperatures, calculated for each 100 m interval in altitude as explained in Section 3.3.2.4. The lowest temperatures are found on Mt. Mulanje, where they are between 10.0° and 12.5 °C at an altitude of between 2,500 and 3,000 m asl, while the highest are found in the Lower Shire area: just over 25.0 °C at an altitude of about 100 m asl.

3.3.2.10 Mean minimum temperature of the coolest month

The mean minimum temperature of the coolest month is mainly of importance for perennials. July is the coolest month in most places of Malawi. The mean monthly minimum temperature is also closely related to altitude and was calculated through multiple linear regression analysis. The lowest mean minimum temperatures are found on Mt. Mulanje, where the mean minimum temperature for July is between 3.0° and 5.5 °C for the altitude range from 2,500 to 3,000 m asl. The highest mean minimum temperatures are found in the Lower Shire area, where they are around 15.0 °C.

Unfortunately limited data is available on the occurrence of night frost. However, the lower the mean minimum temperature the higher the risk. In general, areas above 1,500 m may experience night frost occasionally, during the months of June, July and August.

3.3.3 Agro-climatic Zones Map

Seven of the above described agro-climatic parameters have been combined into mapping units and correlated on a national level. They are:

- LGP (in days)

- P/PET

- mean temperature during the growing period (in °C)

- mean annual rainfall (in mm)

- mean number of dry months per year

- mean annual temperature (in °C)

- mean minimum temperature of the coolest month (July) (in °C)

The resulting Agro-climatic Zones have been numbered and their spatial distribution has been indicated on maps at scale 1 : 250,000, one for each ADD. These maps are not isoline maps, but show mapping units (Agro-climatic Zones). The maps are included in the land resources appraisal reports for each ADD in Malawi and provide all the required information for land evaluation at reconnaissance to semi-detailed level, as explained in Chapters 4 and 5 of this report. The accompanying legend is in a tabular form and provides the particulars of the above mentioned seven agro- climatic parameters that make up an Agro-climatic Zone.

A total of 149 Agro-climatic Zones has been identified in Malawi, a rather high number but it should be remembered (see Sections 3.3.2.1 to 3.3.2.10) that there is considerable variation within a particular parameter, let alone when these parameters are combined. In Appendix VIII the legend of the Agro-climatic Zones Map for the whole of Malawi is given.

3.4 PRESENT LAND USE AND VEGETATION.

In order to compare the outcome of a land resources appraisal with the present situation on the ground an inventory is made of present land use and vegetation. The inventory is also a useful independent output providing a recent picture of land use and vegetation for the whole of Malawi.

3.4.1 Methodology.

Maps of Present Land Use and Vegetation were compiled on an ADD basis at a scale of 1:250,000. They show the distribution of the various types of arable farming, plantation forests and the vegetation of land not cultivated. Other land uses are not explicitly shown on the map. It may be assumed, however, that all grasslands and most woodlands and forests outside the reserved areas are used for grazing and the collection of firewood, building materials, wild fruits and game.

The assessment of present land use and vegetation is based on field observations and aerial photo guided interpretation of satellite images. False color composites of Landsat-5 Thematic Mapper (TM) satellite images at a scale of 1:250,000 have been used. Bands 2 and 3 in the visible spectrum (green and red) and band 4 in the near infrared, which give the most accurate spectral response for vegetation discrimination, have been chosen. The most recent dry season images of 1989 and 1990 were used.

In order to delimit the land use and vegetation units, pattern recognition on the TM images has been guided by panchromatic aerial photos at a scale of 1:40,000 and 1:25,000 (1990 and 1986). All TM images have been checked by means of a template which indicates the position of an aerial photo projected at a scale of 1:250,000.

After this assessment directly from satellite images and aerial photos, field observations on land use and vegetation obtained during the field survey have been incorporated and used to define:

- crops and crop mixes for each land use unit

- species of forest plantations

- vegetation types

All available and relevant literature and maps already existing on land use and vegetation have been consulted and additional land use and vegetation field surveys have been executed to complete the exercise.

The extent of all mapping units has been calculated for each ADD by means of the dot-count method and by measurement with a digital planimeter. Figures were rounded off to the nearest hundred hectares. The interpretation of the total areas must take into account that the smaller mapping units (e.g. B1 - wetland cultivation, C1 - dimba cultivation, E - grassland, etc.) are largely underestimated, as they are either too small to represent on a 1:250,000 scale as pure units, or they occur as a sub-unit of complex mapping units with a coverage of less than 25%.

Another aspect in interpreting the map is the existence of multiple land use (more than one kind of use simultaneously undertaken) and compound land use (more than one kind of use sequentially undertaken). It results in a sometimes arbitrary assessment of, for example, rainfed cultivation, wetland cultivation, dimba cultivation, natural cover and wet grassland in a lowland area where more than one or two uses can occur, depending on season.

The areas of the rainfed cultivation units include recent fallow land.

3.4.2 The legend

The legend of the map is self-explanatory. Cultivated land is subdivided according to crop combinations. Only the dominant crops are listed in the legend. The mapping symbols consist of pure mapping units and complex mapping units. The pure mapping units are those units which are occupied by more than 75% of a single land use or vegetation type. The complex mapping units indicate a major land use or vegetation type which occupies 50-75% of the surface and a minor type, occupying 25-50%.

The legend of the Present Land Use and Vegetation Map is presented in Appendix IX.

3.5 LAND UNITS

3.5.1 Methodology

For land suitability evaluation land units are used, which are defined by characteristics of soil, physiography and agro-climate. The definition and mapping of land units is done as follows:

1. The Agro-climatic Zones Map is superimposed on the Soils and Physiography Map and an inventory is made of all significant combinations of units of both maps

2. Land units are defined as a combination of the characteristics of soil units and agro-climatic zones

3. Land units are mapped on a ADD basis; the land unit map showing all original soil boundaries with addition of a few extra lines to split up soil mapping units which continue through more than one agro-climatic zone

The number of land units per ADD at reconnaissance level varies from approximately 200 to 320. Few land units occur in more than one ADD and the total of land units for the whole country is about 2,000. The symbol for a land unit is a serial number but can also be written as the combined symbols for the relevant soil unit and agro-climatic zone as shown in an example below:

land unit no. 430 = X2p2(7)

- (7) — code for agro-climatic zone
- X2p2 — code for soil unit

An example of the list of land units is shown in Appendix X. The land units were numbered systematically for the three southern ADDs, which were surveyed first, but this system could not be maintained after new and unforeseen combinations of soil unit and agro-climatic zone were found in other ADDs.

3.5.2 The Land Unit Map

Land units have been mapped at a scale of 1:250,000. The areas delineated on the map are called land mapping units. Land mapping units are defined by one land unit in the case of a homogeneous land mapping unit and by two land units in the case of a complex land mapping unit. A complex land mapping unit is made up of two soil units or one soil unit and one miscellaneous land unit in combination with one climatic zone. The symbol for a land mapping unit is made up of the symbols for the relevant land units and miscellaneous land units, e.g. 123, 16/256, 185/R. In case of complex land mapping units it is assumed that the first land unit takes up 70% of the area and the second land unit the remaining 30%.

The Land Unit Map has no legend. Individual land units are described in an Appendix of the relevant report and the information is also contained in the computerised Data Base. An example of a land unit description is shown in Appendix X1.

CHAPTER 4

LAND SUITABILITY APPRAISAL

4.1 LAND UTILIZATION TYPES

4.1.1 Introduction

A distinction is made between major kinds of land use and land utilization types (LUTs). A major kind of land use is a major subdivision of rural land use and has clearly defined levels of technical inputs and an associated socioeconomic setting. For instance, land suitability for a crop varies considerably according to the circumstances under which it is produced: lands with slopes of more than 13%, or of a very stony nature, are normally not suited to mechanical cultivation, but can be cultivated with hand tools when adequate soil conservation measures have been taken. Thus, a description of the circumstances of cultivation is vital to any sound evaluation of land.

The major kinds of land use considered by LREP are as follows:

- rainfed cropping under traditional management
- rainfed cropping under improved traditional management
- wetland rice cropping under traditional management
- forestry

A LUT is a specific kind of land use defined in more detail. In the ADD appraisals LUTs are single crops grown in pure stands in the case of rainfed and wetland cropping, and single tree species in the case of forestry. The LUTs have been selected on the basis of their agro-climatic suitability, present existence within the ADD and in some cases on the basis of market demand and Government policy.

Details of each major kind of land use listed above are presented in the following sections. An overview of the land utilization types within each major kind of land use considered is presented in Table 8.

4.1.2 Rainfed cropping

For the purpose of the ADD appraisals, specific land utilization types have been considered. These are based on single crops and are evaluated at two levels of inputs, a low and an intermediate. The former corresponds to traditional farming, while the second corresponds to improved traditional farming. The attributes pertaining to both levels of management have been listed in Table 9.

TABLE 8: LAND UTILIZATION TYPES.

RAINFED CROPPING, TRADITIONAL MANAGEMENT (1) (tm-model)	RAINFED CROPPING, IMPROVED TRADITIONAL MANAGEMENT (2) (itm-model)	IRRIGATED CROPPING, TRADITIONAL MANAGEMENT (r-model)	FORESTRY (3) (f-model)	Main use
Bulrush millet	Bulrush millet	Bunded rice	Acacia albida	A
Cashew	Cashew		Azadirachta indica	F,P,T
Cassava	Cassava - long cycle		Callitris calcarata	P,T
Citrus	Cassava - short cycle		Callitris hugellii	P,T
Cotton	Citrus		Cassia siamea	F,P
Cowpea	Coffee arabica		Cordyla africana	F,P,T
Finger millet	Cotton		Eucalyptus camaldulensis	F,P
Groundnuts	Cowpea		Eucalyptus grandis	F,P
Guar beans	Finger millet		Eucalyptus maidenii	F,P,(T)
Irish potato	Groundnuts - long cycle		Eucalyptus tereticornis	F,P
Maize	Groundnuts - short cycle		Gmelina arborea	F,P,(T)
Phaseolus beans	Irish potato		Melia azedarach	F,P
Pigeon pea	Maize - long cycle		Pinus caribaea	T
Sorghum	Maize - short cycle		Pinus kesiya	T
Soya beans	Phaseolus beans - long cycle		Pinus oocarpa	T
Sunflower	Phaseolus beans - short cycle		Pinus patula	T
Sweet potato	Pigeon pea			
Wheat	Sorghum			
	Soybeans			
	Sunflower			
	Tea			
	Tobacco - air- and fire-cured			
	Tobacco - flue-cured			
	Wheat			

(1) Only varieties available to the traditional farmer.
(2) Improved varieties if available.
(3) Explanation of abbreviations for main use: A = Agro-forestry
F = fuelwood
P = pole wood
T = timber

TABLE 9: ATTRIBUTES OF THE TWO MANAGEMENT LEVELS CONSIDERED IN LAND EVALUATION FOR RAINFED CROPPING.

	traditional management	improved traditional management
PRODUCTION SYSTEM	Rainfed cultivation of presently grown crop mixture.	Rainfed cultivation of crops grown usually in pure stands.
TECHNOLOGY EMPLOYED	Local cultivars. No fertilizers or chemical pest, disease and weed control. Use of poorly alligned ridges with sub-optimal spacing or planting on the flat. Sub-optimal plant densities and generally poor cultivation practices.	Improved cultivars. Early land preparation and timely planting. Limited use of fertilizers and pesticides. Composting and manuring. Correct plant spacing and plant densities. Cultivation on correctly spaced contour-aligned cultivation ridges. Adequate weeding and extension is followed.
POWER SOURCES	Exclusive use of manual uncosted family labour with hand tools.	Use of (hired) manual labour with hand tools or animal traction with improved implements.
LABOUR INTENSITY	High, but only family labour.	High, family labour as well as hired labour.
CAPITAL INTENSITY	Low, no use of credit.	Intermediate, access to and use of credit facilities.
MARKET ORIENTATION	Basically subsistence farming, although some cashcrops may be grown.	Subsistence production & commercial sale of cashcrops and excess food crops.
INFRASTRUCTURE REQUIREMENTS	Limited access to markets and agricultural services.	Free access to market facilities and agricultural services.
LAND TENURE	Customary land with traditional rights.	Idem.
LAND HOLDINGS	Small and usually fragmented.	Small but often consolidated.
RECURRENT INPUTS REQUIRED	Traditional seed, human labour.	Improved seed, human (costed) labour and animal power, fertilizers and pesticides.

4.1.2.1 Rainfed cropping under traditional management

The main characteristics of the traditional input level are: the growing of traditional crops using local varieties, manual labour with simple hand tools, no use of fertilizer or pesticides, traditional cultivation practices and no use of extension and credit facilities. This input level coincides with conditions of subsistence farming with very limited market orientation as is prevalent in most parts of Malawi.

A total of about 16 land utilization types (crops) have been considered, depending on ADD, under this major kind of land use (see Table 8, and Appendix XII for their crop requirements).

4:1.2.2 Rainfed cropping under improved traditional management

The improved traditional management level is practised by a relatively small number of more advanced farmers who are in a position to acquire external inputs and who sell part of their produce. The improved traditional management level assumes the availability of improved cultivars, the application of fertilizer and pesticides when required, hired labour or ox-drawn implements may be used, extension advice is frequently obtained and generally improved cultivation practises are applied. These farmers obtain credit if required and are market oriented.

The requirements of the 24 crops considered under this major type of land use (see Table 8) are listed in Appendix XII. For some crops short- and long-cycle varieties have been included in the evaluation.

4.1.3 Wetland rice cropping under traditional management

The varieties of rice used are improved strains of the traditionally grown Faya variety. Assumed conditions are similar to rainfed cropping under traditional management. Irrigation works, other than some simple ditches and bunds made by hoe, are absent. Water is supplied by natural flooding from a nearby river and/or adjacent slopes, supplemented by rainfall. Planting is done on the flat after an initial nursery stage.

This land utilization type does not apply to irrigation schemes, where flooding of rice fields is controlled through a network of canals, ditches and gates and where the water usually is diverted from a river via a specially constructed intake.

4.1.4 Forestry

The land evaluation model for forestry assesses the suitability of the land for a number of forestry species already known in Malawi and for which suitability has already been confirmed in at least some parts of the country. The forestry model provides valuable information for farmers (woodlots) and commercial forestry activities. Trees are grown mainly for the purposes listed in Table 8.

The requirements of 16 tree species have been listed in Appendix XIII.

4.2 LAND QUALITIES AND LAND CHARACTERISTICS

4.2.1 Introduction

Land Qualities (LQ) are properties of the land and influence land use in a particular manner. They can be matched with a particular requirements of a specific land utilization type. For example, nutrient availability is a LQ which can be compared with the nutrient requirements for the growth of maize. LQs refer to the physiological and/or management requirements of crops, forestry species or animals.

Land qualities are composed of a limited number of land characteristics. The number of land characteristics needed to assess a particular LQ varies. For example, for an assessment of LQ "moisture availability" six land characteristics have been considered relating to climate, soil and physiography; for LQ "oxygen availability" only one land characteristic, i.e. soil drainage class, is required. The LQs and the LCs that define the LQs are presented in Table 22. Table 23 lists all diagnostic land characteristics for the four major kinds of land use.

LQs are usually obtained through an inventory of relevant land characteristics, which are either measured, inferred or sometimes estimated. For example the LQ "nutrient availability" can be assessed through the determination of such land characteristics as: available nitrogen, phosphorus and potassium in the topsoil.

A total of 10 land qualities and 29 diagnostic land characteristics have been identified for consideration in the evaluations. Table 10 shows a listing of land qualities and their composition in terms of land characteristics, according to each major kind of land use considered. Table 11 gives the names of each diagnostic land characteristic and provides an overview of their application in the evaluation models. All land characteristics of the land units identified at reconnaissance level can be derived from the LRDB (see Chapter 6).

Below follows a description, for each major kind of land use, of how each land quality is assessed for each LUT. For each land quality, its nature and effects, application to the evaluations and its assessment, is presented. The factor ratings which are given for each land quality refer to the effects of individual land qualities, for example, the effect of temperature on the growth of maize. These ratings are signified by a lower case letter to avoid confusion with the land suitability classes which are defined in the same way. Land suitability classes, however, are the end product of the evaluation and are indicated with capital letters. Definitions of land suitability classes and factor ratings have already been presented in Table 3.

TABLE 10: LAND QUALITIES AND THEIR COMPOSITION IN TERMS OF LAND CHARACTERISTICS.

		Land Qualities	Land Characteristics
RAINFED CROPPING, TRADITIONAL MANAGEMENT (tm-model)	c	Temperature regime	T-an, T-EGP, T-GP, T-min
	e	Erosion hazard	Erod, P-an, Sd, Sl
	f	Flooding hazard	Fl
	k	Soil workability	Mop, Sr, Ver
	m	Moisture regime	DM, LGP, P-an, P/PET, Sd, Sl, Soil-c, Tl
	n	Nutrient availability	K, N, P
	r	Rooting conditions	Mop, Par, Sd, Sr, Ver
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal
RAINFED CROPPING, IMPROVED TRADITIONAL MANAGEMENT (itm-model)	c	Temperature regime	T-an, T-EGP, T-GP, T-min
	e	Erosion hazard	Erod, P-an, Sd, Sl
	f	Flooding hazard	Fl
	k	Soil workability	Mop, Sr, Ver
	m	Moisture regime	DM, LGP, P-an, P/PET, Sd, Sl, Soil-c, Tl
	r	Rooting conditions	Mop, Par, Sd, Sr, Ver
	t	Nutrient retention capacity	CEC
	w	Oxygen availability	Dr
	x	Toxicity/acidity	pH, Sal
IRRIGATED CROPPING, TRADITIONAL MANAGEMENT (r-model)	c	Temperature regime	T-GP
	m	Moisture regime	P-an, Sl, Tl, Dr, Fl
	n	Nutrient availability	K, N, P
	r	Rooting conditions	Sd
	x	Toxicity/acidity	pH, Sal
FORESTRY (f-model)	c	Temperature regime	T-an
	m	Moisture regime	DM, P-an
	r	Rooting conditions	Sd
	s	Soil related factors	Dr, Soil

Note: The abbreviations used for the land characteristics are explained in Table 11.

Factor ratings are based on the land use requirements of a specific LUT. The land use requirements have been derived from various literature as listed in Appendices XII and XIII.

Parts of the text in the following Sections "Nature and Effects" have been drawn directly from FAO's Guidelines for Land Evaluation (FAO, 1976, 1983, 1984, 1985, 1987b).

TABLE 11: DIAGNOSTIC LAND CHARACTERISTICS.

Land Characteristics group	symbol	name	RAINFED CROPPING, TRADITIONAL MANAGEMENT (tm-model)	RAINFED CROPPING, IMPROVED TRADITIONAL MANAGEMENT (itm-model)	IRRIGATED CROPPING, TRADITIONAL MANAGEMENT (r-model)	FORESTRY (f-model)
CLIMATE	DM	Mean number of dry months/year	X	X		X
	LGP	Reference length of growing period	X	X		
	P-an	Mean annual precipitation	X	X	X	X
	P/PET	Quality of moisture supply	X	X		
	T-an	Mean annual temperature	X	X		X
	T-EGP	Mean temp. during end growing period	X	X		
	T-GP	Mean temp. during growing period	X	X	X	
	T-min	Mean minimum temp. of coolest month	X	X		
SOIL	CEC	Cation exchange capacity (0-50cm)		X		
	Dr	Median soil drainage class	X	X	X	X
	Erod	Soil erodibility factor (1)(2)	X	X		
	K	Potassium (0-50cm)	X		X	
	Mop	Mopanic soil properties	X	X		
	N	Nitrogen (0-50cm)	X		X	
	P	Phosphorus (0-50cm)	X		X	
	Par	Paralithic soil properties	X	X		
	PH	Median soil reaction (0-50cm)	X	X	X	
	Rmf	Rock and mineral fragments profile	X	X		
	Sal	Salinity	X	X		
	Sd	Effective soil depth	X	X	X	X
	Soil	Soil group	X	X	X	X
	Soil-c	Soil properties combined (3)	X	X		
	Sr	Surface stoniness and rockiness	X	X		
	Tex-p	Texture profile	X	X		
	Tex-t	Texture topsoil	X	X		
	Ver	Vertic soil properties	X	X		
TOPOGRAPHY and OTHERS	Fl	Frequency of flooding	X	X	X	
	Sl	Dominant slope class	X	X	X	
	Tl	Topolocation (4)	X	X	X	

(1) "Erod" has different values in the itm-model (factor for ridging included) and in the tm-model (no ridging factor included).

(2) "Erod" is derived from "P-an", "Soil" and "Tex-t".

(3) "Soil-c" includes the following soil characteristics: "Mop", "Rmf", "Tex-p", "Tex-t" and "Ver".

(4) "Tl" is derived from "Dr" and "Soil".

4.2.2 Temperature regime (LQ "c")

LQ "c" applies to the evaluations for rainfed (tm and itm models) and wetland (r model) cropping, and forestry (f model).

4.2.2.1 Nature and effects

Plant growth increases more or less in linearity with increasing temperatures until it reaches an optimum after which it falls off. Crop requirements with respect to temperature regime are therefore defined in an optimum range, i.e., the highest potential for growth is achieved with temperature and radiation in the optimal range, and in an operative range, i.e., the limits within which photosynthesis will take place but not necessarily at an optimum level. Very high mean temperatures, >35°C, or very low mean temperatures, <6°C, which have a strong adverse effect on the rate of growth, do not occur to a significant extent during the growing period in Malawi. The mean temperature during the growing period is also of importance for the choice of variety; the long season varieties being usually grown in the cooler areas, while the short cycle crops are grown in the warmer areas.

The lowest temperatures occur during the dry season and annual crops are therefore not affected. For perennials, however, the lowest temperatures may need to be considered, particularly for areas above 1,300 m where night frost may occur.

4.2.2.2 Application to the evaluations

Diagnostic land characteristics:

For annuals : monthly averages of the mean daily temperature (in °C) during the growing period (T-GP), or at the end of the growing period (T-EGP) (LUT "wheat" only)

For perennials : mean annual temperature (T-an) and the mean minimum temperature (in °C) of the coolest month which is July (T min)

In studies covering a relatively limited area, such as a Region or ADD, LQ "c" mainly operates through the effects of altitude. The effect of slope and aspect vary widely and may need to be taken into consideration at detailed level. At reconnaissance to semi-detailed level, however, this is not considered. Original temperature records from all meteorological stations in Malawi have been used to establish regression formulae on a monthly basis and for each 100 m interval in altitude, in order to calculate the following agro-climatic parameters for any location in Malawi:

-mean temperature during the growing period (in °C)

-mean temperature during the end of the growing period (in °C): only relevant for LUT "wheat" under rainfed conditions (tm and itm model), where the LGP is >225 days

-mean annual temperature (in °C)

-mean minimum temperature of the coolest month (in °C)

The above data are derived from the Agro-climatic Resources Inventories (Eschweiler and Nanthambwe, 1988 (Southern Region), 1990 (Northern Region) and Nanthambwe 1990 (Central Region).

4.2.2.3 Assessment for rainfed cropping (tm and itm models)

The assessment of the land quality "temperature regime" is similar for both levels of management considered. However, a different procedure is followed for annual and perennial crops.

Annual crops

The thermal characteristics of each LGP zone have been indicated on the accompanying maps in the Agro-climatic Resources Inventories. The monthly averages of the mean daily temperature have been used to determine the mean temperature during the growing period. This temperature is then matched with the temperature requirements of the LUT under consideration and the land suitability rating is obtained. In Table 12 factor ratings of mean temperature during the growing period are presented for various crops. Here it should be noted that for LUT "wheat", the mean temperature has been taken for the last 120 days of the growing period. Although this temperature is usually similar to the mean temperature during the entire growing period, the higher areas with a relatively long growing period are often cooler towards the end. In the higher elevations of Malawi, such as the Kirk Range, wheat is usually planted towards the end of the rainy season.

Perennial crops

For perennials the mean annual temperature is used for comparison with their temperature requirement (see Table 12). In addition, the mean minimum temperature of the coolest month is considered and these factor ratings are presented in Table 13. The mean minimum temperature of the coolest month for each 100 m interval in altitude can be obtained from a table in the Agro-climatic Resources Inventories. The rating obtained by comparing the mean annual temperature with the temperature requirement of a particular tree crop is modified by the rating for the mean minimum temperature of the coolest month. The lowest rating found determines the land suitability rating for LQ "c".

4.2.2.4 Assessment for wetland rice cropping (r model)

The assessment is done in the same way as described for annual crops in Section 4.2.2.3. The factor ratings have been presented in Table 12. The land suitability rating of LQ "c" is obtained by comparing the thermal requirements of the LUT "wetland rice" with the actual thermal characteristics of a given land unit.

TABLE 12: FACTOR RATINGS OF MEAN TEMPERATURE FOR VARIOUS CROPS (TM , ITM AND R MODELS).

crop	mean temperature (in °C) during the growing period						
	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	25.0-27.5	27.5-30.0
Maize 1]	n	n	s3	s2	s1	s1	s1/s2
2]	s3	s2/s1	s1	s1	s2	s3	n
Bulrush millet	n	n	n	s3	s2	s1	s1
Finger millet	n	n	s3	s2	s1	s1	s1
Wetland rice	n	n	n	s3/s2	s1	s1	s1
Sorghum	n	n	s3	s2/s1	s1	s1	s1
Groundnuts 1]	n	n	n	s3/s2	s1	s1	s2
2]	n	n	s3/s2	s1	s1	s2	s3
Soya beans	n	n	s3	s2	s1	s1	s2/s3
Sunflower	n	s3	s2	s1	s1	s1	s1
Cowpea	n	n	s3	s2	s1	s1	s1
Guar beans	n	n	n	s3	s2	s1	s1
Phaseolus beans 1]	n	n	s3	s2	s1	s1	s2
2]	s3	s2	s1	s1	s2/s3	n	n
Pigeon pea	n	n	s3	s2	s1	s1	s1
Irish potato	s2	s1	s2	s3	n	n	n
Sweet potato	n	s3	s3	s2	s1	s1	s2
Cassava 1]	n	n	n	s3	s2	s1	s1
Cotton	n	n	n	s3	s2/s1	s1	s1
Tobacco 3]	n	n	s3/s2	s1	s1	s2	s2/s3
4]	n	s3	s2	s1	s1	s2	s3
	mean temperature (in °C) during the end of the growing period						
	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0		
Wheat 5]	s2	s1	s2	s3	n		
	mean annual temperature (in °C)						
	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	25.0-27.5	
Cassava 2]	n	n	s3	s2	s1	s1	
Cashew	n	n	n	n/s3	s2	s1	
Citrus	n	s3	s2	s1	s1	s1	
Coffee arabica	n	s3	s1	s1/s2	s3	n	
Tea	s3	s2	s1	s2/s3	n	n	

1] Short cycle varieties
2] Long cycle varieties
3] Air-cured (Burley) and Fire-cured tobacco
4] Flue-cured tobacco
5] A wide variation in mean monthly temperatures may occur within relatively long LGP's. Short to medium cycle crops could be fitted into a particular temperature range, e.g. wheat.

TABLE 13: FACTOR RATINGS OF MINIMUM TEMPERATURE REQUIREMENTS FOR PERENNIALS (TM AND ITM MODELS).

crop	mean minimum temperature (in °C) of the coolest month (July)						
	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5
Cassava 1]	n	s3	s2	s1	s1	s1	s1
Cashew	n	n	n	s3	s3	s2	s2
Citrus	s3	s3	s2	s1	s1	s2	s3
Coffee arabica	n	n	s3	s2	s2	s1	s1
Tea	n	n	n	s3	s2	s1	s1

Note: For areas over 1,300 m adjustments may need to be made for the occurrence of frost, according to duration and severity.

1] Long cycle variety.

4.2.2.5 Assessment for forestry (f model)

The assessment is solely based on a comparison between mean annual temperature and the temperature requirements of forestry species. Ratings are presented in Table 14. The rating found in this table for a particular species (LUT)/land unit combination is the land suitability rating of LQ "c". Ratings for the mean minimum temperature have not been applied due to insufficient data on species requirements.

TABLE 14: FACTOR RATINGS OF TEMPERATURE REGIME FOR VARIOUS FORESTRY SPECIES (F MODEL).

species	mean annual temperature (in °C)					
	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	25.0-27.5
Acacia albida	n	n	s3	s2	s1	s1
Azadirachta indica	n	s3	s2	s1	s1	s1
Callitris calcarata	n	s2/s3	s1	s1	s2/s3	n
Callitris hugellii	n	n	s3	s2	s1	s1
Cassia siamea	n	n	s3	s2	s1	s1
Cordyla africana	n	n	s3	s2	s1	s1
Eucalyptus camaldulensis	n	s3	s2	s1	s1	s2
Eucalyptus grandis	s3	s2	s1	s1	s2	s3
Eucalyptus maidenii	s3	s2	s1	s1	s2	s3
Eucalyptus tereticornis	n	s3	s2	s1	s1	s2
Gmelina arborea	n/s3	s2	s1	s2	s3/n	n
Melia azedarach	n	s3	s2	s1	s1	s1
Pinus caribaea	s2	s1	s1	s2	s3	n
Pinus kesiya	s3	s2	s1	s1	s2	s3
Pinus oocarpa	s3	s2	s1	s1	s2	s3
Pinus patula	s2	s1	s1	s2	s3	n

4.2.3 Moisture regime (LQ "m")

LQ "m" applies to the evaluations for rainfed (tm and itm models) and wetland rice (r model) cropping, and forestry (f model).

4.2.3.1 Nature and effects

Crops and trees are affected by moisture availability through the effects of moisture stress on growth and possibly death through drought. Moisture stress occurs when soil water in the rooting zone becomes limited. However, crops and trees vary considerably in their response to moisture stress and therefore the moisture level at which stress effects first become apparent. When soil moisture falls below wilting point for more than a certain period, which varies from crop to crop and tree to tree, this will eventually cause the death of the crop or tree. The most likely period for complete crop failure through drought is during emergence and establishment before an adequate rooting system has been established.

Moisture availability is affected by many factors: climate, landform, soil and hydrology. A primary determinant is rainfall; therefore its temporal variability is an important aspect of this quality and deserves special attention.

4.2.3.2 Application to the evaluations

Diagnostic land characteristics:

a) Agro-climatic parameters:

- precipitation (P, in mm); monthly (for the calculation of LGP) and mean annual rainfall (P-an)

- potential evapotranspiration (PET-modified Penman, in mm) monthly values (for the calculation of LGP)

- mean number of dry months/year (DM); i.e., months with <50 mm of rainfall/year

b) Physiographic/edaphic parameters:

- topolocation (Tl); distinction is made between water-receiving (wr) and water-shedding (ws) sites. A wr site has been defined as having "gleyic", "vertic" or "salic" soil groups, or a "fluvic" soil group that is very poorly, poorly, or imperfectly drained.

- dominant slope class (Sl); runoff increases with slope angle

- infiltration capacity; as a function of topsoil particle size, (Tex-t)and the presence of vertic (Ver) or mopanic (Mop) soil properties

- available water holding capacity (AWHC); as a function of effective soil depth (Sd) and particle size (Tex-p) and the content of rock and mineral fragments in the profile (Rmf)

- soil drainage class (Dr); according to the FAO classification (FAO, 1977)

- frequency of flooding (Fl); for classes see Section 4.2.8.3

Moisture availability plays a major role in all LUTs considered. At the same time it is one of the most difficult land qualities to assess, as it is influenced by many land characteristics, either in a direct or an indirect way. For rainfed cropping of annual crops, moisture regime is determined from two agro-climatic parameters, P and PET; combined into the Reference Length of Growing Period (LGP), and modified through the combination of physiographic and edaphic characteristics. Also the ability of annual crops to survive a certain period with inadequate moisture supply has been included in the evaluation. For wetland rice the moisture regime is determined primarily by the flooding regime (Fl) and soil drainage (Dr) while the total annual rainfall (P-an) plays a minor role. For forestry only two agro-climatic parameters are considered: P-an and DM.

4.2.3.3 Assessment for rainfed cropping under traditional management (tm model)

<u>Annual crops</u>

The LGP as defined in Section 3.3.2.1, has been used to determine moisture availability from a climatic viewpoint alone (FAO, 1978, Kassam et al., 1981, 1982). The LGP is derived from the Agro-climatic Resources Inventories.

Factor ratings are presented in Table 15 and are based on the agro-climatically attainable yield of a given crop. For water-receiving sites the factor rating derived from Table 15 is taken as the final factor rating for LQ "m". For water-shedding sites, adjustments are made for the quality of moisture supply, expressed as the P/PET ratio, the ability of a crop to survive periods of water stress, the infiltration capacity (runoff), and available water holding capacity (AWHC) of the soil.

First, the factor rating found in Table 15 is modified by the combined effect of the quality of moisture supply for a given area (land unit) and the drought resistance of a given crop. P/PET ratios signify the following:

P/PET=0.8-1.0: rainfall does not fully meet the PET requirements so creating a moderate moisture stress during a considerable part of the growing period

P/PET=1.0-1.3: periods of slight to moderate moisture stress may be present for short periods during the growing period. In this situation soil moisture storage may not be achieved completely

TABLE 15: FACTOR RATINGS OF LGP REQUIREMENTS FOR ANNUAL CROPS (TM-MODEL).

crop	LGP (in days)												drought resistance	downgrading [1]		
	105-120	120-135	135-150	150-165	165-180	180-195	195-210	210-225	225-240	240-270	270-300	300-330		0.8-1.0	1.0-1.3	>1.3
Maize	s3	s3	s2	s1	s1	s1	s1	s1	s2	s2	s3	s3	low	1	½	0
Bulrush millet	s2	s2	s1	s1	s1	s2	s2	s2	s3	s3	n	n	moderate	½	0	0
Finger millet	s3	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	n	moderate	½	0	0
Sorghum	s3	s3	s2	s1	s1	s1	s1	s2	s3	s3	n	n	high	0	0	0
Wheat	s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	low	1	½	0
Groundnuts	s3	s3	s2	s1	s1	s1	s1	s1	s2	s3	s3	n	moderate	½	0	0
Soya beans	s3	s2	s2	s1	s1	s2	s2	s2	s3	s3	s3	n	low	1	½	0
Sunflower	s3	s2	s2	s1	s1	s1	s2	s2	s3	s3	s3	n	moderate	½	0	0
Phas. beans	s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	s3	s3	low	1	½	0
Guar beans	s2	s2	s1	s1	s1	s2	s2	s2	s3	n	n	n	high	0	0	0
Cowpea	s3	s2	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	moderate	½	0	0
Pigeon pea	s3	s2	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	moderate	½	0	0
Irish potato	n	s3	s2	s1	s1	s1	s1	s2	s2	s3	n	n	low	1	½	0
Sweet potato	s3	s3	s3	s2	s1	s1	s1	s2	s2	s2	s3	s3	moderate	½	0	0
Cassava	s3	s3	s3	s3	s3	s3	s2	s2	s2	s2	s1	s1	high	0	0	0
Cotton	s3	s2	s2	s1	s1	s1	s1	s2	s3	s3	s3	n	moderate	½	0	0

1] Downgrade by the number of classes indicated. Downgrading is based on the combined effect of the P/PET ratio and drought resistance of a particular crop.

P/PET=>1.3 : rainfall exceeds by far the PET requirements and crops are unlikely to suffer from moisture stress

P/PET ratio's of less than 1.3 normally occur in areas with relatively short LGP's. Generally the shorter the LGP, the more pronounced the risk of having droughts. Depending on the drought resistance of a crop the factor rating obtained in Table 15 is adjusted accordingly, as indicated in the same table. Shown are the number of classes by which the LGP factor rating is to be adjusted. Subsequently a correction is made to compensate for limited infiltration capacity and AWHC of the soil, according to the conditions of the land unit under consideration, as indicated in Tables 16 and 17.

TABLE 16: RUNOFF AS A FUNCTION OF TOPSOIL CHARACTERISTICS (INFILTRATION CAPACITY) AND SLOPE ANGLE (TM MODEL).

topsoil characteristics	dom. slope class		
	<6%	6-13%	>13%
coarse texture	low	low	mod.
medium or fine texture (non-vertic)	low	mod.	high
medium or fine texture with vertic soil prop.	mod.	high	high

TABLE 17: AVAILABLE WATERHOLDING CAPACITY (AWHC) AS A FUNCTION OF SOIL DEPTH AND PARTICLE SIZE (TM and ITM MODELS).

soil characteristics	effective soil depth (cm)		
	<50	50-100	>100 1]
coarse texture with >40% coarse fragments, or soils with mopanic properties	low	low	low
coarse texture with <40% coarse fragments,or medium or fine texture with >40% coarse fragments	low	low	medium
medium or fine textured soils with <40% coarse fragments	low	medium	high

Note: The effective soil depth is the depth to an impermeable layer or layer with >70% coarse fragments.

1] Average over upper 150 cm, or proportionately less if the depth is between 100-150 cm.

The combined effect of these characteristics may result in a further adjustment of the factor rating obtained so far, as indicated in Table 18. The now obtained rating is the land suitability rating of LQ "m" for a specific LUT (within the major kind of land use "rainfed cropping under traditional management") and land unit combination.

TABLE 18: ADJUSTMENTS TO COMPENSATE FOR THE COMBINED EFFECT OF INCREASED RUNOFF AND LIMITED AVAILABLE WATERHOLDING CAPACITY (TM and ITM MODELS).

AWHC	runoff		
	low	moderate	high
low	½	½	1
medium	0	½	1
high	0	0	½

Note: Indicated is the number of classes to downgrade the factor rating obtained from Table 15.

Perennial crops

For perennials the mean annual rainfall in combination with the mean number of dry months per year is used in the assessment of LQ "m". These two agro-climatic parameters are obtained from the maps accompanying the Agro-climatic Resources Inventories. In Table 19 factor ratings, reflecting the requirements in terms of precipitation for two perennials, have been indicated. The obtained factor rating is adjusted for the mean number of dry months per year, as indicated in Table 20.

The lowest rating found in either of these tables, determines the factor rating which is further downgraded, in case of a water-shedding site, based on the combined effect of infiltration capacity and AWHC, in the same way as already indicated for annual crops. No downgrading is done for the combined effect of drought resistance and quality of moisture supply, due to the deep rooting nature of perennials.

TABLE 19: FACTOR RATINGS OF MEAN ANNUAL PRECIPITATION (IN MM) FOR PERENNIALS (TM MODEL).

crop	mean annual precipitation (in mm)				
	600-800	800-1200	1200-1600	1600-2000	>2000
Cashew	s3	s3/s2	s1	s1	s2
Citrus	n	s3	s2	s1	s2

TABLE 20: FACTOR RATINGS OF MEAN NUMBER OF DRY MONTHS/YEAR FOR PERENNIALS (TM-MODEL).

crop	mean no. of dry months/year [1]			
	1-2	3-4	5-6	7-8
Cashew	n	s3/s2	s1	s2/s3
Citrus	s3/s2	s1	s2	s3/n

1] A dry month is defined as having <50 mm rainfall.

4.2.3.4 Assessment for rainfed cropping under improved traditional management (itm model)

Annual crops

Procedures are the same as outlined for annual crops in Section 4.2.3.3. Table 21 lists the factor ratings for LGP requirements and indicates the downgrading based on drought resistance of a particular LUT and the quality of moisture supply. For further downgrading, in the case of a water-shedding site, based on infiltration capacity and AWHC, Table 22 and Table 17 are used, respectively.

TABLE 22: RUNOFF AS A FUNCTION OF TOPSOIL CHARACTERISTICS (INFILTRATION CAPACITY) AND SLOPE ANGLE (ITM MODEL).

topsoil characteristics	dom. slope class		
	<6%	6-13%	>13%
coarse texture	low	low	low
medium or fine texture (non-vertic)	low	low	mod.
medium or fine texture with vertic soil prop.	low	mod.	mod.

The number of classes to downgrade, based on the combined effect of these characteritics, have been given already in Table 18. The resulting rating represents the land suitability rating of LQ "m", for a given LUT and land unit.

Perennial crops

The procedure is the same as outlined for annual crops in Section 4.2.3.3. Factor ratings for mean annual precipitation and mean number of dry months per year have been indicated in Tables 23 and 24, respectively. For water-shedding sites, downgrading is done based on the combination of Table 22 and 17. The number of classes to downgrade have been indicated already in Table 18. The resulting rating represents the land suitability rating of LQ "m" for a particular tree crop (LUT) and land unit.

TABLE 21: FACTOR RATINGS OF LGP REQUIREMENTS AND DROUGHT RESISTANCE FOR ANNUAL CROPS (ITM MODEL).

crop		LGP (in days)												drought resistance	downgrading [1]		
		105-120	120-135	135-150	150-165	165-180	180-195	195-210	210-225	225-240	240-270	270-300	300-330		0.8-1.0	1.0-1.3	>1.3
Maize	2]	s3	s2	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	low	1	½	0
	3]	n	s3	s3	s2	s2	s1	s1	s1	s1	s1	s2	s3	low	1	½	0
Bulrush millet		s2	s2	s1	s1	s1	s1	s2	s2	s3	n	n	n	moderate	½	0	0
Finger millet		s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	n	n	moderate	½	0	0
Sorghum		s3	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	n	high	0	0	0
Wheat		s3	s2	s1	s1	s1	s1	s1	s2	s2	s2	s3	n	low	1	½	0
Groundnuts	2]	s3	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	n	moderate	½	0	0
	3]	n	s3	s2	s1	s1	s1	s1	s1	s2	s2	s3	n	moderate	½	0	0
Soya beans		s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s3	n	low	1	½	0
Sunflower		s3	s2	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	moderate	½	0	0
Cowpea		s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s3	n	moderate	½	0	0
Phaseolus beans	2]	s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	n	n	low	1	½	0
	3]	n	s3	s3	s2	s1	s1	s1	s1	s1	s2	s3	s3	low	1	½	0
Pigeon pea		s3	s2	s1	s1	s1	s1	s1	s1	s1	s2	s3	n	moderate	½	0	0
Irish potato		s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	low	1	½	0
Cassava	2]	n	n	n	n	n	s3	s3	s2	s2	s1	s1	s1	high	0	0	0
	3]	s3	s3	s3	s3	s3	s3	s3	s3	s2	s2	s1	s1	high	0	0	0
Cotton		s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	n	n	moderate	½	0	0
Tobacco		n	s3	s2	s1	s1	s1	s1	s2	s3	n	n	n	low	1	½	0

1] Downgrade by the number of classes indicated. Downgrading is based on the combined effect of the P/PET ratio and drought resistance of a particular crop.

2] Short cycle varieties.

3] Long cycle varieties.

TABLE 23: FACTOR RATINGS OF MEAN ANNUAL PRECIPITATION (IN MM) FOR PERENNIALS (ITM MODEL).

crop	mean annual precipitation (in mm)				
	600-800	800-1200	1200-1600	1600-2000	>2000
Cashew	s3	s2/s1	s1	s1	s1
Citrus	n	s3	s2/s1	s1	s2
Coffee arabica	n	s3/n	s3	s2	s1
Tea	n	n	s3/s2	s1	s1

TABLE 24: FACTOR RATINGS OF MEAN NUMBER OF DRY MONTHS/YEAR FOR PERENNIALS (ITM MODEL).

crop	mean no. of dry months/year [1]			
	1-2	3-4	5-6	7-8
Cashew	n	s3/s2	s1	s2/s3
Citrus	s3/s2	s1	s2	s3/n
Coffee arabica	s2/s1	s1/s2	s3	n
Tea	s1	s1/s2	s3/n	n

1] A dry month is defined as having <50 mm rainfall.

4.2.3.5 Assessment for wetland rice cropping (r model)

Areas unsuitable for wetland rice are water shedding sites, or sites having moderately well to excessively drained soils, or having slopes greater than 2%. Suitability is primarily determined by the flooding regime and the soil drainage class. In Table 25 the factor ratings are presented. Note that the mean annual rainfall (P-an) has been used as a modifier in two particular cases.

4.2.3.6 Assessment for forestry (f model)

The assessment for forestry is based on the combined effect of mean annual rainfall and number of dry months/year. The lowest rating obtained from Tables 26 and 27 represents the land suitability rating of LQ "m" for any land unit/LUT combination belonging to this major kind of land use.

TABLE 25: FACTOR RATINGS OF MOISTURE REGIME AS A FUNCTION OF FLOODING REGIME AND SOIL DRAINAGE FOR WETLAND RICE (R MODEL)

frequency of flooding [1]	soil drainage class [2]			
	very poor	poor	imperfect	mod. well to excessive
none	na	n	n	n
none to exceptional	na	n	n	n
exceptional	s2	s2	n	n
frequent	s2	s1	s1	n

Note: [1] Classes are defined in Section 4.2.8.3.
[2] Soil drainage classes according to FAO (1977).

Poorly drained but exceptionally flooded sites become not suitable (n) when P-an is less than 1,200 mm and are downgraded by one class (to s3) when P-an is between 1,200 and 1,600 mm. Imperfectly drained but frequently flooded sites are also not suitable (n) when P-an is less than 1,200 mm, are downgraded by 1½ class (to s2/s3) when P-an is between 1,200 and 1,600 mm, and by one class (to s2) when P-an is greater than 2,000 mm.

TABLE 26: FACTOR RATINGS OF MEAN ANNUAL PRECIPITATION FOR VARIOUS FORESTRY SPECIES (F MODEL).

species	mean annual precipitation (in mm)				
	600-800	800-1200	1200-1600	1600-2000	>2000
Acacia albida	s1	s1	s2	s3	n
Azadirachta indica	s1	s1	s2	s3	n
Callitris calcarata	n/s3	s2	s1	s2	s3
Callitris hugellii	s1	s1	s2	s3	n
Cassia siamea	s2	s1	s2	s3	n
Cordyla africana	s1	s1	s2/s3	n	n
Eucalyptus camaldulensis	s1	s1	s1	s2	s3
Eucalyptus grandis	s3	s2	s1	s1	s2
Eucalyptus maidenii	s3	s2	s1	s1	s2
Eucalyptus tereticornis	s2	s1	s1	s2	s3
Gmelina arborea	s2	s1	s1	s2	s3
Melia azedarach	s2	s1	s2/s3	n	n
Pinus caribaea	n	s3/s2	s1	s1	s2
Pinus kesiya	n	s3/s2	s1	s2	s3
Pinus oocarpa	n	s3/s2	s1	s2	s3
Pinus patula	n	s3	s2	s1	s1

TABLE 27: FACTOR RATINGS OF MEAN NUMBER OF DRY MONTHS/YEAR FOR VARIOUS FORESTRY SPECIES (F MODEL).

species	mean number of dry months/year			
	1-2	3-4	5-6	7-8
Acacia albida	n	n	s3/s2	s1
Azadirachta indica	n	s3	s2	s1
Callitris calcarata	s2	s1	s2	s3
Callitris hugellii	n	s3	s2	s1
Cassia siamea	n	s3/s2	s1	s2
Cordyla africana	n	n/s3	s2/s1	s1
Eucalyptus camaldulensis	s3	s2	s1	s2
Eucalyptus grandis	s2	s1	s2	s3
Eucalyptus maidenii	s2	s1	s2	s3
Eucalyptus tereticornis	s3	s2	s1	s2
Gmelina arborea	n	s3/s2	s1	s2
Melia azedarach	n	s3/s2	s1	s2
Pinus caribaea	s1	s1	s2	s3
Pinus kesiya	s2	s1	s1	s2
Pinus oocarpa	s2	s1	s1	s2
Pinus patula	s1	s1	s2	s3

Note : A dry month is defined as having <50mm of rainfall.

4.2.4 Oxygen availability (LQ "w")

LQ "w" applies to the evaluations for rainfed cropping (tm and itm models).

4.2.4.1 Nature and effects

With a few exceptions, notably wetland rice, plants need to take in oxygen through their rooting system. Growth is affected when oxygen is only available in limited amounts. Oxygen is normally only available above the groundwater table. Waterlogging, due to excessive rainfall, usually is less damaging initially, but becomes more damaging the longer the water remains stagnant. Such conditions are generally favoured by the following factors, usually operating in combination with each other:

- rainfall considerably in excess of evapotranspiration requirements of soil and crop

- poor ability of a site to shed excess water through runoff, infiltration or percolation

- low capacity of the soil to absorb water between field capacity and saturation.

- presence of a shallow groundwater table

Hence landforms, hydrological conditions and soil type affect this quality against a background of the amount of rainfall. The existence of this limitation may sometimes be viewed as an indication of the need for drainage works.

4.2.4.2 Application to the evaluations

Diagnostic land characteristic:

- soil drainage class (Dr); according to the FAO classification (FAO, 1977)

This land quality will differentiate poorly drained sites of impermeable soils from those that are freely drained. Normally the soil drainage class, derived from soil colour, mottling, presence of shallow water table during the growing period, or the presence of certain vegetation species, is used as the diagnostic land characteristic. It should be noted that the availability of soil oxygen varies in its effect, depending not only on crop characteristics (sorghum and cotton, for example, withstand waterlogging better than maize or tobacco), but also on the stage of the crop in its growth cycle. Maize is particularly sensitive during its early vegetative or seedling stage.

4.2.4.3 Assessment for rainfed cropping (tm and itm models)

Oxygen availability is rated for individual LUTs irrespective of management level. The oxygen requirements of the crops have been matched with the applied soil drainage classes and the resulting ratings are presented in Table 28. The rating obtained from this table represents the land suitability rating of LQ "w" for a particular LUT/land unit combination.

4.2.5 Nutrient availability (LQ "n")

LQ "n" applies to the evaluations for rainfed cropping under traditional management (tm model) and wetland rice cropping (r model).

4.2.5.1 Nature and effects

Together with oxygen and moisture availability, the availability of nutrients is generally considered as one of the most important land qualities for rainfed cropping. Both at the traditional and the improved traditional management level, soil management is usually directed towards ensuring an adequate and balanced supply of nutrients to the crop. Nutrient availability involves the following:

- quantities of nutrients present in the soil; of particular importance to the farmer who does not apply any fertilizers (traditional management).

- form in which they are present; whether readily available or in forms unavailable to plants.

TABLE 28: FACTOR RATINGS OF OXYGEN AVAILABILITY AS A FUNCTION OF DRAINAGE FOR VARIOUS CROPS (TM- AND ITM-MODELS).

crop	drainage class [1]				
	very poor	poor	imperfect	moderately well	well to excessive
Maize	n	n	s3	s1	s1
Bulrush millet	n	n	s3	s1	s1
Finger millet	n	n	s3	s1	s1
Sorghum	n	n	s2	s1	s1
Wheat	n	n	s3	s1	s1
Groundnuts	n	n	s3	s1	s1
Soya beans	n	n	s2	s1	s1
Sunflower	n	n	s3	s1	s1
Cowpea	n	n	s3	s1	s1
Guar beans	n	n	s3	s2	s1
Phaseolus beans	n	n	s3	s1	s1
Pigeon peas	n	n	s3	s1	s1
Irish potato	n	n	s3	s2	s1
Sweet potato	n	n	s3	s1	s1
Cassava	n	n	s3	s1	s1
Cotton	n	n	s3	s1	s1
Tobacco	n	n	n	s2	s1
Cashew	n	n	n	s2	s1
Citrus	n	n	n	s2	s1
Coffee arabica	n	n	n	s2	s1
Tea	n	n	n	s2	s1

[1] Soil drainage classes according to FAO (1977)

- capacity of the soil-vegetation system to restore nutrient supply during periods of rest from cropping.

In itm farming systems, using fertilizers and no rest periods, low quantities of nutrients are a less serious limitation. In this case, the form in which nutrients are present and the capacity of the soil to retain added fertilizer become more important.

4.2.5.2 Application to the evaluations

Diagnostic land characteristics:

- available nitrogen (N); measured in the top 50 cm of the soil and expressed in %

- available phosphorus (P); measured in the top 50 cm of the soil and expressed in ppm

- exchangeable potassium (K); measured in the top 50 cm of the soil and expressed in me/100 g

LQ "n" is assessed as a function of the availability of the three macro-nutrients N, P and K, which are determined by standard analyses in the soil laboratory. Micro-nutrients may play an important role, but unfortunately little is known about their effects so far. N, P and K are individually assessed and limits have been set for their levels of occurrence. Three classes have been identified as indicated in note 1 of Table 29.

4.2.5.3. Assessment for rainfed cropping under traditional management (tm model)

Two crop groups have been made for the assessment; one group contains those crops with low nutrient requirements, such as finger and bulrush millet, guar beans and cashew, and a second group containing the remaining crops which have a medium to high fertility requirement. Table 29 lists the ratings which resulted from matching the macro-nutrient requirements of the two crop groups with the three defined classes for each macro-nutrient.

4.2.5.4 Assessmant for wetland rice cropping (r model)

For LUT wetland rice factor ratings are included in Table 29 under crop group 3. The assessment is done in the same way as outlined in Section 4.2.5.3.

4.2.6 <u>Nutrient retention capacity</u> (LQ "t")

LQ "t" applies only to the evaluation for rainfed cropping under improved traditional management (itm model).

4.2.6.1 Nature and effects

This land quality refers to the capacity of the soil to retain added nutrients, as against losses caused by leaching. It is thus specifically relevant to the assessment of required fertilizer inputs and applies to the itm model.

Plant nutrients are held in the soil on exchange sites (cation or anion) which are provided largely by clay-particles, organic matter or humus-clay complex. Losses vary with intensity of leaching, as determined by the size of the moisture surplus, coupled with the rate of movement of moisture through the soil.

4.2.6.2 Application to the evaluations

Diagnostic land characteristic:

TABLE 29: FACTOR RATINGS OF NUTRIENT AVAILABILITY, BASED ON N, P AND K LEVELS IN THE UPPER 50 CM OF THE SOIL (TM AND R MODEL).

chemical parameter and nutrient class [1]			crop group [2]		
N	P	K	1 [2]	2 [3]	3 [4]
very low	very low	very low	n/s3	s3	s3
		low	s3	s3/s2	s3/s2
		medium-v.high	s3/s2	s2	s2
	low	very low	s3	s3/s2	s3/s2
		low	s3/s2	s2	s2
		medium-v.high	s3/s2	s2	s2
	medium-v.high	very low	s3/s2	s2	s2
		low	s3/s2	s2	s2
		medium-v.high	s3/s2	s2	s2/s1
low	very low	very low	s3	s3/s2	s3/s2
		low	s3/s2	s2	s2
		medium-v.high	s3/s2	s2	s2
	low	very low	s3/s2	s2	s2
		low	s2	s2/s1	s2
		medium-v.high	s2	s2/s1	s2/s1
	medium-v.high	very low	s3/s2	s2	s2
		low	s2	s2/s1	s2/s1
		medium-v.high	s2/s1	s1	s1
medium-v.high	very low	very low	s3/s2	s2	s2
		low	s3/s2	s2	s2
		medium-v.high	s3/s2	s2	s2/s1
	low	very low	s3/s2	s2	s2
		low	s2	s2/s1	s2/s1
		medium-v.high	s2/s1	s1	s1
	medium-v.high	very low	s3/s2	s2	s2/s1
		low	s2/s1	s1	s1
		medium-v.high	s1	s1	s1

[1] Nutrient classes (0-50 cm):
N (total Nitrogen in %) ; very low=<0.08, low=0.08-0.12 medium-very high=>0.12.
P (available Phosphorus in ppm) ; very low=<6, low=6-18, medium-very high=>18
K (exchang. Potassium in me/100 g); very low= <0.1, low=0.1-0.2, medium-very high=>0.2

[2] Crop group 1: all crops except cashew, millet, guar beans and wetland rice.
Crop group 2: cashew, millet and guar beans.
Crop group 3: wetland rice.

- cation exchange capacity (CEC); in me/100 g soil, in the top 50 cm soil determined in the soil laboratory.

4.2.6.3 Assessment for rainfed cropping under improved traditional management (itm model)

The factor ratings for this land quality are presented in Table 30. A differentiation has been made into two crop groups, based on total nutrient requirements and extracting characteristics of each.

TABLE 30: FACTOR RATINGS OF NUTRIENT RETENTION CAPACITY AS A FUNCTION OF CEC (ITM MODEL).

CEC (me/100 g) in upper 50 cm soil	crop group [1]	
	1	2
very low :<5	s2	s2/s3
low : 5-10	s1/s2	s2
medium-v.high: >10	s1	s1

[1] Crop group 1: all crops except maize, wheat, cotton, tobacco and sweet potato.
Crop group 2: maize, wheat, cotton, tobacco and sweet potato.

4.2.7 Rooting conditions (LQ "r")

LQ "r" is applied in the evaluations for rainfed (tm and itm models) and wetland (r model) cropping and forestry (f model).

4.2.7.1 Nature and effects

Rooting conditions refer to the conditions for the development of an effective rootsystem, including the growth of tubers and bulbs. The rooting conditions of a soil determine:

- whether the crop encounters sufficient foothold for its roots in order to keep the plant in place

- whether a normal rootsystem can be developed which is effective in extracting available soil nutrients and moisture from the soil (note the availability of both is evaluated under LQ "n")

- whether the rooting system can expand latterly if hard rock, a very compact layer or a hardpan is encountered at relatively shallow depth, causing competition with neighbouring plants for moisture and nutrients

- whether tubers and bulbs can freely develop, not hindered by the presence of coarse elements or compact layers coupled with a very firm consistence

4.2.7.2 Application to the evaluations

Diagnostic land characteristics:

- effective soil depth (Sd); determined by horizons limiting root penetration, such as hard rock, gravel or stone layers, ironstone, very compact subsoil or a waterlogged horizon

- surface stoniness and rockiness (Sr); content of rock and mineral fragments on the surface and in the topsoil

- presence of vertic (Ver), mopanic (Mop) or paralithic (Par) soil properties

The above land characteristics can be fairly easy assessed using the standard data from soil profile descriptions and the soil classification developed for Malawi (see Section 3.2.2).

4.2.7.3 Assessment for rainfed cropping (tm and itm models)

In Table 31 factor ratings are presented for all LUTs under the major kind of land use - rainfed cropping - for both management levels. Note that a downgrading is applied in the case of soils having more than 15% coarse fragments on the surface and in the topsoil or having vertic, mopanic or paralithic properties. When downgrading is not applicable, the factor rating represents the land suitability rating of LQ "r" for a particular land unit/LUT combination.

4.2.7.4 Assessment for wetland rice cropping (r model)

Factor ratings for wetland rice are presented in Table 32. Note that no downgradings are applied. The presence of vertic or mopanic soil properties are considered to be favourable. Paralithic soil properties or a high percentage of surface stoniness and rockiness do not occur in the land units considered for this LUT.

TABLE 32: FACTOR RATINGS OF ROOTING CONDITIONS FOR WETLAND RICE (R MODEL)

	effective soil depth (in cm)				
	<30	30-50	50-100	100-150	>150
ratings	n	s3/s2	s1	s1	s1

4.2.7.5 Assessment for forestry (f model)

Factor ratings for all LUTs considered are presented in Table 33. Note that no downgradings are applied.

TABLE 31: FACTOR RATING OF ROOTING CONDITIONS FOR VARIOUS CROPS (TM AND ITM MODELS).

crop	soil property [1]	effective soil depth (cm)				
		<30	30-50	50-100	100-150	>150
Maize		n	s3	s1	s1	s1
Bulrush millet		n	s2/s3	s1	s1	s1
Finger millet		n	s2/s3	s1	s1	s1
Sorghum		n	s3	s1	s1	s1
Wheat		n	s3	s1	s1	s1
Groundnuts		n	s3	s1	s1	s1
	vertic or mopanic	na	na	na	s2	s2
Soya beans		n	s3	s1	s1	s1
Sunflower		n	s3/n	s1	s1	s1
Cowpea		n	s2/s3	s1	s1	s1
Guar beans		n	s2/s3	s1	s1	s1
Phaseolus beans		n	s2/s3	s1	s1	s1
Pigeon pea		n	s3/n	s1	s1	s1
Irish potato		n	s3	s1	s1	s1
	vertic, mopanic or >15% surface stoni/rockiness	n	n	s2	s2	s2
Sweet potato		n	s3	s1	s1	s1
	vertic, mopanic or >15% surface stoni/rockiness	n	n	s2	s2	s2
Cassava		n	n	s1/s2	s1	s1
	vertic, mopanic or >15% surface stoni/rockiness	n	n	s2/s3	s2	s2
Cotton		n	n	s1/s2	s1	s1
Tobacco		n	n	s1/s2	s1	s1
	vertic or mopanic	na	na	na	s2	s2
Cashew		n	n	s3	s2	s1
Citrus		n	n	s3/n	s2	s1
Coffee arabica		n	n	s3/n	s2	s1
Tea		n	n	s3/n	s2	s1

[1] All annual crops rate s3 for paralithic soils.
All crops should be downgraded by half a class for mopanic soils, except in those cases as indicated above (groundnuts, Irish potato, sweet potato, cassava and tobacco have been downgraded by a full class).

na = not applicable

TABLE 33: FACTOR RATING OF ROOTING CONDITIONS FOR VARIOUS FORESTRY SPECIES (F MODEL).

species	effective soil depth (in cm)				
	<30	30-50	50-100	100-150	>150
Acacia albida	n	n	s3	s2	s1
Azadirachta indica	n	n	s2	s1	s1
Callitris calcarata	n	n	s2	s1	s1
Callitris hugellii	n	n	s2	s1	s1
Cassia siamea	n	s3	s1	s1	s1
Cordyla africana	n	n	s2	s1	s1
Eucalyptus camaldulensis	n	s3	s2	s1	s1
Eucalyptus grandis	n	s3	s1	s1	s1
Eucalyptus maidenii	n	s3	s1	s1	s1
Eucalyptus tereticornis	n	s3	s2	s1	s1
Gmelina arborea	n	n	s2	s1	s1
Melia azedarach	n	n	s2	s1	s1
Pinus caribaea	n	s3	s2	s1	s1
Pinus kesiya	n	s3	s2	s1	s1
Pinus oocarpa	n	s3	s2	s1	s1
Pinus patula	n	s3	s2	s1	s1

4.2.8 Flooding hazard (LQ "f")

LQ "f" applies only to the evaluations for rainfed cropping (tm and itm models).

4.2.8.1 Nature and effects

Flooding hazard refers to the damage by water on the ground surface. This may be caused by either the effect of running water, or due to ponding for a relatively short period. This is distinct from waterlogging due to poor drainage, which has been treated under LQ "w". Periods with standing water (inundation) cause damage to crops in the same way as severe drainage impedance, by depriving them of soil oxygen. Moving water can often flatten or uproot crops or cover them with silt. Flood damage is normally expected to occur on specific sites, such as floodplains or where streams issue from mountain basins or escarpments onto plains. The pattern of incidence is thus caused by landforms, against a background of hydrology and, indirectly, rainfall.

4.2.8.2 Application to the evaluations

Diagnostic land characteristic:

- frequency of flooding (Fl)

Usually LQ "f" only applies to low lying water-receiving sites.

The flood frequency is the probability of occurence during the year of damaging floods; a damaging flood being one that causes severe damage or even destroys crops completely. Usually, this information is obtained in the field from local residents and entered on the field sheet.

4.2.8.3 Assessment for rainfed cropping (tm and itm models)

Factor ratings for LQ "f" are presented in Table 34 for both management levels considered under "rainfed cropping".

TABLE 34: FACTOR RATING OF FLOODING HAZARD FOR VARIOUS CROPS (TM AND ITM MODELS).

frequency of flooding [1]	annuals	perennials
none	s1	s1
none to exceptional	s1	s1
exceptional	s1/s2	s3
frequent	n	n

[1] None to exceptional = less than once in 10 years
Exceptional = less than once in 2 years but more than once in 10 years
Frequent = at least once in two years

4.2.9 <u>Toxicity/acidity</u> (LQ "x")

LQ "x" applies to the evaluations for rainfed (tm and itm models) and wetland (r model) cropping.

4.2.9.1 Nature and effects

Grouped together under LQ "x" are widely differing conditions, only one of which is likely to affect crops in a particular land unit. Some nutrients may be present in the soil in amounts that become toxic to plants. Below a soil pH of 5.0, Fe, Mn and Al, and above a soil pH of 7.0, Na - or other free salts - may be present in excessive amounts affecting plant growth.

Aluminium saturation at about pH 5.0 is approximately 20%, at pH 4.0 it is 50% or more. What is usually referred to as the adverse effects of strong acidity are in part those arising from Al toxicity. Manganese can become toxic at concentrations in the soil solution above 4 ppm. Toxicity is most likely in acid soils with impeded drainage. Fe is a trace element which can cause adverse effects, particularly in paddy rice.

Salinity, or excess of free salts, and sodicity, or saturation of the exchange complex with Na ions, have distinct effects on plant growth. Salinity affects crops through inhibiting the uptake of water by osmosis. Sodicity has two effects on crops; firstly, through direct toxicity of the sodium ion and secondly, by giving rise to massive or coarse columnar soil structure and low permeability. This second effect is much worse if a high exchangeable sodium percentage is combined with a low level of soluble salts. Salinity and sodicity are common in depressional sites where incoming water, containing dissolved salt, is lost by evaporation.

4.2.9.2 Application to the evaluations

Diagnostic land characteristics:

- soil reaction (pH); measured in the top 50 cm soil

- salinity (Sal); electrical conductivity (EC) of the saturation extract in mmhos/cm measured in the top 50 cm soil

Excess of salts is generally less important for rainfed than for irrigated cropping and is only found in depressional sites in Malawi. Soils classified as salic have an average EC of 4 mmhos/cm in the topsoil. Aluminium toxicity may be widely present in soils belonging to the ferralic soil group (see Section 3.2.2). pH and EC are standard determinations in the soil laboratory but can also be done in the field.

4.2.9.3 Assessment for rainfed cropping (tm and itm models)

The effect of toxicity/acidity is rated for individual LUTs, irrespective of management level, as indicated in Table 35.

4.2.9.4 Assessment for wetland rice cropping (r model)

The factor ratings for LQ "x" are indicated in Table 36.

4.2.10 Soil workability (LQ "k")

LQ "k" applies only to the evaluations for rainfed annual cropping (tm and itm models).

4.2.10.1 Nature and effects

Workability, or ease of tillage, is the ease with which the soil can be cultivated. It refers to ox-drawn implements or hand tools as limitations specific to mechanized cultivation are excluded here. The workability of a soil is influenced by often interrelated soil characteristics such as soil texture, organic matter content, soil structure and consistence and stoniness and rockiness of the topsoil. Obviously optimal land conditions for soil workability are that the topsoil can be easily worked with relatively little physical effort. Generally, coarse textured soils are easier to work than fine textured soils; well structured soils easier than massive soils. Moisture content also plays an important role; certain soils are easy to work at nearly any moisture content, while others have a very narrow moisture range within which they can be worked.

TABLE 35: FACTOR RATINGS OF TOXICITY/ACIDITY FOR VARIOUS CROPS (TM AND ITM MODELS).

crop	pH																	
	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5			7.5-8.0			8.0-8.5			>8.5
								salinity levels (in mmhos/cm)									
								<2	2-4	4-8	<2	2-4	4-8	<2	2-4	4-8	
Maize	n	n	s3	s2	s1	s1	s1	s1	s1	s3	s2	s2	s3	s3	s3	n	n
Bulrush millet	n	n	s3	s2	s1	s1	s1	s1	s1	s2	s2	s2	s2	s3	s3	n	n
Finger millet	n	n	s3	s2	s1	s1	s1	s1	s1	s2	s2	s2	s2	s3	s3	n	n
Sorghum	n	n	s3	s2	s1	s1	s1	s1	s1	s1	s2	s2	s2	s3	s3	s3	n
Wheat	n	n	n	s3	s2	s1	s1	s1	s1	s1	s2	s2	s2	s3	s3	s3	n
Groundnuts	n	n	s3	s3	s2	s1	s1	s1	s1	s3	s2	s2	s3	s3	s3	n	n
Soya beans	n	n	n	s3	s2	s1	s1	s1	s1	s2	s2	s2	s2	s3	s3	n	n
Sunflower	n	n	n	s3	s2	s1	s1	s1	s1	s2	s2	s2	s2	s3	s3	n	n
Cowpea	n	n	n	s3	s2	s1	s1	s2	s2	s3	s3	s3	s3	n	n	n	n
Guar beans	n	n	n	s3	s2	s1	s1	s1	s2	s3	s2	s2	s3	s3	n	n	n
Phaseolus beans	n	n	n	s3	s2	s1	s1	s1	s3	n	s2	s3	n	s3	n	n	n
Pigeon pea	n	n	s3	s2	s1	s1	s1	s2	s2	n	s3	s3	n	s3	s3	n	n
Irish potato	n	n	s3	s2	s1	s1	s1	s2	s2	s3	s3	s3	s3	n	n	n	n
Sweet potato	n	n	s3	s2	s1	s1	s1	s1	s2	s3	s2	s2	s3	s3	n	n	n
Cassava	n	s3	s3	s2	s1	s1	s1	s2	s3	n	s3	s3	n	n	n	n	n
Cotton	n	n	n	s3	s2	s1	s1	s1	s1	s1	s3	s3	s3	n	n	n	n
Tobacco	n	n	s3	s2	s1	s1	s1	s2	s3	n	s3	s3	n	n	n	n	n
Cashew	n	n	s3	s2	s1	s1	s1	s2	s2	s3	s3	s3	s3	n	n	n	n
Citrus	n	n	n	s3	s2	s1	s1	s2	s2	s3	s3	s3	s3	n	n	n	n
Coffee arabica	n	s3	s2	s1	s1	s2	s2	s3	n	n	n	n	n	n	n	n	n
Tea	s3	s2	s1	s2	s2	s3	n	n	n	n	n	n	n	n	n	n	n

Note: pH and salinity levels are measured in the upper 50 cm soil.

TABLE 36: FACTOR RATINGS OF TOXICITY/ACIDITY FOR WETLAND RICE (R MODEL)

	pH (0-50 cm)										
	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0	8.0-8.5	>8.5
ratings	n	n	s3	s2	s1	s1	s2	s2/s3	s3	n	n

4.2.10.2 Application to the evaluations

Diagnostic land characteristics:

- surface stoniness and rockiness (Sr); the combined effect of rock outcrops, stones and boulders on the surface and in the upper 30 cm of soil

- presence of vertic (Ver) or mopanic (Mop) soil properties in the topsoil

The first land characteristic is obtained from the field sheets, while the second characteristic is derived from the soil classification (see Section 3.2.2).

Workability is widely applicable to land evaluations which consider animal traction and manual cultivation. For perennials, soil workability is only of importance at the initial planting stage and plays no important role thereafter. Hence, it has not been considered in the evaluation of perennials. Also, for wetland cropping, due to the nature of the particular LUT considered, it has not been applied.

In areas with sufficient arable land available, it may be a very important factor of direct influence on the present land use. However, in densely populated areas workability of the soil has become less important as no other land is still available for cultivation.

4.2.10.3 Assessment for rainfed cropping (tm and itm models)

The factor ratings of soil workability for rainfed cropping are presented in Table 37, irrespective of management level.

TABLE 37: FACTOR RATINGS OF SOIL WORKABILITY FOR ANNUAL CROPS AS A FUNCTION OF SURFACE STONINESS AND ROCKINESS (TM AND ITM MODELS).

surface stones, boulders and rock outcrops (in %) 1]	soil property	rating
<15		s1
	vertic or mopanic	s2
>15		s2/s3

1] Measured in the upper 0-30 cm soil.

4.2.11 <u>Erosion hazard</u> (LQ "e")

LQ "e" is applied in the evaluations for rainfed cropping (tm and itm models)

4.2.11.1 Nature and effects

The detrimental effects of topsoil removal by water through splash, sheet and rill erosion on present and future production is sufficiently well known in Malawi and does not need further elaboration here. Wind erosion hazard has not been considered, due to its rare occurrence in Malawi.

The most effective way to reduce water erosion is by establishing a ground or basal cover because exposed soil is the cause of erosion at the start of the rainy season, when the ground cover has been removed by cultivation, fire, grazing and/or decomposition. The anti-erosion effect of tree and shrub cover is negligible compared with the basal cover of vegetation, crop residues or litter

4.2.11.2 Application to the evaluations

Diagnostic land characteristics:

- mean annual precipitation (P-an); in mm/year

- soil erodibility factor (Erod); K-factor derived from the soil group classification

- dominant slope class (Sl); in %, using the five FAO slope classes: 0-2%, 2-6%, 6-13%, 13-25% and 25-55%

- effective soil depth (Sd); three classes are used: 30-50, 50-100 and >100 cm

Particularly for Malawi, the assessment of this land quality is of importance, as flat areas with low soil erodibility and low rainfall erosivity are only of limited extent. Soil loss mainly depends on land and crop husbandry and the type of crop, cropping pattern, yield (cover), physical and agronomic erosion control measures. Land requirements for topography are fairly strict for annual crops grown without physical conservation measures, but perennial crops on correctly spaced and aligned terraces can be grown on fairly steep slopes. Moreover, limited soil loss can be tolerated for sustained production, depending on soil depth.

A modified version of the Soil Loss Estimation Model for Southern Africa (SLEMSA) has been developed by Paris (1990). For details, the reader is referred to this publication. A brief summary is given below.

The original model (Elwell, 1980) has been developed and extensively tested in Zimbabwe. SLEMSA consists of three submodels:

- K: Mean annual soil loss (t/ha/yr) from a standard tilled field, i.e., bare soil, 4.5% slope, length 30 m. K is a function of rainfall energy (E) and soil erodibility (Erod)

- X: The ratio of soil loss from a plot length of L meters and slope percent S, to that lost from the standard plot

- C: The ratio of soil loss from a cropped plot to that from bare fallow

The annual soil loss Z, in t/ha/yr, is found by multiplication of K, C and X.

Calculation of K:

K, the climate and soil factor, is a function of mean seasonal rainfall energy (E) and soil erodibility (Erod).

In the original model a linear relationship exists between P-an and E. In Malawi, this is found to be unsatisfactory for P-an values lower than approximately 800 mm and also for P-an values higher than approximately 1200 mm. E values for areas with P=<800 mm and P=>1200 mm have been equated with E values for 800 mm and 1200 mm, respectively. The subdivision in the original model between "Guti" and "non-Guti" has not been maintained and only the latter curve was used to obtain E.

In the original model, the soil erodibility factor (F) is determined by three factors; soil group according to the Zimbabwean soil classification, topsoil texture and a correction factor for soil management. In the modified version, the Zimbabwean soil groups and texture classes have been translated into LREP soil groups and texture classes as defined by Venema (1990) based on the FAO classification (FAO, 1988). No management factor is considered for the tm model and only one management factor, the presence of properly aligned contour ridges, is used for the itm model. Erodibility values are presented in Table 38.

TABLE 38: EROD (soil erodibility factor) VALUES FOR ALL SOIL GROUPS

soil erodibility factor (Erod)		soil group
tm- and g-model	itm-model	
1.5	2.5	vertic - with fine, granular topsoil structure
3.5	4.5	salic mopanic vertic - with coarse topsoil structure
4.5	5.5	lithic paralithic fluvic gleyic arenic calcaric dystric-ferralic, with coarse topsoil texture eutric-ferralic, with coarse topsoil texture dystric-fersialic, with coarse topsoil texture eutric-fersialic
6.5	7.5	dystric-ferralic, with medium-fine topsoil texture eutric-ferralic, with medium-fine topsoil texture dystric-fersialic, with medium-fine topsoil texture

E and Erod values are entered in a graph and the corresponding K value is read from the Y-axis (see Paris, 1990).

Calculation of X:

X, the topographic factor, is a function of gradient (S) and slope length (L).

In the modified model five gradient ranges have been used. Slope class upper limits of 2%, 6% and 13% are used for the calculation of X for the first three gradient ranges; 20% is used for the calculation of X for the fourth range (13-25%), since SLEMSA is not valid for slopes steeper than 20%; X values for the fifth gradient range (25-55%) are not based on SLEMSA calculations but are extrapolated from the first four classes and based on field experience.

A standard slope length of 20 m is used for the tm model, and of 10 m for the itm model. The short slope lengths are used since the construction of cultivation ridges is common practise in Malawi, and since ridges are assumed to reduce slope length drastically.

S and L are entered in a graph and the corresponding X value is read from the Y-axis.

Calculation of C

C, the crop factor, is derived from the energy interception factor (i), which is determined by crop type, yield and emergence date.

The simplified model is primarily meant to predict erosion hazard. Therefore, three widely different cropping situations are considered, as listed in Table 39.

TABLE 39: CROP GROUPS FOR EROSION HAZARD ASSESSMENT.

poor-cover annual crops	good-cover annual crops	perennial crops
Bulrush millet	Cowpea	Cashew
Cassava	Groundnuts	Citrus
Cotton	Guar beans	Coffee
Finger millet	Irish potato	Tea
Pigeon pea	Maize	
Sorghum	Phaseolus beans	
Sunflower	Soya beans	
Tobacco	Sweet potato	
	Wheat	

The energy interception factors for the three groups and for the two management levels are estimated on the basis of the original crop-cover tables (Elwell, 1980). Formula C1 was used for the calculation of C values in five of the six cases; Formula C2 was used only in the case of good-cover crops for the itm model.

Calculation of Z

Z, predicted mean annual soil loss in t/ha/yr, is calculated by multiplication of K, X and C.

Finally the tolerance to a decline in productivity of the eroding soil is considered. It is assumed that a shallow soil is in greater danger of losing its productivity than a deeper soil, therefore three different soil depth situations are considered:

- soils deeper than 100 cm are moderately tolerant to soil loss

- soils between 50 and 100 cm deep are sensitive to soil loss

- soils between 30 and 50 cm deep are very sensitive to soil loss

The factor ratings for each of the above soil depth classes are given in Table 40. These ratings are used to translate the calculated soil loss figures into the suitability ratings of LQ "e" presented below.

TABLE 40: FACTOR RATINGS OF EROSION HAZARD AS A FUNCTION OF Z (soil loss in t/ha/yr) AND SOIL DEPTH.

rating	soil depth classes (in cm)		
	30-50	50-100	>100
s1	0-5	0-5	0-7
s1/s2	6	6-7	8-12
s2	7	8-9	13-17
s2/s3	8	10-11	18-22
s3	9	12-13	23-27
s3/n	10	13-14	28-32
n	>10	>15	>32

In evaluations it should be stressed that only the s1 class indicates that erosion poses no problem to sustainable agriculture. The s2 and s3 classes indicate different degrees of an erosion problem, which, if the problem remains unaddressed, may increase in the future and may eventually lead to unsuitability of the land.

The differences in management, between the tm and itm models are reflected by the choice of crop factor, in the slope length factor and in the soil erodibility factor. The crop factor (ground cover) has different values for the tm and the itm model. Different values for ridging are included in the soil erodibility factor, reflecting the differences between traditional and improved traditional management.

4.2.11.3 Assessment for rainfed cropping under traditional management (tm model)

Under traditional management, ridging is commonly practised but ridges are usually not properly aligned on the contour (basic soil erodibility factor is used) and because of this, a slope length has been taken of 20 m.

Factor ratings are presented in Table 41.

4.2.11.4 Assessment for rainfed cropping under improved traditional management (itm model)

Under improved traditional management a better ground cover will be obtained (better crop factor) and it is assumed that ridging on the contour is common practice (basic soil erodibility factor plus 1).

In Table 42 the factor ratings are listed.

4.2.12 Soil related factors (LQ "s")

LQ "s" applies to the evaluation for forestry (f model) only.

4.2.12.1 Nature and effects

This land quality has been introduced to assess a combination of edaphic effects on the growth of forestry LUTs. It actually incorporates many of the effects listed before, particularly those under LQ "w", LQ "n", LQ "t", LQ "x" and LQ "f". LQ "s" represents the combined effects of major soil characteristics, such as soil nutrient status, presence of toxic elements in the soil and oxygen availability.

4.2.12.2 Application to the evaluation

Diagnostic land characteristic:

- major soil characteristics as reflected in the name of the soil group (Soil); LREP soil classification (see Section 3.2.2)

- soil drainage class (Dr); 7 classes

LQ "s" is introduced because little information is available on how the considered LUTs react on individual land characteristics or land qualities. Those land qualities for which more information is avalaible on land use requirements, i.e., LQ "c", LQ "m" and LQ "r" have been treated separately (see Sections 4.2.2, 4.2.3 and 4.2.7).

TABLE 41: FACTOR RATINGS OF EROSION HAZARD FOR RAINFED CROPPING UNDER TRADITIONAL MANAGEMENT (TM MODEL).

			POOR-COVER ANNUAL CROPS (1) i=35					GOOD-COVER ANNUAL CROPS (2), PERENNIAL CROPS (3) i=50				
			Slope class (%)									
EFFECTIVE SOIL DEPTH (cm)	P-an (4) (mm)	Erod (5)	0-2	2-6	6-13	13-25	25-55	0-2	2-6	6-13	13-25	25-55
30-50	<800	4.5	s1	s2/s3	n	n	n	s1	s1	s3/n	n	n
	800-1200	4.5	s1/s2	n	n	n	n	s1	s2/s3	n	n	n
	>1200	4.5	n	n	n	n	n	s1	n	n	n	n
50-100	<800	1.5	n	n				s2/s3	n			
		3.5	s1	n				s1	s1/s2			
		4.5	s1	s2	n	n	n	s1	s1	s2/s3	n	n
		6.5	s1	s1	s1	s2/s3	n	s1	s1	s1	s1	n
	800-1200	3.5	s2/s3	n				s1	s3/n			
		4.5	s1/s2	n	n	n	n	s1	s2	n	n	n
		6.5	s1	s1/s2	n	n	n	s1	s1	s1/s2	s3/n	n
	>1200	3.5	n	n				s2	n			
		4.5	s3	n	n	n	n	s1	n	n	n	n
		6.5	s1	n	n	n	n	s1	s1/s2	n	n	n
>100	<800	1.5	s3	n				s1/s2	s3/n			
		3.5	s1	s2				s1	s1			
		4.5	s1	s1/s2	s3	n	n	s1	s1	s1/s2	s2/s3	n
		6.5	s1	s1	s1	s1/s2	n	s1	s1	s1	s1	n
	800-1200	1.5	n					s2				
		1.5	n					s2				
		3.5	s1/s2	n				s1	s2			
		4.5	s1	s2/s3	n	n	n	s1	s1/s2	s3	n	n
		6.5	s1	s1	s2/s3	n	n	s1	s1	s1	s2	n
	>1200	1.5	n					s2/s3				
		3.5	s2/s3	n				s1/s2	s3			
		4.5	s1/s2	n	n	n	n	s1	s2	n	n	n
		6.5	s1	s2	n	n	n	s1	s1	s2/s3	n	n

(1) - Bulrush millet, cassava, cotton, finger millet, pigeon pea, sorghum, sunflower.
(2) - Cowpea, groundnuts, guar beans, Irish potato, maize, phaseolus beans, soybeans, sweet potato, wheat.
(3) - Cashew, citrus.
(4) - mean annual rainfall.
(5) - soil erodibility factor.

TABLE 42: FACTOR RATINGS OF EROSION HAZARD FOR RAINFED CROPPING UNDER IMPROVED TRADITIONAL MANAGEMENT (ITM MODEL)

			POOR-COVER ANNUAL CROPS (1) i=45					GOOD-COVER ANNUAL CROPS (2) i=70					PERENNIAL CROPS (3) i=70				
			Slope class (%)														
EFFECTIVE SOIL DEPTH (cm)	P-an (4) (mm)	Erod (5)	0-2	2-6	6-13	13-25	25-55	0-2	2-6	6-13	13-25	25-55	0-2	2-6	6-13	13-25	25-55
30-50	<800	5.5	s1	s1	s1	s3	n	s1	s1	s1	s2	n	s1	s1	s1	s1	n
	800-1200	5.5	s1	s1	n	n	n	s1	s1	s3/n	n	n	s1	s1	s1	s1	n
	>1200	5.5	s1	s3/n	n	n	n	s1	s2/s3	n	n	n	s1	s1	s2	n	n
50-100	<800	2.5	s1	s3/n				s1	s2/s3				s1	s1			
		4.5	s1	s1				s1	s1				s1	s1			
		5.5	s1	s1	s1	s2	n	s1	s1	s1	s1/s2	n	s1	s1	s1	s1	n
		7.5	s1	s1	s1	s1	n	s1	s1	s1	s1	n	s1	s1	s1	s1	s3/n
	800-1200	4.5	s1	s1/s2				s1	s1/s2				s1	s1			
		5.5	s1	s1	s3	n	n	s1	s1	s2/s3	n	n	s1	s1	s1	s1/s2	n
		7.5	s1	s1	s1	s2	n	s1	s1	s1	s1/s2	n	s1	s1	s1	s1	n
	>1200	4.5	s1	s3/n				s1	s3				s1	s1			
		5.5	s1	s2/s3	n	n	n	s1	s2	n	n	n	s1	s1	s1/s2	s3/n	n
		7.5	s1	s1	s3	n	n	s1	s1	s2/s3	n	n	s1	s1	s1	s1/s2	n
>100	<800	2.5	s1	s2				s1	s1/s2				s1	s1			
		4.5	s1	s1				s1	s1				s1	s1			
		5.5	s1	s1	s1	s1/s2	n	s1	s1	s1	s1	n	s1	s1	s1	s1	s2/s3
		7.5	s1	s1	s1	s1	n	s1	s1	s1	s1	n	s1	s1	s1	s1	s2
	800-1200	2.5	s1					s1									
		4.5	s1	s1				s1	s1				s1	s1			
		5.5	s1	s1	s2	s3	n	s1	s1	s1/s2	s2/s3	n	s1	s1	s1	s1	n
		7.5	s1	s1	s1	s1/s2	n	s1	s1	s1	s1	n	s1	s1	s1	s1	s2/s3
	>1200	4.5	s1	s2				s1	s1/s2				s1	s1			
		5.5	s1	s1/s2	s3/n	n	n	s1	s1/s2	s3	n	n	s1	s1	s1	s2	n
		7.5	s1	s1	s1/s2	s3	n	s1	s1	s1/s2	s2/s3	n	s1	s1	s1	s1	s3

(1) - Bulrush millet, cassava, cotton, finger millet, pigeon pea, sorghum, sunflower, tobacco.
(2) - Cowpea, groundnuts, Irish potato, maize, phaseolus beans, soybeans, wheat.
(3) - Cashew, citrus, coffee, tea.
(4) - mean annual rainfall.
(5) - soil erodibility factor.

4.2.12.3 Assessment for forestry (f model)

Land use requirements for LQ "s" have been derived mainly from Hardcastle (1977). In Table 43 factor ratings are presented for the LUTs considered. For the "fluvic" soil group a subdivision has been made according to drainage class, as a wide range of drainage conditions normally occur within this soil group. Factor ratings for the "fluvic" soil group are presented in Table 44.

TABLE 43: FACTOR RATINGS OF SOIL REQUIREMENTS FOR VARIOUS FORESTRY SPECIES (NON-FLUVIC SOIL GROUPS, F MODEL).

species	soil group [1]									
	g	s	m	v	a	d/e	r/x	c	p	u
Acacia albida	n	n	n	n	s3	s2	n	s2	s3	n
Azadirachta indica	n	s3	s2	s1	s1	s1	s1	s1	s1	n
Callitris calcarata	n	n	n	s3	s3	s1	s2	s1	s1	n
Callitris hugellii	n	n	n	n	s1	s1	s1	s1	s1	s3
Cassia siamea	n	n	n	s3	s3	s1	s2	s2	s2	s3
Cordyla africana	n	n	n	s3	s1	s1	s1	s1	s1	s3
Eucalyptus camaldulensis	s3	s3	s2	s1	s1	s1	s1	s2	s2	s3
Eucalyptus grandis	n	s2	s2	s2	s2	s1	s2	s2	s2	s3
Eucalyptus maidenii	s3	s2	s2	s3	s2	s1	s2	s3	s2	s3
Eucalyptus tereticornis	n	s3	s2	s1	s1	s1	s2	s2	s2	s3
Gmelina arborea	s3	n	n	s2	s1	s1	s1	s1	s1	n
Melia azedarach	n	n	n	s1	s1	s1	s1	s2	s2	n
Pinus caribaea	n	n	n	s3	s2	s1	s2	s2	s2	n
Pinus kesiya	n	n	n	s2	s2	s1	s2	s2	s2	s3
Pinus oocarpa	n	n	n	s2	s2	s1	s2	s2	s2	s3
Pinus patula	n	n	n	n	s2	s1	s1	s2	s3	n

1] Soil groups are defined by Venema (1990).

g= gleyic	d/e= dystric/eutric fersialic
s= salic	r/x= dystric/eutric ferralic
m= mopanic	c = calcaric
v= vertic	p = paralithic
a= arenic	u = lithic

TABLE 44: FACTOR RATINGS OF SOIL REQUIREMENTS FOR VARIOUS FORESTRY SPECIES (FLUVIC SOIL GROUP, F MODEL).

species	soil drainage class					
	very poor & poor	imperfect	mod. well	well	somew. exces.	excessive
Acacia albida	n	s3	s1	s1	s2	s3
Azadirachta indica	n	s3	s1	s1	s1	s2
Callitris calcarata	n	n	s2	s1	s1	s2
Callitris hugellii	n	n	s2	s1	s1	s2
Cassia siamea	n	n	s1	s1	s2	s2
Cordyla africana	n	n	s2	s1	s1	s2
Eucalyptus camaldulensis	n	s3	s1	s1	s1	s2
Eucalyptus grandis	n	s3	s1	s1	s1	s2
Eucalyptus maidenii	n	s3	s1	s1	s1	s2
Eucalyptus tereticornis	n	s3	s1	s1	s1	s2
Gmelina arborea	n	s3	s1	s1	s1	s2
Melia azedarach	n	n	s2	s1	s1	s2
Pinus caribaea	n	s3	s2	s1	s1	s2
Pinus kesiya	n	n	s2	s1	s1	s2
Pinus oocarpa	n	n	s2	s1	s1	s2
Pinus patula	n	n	s2	s1	s1	s2

Note :Soil group defined by Venema (1988).

4.3 OVERALL LAND SUITABILITY AND POTENTIAL YIELDS

4.3.1 Overall land suitability

The land suitability classification system consists of three levels of generalization and has been described in Section 2.6. Definitions of land suitability classes have been presented in Table 3.

As already explained in Section 2.6, overall land suitability is obtained through the application of the "law of the minimum" i.e. a particular type of land use cannot have a higher overall land suitability than that determined by the most limiting factor. Therefore a comparison between the factor ratings obtained for the individual land qualities of a particular land unit is made and the lowest rating, posing the severest limitation(s), determine(s) the overall land suitability. The advantages of the procedure of limiting conditions are its simplicity and the fact that it will lead in most cases to an overall assessment which is on the cautious side, either correctly estimating or somewhat underestimating overall land suitability. The disadvantage perhaps is its failure to take account of interactions - the different way in which individual land qualities combine to influence overall suitability.

At the lowest level in the classification system, lower-case letter suffixes are added to the suitability classes to indicate the type of limitation(s); for example "m" (insufficient availability of soil moisture). If more than three limitations occur, only the three most important ones are indicated. The suffixes used for a particular limitation have been presented in Table 1.

It should be noted that in this study only the physical land suitability for a certain type of land use is assessed. Socioeconomic considerations may indicate that it can be desirable to grow a certain crop even though only half or less of its potential yield can be obtained. Alternatively, a crop for which the physical suitability is high may not be desirable for economic or cultural reasons.

4.3.2 Potential yields

A quantitative land suitability has been elaborated for the cultivation of annual and perennial crops. The land suitability classes are expressed in terms of a percentage of the maximum attainable yield. For each management level, traditional and improved traditional, the maximum yields attained are presented below and are based on yield data available for Malawi. The attributes of both management levels have been presented in Table 9. No attempt has been made to quantify outputs for forestry.

4.3.2.1 Yields attainable under traditional management

For each land suitability class the attainable yields have been indicated in Table 47. They reflect the yields that can be obtained for land utilization types within two major types of land use - rainfed and wetland cropping under traditional management. The maximum attainable yield (100%) has been derived from yield data from the Annual Surveys of Agriculture, reports from the ADDs and other sources.

4.3.2.1 Yields attainable under improved traditional management

For each land suitability class the attainable yields have been indicated in Table 48. They reflect the yields that can be obtained for land utilization types within rainfed cropping under improved traditional management. The maximum attainable yield (100%) has been derived from yield data recorded at Research Stations, ADD Adaptive Research trials, RDP/EPA Demonstration plots, Tea Research Foundation of Central Africa, Smallholder Coffee Authority, Tobacco Research Authority, publications by DAR, Annual Guides to Agricultural Production in Malawi and crop specific extension aids leaflets. Some aditional data has been obtained from Acland (1971) and Landon (1984).

TABLE 45 : YIELD LEVELS FOR CROPS GROWN UNDER TRADITIONAL MANAGEMENT IN MALAWI (tons/ha/yr)

CROPS	POTENTIAL YIELD (tons/ha)				
	100%	S1 100-80%	S2 80-50%	S3 50-20%	N <20%
Cereals					
Maize	1.6	1.6-1.3	1.3-0.8	0.8-0.3	<0.3
Rice	2.3	2.3-1.8	1.8-1.1	1.1-0.4	<0.4
Sorghum	1.0	1.0-0.8	0.8-0.5	0.5-0.2	<0.2
Finger millet	1.0	1.0-0.8	0.8-0.5	0.5-0.2	<0.2
Bulrush millet	0.8	0.8-0.6	0.6-0.4	0.4-0.2	<0.2
Wheat	1.5	1.5-1.2	1.2-0.8	0.8-0.3	<0.3
Legumes					
Groundnuts	0.6	0.6-0.5	0.5-0.3	0.3-0.1	<0.1
Soya beans	1.0	1.0-0.8	0.8-0.5	0.5-0.2	<0.2
Phaseolus beans	0.7	0.7-0.6	0.6-0.4	0.4-0.1	<0.1
Pigeon pea	0.9	0.9-0.7	0.7-0.5	0.5-0.2	<0.2
Cowpea	0.7	0.7-0.6	0.6-0.4	0.4-0.1	<0.1
Roots and tubers					
Cassava	5.0	5.0-4.0	4.0-2.5	2.5-1.0	<1.0
Sweet potato	4.0	4.0-3.2	3.2-2.0	2.0-0.8	<0.8
Irish potato	4.0	4.0-3.2	3.2-2.0	2.0-0.8	<0.8
Cashcrops					
Cotton	1.0	1.0-0.8	0.8-0.5	0.5-0.2	<0.2
Sunflower	0.9	0.9-0.6	0.6-0.5	0.5-0.2	<0.2
Guar beans	0.9	0.9-0.6	0.6-0.5	0.5-0.2	<0.2
Treecrops					
Cashew	0.8	0.8-0.6	0.6-0.4	0.4-0.2	<0.2
Citrus	5.0	5.0-4.0	4.0-2.5	2.5-1.0	<1.0

Note: all crops local varieties.

TABLE 46: YIELD LEVELS FOR CROPS GROWN UNDER IMPROVED TRADITIONAL MANAGEMENT IN MALAWI (tons/ha, pure stands).

CROPS	VARIETY	POTENTIAL YIELD (tons/ha)				
		100%	S1 100-80%	S2 80-50%	S3 50-20%	N <20%
Cereals						
Maize	Local varieties	2.6	2.6-2.1	2.1-1.3	1.3-0.5	<0.5
	Composites	4.3	4.3-3.4	3.4-2.2	2.2-0.9	<0.9
	Hybrids	6.2	6.2-5.0	5.0-3.1	3.1-1.2	<1.2
Sorghum	Local varieties	1.7	1.7-1.4	1.4-0.9	0.9-0.3	<0.3
	PN3	4.1	4.1-3.3	3.3-2.1	2.1-0.8	<0.8
Bulrush millet	Local varieties	1.0	1.0-0.8	0.8-0.5	0.5-0.2	<0.2
	Nigerian composite	2.0	2.0-1.6	1.6-1.0	1.0-0.4	<0.4
Finger millet	Local varieties	1.0	1.0-0.8	0.8-0.5	0.5-0.2	<0.2
	40,366,516,Dobaloba	2.0	2.0-1.6	1.6-1.0	1.0-0.4	<0.4
Wheat	Kenya Nyati	4.0	4.0-3.2	3.2-2.0	2.0-0.8	>0.8
Legumes						
Groundnuts	Chalimbana	1.7	1.7-1.4	1.4-0.9	0.9-0.3	<0.3
	Manipintar, Mawanga	2.1	2.1-1.7	1.7-1.1	1.1-0.4	<0.4
	Malimba	1.2	1.2-1.0	1.0-0.6	0.6-0.2	<0.2
Phaseolus beans	-	1.2	1.2-1.0	1.0-0.6	0.6-0.2	<0.2
Soya beans	-	2.0	2.0-1.6	1.6-1.0	1.0-0.4	<0.4
Cowpea	-	1.3	1.3-1.0	1.0-0.6	0.6-0.3	<0.3
Pigeon pea	-	1.5	1.5-1.2	1.2-0.8	0.8-0.3	<0.3
Roots and tubers						
Cassava	Local varieties	10.0	10.0-8.0	8.0-5.0	5.0-2.0	<2.0
	Gomani, Mbundumali, Manyokola	15.0	15.0-12.0	12.0-8.0	8.0-3.0	<3.0
Irish potato	-	20.0	20.0-16.0	16.0-10.0	10.0-4.0	<4.0
Cashcrops						
Cotton	Makoka 72, Rasam 17 Ezam 6	2.3	2.3-1.8	1.8-1.2	1.2-0.5	<0.5
Tobacco air-c.	Banket-A1, Burley 37	3.4	3.4-2.7	2.7-1.7	1.7-0.7	<0.7
fire-c.	Malawi western	1.7	1.7-1.4	1.4-0.9	0.9-0.3	<0.3
flue-c.	KE-1, K51E, K110, Coker 347	3.0	3.0-2.4	2.4-1.5	1.5-0.6	<0.6
Sunflower	NSCO varieties	2.2	2.2-1.8	1.8-1.1	1.1-0.4	<0.4
Treecrops						
Cashew	-	1.5	1.5-1.2	1.2-0.8	0.8-0.3	<0.3
Citrus	Valencia (oranges) tangerines	20.0	20.0-16.0	16.0-10.0	10.0-4.0	<4.0
Coffea arabica	Agaro 56, NTE G1,11,61	2.2	2.2-1.8	1.8-1.1	1.1-0.4	<0.4
Tea	SFS and PC varieties	2.5	2.5-2.0	2.0-1.3	1.3-0.5	<0.5

CHAPTER 5

COMPUTERIZED LAND EVALUATION

5.1 ALES

The computerized land evaluation relies mainly on the Automated Land Evaluation System (ALES), version 2.0 (Rossiter and Van Wambeke, 1989). Additional software for interfacing ALES with the Land Resources Data Base and for manipulating output was created in the project (Sichra, 1991b).

ALES is a microcomputer programme that implements the FAO land evaluation methodology. ALES is a framework in which the user builds evaluation models; it is not an expert system and does not include any crop rules of its own.

ALES provides the structure to create models in terms of land characteristics (LCs), land qualities (LQs) and land use requirements (LURs). A strictly parametric approach is followed in which severity levels are assigned to relevant combinations of LC values. The models take the form of "decision trees". Production costs and yields can be incorporated in the models, but this option is not used in the LREP work. ALES computes the land suitability of each land utilization type (LUT) - land unit combination, either by selecting the lowest factor rating - as in the present study - or by following user-made suitability rules, and presents the results in a physical suitability evaluation matrix.

ALES is written in the MUMPS programming language (Data Tree Inc., 1986). The hardware required consists of an IBM-PC XT (8086) or compatible computer with 640 Kb or more and a hard disk with a minimum of 5 Mb available disk space. The operating system is MS-DOS or PC-DOS version 2.0 or higher.

The four major kinds of land use considered in this study appear at the highest level in ALES, in the Main Menu:

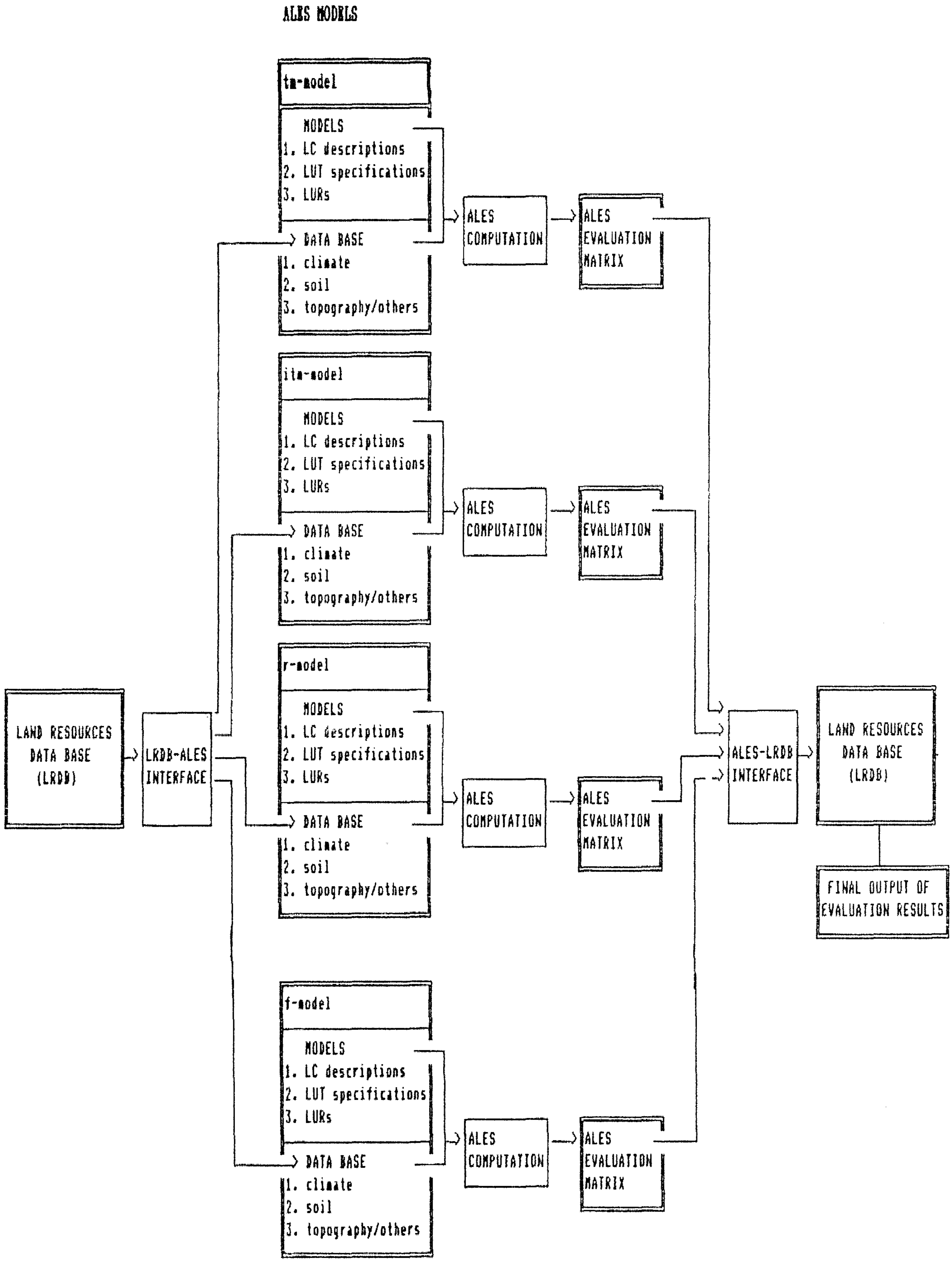
- tm model = rainfed cultivation, traditional management
- itm model = rainfed cultivation, improved traditional management
- r model = wetland cultivation, traditional management
- f model = forestry

The four evaluation models are run by ALES completely independently of each other: each evaluation model uses its own decision trees and its own data base, and has its own evaluation output - see Figure 11. Considerable overlap occurs between different evaluation models (for example between itm and tm models).

At the next level, in Menu 1 - Main options, ALES has three main components:

- models
- data

FIGURE 3 : INPUT AND OUTPUT TO AND FROM ALES



- evaluations

To fully understand the explanations given in the following sections, it is recommended that the reader checks with relevant sections in the ALES manual and runs the ALES applications on screen.

5.2 MODELS

5.2.1 Land characteristic descriptions

LCs in ALES are defined in terms of units of measurement, number of classes, class symbols and class limits; e.g for Sl - dominant slope class (compare with Table 5): unit of measurement is percent, classes are 1, 2, 3, 4 and 5, and class limits are respectively 2, 6, 13, 25 and 55. The LC definitions are identical to the specifications given in the Land Resources Data Base (LRDB).

ALES allows the user to group a number of LCs together and create a new LC, which can be used instead in the decision trees. Thus, the number of LCs used in the decision trees can be limited, which makes the models easier to construct and understand. Such new LCs are inferred from existing LCs by means of a "LC --> LC decision tree". Three LCs, Soil-c, Tl, and Erod, are thus inferred from other LCs. An example is presented in Figure 12.

5.2.2 Land utilization type specifications

LUTs are single crops or single tree species under specified management, and there are 18 LUTs in the tm-model, 24 LUTs in the itm model, one LUT in the r model and 16 LUTs in the f model, totalling 59 (see Table 8). Firstly, LUTs are briefly characterized and the number of factor ratings used for each LUT is given (seven in the present study). Secondly, LURs are defined for each LUT.

5.2.3 Land use requirements

In ALES, LURs are defined through decision trees. Decision trees are land quality models in which severity levels (which are identical to factor ratings) are assigned to each combination of LCs. Thus LURs are related to LQs and a structure for matching is created. In Figure 13 an example of a severity level decision tree is presented. The number of severity levels used in the decision trees is seven:

1 = s1 - highly suitable
2 = s1/s2 - highly to moderately suitable
3 = s2 - moderately suitable
4 = s2/s3 - moderately to marginally suitable
5 = s3 - marginally suitable
6 = s3/n - marginally to not suitable
7 = n - not suitable

FIGURE 4: EXAMPLE OF INFERRED LAND CHARACTERISTIC: LC Erod (soil erodibility factor) inferred from LCs Soil, LGP and TEX-T" by means of a "LC --> LC decision tree"

```
1ST LC                                  | 2ND LC
-----------------------------------------------------------------------------
Soil 1  g (gleyic)             *5.5
     2  f (fluvic)             =1
     3  s (salic)              *4.5
     4  m (mopanic)            =3
     5  v (vertic)             ------? LGP 1  105-120 *2.5
     6  a (arenic)             =1          2  120-135 *4.5
     7  d (dystric-fersialic)----+         3  135-150 =2
     8  e (eutric-fersialic) =1  |         4  150-165 =2
     9  r (dystric-ferralic) =7  |         5  165-180 =2
     10 x (eutric-ferralic)  =7  |         6  180-195 =2
     11 c (calcaric)         =1  |         7  195-210 =2
     12 p (paralithic)       =1  |         8  210-225 =2
     13 u (lithic)           =1  |         9  225-240 =2
                                 |         10 240-270  ?
                                 |         11 270-300  ?
                                 |         12 300-330  ?
                                 |
                                 +--> Tex-t 1  c    (coarse)            *5.5
                                            2  m+f  (medium and fine)   *7.5
```

Soil - Soil group
LGP - Reference Length of Growing Period (in days)
Tex-t - Texture topsoil
? - The branch of the tree following a question mark is not completed as not relevant combinations of LC values occur.
= - An "equal to" sign is followed by a serial number, and refers back to that number in the same list.

> - A "more than" sign indicates that this branch is completed.
* - Final LC values are preceded by an asterisk.

The LQs used in this study are listed in Table 10. There is a decision tree for each LQ for each LUT, resulting in 160 decision trees to define the tm model, 212 for the itm model, 5 for the r model and 64 for the f model, totalling 441. See Table 49. Within one major kind of land use, all LUTs use the same set of LQs for land suitability assessment, with only perennial crops using one LQ less (k, workability). A detailed overview of the composition of decision trees in terms of LCs is presented in Table 50. The severity level decision trees are made up of a number of LCs varying from one to seven. For example the decision tree for temperature regime (c) for wheat under traditional management (tm) consists of only one LC: T-EGP, and the decision tree for moisture regime (m) for perennial crops under traditional management (tm) consists of seven LCs: DM, P-an, P/PET, Sd, Soil-c, Sl and Tl. Three LCs, Rmf, Tex-p and Tex-t, appear unchecked in Table 50 because they only occur in inferred LCs (see Sections 5.2.1 and 5.3).

FIGURE 5.1: EXAMPLE OF DECISION TREE: e (erosion hazard), itm, poor-cover annual crops.

2.(continued from 1)

```
1ST LC     2ND LC            3RD LC        4TH LC

Sd 30-50 --? P-an 600-800 ---? Erod 2.5 ?
   50-100 -|      800-1200 --|      4.5 ?
   100-150-|      1200-1600--|      5.5 ---> Sl 0-2  *1
   >150   =|      1600-2000 =|      7.5 ?       2-6   =
           |      >2000     =|                  6-13  =
           |                 |                  13-25*5
           |                 L-? Erod 2.5 ?     25-55*7
           |                        4.5 ?
           |                        5.5 ---> Sl 0-2  *1
           |                        7.5 ?       2-6   =
           |                                    6-13 *7
           |                                    13-25 =
           |                 L-? Erod 2.5 ?     25-55 =
           |                        4.5 ?
           |                        5.5 ---> Sl 0-2  *1
           |                        7.5 ?       2-6   =
           |                                    6-13 *7
           |                                    13-25 =
           |                                    25-55 =
           |
           L-? P-an 600-800 ---? Erod 2.5 --? Sl 0-2  *1
                  800-1200 --|      4.5 *1      2-6  *6
                  1200-1600--|      5.5 -|      6-13  ?
                  1600-2000 =|      7.5 -|      13-25 ?
                  >2000     =|           |      25-55 ?
                             |           |
                             |           L-> Sl 0-2  *1
                             |                  2-6   =
                             |                  6-13  =
                             |                  13-25*3
                             |                  25-55*7
                             |
                             |           L-> Sl 0-2  *1
                             |                  2-6   =
                             |                  6-13  =
                             |                  13-25 =
                             |                  25-55*7
                             L-? Erod 2.5 ?
                                    4.5 --? Sl 0-2  *1
                                    5.5 -|      2-6  *2
                                    7.5 -|      6-13  ?
                                         |      13-25 ?
                                         |      25-55 ?
                                         |
                                         L-> Sl 0-2  *1
                                                2-6   =
                                                6-13 *5
                                                13-25*7
                                                25-55 =
                                         
                                         L-> Sl 0-2  *1
                                                2-6   =
                                                6-13  =
                                                13-25*3
                                                25-55*7
                             L-? Erod 2.5 ?
                                    4.5 --? Sl 0-2  *1
                                    5.5 -|      2-6  *6
                                    7.5 -|      6-13  ?
                                                13-25 ?
                                                25-55 ?
```

```
1ST LC  2ND LC            3RD LC          4TH LC

     |(Sd 100-150)        (Erod 7.5)||(Erod 5.5)
     |                              |
     |                              L-> Sl 0-2  *1
     |                                     2-6  *4
     |                                     6-13 *7
     |                                     13-25 =
     |                                     25-55 =
     |
     |                              L-> Sl 0-2  *1
     |                                     2-6   =
     |                                     6-13 *5
     |                                     13-25*7
     |                                     25-55 =
     |
     L-? P-an 600-800 ----? Erod 2.5 --? Sl 0-2  *1
             800-1200 --|      4.5 *1      2-6  *3
             1200-1600--|      5.5 -|      6-13  ?
             1600-2000 =|      7.5 -|      13-25 ?
             >2000     =|           |      25-55 ?
                        |           |
                        |           L-> Sl 0-2  *1
                        |                  2-6   =
                        |                  6-13  =
                        |                  13-25*2
                        |                  25-55*7
                        |
                        |           L-> Sl 0-2  *1
                        |                  2-6   =
                        |                  6-13  =
                        |                  13-25 =
                        L-? Erod 2.5 ?     25-55*7
                               4.5 *1
                               5.5 ---> Sl 0-2  *1
                               7.5 -|      2-6   =
                                    |      6-13 *3
                                    |      13-25*5
                                    |      25-55*7
                                    |
                                    L-> Sl 0-2  *1
                                           2-6   =
                                           6-13  =
                                           13-25*2
                                           25-55*7
                        L-? Erod 2.5 ?
                               4.5 --? Sl 0-2  *1
                               5.5 -|      2-6  *3
                               7.5 -|      6-13  ?
                                    |      13-25 ?
                                    |      25-55 ?
                                    |
                                    L-> Sl 0-2  *1
                                           2-6  *2
                                           6-13 *6
                                           13-25*7
                                           25-55 =
                                    
                                    L-> Sl 0-2  *1
                                           2-6   =
                                           6-13 *2
                                           13-25*5
                                           25-55*7
```

Sd (Effective soil depth):	P-an (Mean annual precipitation):	Erod (Soil erodibility factor):	Sl (Dominant slope class):
30-50 cm	600-800 mm	2.5	0-2 %
50-100 cm	800-1200 mm	4.5	2-6 %
100-150 cm	1200-1600 mm	5.5	6-13 %
>150 cm	1600-2000 mm	7.5	13-25 %
	>2000 mm		25-55 %

"?" Means that the branch of the tree following this mark is not completed [(combination of) LC value(s) is not relevant].
"=" Means that this branch or severity level equals the one above.
">" Means that the branch following this sign is completed.
"*" Severity levels run from 1 to 7 and are preceded by an asterisk.

TABLE 47 : NUMBER OF DECISION TREES PER MAJOR KIND OF LAND USE, PER LAND QUALITY AND PER LUT (For explanation of codes see footnote of Table 50)

MODEL		LAND UTILIZATION TYPES (LUTs)	NO. OF DECISION TREES
tm	c	Wheat	1
		Other annuals	15
		Perennials	2
	e	All crops	18
	f	All crops	18
	k	Annual crops	16
	m	Annual crops	16
		Perennial crops	2
	n	All crops	18
	r	Gronuts, tobacco	2
		Rootcrops	3
		Other annuals	11
		Perennials	2
	w	All crops	18
	x	All crops	18
		TOTAL	160

MODEL		LAND UTILIZATION TYPES	NO. OF DECISION TREES
itm	c	Wheat	1
		Other annuals	19
		Perennials	4
	e	All crops	24
	f	All crops	24
	k	Annual crops	20
	m	Annual crops	20
		Perennial crops	4
	r	Gronuts, tobacco	2
		Rootcrops	3
		Other annuals	15
		Perennials	4
	t	All crops	24
	w	All crops	24
	x	All crops	24
		TOTAL	212

MODEL		LAND UTILIZATION TYPES	NO. OF DECISION TREES
r	c	Rice	1
	m	Rice	1
	n	Rice	1
	r	Rice	1
	x	Rice	1
		TOTAL	5

MODEL		LAND UTILIZATION TYPES	NO. OF DECISION TREES
f	c	All trees	16
	m	All trees	16
	r	All trees	16
	s	All trees	16
		TOTAL	64

OR, IN SUMMARY:

	NO. OF DECISION TREES
tm-model	160
itm-model	212
r-model	5
f-model	64
TOTAL	441

TABLE 48 : SUMMARY OF DECISION TREES IN ALES (See footnote for explanation of symbols)

MODEL		LAND UTILIZATION TYPES	AGRO-CLIMATIC CHARACTERISTICS								SOIL CHARACTERISTICS																		TOPOGRAPHY + OTHER CHARS.		
			DM	LGP	P-an	P/PET	T-an	T-EGP	T-GP	T-min	CEC	Dr	Erod	K	Mop	N	P	Par	pH	Rmf	Sal	Sd	Soil	Soil-c	Sr	Tex-p	Tex-t	Ver	Fl	Sl	Tl
tm	c	Wheat						X																							
		Other annuals							X																						
		Perennials					X			X																					
	e	All crops			X								X									X								X	
	f	All crops																											X		
	k	Annual crops													X										X			X			
	m	Annual crops		X		X																X		X						X	X
		Perennial crops	X		X	X																X		X						X	X
	n	All crops												X		X	X														
	r	Gronuts, tobacco													X			X				X						X			
		Rootcrops													X			X				X			X			X			
		Other annuals													X			X				X									
		Perennials													X							X									
	w	All crops										X																			
	x	All crops																	X		X										
itm	c	Wheat						X																							
		Other annuals							X																						
		Perennials					X			X																					
	e	All crops			X								X									X								X	
	f	All crops																											X		
	k	Annual crops													X										X			X			
	m	Annual crops		X		X																X		X						X	X
		Perennial crops	X		X	X																X		X						X	X
	r	Gronuts, tobacco													X			X				X						X			
		Rootcrops													X			X				X			X			X			
		Other annuals													X			X				X									
		Perennials													X							X									
	t	All crops									X																				
	w	All crops										X																			
	x	All crops																	X		X										

(continued on next page)

TABLE 48: SUMMARY OF DECISION TREES IN ALES (Cont'd)

MODEL		LAND UTILIZATION TYPES	AGRO-CLIMATIC CHARACTERISTICS								SOIL CHARACTERISTICS																			TOPOGRAPHY + OTHER CHARS.		
			DM	LGP	P-an	P/PET	T-an	T-EGP	T-GP	T-min	CEC	Dr	Erod	K	Mop	N	P	Par	pH	Rmf	Sal	Sd	Soil	Soil-c	Sr	Tex-p	Tex-t	Ver	Fl	Sl	Tl
r	c	Rice							X																						
	m	Rice			X							X																	X	X	X
	n	Rice												X		X	X														
	r	Rice																				X									
	x	Rice																	X		X										
f	c	All trees					X																								
	m	All trees	X	X																											
	r	All trees																				X									
	s	All trees										X											X								

Footnote: The models (first column in this table) consist of major kinds of land use broken down into land quality submodels, which in turn consist of a varying number of land characteristics. The abbreviations used are given below:

Major kinds of land use:

tm - Rainfed cultivation under traditional management
itm - Rainfed cultivation under improved traditional management
r - Irrigated cultivation under traditional management (bunded rice)
f - Forestry

Land Qualities:

c - Temperature regime
e - Erosion hazard
f - Flooding hazard
k - Soil workability
m - Moisture regime
n - Nutrient availability
r - Rooting conditions
s - Soil requirements
t - Nutrient retention capacity
w - Oxygen availability
x - Toxicity/acidity

Agro-climatic Characteristics:

DM - Mean number of dry months/year
LGP - Reference length of growing period
P-an - Mean annual precipitation
P/PET - Quality of moisture supply
T-an - Mean annual temperature
T-EGP - Mean temp. during end growing period
T-GP - Mean temp. during growing period
T-min - Mean minimum temp. of coolest month

Soil characteristics:

CEC - Cation exchange capacity (0-50cm)
Dr - Median soil drainage class
Erod - Soil erodibility factor
K - Potassium (0-50cm)
Mop - Mopanic soil properties
N - Nitrogen (0-50cm)
P - Phosphorus (0-50cm)
Par - Paralithic soil properties
PH - Median soil reaction (0-50cm)
Rmf - Rock and mineral fragments profile
Sal - Salinity (0-50cm)
Sd - Effective soil depth
Soil - Soil group
Soil-c - Soil properties combined
Sr - Surface stoniness and rockiness
Tex-p - Texture profile
Tex-t - Texture topsoil
Ver - Vertic soil properties

Topography and other characteristics:

Fl - Frequency of flooding
Sl - Dominant slope class
Tl - Topolocation

The amount of work involved to create 441 severity level decision trees seems prohibitive at first sight. However, ALES offers three ways to make this process manageable:

1. It has a copying and an equating facility so that repetitive work can be avoided. In practice, not all decision trees have to be built from scratch because many are similar. In the whole system of 441 decision trees only 148 trees are unique and have to be created; the other 293 are identical to one of these 148 and can be copied. Within decision trees, different branches are often similar and sometimes identical in terms of LCs and severity levels used. The copying facility of the program allows the user to copy a branch to another location anywhere in the tree and then to make amendments as necessary; the equating facility allows the user to equate branches on the same screen. Similarly, at the level of severity level decision trees, when decision trees are not identical but similar, they can be copied to the new location and amended as necessary.

2. It allows the user to exclude irrelevant combinations of LCs in decision trees. In the example of Figure 13 (erosion hazard for itm), the decision tree consists of four LCs: Sd, P-an, Erod and Sl, two of which are rated into four classes and two into five classes. In theory, 400 (= 4x4x5x5) combinations of classes of different characteristics exist; in practice, however, only 88 combinations have to be assigned severity levels, since the other combinations are not realistic or do not occur in the study area. For example, the combination of shallow soils (Sd = 30-50 cm) and low soil erodibility factor (Erod = 2.5, which is for vertic soils - see Table 38) is not realistic and no severity level has to be assigned.

3. It offers the option to shorten decision trees by combining a number of LCs at an earlier stage by making inferred LCs (see Sections 5.2.1 and 5.3).

5.3 DATA

In the database the land units are described in terms of diagnostic LCs in a sequence determined by predefined templates. ALES uses a separate database for each major kind of land use. The land unit definitions and data are loaded from the Land Resources Data Base (LRDB) through a special interface. Two types of LCs exist in the ALES databases:

- LCs taken directly from LRDB. This applies to 26 LCs, of which 23 LCs occur as such in LRDB, and three LCs - Mop, Par and Ver - are taken from LRDB characteristic "Soil group".

- LCs inferred from other LCs in ALES. This applies to three LCs: Erod, Soil-c and Tl. Erod is inferred from LCs LGP, Soil and Tex-t. Soil-c is inferred from LCs Tex-t, Tex-p, Mop, Ver and Rmf. And Tl is inferred from LCs Soil and Dr.

In the ALES databases the data are organized according to three different templates:

- agro-climatic characteristics (varying from eight LCs for the tm model to two for the r model)

- soil characteristics (varying from 17 LCs for the tm model to three for the f model)

- topography and other characteristics (consisting of three LCs)

5.4 EVALUATIONS

ALES matches the land use requirements with the data in the data base and determines the land suitability of each LUT - land unit combination by the law of the minimum, i.e. the lowest severity level in all models determines the overall land suitability. The results are presented in an evaluation matrix; they are in the form of a number (1 to 7) indicating the overall severity level with LQ letter suffixes (see Table 49) added for main limitations. These matrices can subsequently be exported from ALES and imported into LRDB through an interface and then further be edited and manipulated.

CHAPTER 6

THE LAND RESOURCES DATA BASE (LRDB)

6.1 Introduction

The Land Resources Data Base (LRDB version 2.0) is a menu driven computerized system for storage and retrieval of information relevant to the assessment of land resources, with special emphasis on agriculture. LRDB was specially designed for LREP and has as such many features specific to the kind of land resources data collected and processed by LREP.

LRDB is written in dBASE III+ Ver. 1.1 programming language and can be installed and used on micro computers running under DOS 2.3 or higher. It provides an interface with ALES which enables export of land resources data to ALES and import of land suitability related data from ALES (see Chapter 5).

LRDB version 2.0 is described in the Revised Users´ Manual (Sichra, 1991a). The reader is referred to this manual for detailed information on LRDB.

6.2 Requirements for installing and using LRDB

LRDB is stored on one 3.25" double density diskette (or two 5.5" double density diskettes) from where it can be installed on a hard disk. The programmes and data structures take approximately 370 Kb of storage space. The hardware requirements listed below are the minimum specifications needed in order to install and use LRDB succesfully:

-IBM PC XT (8086) or compatible with one diskette drive (AT or 80386 processor will yield better performance).

-for each ADD: 5 Mb hard disk if only LRDB is used
10 Mb hard disk if LRDB and ALES are used.

-at national level: 50 Mb hard disk

-one EPSON LX-800 or compatible printer.

6.3 LRDB data

LRDB provides the tools to store information on:

-soils and physiography

-agro-climate

-land units (combinations of soil units and agro-climatic zones, see Section 3.5)

-present land use and vegetation

Facilities are included to retrieve the data according to various criteria. The interface between ALES and LRDB enables export of data to ALES and import from ALES. LRDB provides facilities to display suitability and severity level values calculated in ALES, taking account of the FAO standard notations (see Section 2.6).

Most of the information stored in LRDB is coded. A dictionary is provided for decoding and the user can, if necessary, make modifications and amendments to it. Current coding in LRDB is explained in Appendix XIV and follows the methods described in Chapter 3.

Some types of data are stored at ADD level and other types at national level in data files. Four data files contain data at national level, i.e. data which are correlated over the whole country. These data files are:

-soil units,

-agro-climatic zones,

-LRDB code dictionary and

-ALES code dictionary.

Eight data files contain data at ADD level, i.e. data which are not correlated over the whole country:

-land units,

-distribution of soil units,

-present land use and vegetation,

-land mapping units,

-soil mapping units,

-suitabilities per different evaluation model,

-severity levels per model and

-yields per model (not yet implemented in LRDB).

Any five character name can be given to an ADD data file, for example BLADD, MZADD, etc. Data files at national level can be accessed via ADD data files and the latter can be merged into one data set, but available disk space and memory might not be sufficient (see Section 6.2).

The contents of the data files are listed below and are preceded by identification numbers which refer to rules for data entry given in Appendix XIV. Those characteristics which are used in ALES for evaluation are followed by their diagnostic characteristic code between brackets (see Table 11).

A - Soil units

2 - Soil unit code.

Physiography: 10 - landform, 11 - dominant slope class (Sl), 12 - altitude range (m asl) and 13 - present erosion.

Soils general: 14 - parent material, 15 - soil description by general characteristics and soil classification according to 16 - soil group (Soil), 17 - soil family and 18 - FAO 1988 soil legend.

Soil physical properties: 19 - effective soil depth (Sd), 20 - depth limiting factor, 21 - colour subsoil, 22 - surface stoniness and rockiness (Sr), particle size of the topsoil in 23 - detailed and 24 - generalized terms and 25 - according to ALES (Tex-t) and particle size of the subsoil in 26 - detailed and 27 - generalized terms, 28 - general texture of the whole profile (Tex-p), 29 - rock and mineral fragments (Rmf), 30 - soil drainage class according to FAO and 31 - drainage according to ALES (Dr), 32 - frequency of flooding (Fl) and 33 - ponding.

Soil chemical properties (0-50 cm): 34 - soil reaction quantitive and 35 - soil reaction for evaluation in ALES (PH), 36 - salinity (Sal), 37 - cation exchange capacity (CEC) and nutrient status of 38 - N (N), 39 - P (P) and 40 - K (K).

B - Agro-climatic zones

41 - length of the growing period (LGP).
42 - ratio of precipitation and potential evapotranspiration (P/PET).
43 - mean temperature during the LGP (T-GP).
44 - mean annual precipitation (P-an).
45 - mean number of dry months per year (DM).
46 - mean annual temperature (T-an).
47 - mean minimum temperature of the coolest month (T-min).
48 - mean temperature during the last 120 days of the LGP (T-EGP).

C - LRDB dictionary

Codes for all data in the various data fields. See Appendix XIV

D - ALES dictionary

Codes used in ALES for all land use types. See User Manual (Sichra, (1991a).

E - Land units (definitions and extended descriptions).

4 - Study area.

Land unit, definition only: 1 - land unit (numerical code), 2 - corresponding soil unit (code), 3 - corresponding agro-climatic zone (numerical code) and 5 - area occupied (number of ha).

Land unit, extended version: land unit definition combined with soil unit (A), distribution of soil unit (F) and present land use and vegetation (G).

F - Distribution of soil units

2 - Soil unit (code).

4 - Study area.

Distribution: 6 - district(s) and location in the district and 7 - agro-ecological zone(s).

G - Present land use and vegetation

2 - Soil unit (code).

4 - Study area.

8 - Dominant present land use and vegetation type and second and third most important present land use and vegetation type.

9 - Dominant vegetation type (code).

H - Soil mapping units

4 - Study area.

2a - Soil mapping unit (code).

6 - Area occupied by soil mapping unit (number of ha).

I - Land mapping units.

4 - Study area.

1a - Land mapping unit (numerical code).

5 - Area occupied by land mapping unit (number of ha).

J - Results from ALES

This file holds data imported from ALES. The contents of this data field are

study area.

model.

land unit.

soil unit.

agro-climatic zone.

area occupied by land unit.

land use type.

FAO suitability classes with limiting factors attached (to a maximum of three per suitability class) or ALES severity level classes with limiting factors. Yield figures can currently not be accessed through LRDB v.2.0, but can be accessed in dBASE raw mode.

6.4 Programmes and functions

The functions LRDB can perform are grouped into six activities:

- enter/edit,
- display/Print,
- export,
- import,
- calculate and
- housekeeping.

Each of these activities will be briefly explained in the following sections.

6.4.1 Enter/edit

Data entry and modification is the central feature of LRDB. Ten different types of data can be entered and/or modified in this menu, separated into national data and ADD data. At national level there is access to:

A - soil units,
B - agro-climatic zones,
C - LRDB code dictionary,
D - ALES code dictionary.

At ADD level accessible data are:

E - land units (definitions and extended descriptions)
F - distribution of soil units,
G - present land use and vegetation,
H - soil mapping units,
I - land mapping units and
J - results from ALES.

All data can be edited, deleted, appended or shown in a short list except 'J - Results from ALES' which cannot be edited. In addition, study

areas can be corrected for E, F, G, H and I and data entry codes can be quickly and fully listed for A, C and D for checking purposes.
H - soil mapping units data entry can also be derived from the land mapping units through automated calculation in menu Calculate. See below.

6.4.2 Display

The second choice in the LRDB main menu is display/print. This function enables the user to retrieve and list data in several ways. Data are stored in text files so they can be accessed at any given moment on the screen or the printer. Displays are grouped into national data and ADD data. Sorting procedures are sequential, either alphabetically or numerically. Data listing possibilities are as follows:

National data.

A - soil units sorted by parent material, slope class or soil group.
B - agro-climatic zones sorted by ACZ number or mean annual precipitation.
C - LRDB dictionary sorted by dictionary number and code.
D - ALES dictionary sorted by LUT.

ADD data.

E - land units in numerical sequence.
F - soil units sorted by parent material, slope class or soil group.
G - agro-climatic zones sorted by ACZ number.
H - land units per soil unit sorted by ACZ.
I - land units per ACZ sorted by soil unit.
J - land units standard format as it appears in the appendices of the land resources appraisal reports of the ADDs.
K - distribution of soil unit.
L - land use and vegetation per soil unit.
M - soil mapping units.
N - land mapping units.
P - results from ALES (after having imported an evaluation from ALES in LRDB) sorted by land unit or soil unit. This applies to both suitability classes and severity levels. A seperate option under 'P' is the compilation of several suitability summaries. Per ADD up to a maximum of 14 of the following suitability classes or suitability class clusters can be summarised. Outputs give areas (in ha, rounded-off to fifties) and percentages of selected suitability class or suitability class cluster per LUT.

Options: S1, S1/2, S2, S2/3, S3, S3/N, N, total area, S1+S1/2, S2+S2/3, S3+S3/N, S1+..+S3/N, S1/2+S2, S2/3+S3, S1+..+S3, S3/N+N.

6.4.3 Export

The export feature exports land unit data from LRDB to ALES. Export can be done for a complete ADD (all land units) or for a more limited set of soil units sorted by parent material, parent material and slope class or parent material, slope class and soil group. Export is done for one evaluation model at a time. Export of land unit data for other general applications outside ALES, for example export to a geographical information system (GIS), is not yet implemented in LRDB v.2.0.

6.4.4 Import

Prior to importing ALES data into LRDB, ALES evaluation results have to be written to a disk file which can be recognised by LRDB. It is necessary to indicate in LRDB which evaluation model has been used and whether suitability classes or severity levels have been written to the ALES disk file. In importing suitability classes, a maximum of three limiting factors per suitability class are accepted. The import of data into LRDB takes a long time, as numerous conversions take place.

6.4.5 Calculate other values

This calculate feature enables both automatic storing of soil mapping units in the database as read from the land mapping units and the computation of total areas for several units, elements of the soil unit code (e.g. soil group) and agro-climatic zones. It has three options:

A - Make and store soil mapping units from land mapping units. This option enables automised data storage of soil mapping units in LRDB after having entered the land mapping units in the database manually.

B - Compute and store areas of land units and soil mapping units. Areas of land units and soil mapping units (in ha and rounded-off to fifties) are derived from land mapping unit areas using simple formulae (see Appendix XIV)

C - Tabulate area totals of land units. This option provides total areas and percentages of soil groups, slope classes, agro-climatic zones and combinations of these three, plus the total area of land units without miscellaneous units within a study area. Total areas be calculated for:

1 - soil groups.
2 - slope classes.
3 - soil groups and slope classes.
4 - slope classes and soil groups.
5 - soil groups and agro-climatic zones.
6 - agro-climatic zones and soil groups.
7 - agro-climatic zones, soil groups and slope classes.
8 - agro-climatic zones, slope classes and soil groups.
9 - total land units without miscellaneous units.

In sorting by agro-climatic zone at the first level (options 6 to 8), areas of miscellaneous units are not taken into account because they do not have an agro-climatic identifier.

6.4.6 Housekeeping.

The functions performed here are related to display of existing information (generated amongst others through the display menu) and disk file management:

A - Text files. Files created by the display menu and by the calculate menu (see Sections 6.3.2 and 6.3.5).

B - Files for ALES. Files created to export to ALES (see Section 6.3.3).

C - Files from ALES. Files created by ALES to import to LRDB (see Section 6.3.4).

D - Backup/restore log files. Error message files created in using the backup and restore options (see below under I and J).

E - Error log files from ALES. Error message files created in exporting from LRDB to ALES.

In options A to E files can be either viewed, printed, edited or deleted.

F - Statistics. Shows number of records in the data base files, last update, file size in bytes and remaining space on the hard disk.

G - dBASE raw mode. Provides access to dBASE raw mode.

H - Data bases reindex. Allows data files, or part of them, to be reindexed after data manipulations in dBASE raw mode or power disruption in the middle of computer operations.

I - Data bases backup. Copies LRDB programmes and data files from the hard disk to diskette(s).

J - Data bases restore. Restores LRDB programmes and data files from diskettes to hard disk.

L - Exit to DOS. Provides quick access to DOS while staying in LRDB.

CHAPTER 7

PRESENTATION OF RESULTS

7.1 INTRODUCTION

The results of land suitability evaluation are presented in a series of tables in which land suitability classes are listed for each land unit/land uitilization type combination. These tables have the advantage of showing suitability classes and limiting factors for many combinations of land units/land utilization types on just a few pages. They therefore facilitate the comparison between suitability classes of various land units and select the most suitable one for one particular land utilization type, i.e., finding the most suitable tract of land within a given area for one particular land utilization type, for example rainfed cotton production under an improved traditional management level. Land suitability tables will also rapidly indicate the most suitable land utilization type for any particular tract of land (land unit) (see Section 7.2).

However, tables do not show the geographical distribution of suitability classes for a particular area, for instance an ADD. Suitability maps are used for this purpose. They show the spatial distribution of suitability for a particular land utilization type within a given area (see Section 7.3).

The above information is summarised at a level of detail convenient to the reader and the purpose of the exercise. In the LREP reports on land resources appraisal of a certain ADD, summarised descriptions are given by land utilization type within the ADD according to Agro-ecological Zone, and by EPA, also according to Agro-ecological Zone.

The results of land suitability appraisal are of importance to land use planners at the national and regional level. ADD staff can use the information to optimize land utilization and to guide farming practices to solve specific problems related to the physical environment.

7.2 SUITABILITY MATRICES

The results of land evaluation are presented in a set of land suitability tables for each ADD, one for each of the four major types of land use discussed in Section 4.1. In Appendix XV an example is given of the suitability tables for an ADD, for the improved traditional management model. The following can be read from this table (examples have been taken from the first table in Appendix XV):

- the characteristics of each land unit are presented using symbols for soil/physiography and agro-climatic zone and the extent is given in hectares (rounded off to the nearest hundred).

- land utilization types are listed on the horizontal, and land units on the vertical axis. Land units are not listed according to number but according to the soil unit symbols which are in alphabetical order. Reading the tables in a horizontal way, the land suitability of a particular land unit for a variety of land utilization types can easily be found and the best land utilization type or types can be selected. The first capital letter indicates the suitability order, S for suitable or N for not suitable; the second digit indicates the land suitability class, S1, S2, or S3 - and the last lower case letter(s) the type(s) of limitation(s). For instance, the land suitability of land unit 750 for the production of cashew is S2cnw; meaning moderately suitable for cashew production under traditional management with limitations being imposed by a sub-optimal temperature regime (c), low nutrient availability (n), and a lack of oxygen availability (w). Land unit 750 is more suitable for the production of cashew and finger millet when rainfed cropping under traditional management is concerned.

- reading the tables in a vertical direction will select the best land unit for a particular land utilization type. For instance, the land units with the highest suitability for cashew production under traditional management are: 750, 772, 773, 757, 758 and 759; all showing moderate suitability (S2) but having different limitations.

- once the suitability class for a particular land utilization type is known, an indication of the attainable yields under a particular type of management can be obtained from the tables in Section 4.3.2.

7.3 SUITABILITY MAPS

The land unit map is used as a base for drawing land suitability maps. The suitability of each of the land units is derived from the tables in Appendix XV. Four suitability classes are used: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3) and Not Suitable (N). Classes S1, S2 and S3 are shown in decreasing intensities of green; not suitable land is not coloured. In cases were the suitability is given as an intermediate class, for example S2/3, it is upgraded by half a class and will show on the map as S2. In the case of complex land mapping units, only the land suitability of the dominant land unit, i.e. the first member of the complex, is shown. The types of limitation are not shown on the map. The land unit numbers and boundaries remain as a background on the suitability map. They can be used to obtain more detailed information on limitations and the occurrence of intermediate classes through the consultation of the suitability tables.

APPENDIX I: SOIL PROFILE DESCRIPTION SHEET (For explanation see following pages)

FAO/MoA MLW/85/011 SOIL SURVEY FIELD SHEET

LOCATION		MAPSHEET	FIELD No.
PHOTO No.	SAT. IMAGE No.		GRID REF.
AUTHOR(S)		DATE	SOIL UNIT
PARENT MATERIAL			ROCKINESS(%)
LANDFORM			ALTITUDE(m)
TOPOGRAPHY Macro		Micro	
SLOPE Length		Gradient	Position
SURFACE CONDITIONS:	MIN.FRAGM.(%) Bld.	St.	Gr.
	CAPPING	SALTS	
EROSION			
PERMEABILITY (0-50cm)	(50-100cm)		PONDING
(RIVER)FLOODING		(FLASH)FLOODING	
GROUNDWATER		SEEPAGE	
MOISTURE COND.PROFILE			DRAINAGE CLASS
VEGETATION/LAND-USE			
SUITABILITY			

HORIZON SYMBOL					
DEPTH(cm)					
COLOUR moist dry					
MOTTLING					
TEXTURE					
STRUCTURE					
CRACKS					
CONSISTENCE d m w					
CUTANS					
SLICKENSIDES					
CEMENTATION					
PORES					
ROCK FRAGM.					
MIN. NODULES					
ROOTS					
BOUNDARY					
REACTION HCl					
pH (field)					
SAMPLES					

SOIL CLASSIFICATION (FAO)
REMARKS

APPENDIX 1 (continued):

EXPLANATION OF SOIL PROFILE DESCRIPTION SHEET

LOCATION: Nearest town/village as shown on 1:250,00 topographic map

MAPSHEET: Sheet number of 1:50,000 topographic map
e.g 1635 A1

FIELD No.: Code consisting of two letters indicating district followed by serial number
e.g. Ns 28
(The district codes used are, from north to south:
Ct, Kr, Ru, Mz, Nb, Ks, Ni, Mj, Do, Nk, Sa;
Li, De, Ne; ma, Mc, Zo; Mw, Cr, Bl, Th, Mu; Ck, Ns)

PHOTO No.: Serial number of aerial photograph (run and photo number)
e.g. 2/457

SAT. IMAGE No.: Index number of satellite image (path and row resp.)
e.g. 168/70

GRID REF.: UTM grid reference to nearest 100 m as indicated on 1:50,000 topographic map
e.g. YT 254 251

AUTHOR(S): Surnames or initials of surveyor(s)

DATE: Day, month, year

SOIL UNIT: Symbol of soil unit as will be defined during advanced stage of survey
e.g. Alf2

PARENT MATERIAL: Indication of rocks, materials from which soil has developed

ROCKINESS: % of land, within mapping unit and within a radius of 100 - 250 m from observation point, taken up by outcrops of hard rock or large boulders

LANDFORM: Geomorphic unit in which observation point is located
e.g. plateau, hill, footslope, floodplain, depression

ALTITUDE: Altitude in m of observation point (from 1:50,000 topographic map)

TOPOGRAPHY:

a) Macro: Topography of surrounding country (within radius of several km of observation point) as described in FAO Guidelines
e.g. undulating

b) Micro: Relief features of small dimensions (natural and man-made) within radius of 100 - 250 m from observation point.
indicate frequency, dimensions and type
e.g. few high (3 m) anthills

SLOPE:

a) Length: Approximate length of slope on which observation point is located (sum of distance upslope to watershed and downslope to stable waterway)

b) Shape: Shape of slope-section on which observation point is located:
linear, convex, concave or complex

c) Gradient: Gradient in % of slope-section on which observation point is located

d) Position: Position of observation point, considering the whole length of slope:
top, upper, middle, lower, bottom

MIN. FRAGM.: Percentage of land within radius of appr. 100 m covered with boulders(> 25 cm diameter), stones (7.5 - 25 cm) and gravel (0.2 - 7.5 cm) respectively

CAPPING: (or crusting) Presence of thin (2-20 mm) surface layer with relatively high bulk density (low porosity) and/or relatively hard consistence when dry
(+ = faint, ++ = distinct, +++ = prominent)

SALTS: Presence of visible crust or efflorescence of salts at surface
(+ = faint, ++ = distinct, +++ = strong)

EROSION: Degree of accelerated soil erosion within a radius of 100 - 250 m from observation point
- Degree: slight, moderate or severe
- Nature: sheet, rill, gully, streambank, landslide

PERMEABILITY: Permeability of least permeable horizon within upper 50 cm and between 50 and 100 cm of profile respectively
four classes: v. slow, slow, moderate and rapid

PONDING: Duration of prolonged saturation of topsoil after heavy rainfall as a result of flat topography and low infiltration rate
four classes: slight (1-2 days), moderate (2-3 days), severe (3-7 days) or very severe (> 7 days)

(RIVER) FLOODING: Frequency of inundation of floodplains;
three classes: nil, exceptional (once every 3-20 years), or frequent (usually several times every year)

(FLASH) FLOODING: Occurrence of fast-moving sheetfloods of short duration at lower slope as a result of runoff after heavy rainfall
two classes: (-) nil to exceptional
(+) frequent

GROUNDWATER: Presence of groundwater table within upper few metres from surface

SEEPAGE: Occurrence lateral supply of water through upper few metres of soil profile for weeks or months after last rains

MOISTURE COND. PROFILE: Indication of parts of profile which are dry, moist or wet during the time of description e.g. moist 0-25 cm, dry below

DRAINAGE CLASS: Drainage class as described and numbered in FAO Guidelines

VEGETATION/LAND USE: Brief description of species and physiognomy of natural vegetation and of present land use (incl. crops, if any, and level of management)

SUITABILITY: Indicate physical potential of land if considerably higher than realized at present

HORIZON SYMBOL: Tentative horizon designation as proposed in the Legend of the FAO-UNESCO Soil Map of the World

DEPTH (cm): Depth (from surface) of upper and lower boundary of horizon in cm

COLOUR: Colour moist and dry (if possible) of matrix of horizon, expressed in units of the Munsell Soil Colour Charts
e.g. 10YR3/4

MOTTLING: More than faint mottling in horizon in terms described in FAO Guidelines:
- Abundance (1=few, 2=common, 3=many)
- Size (f=fine, m=medium, c=coarse)
- Contrast (d=distinct, p=prominent)
- Colour

e.g. 2 m d red

TEXTURE: Textural class of fine earth of horizon in terms described in FAO Guidelines
Symbols: s=sand(y), si=silt(y), l=loam(y), c=clay
e.g. scl (=sandy clay loam)

In case of sandy soils the size of the sand fraction could be specified as follows:
vf. =very fine, f.=fine, c=coarse, vc=very coarse (e.g. f.sl=fine sandy loam)

STRUCTURE: Structure of horizon as described in FAO Guidelines
- Grade (1=weak, 2=moderate, 3=strong)
-Class or size (vf=very fine, f=fine, m=moderate, c=coarse, vc=very coarse)
-Type (cr=crumb, gr=granular, abk=angular blocky, sbk=subangular blocky, pr=prismatic, col=columnar, pl=platy

CRACKS: Cracks present (=) or not present (-) in horizon: indicate width (in cm) if present

CONSISTENCE: Dry (d), moist (m) and wet (w) consistence of horizon as defined in FAO Guidelines
Symbols: dry: lo-loose, sh=slightly hard, h=hard, vh=very hard, eh=extremely hard
moist: lo=loose, vfr=very friable, fr=friable fi=firm, vfi=very firm, efi=extr.firm
wet: nst=non sticky, sst=slightly sticky, st=sticky, vst=very sticky

CUTANS: Frequency of cutans on peds expressed in three classes
few (+), common (++), many (+++)
thickness and nature could be added

SLICKENSIDES: Presence slickensides in horizon expressed in their general classes:
weakly (=), moderately (++) or strongly (+++) developed

CEMENTATION: Cementation of horizon by substances other than clay minerals (usually cilica or carbonates)
(cemented soil remains "brittle" when moist)
classes: weak (+), moderate (++), strong (+++)

PORES: Presence of pores in horizon, simplified after FAO Guidelines:
- Abundance: (1=few, 2=common, 3=may)
- Size: (vf=very fine, f=fine, m=medium, c=coarse)

ROCK FRAGM.: Volume % of horizon taken up by coarse (> 2 mm) fragments. Also indicate size of fragments (fgr=fine gravel, gr=gravel, st=stones, bld=boulders)

MIN. NODULES: Volume % of horizon taken up by coarse (> 2 mm) mineral nodules
Also indicate:
- Size (f= < 0.5 cm, m= 0.5-2 cm, c= >2 cm diameter)
- Nature (fe=iron, Mn=manganese, Ca=lime, etc)

ROOTS: Presence of roots in horizon simplified after FAO Guidelines:
- Abundance (1=few, 2=common, 3=many)
- Size (vf, f, m, c, vc)

BOUNDARY: Description of lower boundary or horizon as defined in FAO Guidelines:
- Width (abr=abrupt, cl=clear, grad=gradual, dif=diffuse)
- Topography (sm=smooth, wavy=wavy, irr=irregular, br=broken)

REACTION HCl: Reaction to test with dilute hydrochloric acid to estimate relative content of calciumcarbonates
+= feeble effervescence (slightly calcareous)
++= visible effervescence (moderately calcareous)
+++= strong effervescence (strongly calcareous

pH (field): Result of field pH test

SAMPLES: Indication of sample(s) taken in horizon
Serial number (starting with 1 for sample highest in profile) and depth in cm (if not coinciding with depth of horizon)
e.g. 1 (0-20) and 2 (40-60)

Note: the complete symbol of the sample will be the field number of the profile, followed by the serial number indicating its relative position in the profile e.g. Ns 28-1

SOIL CLASSIFICATION: Tentative classification of soil according to FAO (1988)
e.g. Eutric Cambisol

APPENDIX II: LABORATORY METHODS

- texture

Hydrometer method. The soil sample is dispersed with a calgon solution: a mixture of sodium hydroxide and sodium hexametaphosphate. Clay and silt are read with a hydrometer after the samples have stood two hours.

- soil reaction

pH values are read with a pH meter in a suspension of a 1:2.5 soil:water mixture

- total organic carbon

Walkley and Black method: wet combustion of the organic matter with a potassium dichromate/sulphuric acid mixture and titration of residual dichromate with ferrous sulphate. Organic matter content is derived from total organic carbon by the following formula: org.matter = org.C x 1.724

- total nitrogen

Kjeldahl method: a 40-mesh sieved soil sample is digested with the use of concentrated sulphuric acid. The digest is distilled and the distillate, containing the ammonium nitrogen, is titrated against a weak hydrochloric acid solution. The amount of HCl used in the titration correlates with the amount of nitrogen in the sample.

- available phosphorus

Bray(I) method: an extracting solution is used, consisting of a mixture of hydrochloric acid and ammonium fluoride. After filtering the soil suspension an aliquot is taken. Ammonium molybdate is added and with the use of stannous chloride indicator a blue colour is developed which is read colorimetrically.

- exchangeable cations

Cations are extracted with a neutral ammonium acetate solution. After filtering the suspension aliquots are taken which are passed on to a flame photometer for determination of sodium (Na) and potassium (K). Another aliquot is taken to be passed on to an atomic absorption spectrophotometer (AAS) for magnesium (Mg) and calcium (Ca) determination.

- cation exchange capacity (CEC)

After percolation with ammonium acetate at pH 7, the sample is percolated with sodium acetate at pH 7, washed free of excess salt and percolated with ammonium acetate. Sodium in the percolate is measured spectrophotometrically.

KEY TO THE SOIL GROUPS OF MALAWI (LAND RESOURCES EVALUATION PROJECT)

soil group symbol	soil group name	diagnostic soil characteristics	correlation with FAO (1988) Soil Units and phases: completely included	correlation with FAO (1988) Soil Units and phases: partly included
u	lithic	effective depth 30-50 cm and > 20% fine earth	lithic phase	
v	vertic	clayey topsoil (> 30% clay) and deep, wide cracks when dry	Vertisols Vertic Luvisols and Cambisols	
f	fluvic	flooding and sedimentation at regular intervals	Fluvisols	
s	salic	high salinity (> 4 mmho/cm) in most of the upper 100 cm	Solonchaks & salic phase of Gleysols, Phaeozems, Calcisols Cambisols and Luvisols	
g	gleyic	seriously impeded drainage, with or without seasonal high groundwater	Gleysols	
a	arenic	sand or loamy sand texture throughout upper 100 cm or less if soil depth is less	Arenosols	
m	mopanic	within 50 cm from surface a horizon with: - high bulk density and - extremely hard consistence (dry) and - very low permeability		Planosols, Luvisols
c	calcaric	calcareous in most of upper 100 cm or les if soil depth is less	Calcisols & Calcaric Regosols, Phaeozems and Cambisols & Calcic Luvisols	
p	paralithic	highly weathered rock at least between 75 and 150 cm from the surface and > 20% fine earth in upper 75 cm		Regosols, Phaeozems and Cambisols
r	dystric-ferralic	- low base saturation (< 50%) in at least part of the upper 50 cm and - low CEC clay (< 24me/100g) in most of upper 100 cm	Acrisols	Ferralsols, Cambisols
x	eutric-ferralic	- high base saturation (> 50%) throughout the upper 50 cm and - low CEC clay (< 24 me/100g) in most of upper 100 cm	Lixisols	Phaeozems, Ferralsols and Cambisols
d	dystric-fersialic	- low base saturation (< 50%) in at least part of the upper 50 cm and - medium-high CEC clay (> 24 me/100g) in most of upper 100 cm	Alisols	Nitisols, Cambisols
e	eutric-fersialic	- high base saturation (> 50%) throughout the upper 50 cm and - medium-high CEC clay (> 24 m3/100g) in most of upper 100 cm	Luvisols	Phaeozems, Nitisols and Cambisols

PARENT MATERIAL & SOIL GROUP	SOIL FAMILY	SOIL DEPTH (cm)	SOIL DRAINAGE	PARTICLE SIZE topsoil (0-30cm)	PARTICLE SIZE subsoil (>30cm)	pH(H2O) (0-50cm)	CEC-soil (me/100g) (0-50cm)	NPK (*) (0-50cm)	COLOUR subsoil	SOIL CLASSIFICATION SOIL UNIT (FAO)	SOIL CLASSIFICATION PHASE (FAO) (p.=partly)	LANDFORM	SOIL UNITS
A - FLUVIAL, COLLUVIAL AND/OR LACUSTRINE SEDIMENTS													
Aa - ARENIC													
	Mangochi	>150	well	coarse	coarse	5.5-6.5	<5	=++	yellowish brown	Cambic Arenosols		beach ridges	A1a1
Ae - EUTRIC-FERSIALIC													
	Zayuka	>150	mod.well	medium + fine	medium + fine	5.0-5.5	5-10	---	brown	Eutric Cambisols		river terraces	A1e6
	Mikaju	>150	mod.well + well	coarse + medium	coarse + medium	5.0-6.5	5-10	=--	brown	Haplic Luvisols Eutric Cambisols		outwash plains; footslopes river terraces	A1e7
Af - FLUVIC													
	Namitalala	>150	very poor + poor	variable	variable	5.0-6.5	5-10	--+	variable	Eutric Fluvisols Mollic Fluvisols	inundic	floodplains; depressions marshes	A1f2
	Chiromo	>150	poor	medium + fine	medium + fine	5.5-6.5	>10	+-+	dark grey	Eutric Fluvisols	inundic	floodplains	A1f3
	L. Linjisi	>150	poor + imperfect	medium + fine	medium + fine	5.5-6.5	>10	-++	dark grey	Eutric Fluvisols	inundic	depressions; floodplains	A1f4
	Mlangeni	>150	imperfect + mod.well	medium	medium + fine	5.5-6.5	>10	--+	dark brown	Eutric Fluvisols Mollic Fluvisols	p. inundic	outwash plains; floodplains	A1f5 A1f12 A2f6
	Lisungwe	>150	mod.well + well	medium + coarse	medium	5.0-6.5	5-10	==+	brown	Eutric Fluvisols		plains; lake margin plains footslopes	A2f7
	Phalombe	>150	mod.well + well	medium + coarse	medium + fine	5.0-6.5	5-10	=--	dark brown	Eutric Fluvisols Mollic Fluvisols		footslopes; levees; valleys in uplands	A1f13 A2f5 A3f5 A3f6

(*) N (Nitrogen): = <0.08 % (very low)
- 0.08-0.12 % (low)
+ >0.12 % (medium-very high)

P (Phosphorus): = <6 ppm (very low)
- 6-18 ppm (low)
+ >18 ppm (medium-very high)

K (Potassium): = <0.1 me/100 g (very low)
- 0.1-0.2 me/100 g (low)
+ >0.2 me/100 g (medium-very high)

APPENDIX V: SIMPLIFIED KEY TO THE RELEVANT UNITS OF THE SOIL MAP OF THE WORLD (FAO, 1988)

step	dominant characteristic	diagnostic horizon or property (*)	step	dominant characteristic	diagnostic horizon or property (*)	step	dominant characteristic	Soil Unit (FAO, 1988)
1	effective depth < 30 cm or < 20% fine earth upper 75 cm							Leptosols
2	clayey texture; cracks when dry; evidence of "pedoturbation"							Vertisols
3	flooding and sedimentation	fluvic properties						Fluvisols
4	high salinity (> 15 mmho/cm) in upper 30 cm	salic properties						Solonchaks
5	severe waterlogging and/or high groundwater table	gleyic properties						Gleysols
6	sand or loamy sand texture throughout upper 100 cm							Arenosols
7	v.low CEC clay (< 16 me/100g) and few (< 10%) weatherable minerals	ferralic B horizon						Ferralsols
8	slowly permeable subsoil and evidence of waterlogging in topsoil	E horizon with stagnic properties						Planosols
9	high exchangeable sodium (> 15%) within upper 40 cm	natric B horizon						Solonetz
10	deep, well-structured and pronounced topsoil	mollic A horizon						Phaeozems
11	considerable increase in clay content with depth, caused by soil forming processes (textural differences resulting from lithological discontinuities only are excluded)	argic B horizon	11.1	deep (> 150 cm) soil with deep B horizon and shiny ped surfaces	nitic properties			Nitisols
			11.2	low base saturation (< 50%) in at least part of B horizon		11.2.1	B horizon with mod.-high CEC clay (> 24 me/100g)	Alisols
						11.2.2	B horizon with low CEC clay (< 24 me/100g)	Acrisols
			11.3	high base saturation (> 50%) throughout B horizon		11.3.1	B horizon with mod.-high CEC clay (> 24 me/100g)	Luvisols
						11.3.2	B horizon with low CEC clay (< 24 me/100g)	Lixisols
12	subsoil markedly different in colour, structure, etc. from underlying (weathered) parent material	cambic B horizon						Cambisols
13	other							Regosols

(*) see Revised Legend of the Soil Map of the World (FAO, 1988)

SOIL UNIT	AREA (ha)	SOIL FAMILY	SOIL CLASSIFICATION (FAO, 1988)	SOIL DEPTH (cm)	SOIL DRAINAGE	PARTICLE SIZE topsoil (0-30cm)	PARTICLE SIZE subsoil (>30cm)	pH(H2O) (0-50cm)	CEC-soil (me/100g) (0-50cm)	NPK * (0-50cm)	COLOUR (subsoil)	SURFACE STONINESS + ROCKINESS (%)	PRESENT EROSION	FLOODING	LANDFORM
A _ LAND WITH SOILS IN FLUVIAL, COLLUVIAL AND/OR LACUSTRINE SEDIMENTS															
A1 - Flat or almost flat land (0-2%)															
A1e - With EUTRIC-FERSIALIC soil characteristics															
A1e7	3,500	Mikaju	Haplic Luvisols Chromic Cambisols	>150	well	coarse + medium	medium	5.5-6.5	5-10	==+	brown	<1	slight	none	river terraces; outwash plains
A1f - With FLUVIC soil characteristics															
A1f2	20,500	Namitalala	Eutric Fluvisols Mollic Fluvisols	>150	poor	variable	variable	5.0-6.5	5-10	-v+	variable	<1	none	frequent	floodplains
A1g - With GLEYIC soil characteristics															
A1g5	750	Nyenyesi	Eutric Gleysols Dystric Gleysols	>150	Poor + imperfect	coarse	medium + fine	4.5-5.5	5-10	-=+	greyish brown	<1	slight	exceptional	dambos
A1g8	4,500	Mpasa	Gleyic Cambisols Eutric Gleysols	>150	imperfect	medium	medium + fine	5.0-6.0	5-10	-=-	grey	<1	slight	none	depressions
A1g13	111,700	Tenthema	Eutric Gleysols	>150	poor	variable	variable	5.5-6.5	5-10	v=v	grey	<1	none	exceptional + none	dambos
A1g14	2,450	Mponela	Calcaric Gleysols	>150	poor + imperfect	variable	variable	7.5-8.5	>10	v=v		<1	none	exceptional + none	dambos
A2 _ Gently Sloping Land (2-6%)															
A2a - With ARENIC soil characteristics															
A2a3	1,300	Thangadzi	Cambic Arenosols	>150	well	coarse	coarse	5.0-6.5	<5	===	brown	<1	slight	none	footslopes
A2x - With EUTRIC FERRALIC characteristics															
A2x2	2,150	Liphala	Haplic Lixisols Ferralic Cambisols	>150	mod.well	medium	medium + fine	5.0-6.0	5-10	--+	strong brown	<1	slight	none	footslopes

*N (Nitrogen): = <0.08 % (very low)
- 0.08-0.12 % (low)
+ >0.12 % (medium-very high)

P (Phosphorus): = < 6 ppm (very low)
- 6-18 ppm (low)
+ >18 ppm (medium-very high)

K (Potassium): = <0.1 me/100g (very low)
- 0.1-0.2 me/100g (low)
+ >0.2 me/100g (medium-very high)

APPENDIX VII: CHARACTERISTICS AND CLASSES USED IN THE DESCRIPTION OF SOIL UNITS IN THE LEGEND OF THE SOILS AND PHYSIOGRAPHY MAP.

Each soil unit is described in the following terms:

- AREA: to the nearest 100 ha

- PARENT MATERIAL: one of the classes given in Table 4.

- SLOPE: one of the following classes:

  0 - 2 % (flat or almost flat)
  2 - 6 % (gently sloping)
  6 - 13 % (sloping)
  13 - 25 % (moderately steep)
  25 - 55 % (steep)

- SOIL GROUP: one of the groups defined in Section 3.2.2.2 and Appendix 4.

- SOIL FAMILY: one of the soil families given in Field Document No. 30. (Venema, 1991)

- DEPTH: one of the following classes:

  > 150 cm (very deep)
  100-150 cm (deep)
  50-100 cm (moderately deep)
  30- 50 cm (shallow)

- DRAINAGE: one or two of the following classes:

  very poor
  poor
  imperfect
  moderately well
  well
  somewhat excessive
  excessive

  (for definition see Guidelines for Soil Profile Description, FAO, 1977)

- PARTICLE SIZE TOPSOIL (mean, 0-30 cm) and SUBSOIL (mean, 30-100 cm): one or two of the following classes:

  coarse (< 15% clay and > 70% sand)
  coarse, skeletal
  medium (15-35% clay and < 85% sand, or < 15% clay and < 70% sand)
  medium, skeletal

fine (> 35% clay)
fine, skeletal

(skeletal = > 35% ,by volume, coarse mineral fragments)

- pH (soil reaction; mean upper 50 cm):
  one, two or three of the following classes:

3.5-4.0	(very strongly acid)
4.0-4.5	(very strongly acid)
4.5-5.0	(strongly acid)
5.0-5.5	(acid)
5.5-6.0	(moderately acid)
6.0-6.5	(slightly acid)
6.5-7.0	(almost neutral)
7.0-7.5	(very slightly alkaline)
7.5-8.0	(slightly alkaline)
8.0-8.5	(moderately alkaline)
>8.5	(strongly alkaline)

- CEC (cation exchange capacity; mean upper 50 cm):
  one of the following classes (me/100 g):

< 5	(very low)
5-10	(low)
>10	(medium to very high)

- N (total Nitrogen in %; mean upper 50 cm):
  one of the following classes:

<0.08	(=)	(very low)
0.08-0.12	(-)	(low)
>0.12	(+)	(medium to very high)

- P (available Phosphorus in ppm; mean upper 50 cm):
  one of the following classes:

< 6	(=)	(very low)
6-18	(-)	(low)
>18	(+)	(medium to very high)

- K (exchangeable Potassium in me/100 g; mean upper 50 cm):
  one of the following classes:

<0.1	(=)	(very low)
0.1-0.2	(-)	(low)
>0.2	(+)	(medium to very high)

- COLOUR (subsoil): one or two of the Munsell soil colour names
  (Munsell, 1975)

- SURFACE STONINESS & ROCKINESS (cover %):
  one of the following classes:

  < 1
  1-15
  >15

- PRESENT EROSION: one or two of the following classes:

  slight
  moderate
  severe

- FLOODING: one of the following classes:

  none
  none - exceptional (very rarely, or only in the past)
  exceptional (in years of exceptional high rainfall only)
  frequent

- LANDFORM: one or more of the following:

  alluvial fans
  alluvial plains
  bottomlands
  badlands
  beach ridges
  depressions
  dambos
  dissected escarpments
  dissected footslopes
  dissected hills
  dissected hillsides
  dissected mountainsides
  dissected plateaux
  dissected ridges
  dissected uplands
  escarpments
  footslopes
  floodplains
  inselbergs
  hillsides
  lakes
  levees
  low hills
  lowland plains
  lake margin plains
  marshes
  marsh margins
  mountain sides
  old dunes
  outwash plains
  plains
  plateaux
  rock outcrops
  ridges
  recent dunes
  ridges in footslopes
  rivers
  ridges in uplands
  uplands
  uplands with inselbergs
  valleysides
  valleys in uplands

APPENDIX VIII: AGRO-CLIMATIC ZONES OF MALAWI

A classification for land resources appraisal based on seven climatic parameters.

Agroclim. zone no.	LGP (days)	P/PET	T-GP (°C)	P-an (mm)	DM (months)	T-an (°C)	T-min (°C)	Occurrence
1	105-120	0.8-1	27.5-30.0	600-800	7-8	25.0-27.5	12.5-15.0	N
2	"	"	25.0-27.5	"	"	22.5-25.0	"	N,BL
3	"	"	"	800-1200	"	"	"	N
4	120-135	0.8-1	27.5-30.0	800-1200	7-8	25.0-27.5	12.5-15.0	N
5	"	"	25.0-27.5	600-800	"	22.5-25.0	"	BL
6	"	"	"	800-1200	"	"	"	N,BL
7	"	1-1.3	"	600-800	"	"	"	N,BL,LW,L
8	"	"	"	800-1200	"	"	"	LW
9	"	"	22.5-25.0	600-800	"	"	"	BL,LW
10	"	"	"	800-1200	"	"	"	LW
12	135-150	0.8-1	25.0-27.5	800-1200	7-8	22.5-25.0	12.5-15.0	N
13	"	"	22.5-25.0	"	"	"	"	N
14	"	1-1.3	27.5-30.0	"	5-6	"	"	N
15	"	"	25.0-27.5	800-1200	7-8	"	"	N,BL,LW,SL
16	"	"	"	"	5-6	"	"	N,SL
17	"	"	22.5-25.0	600-800	7-8	"	"	BL
18	"	"	"	800-1200	"	"	"	N,BL,LW,MZ,L,SL
19	"	"	"	"	"	20.0-22.5	10.0-12.5	BL,LW
20	"	"	"	"	5-6	22.5-25.0	12.5-15.0	LW,L
21	"	"	20.0-22.5	600-800	7-8	20.0-22.5	10.0-12.5	MZ,K
22	"	"	"	600-800	"	17.5-20.0	7.5-10.0	MZ,K
148	"	"	"	800-1200	"	20.0-22.5	10.0-12.5	K
149	"	"	"	"	"	17.5-20.0	7.5-10.0	K
150	"	"	17.5-20.0	600-800	"	"	"	K
154	"	>1.3	25.0-27.5	800-1200	5-6	22.5-25.0	12.5-15.0	SL
151	"	"	22.5-25.0	"	7-8	"	"	K
152	"	"	20.0-22.5	600-800	"	20.0-22.5	10.0-12.5	K
23	"	"	"	800-1200	"	"	"	L,K
142	"	"	"	"	5-6	"	"	L
143	"	"	"	"	7-8	17.5-20.0	7.5-10.0	L,K
24	150-165	1-1.3	25.0-27.5	800-1200	7-8	22.5-25.0	12.5-15.0	N,BL
25	"	"	"	"	5-6	"	"	N,BL
26	"	"	22.5-25.0	"	7-8	"	"	N,BL,LW,KR,L,SL
27	"	"	"	"	"	20.0-22.5	"	BL,LW,L
28	"	"	"	"	5-6	22.5-25.0	"	N,LW,L,SL
29	"	"	"	"	"	20.0-22.5	"	N,BL
30	"	"	20.0-22.5	600-800	7-8	"	10.0-12.5	MZ,K
31	"	"	"	"	"	17.5-20.0	7.5-10.0	MZ,K
32	"	"	"	800-1200	"	20.0-22.5	10.0-12.5	BL,LW,MZ,L,SL
33	"	"	"	"	"	17.5-20.0	7.5-10.0	MZ
34	"	"	"	"	5-6	20.0-22.5	10.0-12.5	BL,LW,L
35	"	"	"	1200-1600	"	"	"	BL

(Contnued)

APPENDIX VIII (continued)

Agroclim zone no.	LGP (days)	P/PET	T-GP (°C)	P-an (mm)	DM (months)	T-an (°C)	T-min (°C)	Occurrence
36	150-165	>1.3	25.0-27.5	800-1200	5-6	22.5-25.0	12.5-15.0	N,BL
155	"	"	"	1200-1600	7-8	"	"	SL
156	"	"	22.5-25.0	800-1200	"	"	"	SL,K
37	"	"	"	"	"	20.0-22.5	10.0-12.5	BL,L,K,SL
38	"	"	"	"	5-6	22.5-25.0	"	LW,K,SL
153	"	"	"	"	"	20.0-22.5	"	K,SL
39	"	"	"	1200-1600	"	22.5-25.0	12.5-15.0	LW,SL
157	"	"	"	"	"	20.0-22.5	10.0-12.5	SL
40	"	"	20.0-22.5	600-800	7-8	17.5-20.0	7.5-10.0	MZ,K
137	"	"	"	"	"	20.0-22.5	10.0-12.5	MZ,K
41	"	"	"	800-1200	"	"	"	BL,LW,KR,MZ,L,K,SL
42	"	"	"	"	"	17.5-20.0	7.5-10.0	MZ,L,K
43	"	"	"	"	5-6	20.0-22-5	10.0-12.5	BL,LW,L,K,SL
44	"	"	"	"	"	17.5-20.0	7.5-10.0	L
144	"	"	"	1200-1600	"	"	"	L
45	"	"	17.5-20.0	800-1200	7-8	"	"	MZ,L,K
145	"	"	"	"	5-6	"	"	L,K
46	165-180	1-1.3	25.0-27.5	800-1200	5-6	22.5-25.0	12.5-15.0	BL
47	"	"	22.5-25.0	"	7-8	"	"	KR
48	"	"	"	"	5-6	"	"	N,KR
50	"	"	20.0-22.5	800-1200	5-6	20.0-22.5	10.0-12.5	BL
51	"	>1.3	25.0-27.5	"	"	22.5-25.0	12.5-15.0	N,BL
52	"	"	22.5-25.0	"	7-8	20.0-22.5	10.0-12.5	BL
53	"	"	"	"	5-6	22.5-25.0	12.5-15.0	KR,SL
54	"	"	"	"	"	20.0-22.5	"	BL,SL
55	"	"	"	"	"	"	10.0-12.5	KR
141	"	"	"	1200-1600	"	22.5-25.0	12.5-15.0	MZ,SL
158	"	"	"	1600-2000	5-6	"	"	SL
57	"	"	20.0-22.5	800-1200	7-8	17.5-20.0	7.5-10.0	KR,MZ
138	"	"	"	"	"	20.0-22.5	10.0-12.5	MZ
58	"	"	"	"	5-6	"	"	BL,LW,KR,MZ,L,K,SL
59	"	"	"	"	"	17.5-20.0	7.5-10.0	KR,L,K
60	"	"	"	1200-1600	5-6	20.0-22.5	10.0-12.5	BL,LW
146	"	"	"	"	"	17.5-20.0	7.5-10.0	L,K
61	"	"	17.5-20.0	800-1200	7-8	"	"	KR,MZ,L,K
62	"	"	"	"	5-6	"	"	KR,L,K
147	"	"	"	1200-1600	"	"	"	L
63	180-195	1-1.3	22.5-25.0	800-1200	5-6	20.0-22.5	10.0-12.5	N
64	"	>1.3	"	"	7-8	"	"	BL
65	"	"	"	"	5-6	"	"	BL,KR,MZ,SL
66	"	"	"	"	"	22.5-25.0	12.5-15.0	BL,KR
67	"	"	"	1200-1600	"	"	"	BL,KR,MZ,SL
68	"	"	"	"	"	20.0-22.5	10.0-12.5	N,BL,KR,SL
159	"	"	"	1600-2000	"	22.5-25.0	12.5-15.0	SL
69	"	"	20.0-22.5	800-1200	7-8	20.0-22.5	10.0-12.5	BL,MZ
70	"	"	"	"	5-6	"	"	BL,LW,KR,MZ,L
71	"	"	"	1200-1600	"	"	"	BL,LW,KR,MZ,SL
72	"	"	"	"	"	17.5-20.0	7.5-10.0	KR,MZ
73	"	"	17.5-20.0	800-1200	7-8	"	"	KR,MZ
74	"	"	"	"	5-6	"	10.0-12.5	LW
75	"	"	"	"	"	"	7.5-10.0	KR,MZ,L,K,SL
76	"	"	"	1200-1600	"	"	10.0-12.5	BL,L
77	"	"	"	"	"	"	7.5-10.0	BL,KR,MZ,L
78	"	"	15.0-17.5	800-1200	"	15.0-17.5	5.0-7.5	KR,L

APPENDIX VIII (continued)

Agroclim zone no.	LGP (days)	P/PET	T-GP (°C)	P-an (mm)	DM (months)	T-an (°C)	T-min (°C)	Occurrence
79	195-210	1-1.3	22.5-25.0	800-1200	5-6	20.0-22.5	12.5-15.0	BL
80	"	"	20.0-22.5	"	"	"	10.0-12.5	BL
81	"	>1.3	22.5-25.0	1200-1600	"	22.5-25.0	12.5-15.0	KR,MZ
82	"	"	"	"	"	20.0-22.5	"	N,BL
83	"	"	"	"	"	"	10.0-12.5	BL
84	"	"	"	1600-2000	"	22.5-25.0	12.5-15.0	KR
85	"	"	20.0-22.5	800-1200	5-6	20.0-22.5	10.0-12.5	BL
87	"	"	"	1200-1600	"	"	"	BL,KR,MZ,SL
88	"	"	"	"	"	17.5-20.0	7.5-10.0	MZ,SL
89	"	"	"	1600-2000	"	20.0-22.5	10.0-12.5	KR
91	"	"	17.5-20.0	800-1200	5-6	17.5-20.0	"	BL,LW
92	"	"	"	"	"	"	7.5-10.0	MZ
94	"	"	"	1200-1600	"	"	10.0-12.5	LW
95	"	"	"	"	"	"	7.5-10.0	KR,MZ,SL
96	"	"	"	"	"	15.0-17.5	5.0-7.5	MZ,L
97	"	"	15.0-17.5	800-1200	"	"	7.5-10.0	KR
98	"	"	"	1200-1600	"	"	5.0-7.5	KR,MZ
99	210-225	>1.3	22.5-25.0	1200-1600	5-6	22.5-25.0	12.5-15.0	BL,MZ
100	"	"	"	"	3-4	"	"	MZ
101	"	"	"	1600-2000	5-6	"	"	MZ
102	"	"	"	"	3-4	"	"	KR,MZ
103	"	"	"	>2000	5-6	"	"	MZ
104	"	"	20.0-22.5	1200-1600	"	20.0-22.5	"	BL
105	"	"	"	"	"	"	10.0-12.5	MZ
106	"	"	"	"	"	17.5-20.0	7.5-10.0	MZ,SL
107	"	"	"	>2000	"	20.0-22.5	10.0-12.5	KR
108	"	"	17.5-20.0	1200-1600	"	17.5-20.0	7.5-10.0	KR,MZ
110	"	"	"	1600-2000	"	"	"	KR
111	"	"	15.0-17.5	1200-1600	"	15.0-17.5	5.0-7.5	KR,MZ
112	"	"	"	1600-2000	"	"	"	KR
113	225-240	>1.3	22.5-25.0	1200-1600	5-6	20.0-22.5	12.5-15.0	BL
114	"	"	"	"	3-4	"	10.0-12.5	MZ
115	"	"	"	1600-2000	"	22.5-25.0	12.5-15.0	MZ
116	"	"	"	>2000	"	"	"	KR
117	"	"	20.0-22.5	1200-1600	5-6	20.0-22.5	12.5-15.0	BL
118	"	"	"	"	"	"	10.0-12.5	BL
119	"	"	"	"	3-4	"	"	BL
120	"	"	17.5-20.0	"	5-6	17.5-20.0	"	BL,LW
121	"	"	"	1600-2000	"	"	"	LW
122	"	"	15.0-17.5	"	"	15.0-17.5	7.5-10.0	BL
123	"	"	12.5-15.0	1200-1600	"	12.5-15.0	2.5-5.0	KR,MZ
125	240-270	>1.3	22.5-25.0	1200-1600	3-4	20.0-22.5	12.5-15.0	BL
126	"	"	"	>2000	"	22.5-25.0	"	MZ
127	"	"	20.0-22.5	1200-1600	1-2	20.0-22.5	10.0-12.5	BL
128	"	"	"	1600-2000	"	"	12.5-15.0	BL
129	"	"	17.5-20.0	"	3-4	17.5-20.0	10.0-12.5	BL
130	"	"	15.0-17.5	"	5-6	15.0-17.5	7.5-10.0	LW
131	"	"	12.5-15.0	1200-1600	"	12.5-15.0	2.5-5.0	KR,MZ
132	"	"	"	1600-2000	"	"	"	MZ

APPENDIX VIII (continued)

Agroclim zone no.	LGP (days)	P/PET	T-GP (°C)	P-an (mm)	DM (months)	T-an (°C)	T-min (°C)	Occurrence
133	270-300	>1.3	20.0-22.5	>2000	1-2	20.0-22.5	12.5-15.0	BL
134	"	"	15.0-17.5	"	5-6	15.0-17.5	7.5-10.0	LW
135	300-330	>1.3	15.0-17.5	>2000	1-2	15.0-17.5	7.5-10.0	BL
136	"	"	12.5-15.0	"	"	12.5-15.0	5.0-7.5	BL

Notes;

LGP = Length of the growing period (in days)
P/PET = Ratio of precipitation and potential evapotranspiration
T-GP = Mean temperature (in °C) during the LGP
P-an = Mean annual precipitation (in mm)
DM = Mean number of dry months per year, i.e., months with <50mm precipitation
T-an = Mean annual temperature (in °C)
T-min = Mean minimum temperature (in °C) of the coolest month (July)

T-EGP (mean temperature during the last 120 days of the LGP) equals T-GP, except for the following zones:

113, 114, 115, 116 ;T-EGP=20.0-22.5°C.
117, 118, 119, 127, 128, 133;T-EGP=17.5-20.0°C.

Total Agro-climatic Zones in Malawi: 149.

Total Agro-climatic Zones in the Northern Region: 65.

Total Agro-climatic Zones in the Central Region : 64.

Total Agro-climatic Zones in the Southern Region: 80.

Total Agro-climatic Zones by ADD:

KRADD : 38.	SLADD : 31.
MZADD : 47.	LWADD : 28.
KADD : 28.	BLADD : 60.
LADD : 31.	NADD : 23.

APPENDIX IX: PRESENT LAND USE AND VEGETATION - LEGEND.

A Rainfed cultivation

A1 - maize, pulses, groundnuts, cassava (tobacco, sorghum, sweet potato, mango, banana).
A2 - maize, pulses, groundnuts, cotton, cassava (sorghum, sweet potato, mango, banana).
A3 - maize, sorghum, pulses, cotton.
A4 - maize, pulses, finger millet, Irish potato, wheat.
A5 - maize, pulses, cotton, groundnuts, bulrush millet.
A6 - maize, pulses, cassava, banana and other fruits, tea.
A7 - maize, tobacco, soya beans, sunflower, chick peas.
A8 - sorghum, bulrush millet, maize, groundnuts, guar beans.
A9 - tea with forest plantations, coffee, tung, macademia.
A10- tobacco, maize, (coffee).
A11- coffee, maize, pulses (Irish potato).
A12- maize, pulses, groundnuts, finger millet, cassava (sweet potato, mango, banana).
A13- cassava, maize, banana (groundnuts, finger millet, sweet potato, mango).
A14- tobacco, maize.
A15- rubber, tea, macademia (coffee).
A16- tung.
A17- maize, pulses, tobacco, groundnuts (cassava, sweet potato, mango, banana).
A18- maize, pulses, Irish potato, groundnuts.

B Wetland cultivation

B1 - rice.

C Dimba cultivation

C1 - vegetables (tomato, chinese cabbage, onion, pumpkin, rape), sweet potato, maize, beans, sugar cane, banana.

D Irrigated cultivation

D1 - sugar cane.
D2 - rice, maize.
D3 - cashew.
D4 - rice (maize, pulses).

E Grasslands

E1 - montane grassland with forest remnants.
E2 - dry grassland (secondary, cleared from wooded land), may include some fallow and regenerating scrub.
E3 - seasonally wet grassland of floodplains and lake fringes.
E4 - seasonally wet grassland associated with upland drainage systems.
E5 - severely degraded grassland/scrub.

F <u>Plantation forests</u>

F1 - Pinus spp.
F2 - Eucalyptus spp.
F3 - mixed species.

G <u>Natural forests and woodlands</u>

Forests

G1 - evergreen forest.

Woodlands

G2 - semi-evergreen woodland. (Brachystegia spiciformis with Erythrophloeum).
G3 - moist Brachystegia woodland. (B. spiciformis predominant).
G4 - Brachystegia plateau woodland. (B. taxifolia and B. glaucesens).
G5 - Brachystegia plateau woodland. (Julbernardia paniculata prominent).
G6 - Brachystegia hill woodland. (J. globiflora often prominent, many Brachystegia species).
G7 - Brachystegia escarpment woodland. (J. globiflora and B. boehmii).
G8 - Mopane woodland. (Colophospermum mopane).

Woodland savannas

G9 - Terminalia woodland savanna. (T. sericea).
G10- woodland savanna of fertile plateau areas. (Combretum, Acacia, Bauhinia).
G11- open plateau savanna. (Erythrina, Cussonia, Croton, Dombeya).
G12- savannas of fertile lowlands. (Sclerocarya, Adansonia, Cordyla, sterculia, Hyphaene, Acacia albida).

Tree savannas

G13- mixed low altitude savanna. (Combretum, Diplorhynchus, Pseudolachnostylis, Diospyros, Acacia).

Thickets

G14- plateau thicket. (Combretum, Commiphora, Euphorbia: interspersed with Brachystegia woodland).
G15- lowland thicket. (Pterocarpus lucens often prominent).
G16- recent regrowth of undifferentiated woody vegetation.

Specialised vegetation

G17- vegetation of sands.

M <u>Marshes</u> (reed and sedge communities)

R <u>Bare or sparsely vegetated rock outcrops</u>

W <u>Open water</u>

Z <u>Built-up areas</u>

APPENDIX X: EXAMPLE OF THE LIST OF LAND UNITS

SOIL UNIT	CLIM ATIC ZONE	LAND UNIT No.	OCCURRENCE			
Ala1	(7) =	1		LW		
	(8) =	2		LW		
	(99) =	143			MZ	
	(103)=	150			MZ	
	(126)=	237			MZ	
Ala2	(1) =	8				N
	(8) =	3		LW		
	(18) =	4		LW		
	(19) =	5		LW		
	(26) =	6		LW		
	(28) =	7		LW		
Ala3	(81) =	750	KR			
	(116)=	751	KR			
Ala4	(26) =	9		LW		
	(38) =	10		LW		
Ala5	(26) =	11		LW		
	(28) =	12		LW		
	(38) =	13		LW		
Alc1	(1) =	14				N
	(2) =	15				N
	(3) =	16				N
	(4) =	17				N
Alc2	(7) =	18		LW		
	(9) =	19		LW		
	(18) =	20		LW		
	(28) =	21		LW		
	(32) =	22		LW		
Alc3	(1) =	23				N
	(3) =	24				N
Ale1	(7) =	25		LW		
	(8) =	26		LW		
	(9) =	27		LW		
	(10) =	28		LW		
	(18) =	29		LW		
	(26) =	30		LW		
	(39) =	31		LW		

APPENDIX XI: EXAMPLE OF LAND UNIT DESCRIPTION

STUDY AREA: MZADD

LAND UNIT	SOIL UNIT	AGRO-CLIMATIC ZONE	AREA (ha)
1139	X3r5	(100)	2,700
1140		(114)	750
1141		(115)	1,250
1142		(126)	5,500

LAND UNIT	AGRO-CLIMATIC ZONE	AREA (ha)

DISTRIBUTION.
DISTRICT(S): Nkhata Bay (E)
AGRO-ECOLOGICAL ZONE(S): Nkhata Bay Lakeshore Plain
Timbiri-Malenga Lakeshore Plain

DOMINANT PRESENT LAND-USE AND VEGETATION:
Moist Brachystegia woodland

SOILS AND PHYSIOGRAPHY:

LANDFORM: dissected uplands

DOMINANT SLOPE CLASS (%): 6-13 (sloping)
ALTITUDE RANGE (m asl): 470-800 PRESENT EROSION: slight to moderate

PARENT MATERIAL: intermediate metamorphic rocks (gneiss or granulite)
SOIL DESCRIPTION: Deep, well drained, medium over fine textured skeletal, red soils, of very low chemical fertility; pH(0-50 cm)= 4.5-5.0
SOIL CLASSIFICATION, SOIL GROUP: dystric-ferralic
SOIL FAMILY: Nkhata Bay
FAO, 1988: Haplic Acrisols

EFFECTIVE SOIL DEPTH (cm): 100-150 (deep)
DEPTH LIMITING FACTOR: >70 % stones COLOUR SUBSOIL: red
SURFACE STONINESS AND ROCKINESS (%): 1-15 (stony and/or fairly rocky)
PARTICLE SIZE, TOPSOIL (0-30 cm): sandy loam to sandy clay loam
PARTICLE SIZE, SUBSOIL (>30 cm): sandy clay, skeletal

SOIL DRAINAGE CLASS: well
FREQUENCY OF FLOODING: none PONDING: none

SOIL CHEMICAL PROPERTIES (0-50 cm),

SOIL REACTION (pH):	4.5-5.0
SALINITY (EC IN mmhos/cm):	0-2 (non saline)
CATION EXCHANGE CAPACITY (CEC in me/100g soil):	5-10 (low)
NITROGEN (N in %):	<0.08 (very low)
PHOSPHORUS (P in ppm):	<6 (very low)
POTASSIUM (K in me/100g soil):	0.1-0.2 (low)

APPENDIX XII: CROP REQUIREMENTS

This appendix contains a listing of requirements for physical land evaluation for rainfed and irrigated cropping, as described in this report, of the following crops (common crop names listed in alphabetical order):

Bulrush or Pearl millet	(Pennisetum typhoides)
Cashew	(Anacardium occidentale)
Cassava	(Manihot esculenta)
Citrus	(Citrus spp.)
Coffee	(Coffea arabica)
Cotton	(Gossypium hirsutum)
Cowpea	(Vigna unguiculata)
Finger millet	(Eleusine coracana)
Groundnuts	(Arachis hypogaea)
Guar bean	(Cynamopsis tetragonaloba)
Irish potato	(Solanum tuberosum)
Maize	(Zea mays)
Paddy rice	(Oryza sativa)
Phaseolus beans	(Phaseolus spp.)
Pigeon pea	(Cajanus indicus, C. cajan)
Sorghum	(Sorghum bicolor)
Soya beans	(Glycine maxima)
Sunflower	(Helianthus annuus)
Sweet potato	(Ipomoea batatas)
Tea	(Camellia sinensis)
Tobacco	(Nicotiana tabacum)
Wheat	(Triticum aestivum)

Crop requirements have been derived from the following publications (listed in alphabetical order):

Acland (1971)
Bunning and Brinn (1983, unpublished)
Dept. of Agric. Research (1986)
Extension Aids Branch (1988)
Extension Aids Branch (crop specific extension circulars)
FAO (1978, 1980, 1985)
ILACO (1985)
IRRI (1978)
Landon (1984)
Purseglove (1968, 1985)

Note:

- Yields listed under traditional management apply to local varieties while those listed under improved traditional management apply to improved varieties.

- The following soil texture classes and abbreviations have been used: (FAO, 1977)

coarse: sand, loamy sand (LS) and sandy loam (SL)

medium: sandy loam (SL), loam (L) sandy clay loam (SCL) and clay-loam (CL)

fine : clay-loam (CL), sandy clay (SC) and clay (C)

BULRUSH OR PEARL MILLET (Pennisetum typhoides)

Growth cycle (in days)	: 100-130 (local var.), 90-110 (improved var.)
Improved varieties	: Nigerian composite

Maximum yields:

Under traditional management	: 1.0 t/ha
Under improved trad. managem.	: 2.3 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 20-32 Optimum: 25-30
Length of growing period (in days)	: Range: 105-270 (local var.), 105-240 (improved var.) Optimum: 135-180 (local var.), 135-195 (improved var.)
Drought resistance	: moderate

Edaphic requirements:

Soil texture	: Range: coarse to fine Optimum: medium (SL-SCL)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to excessively Optimum: moderately well to excessively
Flooding/waterlogging	: Range: none to exceptional Optimum: none
Soil fertility requirements	: moderate
Soil reaction (pH)	: Range: 4.5-8.5 Optimum: 5.5-7.5
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <4

CASHEW (Anacardium occidentale)

Growth cycle	: perennial (3-4 years to bearing)
Improved varieties	: -

Maximum yields:

Under traditional management	: 0.8 t/ha
Under improved trad. managem.	: 1.5 t/ha

Agro-climatic requirements:

Mean annual temperature (in °C)	: Range: 20-30 Optimum: 25-28
Mean minimum temperature of the coolest month (in °C)	: Range: >7 (damaged by frost) Optimum: >17
Mean annual rainfall (in mm)	: Range: >600 Optimum: 1,200-2,000 (tm), >1,200 (itm)
Mean number of dry months per year (P <50 mm)	: Range: 3-8 Optimum: 5-6
Drought resistance	: high

Edaphic requirements:

Soil texture	: Range: coarse to medium Optimum: coarse to medium (LS-SL)
Soil depth (in cm)	: Range: >50 Optimum: >150
Soil drainage (FAO soil drainage classes)	: Range: moderately well to excessively Optimum: well to excessively
Flooding/waterlogging	: Range: none to exceptional Optimum: none
Soil fertility requirements	: low to moderate
Soil reaction (pH)	: Range: 4.5-8.0 Optimum: 5.5-7.0
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <4

CASSAVA (Manihot esculenta)

Growth cycle (in days)	: perennial (local var.), 270-360 (Gomani), 360-450 (Mbundumali/Manyokola)
Improved varieties	: Gomani, Mbundumali, Manyokola

Maximum yields:

Under traditional management	: 10.0 t/ha
Under improved trad. managem.	: 15.0 t/ha

Agro-climatic requirements:

Mean annual temperature for long-cycle varieties (°C)	: Range: 17-30 Optimum: 22-28
Mean minimum temperature of the coolest month (in °C)	: Range: >3 (damaged by frost) Optimum: >8
Mean daily temperature during the growing period for short-cycle varieties (in °C)	: Range: 20-32 Optimum: 25-30
Length of growing period (in days)	: Range: 210-365+ (local var.), 180-365+ (improved var.) Optimum: 270-365+ (local var.), 240-365+ (improved var.)
Drought resistance	: high

Edaphic requirements:

Soil texture	: Range: coarse to medium Optimum: medium (SL-SCL)
Soil depth (in cm)	: Range: >50 Optimum: >100
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to excessively Optimum: moderately well to somewhat excessively
Flooding/waterlogging	: Range: none to exceptional Optimum: none
Soil fertility requirements	: low to moderate
Soil reaction (pH)	: Range: 4.0-8.0 Optimum: 5.5-7.0
Salinity tolerance (in mmhos/cm)	: Range: <4 Optimum: <2

CITRUS (Citrus spp.)

Growth cycle	: perennial (4 years to bearing)
Varieties	: Orange (Valencia) and Tangerine var.

Maximum yields:

Under traditional management	: 8.0 t/ha
Under improved trad. managem.	: 20.0 t/ha

Agro-climatic requirements:

Mean annual temperature (in °C)	: Range: 15-30 Optimum: 20-27
Mean minimum temperature of the coolest month (in °C)	: Range: not below 0 Optimum: 7-12
Mean annual rainfall (in mm)	: Range: >800 Optimum: 1,600-2,000 (local var.), 1,400-2,000 (improved var.)
Mean number of dry months per year (P <50 mm)	: Range: 1-7 Optimum: 3-4
Drought resistance	: moderate

Edaphic requirements:

Soil texture	: Range: medium to fine Optimum: medium (SL-SCL)
Soil depth (in cm)	: Range: >75 Optimum: >150
Soil drainage (FAO soil drainage classes)	: Range: moderately well to excessively Optimum: well drained
Flooding/waterlogging	: Range: none to exceptional Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 5.0-8.0 Optimum: 6.0-7.0
Salinity tolerance (in mmhos/cm	: Range: <5 Optimum: <2

COFFEE (Coffea arabica)

<u>Growth cycle</u>	: perennial (3-4 years to bearing)
<u>Improved varieties</u>	: Agaro 56, NTE G1 and G11
<u>Maximum yields</u>:	
Under improved trad. managem.	: 2.5 t/ha

<u>Agro-climatic requirements</u>:

Mean annual temperature (in °C)	: Range: 15-25 Optimum: 17-21
Mean minimum temperature of the coolest month (in °C)	: Range: >5.0 Optimum: >12
Mean annual rainfall (in mm)	: Range: 1,200-3,500 Optimum: >2,000
Mean number of dry months per year (P <50 mm)	: Range: 1-5 Optimum: 2-3
Drought resistance	: moderate

<u>Edaphic requirements</u>:

Soil texture	: Range: medium to fine Optimum: medium to fine (L-SCL-CL-SC)
Soil depth (in cm)	: Range: >75 Optimum: >150
Soil drainage (FAO soil drainage classes)	: Range: moderately well to well Optimum: well
Flooding/waterlogging	: Range: none to exceptional Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.0-7.0 Optimum: 5.0-6.0
Salinity tolerance (in mmhos/cm)	: Range: <4 Optimum: <2

COTTON (Gossypium hirsutum)

Growth cycle (in days)	: 110-130 (improved var.), 120-150 (local var.)
Improved varieties	: Makoka 72, Rasam 17, Ezam 6

Maximum yields:

Under traditional management	: 1.0 t/ha
Under improved trad. managem.	: 2.2 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 18-32 Optimum: 25-30
Length of growing period (in days)	: Range: 105-300 (local var.), 105-270 improved var.) Optimum: 150-210 (local var.), 120-180 (improved var.)
Drought resistance	: moderate

Edaphic requirements:

Soil texture	: Range: medium to fine Optimum: medium (SL-L-SCL)
Soil depth (in cm)	: Range: >50 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to well Optimum: moderately well to well
Flooding/waterlogging	: Range: none to exceptional Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 5.0-8.0 Optimum: 6.0-7.5
Salinity tolerance (in mmhos/cm)	: Range: <20 Optimum: <12

COWPEA (Vigna unguiculata)

<u>Growth cycle</u> (in days) : 90-120

<u>Improved varieties</u> : -

<u>Maximum yields</u>:

Under traditional management	: 0.8 t/ha
Under improved trad. managem.	: 1.2 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	: Range: 17-32 Optimum: 22-30
Length of growing period (in days)	: Range: 105-300 Optimum: 150-225 (local var.), 150-240 (improved var.)
Drought resistance	: moderate

<u>Edaphic requirements</u>:

Soil texture	: Range: medium to fine Optimum: medium to fine (L-SCL-SC-CL)
Soil depth (in cm)	: Range: >30 Optimum: >60
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to well Optimum: moderately well to well
Flooding/waterlogging	: Range: none to exceptional (short periods) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 5.0-8.0 Optimum: 6.0-7.0
Salinity tolerance (in mmhos/cm)	: Range: <7 Optimum: <2

FINGER MILLET (Eleusine coracana)

Growth cycle (in days)	:	90-110 (improved var.), 100-120 (local var.)
Improved varieties	:	40, 366, 516, Dobaloba, Mavoli

Maximum yields:

Under traditional management	:	1.0 t/ha
Under improved trad. managem.	:	2.0 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	:	Range: 17-32 Optimum: 22-30
Length of growing period (in days)	:	Range: 105-270 Optimum: 135-195 (local var.), 150-210 (improved var.)
Drought resistance	:	moderate

Edaphic requirements:

Soil texture	:	Range: coarse to fine Optimum: medium (SL-L)
Soil depth (in cm)	:	Range: >30 Optimum: >60
Soil drainage (FAO soil drainage classes)	:	Range: imperfectly to somewhat excessive Optimum: moderately well to well
Flooding/waterlogging	:	Range: none to exceptional Optimum: none
Soil fertility requirements	:	moderate
Soil reaction (pH)	:	Range: 4.5-8.5 Optimum: 5.5-7.5
Salinity tolerance (in mmhos/cm)	:	Range: <8 Optimum: <4

GROUNDNUTS (Arachis hypogaea)

Growth cycle (in days)	: 110-120 (Malimba), 130-140 (Manipintar, Mawanga, RG1), 140-150 (Chalimbana, Chitembana, 100-150 (local varieties)
Improved varieties	: Manipintar, Mawanga, RG1, Chalimbana, Malimba, Chitembana

Maximum yields:

Under traditional management	: 0.8 t/ha
Under improved trad. managem.	: 2.8 t/ha (Manipintar, Mawanga) 2.2 t/ha (Chalimbana) 1.2 t/ha (Malimba)

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 20-33 (short-cycle var.), 17-30 (long-cycle var.) Optimum: 23-28 (short-cycle var.), 20-25 (long-cycle var.)
Length of growing period (in days)	: Range: 105-300 (local var.), 105-270 (short-cycle var.), 120-300 (long-cycle var.) Optimum: 150-225 (local- and long-cycle var.), 135-195 (short-cycle var.)
Drought resistance	: moderate

Edaphic requirements:

Soil texture	: Range: coarse to fine Optimum: coarse to medium (LS-SL-L)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to excessively Optimum: well to somewhat excessively
Flooding/waterlogging	: Range: none to exceptional (short periods) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.5-8.5 Optimum: 6.0-7.5
Salinity tolerance (in mmhos/cm)	: Range: <7 Optimum: <4

GUAR BEAN (Cynamopsis tetragonaloba)

Growth cycle (in days) : 90-120

Improved varieties : Khanpur

Maximum yields:

Under traditional management : 0.8 t/ha
Under improved trad. managem. : 1.6 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 20-35 Optimum: 25-30
Length of growing period (in days)	: Range: 105-240 Optimum: 135-180
Drought resistance	: high

Edaphic requirements:

Soil texture	: Range: coarse to fine Optimum: medium (SL-L-SCL)
Soil depth (in cm)	: Range: >30 Optimum: >60
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessive Optimum: well
Flooding/waterlogging	: Range: none (intolerant of waterlogging) Optimum: none
Soil fertility requirements	: low to moderate
Soil reaction (pH)	: Range: 5.0-8.5 Optimum: 6.0-7.5
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <2

IRISH POTATO (Solanum tuberosum)

Growth cycle (in days)	: 100-120, 120-150, 150-170 (depending upon variety)
Improved varieties	: -

Maximum yields:

Under traditional management	: 8.0 t/ha
Under improved trad. managem.	: 25.0 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 10-25 Optimum: 15-20
Length of growing period (in days)	: Range: 120-270 (local var.), 105-300 (improved var.) Optimum: 150-210
Drought resistance	: low

Edaphic requirements:

Soil texture	: Range: coarse to fine Optimum: medium (L-CL-SCL)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: well to somewhat excessively
Flooding/waterlogging	: Range: none to exceptional (short period) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.5-8.0 Optimum: 5.5-7.0
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <4

MAIZE (Zea mays)

Growth cycle (in days)	: 100-110 (Tuxpeno), 110-130 (NSCM 41, MH 16), 130-150 (MH 12, MH 15), 140-150 (UCA, CCA), 120-160 (local var.)
Improved varieties	: Composites: UCA,CCA, Tuxpeno Hybrids: MH 12, MH 15, MH 16, NSCM 41

Maximum yields:

Under traditional management	: 1.5 t/ha	
Under improved trad. managem.	: 5.0 t/ha	(composites)
	6.5 t/ha	(hybrids)

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 18-32 (short-cycle var.), 13-27 (long-cycle var.) Optimum: 23-29 (short-cycle var.), 16-23 (long-cycle var.)
Length of growing period (in days)	: Range: 105-330 (local var.), 105-300 (short-cycle var.), 120-330 (long-cycle var.) Optimum: 150-225 (local and short-cycle var.), 180-270 (long-cycle var.)
Drought resistance	: low

Edaphic requirements:

Soil texture	: Range: medium to fine Optimum: medium to fine (L-SCL-SC)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	: Range: none Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.5-8.5 Optimum: 5.5-7.5
Salinity tolerance (in mmhos/cm)	: Range: <6 Optimum: <2

PADDY RICE (Oryza sativa)

Growth cycle (in days)	: 90-120 (improved var.), 100-150 (local var.)
Improved varieties	: Blue Bonnet, IET 4094

Maximum yields:

Under traditional management	: 2.0 t/ha
Under improved trad. managem.	: 5.0 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 20-35 Optimum: 22-30
Length of growing period (in days)	: not applicable
Mean annual rainfall (in mm)	: Range: >1,200 Optimum: >1,800
Drought resistance	: low

Edaphic requirements:

Soil texture	: Range: medium to fine Optimum: fine (CL-SC-C)
Soil depth (in cm)	: Range: >30 Optimum: >50
Soil drainage (FAO soil drainage classes)	: Range: very poorly to imperfectly Optimum: poorly to imperfectly
Flooding/waterlogging	: Range: exceptional to frequent Optimum: frequent
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.5-8.0 Optimum: 5.5-6.5
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <4

PHASEOLUS BEANS (Phaseolus spp.)

<u>Growth cycle</u> (in days) : 90-120, 120-150 (depending upon variety)

<u>Improved varieties</u> : -

<u>Maximum yields</u>:

Under traditional management	: 0.6 t/ha
Under improved trad. managem.	: 1.2 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	: Range: 17-30 (short-cycle var.), 10-25 (long-cycle var.) Optimum: 22-27 (short-cycle var.), 17-23 (long-cycle var.)
Length of growing period (in days)	: Range: 105-330 (local var.), 105-270 (short-cycle var.), 120-330 (long-cycle var.) Optimum: 150-210 (local- and short-cycle var.), 165-240 (long-cycle var.)
Drought resistance	: low

<u>Edaphic requirements</u>:

Soil texture	: Range: coarse to fine Optimum: medium (L-CL-SCL)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	: Range: none (no waterlogging tolerated) Optimum: none
oil fertility requirements	: high
il reaction (pH)	: Range: 5.0-8.5 Optimum: 6.0-7.5
inity tolerance (in s/cm)	: Range: <6 Optimum: <2

PIGEON PEA (Cajanus indicus, C. cajan)

<u>Growth cycle</u> (in days)	: 120-150 (improved var.), 150-180 (local var.)
<u>Improved varieties</u>	: -

<u>Maximum yields</u>:

Under traditional management	: 0.8 t/ha
Under improved trad. managem.	: 1.5 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	: Range: 18-35 Optimum: 23-33
Length of growing period (in days)	: Range: 105-300 Optimum: 150-225 (local var.), 135-240 (improved var.)
Drought resistance	: moderate

<u>Edaphic requirements</u>:

Soil texture	: Range: coarse to fine Optimum: coarse to medium (LS-SL-L-SCL)
Soil depth (in cm)	: Range: >40 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: well to somewhat excessively
Flooding/waterlogging	: Range: none (sensitive to waterlogging) Optimum: none
Soil fertility requirements	: moderate to high
Soil reaction (pH)	: Range: 4.5-8.5 Optimum: 5.5-7.0
Salinity tolerance (in mmhos/cm)	: Range: <6 Optimum: <2

SORGHUM (Sorghum bicolor)

<u>Growth cycle</u> (in days)	: 90-110 (improved var.), 110-150 (local var.)
<u>Improved varieties</u>	: PN 3

<u>Maximum yields</u>:

Under traditional management	: 0.8 t/ha
Under improved trad. managem.	: 1.7 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	: Range: 15-35 Optimum: 22-32
Length of growing period (in days)	: Range: 105-270 Optimum: 150-210 (local var.), 135-210 (improved var.)
Drought resistance	: high

<u>Edaphic requirements</u>:

Soil texture	: Range: coarse to fine Optimum: medium to fine (L-SCL-SC-CL-C)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	: Range: none to exceptional (short periods) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.5-8.5 Optimum: 5.5-7.5
Salinity tolerance (in mmhos/cm)	: Range: <12 Optimum: <8

SOYA BEANS (Glycine maxima)

<u>Growth cycle</u> (in days)	: 90-130 (improved var.), 120-150 (local var.)
<u>Improved varieties</u>	: -

<u>Maximum yields</u>:

Under traditional management	: 1.0 t/ha
Under improved trad. managem.	: 2.0 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	: Range: 18-32 Optimum: 22-27
Length of growing period (in days)	: Range: 105-300 Optimum: 150-180 (local var.), 150-240 (improved var.)
Drought resistance	: low

<u>Edaphic requirements</u>:

Soil texture	: Range: coarse to fine Optimum: medium to fine (L-SCL-CL)
Soil depth (in cm)	: Range: >30 Optimum: >60
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	: Range: none (sensitive to waterlogging) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 5.0-8.5 Optimum: 6.0-7.5
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <6

SUNFLOWER (Helianthus annuus)

Growth cycle (in days)	: 100-120 (improved var.), 120-150 (local var.)
Improved varieties	: NSCO varieties

Maximum yields:

Under traditional management	: 0.8 t/ha
Under improved trad. managem.	: 2.0 t/ha

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C)	: Range: 15-32 Optimum: 20-30
Length of growing period (in days)	: Range: 105-300 (local avr.), 105-330 (improved var.) Optimum: 150-195 (local var.), 150-210 (improved var.)
Drought resistance	: moderate

Edaphic requirements:

Soil texture	: Range: coarse to fine Optimum: medium to fine (L-SCL-CL-SC)
Soil depth (in cm)	: Range: >40 Optimum: >60
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	: Range: none (sensitive to waterlogging) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 5.0-8.5 Optimum: 6.0-7.5
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <4

SWEET POTATO (Impomoea batata)

<u>Growth cycle</u> (in days) : 150-180 (local var.)

<u>Improved varieties</u> : -

<u>Maximum yields</u>:

Under traditional management : 4.5 t/ha
Under improved trad. managem. : 20.0 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	: Range: 15-32 Optimum: 22-28
Length of growing period (in days)	: Range: 105-330 Optimum: 165-210
Drought resistance	: moderate

<u>Edaphic requirements</u>:

Soil texture	: Range: coarse to fine Optimum: medium to fine (SL-SCL-CL)
Soil depth (in cm)	: Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	: Range: none (sensitive to waterlogging) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 4.5-8.5 Optimum: 5.5-7.5
Salinity tolerance (in mmhos/cm)	: Range: <8 Optimum: <4

TEA (Camellia sinensis)

Growth cycle	: perennial
Improved varieties	: SFS and PC varieties
Maximum yields:	
Under improved trad. managem.	: 2.5 t/ha.

Agro-climatic requirements:

Mean annual temperature (in °C)	: Range: 12-23 Optimum: 17-20
Mean minimum temperature of the coolest month (in °C)	: Range: >8 Optimum: >12
Mean annual rainfall (in mm)	: Range: 1,200-3,500 Optimum: 1,600-2,800
Mean number of dry months per year (P <50 mm)	: Range: 1-5 Optimum: 1-3
Drought resistance	: low

Edaphic requirements:

Soil texture	: Range: medium to fine Optimum: medium to fine (L-SCL-CL-SC-C)
Soil depth (in cm)	: Range: >75 Optimum: >150
Soil drainage (FAO soil drainage classes)	: Range: moderately well to well Optimum: well
Flooding/waterlogging	: Range: none (no waterlogging tolerated) Optimum: none
Soil fertility requirements	: high
Soil reaction (pH)	: Range: 3.5-6.5 Optimum: 4.5-5.0
Salinity tolerance (in mmhos/cm	: Range: <4 Optimum: <2

TOBACCO (Nicotiana tabacum)

Growth cycle (in days) : 110-140 (fire-cured), 90-140 (Burley)
100-140 (flue-cured)
plus 40-60 days in nursery

Improved varieties : Banket-A1, Barnett's special, Burley 37
(Burley or air-cured tobacco),
Malawi western (fire-cured tobacco)
Kutsaga (E-1, 51E and 110), Coker 347,
Speight G-28 (flue-cured)

Maximum yields:

Under improved trad. managem. : 1.7 t/ha (fire-cured)
3.5 t/ha (air- and flue-cured)

Agro-climatic requirements:

Mean daily temperature during the growing period (in °C) : Range: 18-35 (air- and fire-cured), 15-30 flue-cured)
Optimum: 20-25

Length of growing period (in days) : Range: 120-240
Optimum: 120-165

Drought resistance : low

Edaphic requirements:

Soil texture : Range: medium to fine
Optimum: medium to fine (SCL-CL-SC for air-cured, SL-SCL for flue-cured, and L-SCL-SC-C for fire-cured)

Soil depth (in cm) : Range: >50
Optimum: >75

Soil drainage (FAO soil drainage classes) : Range: moderately well to somewhat excessively
Optimum: well

Flooding/waterlogging : Range: none (sensitive to waterlogging)
Optimum: none

Soil fertility requirements : high

Soil reaction (pH) : Range: 4.5-8.0
Optimum: 5.5-7.0

Salinity tolerance (in mmhos/cm) : Range: <4
Optimum: <2

WHEAT (Triticum aestivum)

<u>Growth cycle</u> (in days)	:	140-150 (improved var.), 150-180 (local var.)
<u>Improved varieties</u>	:	Kenya Nyati

<u>Maximum yields</u>:

Under traditional management	:	1.5 t/ha
Under improved trad. managem.	:	4.0 t/ha

<u>Agro-climatic requirements</u>:

Mean daily temperature during the growing period (in °C)	:	Range: 10-27 Optimum: 15-20
Length of growing period (in days)	:	Range: 105-300 Optimum: 150-210 (local var.), 135-210 (improved var.)
Drought resistance	:	low

<u>Edaphic requirements</u>:

Soil texture	:	Range: medium to fine Optimum: medium to fine (SL-SCL-CL)
Soil depth (in cm)	:	Range: >30 Optimum: >75
Soil drainage (FAO soil drainage classes)	:	Range: imperfectly to somewhat excessively Optimum: moderately well to well
Flooding/waterlogging	:	Range: none (sensitive to waterlogging) Optimum: none
Soil fertility requirements	:	high
Soil reaction (pH)	:	Range: 5.0-8.5 Optimum: 6.0-7.5
Salinity tolerance (in mmhos/cm)	:	Range: <14 Optimum: <10

APPENDIX XIII: FORESTRY SPECIES REQUIREMENTS

This appendix contains a listing of requirements for physical land evaluation for forestry, as described in this report, of the following tree species (scientific names listed in alphabetical order):

Acacia albida
Azadirachta indica
Callitris calcarata
Callitris hugellii
Cassia siamea
Cordyla africana
Eucalyptus camaldulensis
Eucalyptus grandis
Eucalyptus maidenii
Eucalyptus tereticornis
Gmelina arborea
Melia azedarach
Pinus caribaea
Pinus kesiya
Pinus oocarpa
Pinus patula

The requirements for the above listed species have been derived mainly from Hardcastle (1977), FAO (1979), and the U.S. National Academy of Sciences (1980).

ACACIA ALBIDA

<u>Climatic requirements</u>:

Mean annual temperature (in °C):	Range: 17-30	Optimum: 22-28
Mean annual rainfall (in mm) :	Range: 400-2,000	Optimum: 600-1,200
Mean number of dry months per year (P=<50 mm) :	Range: 5-9	Optimum: 7-8

<u>Edaphic requirements</u>:

Soil type	: Preference for alluvial soils, also on relatively fertile, calcareous, sandy, or stony soils with groundwater at greater depth.
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimal:moderately well to well
Soil depth (in cm)	: Range: >50 Optimum: >150

AZADIRACHTA INDICA

Climatic requirements:

Mean annual temperature (in °C):	Range: 15-30	Optimum: 22-28
Mean annual rainfall (in mm) :	Range: 400-2,000	Optimum: 600-1,200
Mean number of dry months per year (P=<50 mm) :	Range: 3-8	Optimum: 7-8

Edaphic requirements:

Soil type	: Grows well on most soil types, except on shallow soils. Does not tolerate waterlogging and makes poor growth on saline soils.
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to excessively Optimum: moderately well to somewhat excessively
Soil depth (in cm)	: Range: >50 Optimum: >100

CALLITRIS CALCARATA

Climatic requirements:

Mean annual temperature (in °C):	Range: 15-25	Optimum 17-23
Mean annual rainfall (in mm) :	Range: 700-2,500	Optimum 1,200-1,600
Mean number of dry months per year (P=<50 mm) :	Range: 1-8	Optimum 3-4

Edaphic requirements:

Soil type	: Prefers moderately fertile soils, which can be stony or calcareous, grows also on less fertile soils, poorly on sandy soils and soils with vertic features. Does not tolerate saline soils or soils with gleyic, or sodic features.
Soil drainage (FAO soil drainage classes)	: Range: moderately well to excessively Optimum: well to somewhat excessively
Soil depth (in cm)	: Range: >50 Optimum: >100

CALLITRIS HUGELLII

<u>Climatic requirements</u>:

Mean annual temperature (in °C):	Range: 18-30	Optimum: 22-27
Mean annual rainfall (in mm) :	Range: 400-2,000	Optimum: 600-1,200
Mean number of dry months per year (P=<50 mm) :	Range: 3-8	Optimum: 7-8

<u>Edaphic requirements</u>:

Soil type	: Grows well on most soils but not on soils with gleyic, sodic, or vertic characteristics. Also not on saline soils. Poor growth on very shallow soils.
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: well
Soil depth (in cm)	: Range: >50 Optimum: >100

CASSIA SIAMEA

<u>Climatic requirements</u>:

Mean annual temperature (in °C):	Range: 18-30	Optimum: 23-28
Mean annual rainfall (in mm) :	Range: 500-2,000	Optimum: 800-1,200
Mean number of dry months per year (P=<50 mm) :	Range: 3-8	Optimum: 4-6

<u>Edaphic requirements</u>:

Soil type	: Prefers relatively fertile soils but also grows on less fertile, calcareous or stony soils. Grows poorly on very shallow, sandy soils or soils with vertic properties and not on saline soils or soils with gleyic or sodic features.
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: moderately well to well
Soil depth (in cm)	: Range: >30 Optimum: >75

CORDYLA AFRICANA

Climatic requirements:

Mean annual temperature (in °C)	: Range: 18-30	Optimum: 22-28
Mean annual rainfall (in mm)	: Range: 400-1,600	Optimum: 600-1,200
Mean number of dry months per year (P=<50 mm)	: Range: 4-8	Optimum: 6-8

Edaphic requirements:

Soil type	: Grows well on most soils, poorly on very shallow soils or soils with vertic properties and not on soils with gleyic or sodic features, or on saline soils.	
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: well	
Soil depth (in cm)	: Range: >50	Optimum: >100

EUCALYPTUS CAMALDULENSIS

Climatic requirements:

Mean annual temperature (in °C)	: Range: 15-30	Optimum: 20-25
Mean annual rainfall (in mm)	: Range: 400-2,200	Optimum: 600-1,600
Mean number of dry months per year (P=<50 mm)	: Range: 1-8	Optimum: 5-6

Edaphic requirements:

Soil type	: Grows well on most soil types, but less well on calcareous or stony soils or soils with sodic characteristics and poorly on very shallow or saline soils. Periodic waterlogging tolerated.	
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to excessively Optimum: moderately well to well	
Soil depth (in cm)	: Range: >30	Optimum: >100

EUCALYPTUS GRANDIS

<u>Climatic requirements</u>:

Mean annual temperature (in °C): Range: 13-28 Optimum: 17-23

Mean annual rainfall (in mm) : Range: 600-2,500 Optimum: 1,200-2,000

Mean number of dry months per year (P=<50 mm) : Range: 1-8 Optimum: 3-4

<u>Edaphic requirements</u>:

Soil type : Prefers relatively fertile soils, but grows on most soil types. Less tolerant to waterlogging than E. camaldulensis.

Soil drainage (FAO soil drainage classes) : Range: imperfectly to somewhat excessively
Optimum: moderately well to well

Soil depth (in cm) : Range: >30 Optimum: >75

EUCALYPTUS MAIDENII

<u>Climatic requirements</u>:

Mean annual temperature (in °C): Range: 13-28 Optimum: 18-23

Mean annual rainfall (in mm) : Range: 600-2,500 Optimum: 1,200-2,000

Mean number of dry months per year (P=<50 mm) : Range: 1-8 Optimum: 3-4

<u>Edaphic requirements</u>:

Soil type : Grows well on most soil types but less well on soils of low fertility, stony, or saline, or on soils with sodic characteristics, poorly on calcareous soils or soils with gleyic or vertic features.

Soil drainage (FAO soil drainage classes) : Range: imperfectly to somewhat excessively
Optimum: moderately well to well

Soil depth (in cm) : Range: >30 Optimum: >75

EUCALYPTUS TERETICORNIS

Climatic requirements:

Mean annual temperature (in °C)	:	Range: 15-30	Optimum: 20-25
Mean annual rainfall (in mm)	:	Range: 400-2,200	Optimum: 800-1,600
Mean number of dry months per year (P=<50 mm)	:	Range: 1-8	Optimum: 5-6

Edaphic requirements:

Soil type	:	Grows best on relatively fertile deep soils of variable texture, but poorly on saline and very shallow soils. Does not tolerate waterlogging.
Soil drainage (FAO soil drainage classes)	:	Range: imperfectly to somewhat excessively Optimum: moderately well to well
Soil depth (in cm)	:	Range: >30 Optimum: >100

GMELINA ARBOREA

Climatic requirements:

Mean annual temperature (in °C)	:	Range: 14-24	Optimum: 17-20
Mean annual rainfall (in mm)	:	Range: 400-2,500	Optimum: 800-1,600
Mean number of dry months per year (P=<50 mm)	:	Range: 3-8	Optimum: 5-6

Edaphic requirements:

Soil type	:	Grows well on most soil types but less well on soils with vertic features. Does not tolerate waterlogging. Does not grow on saline, very shallow soils, or soils with sodic characteristics.
Soil drainage (FAO soil drainage classes)	:	Range: imperfectly to somewhat excessively Optimum: moderately well to well
Soil depth (in cm)	:	Range: >75 Optimum: >100

MELIA AZEDARACH

Climatic requirements:

Mean annual temperature (in °C)	: Range: 15-30	Optimum: 20-27
Mean annual rainfall (in mm)	: Range: 400-1,600	Optimum: 800-1,200
Mean number of dry months per year (P=<50 mm)	: Range: 3-8	Optimum: 5-6

Edaphic requirements:

Soil type	: Grows well on soils of variable texture but less well on stony or calcareous soils. Does not grow on saline soils or soils with sodic or gleyic features	
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: well	
Soil depth (in cm)	: Range: >50	Optimum: >100

PINUS CARIBAEA

Climatic requirements:

Mean annual temperature (in °C)	: Range: 10-25	Optimum: 15-20
Mean annual rainfall (in mm)	: Range: 800-2,500	Optimum: 1,200-2,000
Mean number of dry months per year (P=<50 mm)	: Range: 1-8	Optimum: 1-4

Edaphic requirements:

Soil type	: Grows best on relatively fertile, deep soils, poorly on soils with vertic characteristics and not on saline soils or soils with, gleyic or sodic features.	
Soil drainage (FAO soil drainage classes)	: Range: imperfectly to somewhat excessively Optimum: well	
Soil depth (in cm)	: Range: >30	Optimum: >100

PINUS KESIYA

Climatic requirements:

Mean annual temperature (in °C):	Range: 12-28	Optimum: 17-22
Mean annual rainfall (in mm) :	Range: 800-2,200	Optimum: 1,200-1,600
Mean number of dry months per year (P=<50 mm) :	Range: 1-8	Optimum: 3-6

Edaphic requirements:

Soil type	: Grows well on relatively fertile soils, but reasonably on less fertile, calcareous or stony soils. Does not tolerate waterlogging.
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: well
Soil depth (in cm)	: Range: >30 Optimum: >100

PINUS OOCARPA

Climatic requirements:

Mean annual temperature (in °C):	Range: 13-27	Optimum: 18-23
Mean annual rainfall (in mm) :	Range: 800-2,500	Optimum: 1,200-1,600
Mean number of dry months per year (P=<50 mm) :	Range: 1-8	Optimum: 3-6

Edaphic requirements:

Soil type	: Grows well on relatively fertile soils, with reasonable growth on less fertile, calcareous or stony soils. Does not tolerate waterlogging.
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: well
Soil depth (in cm)	: Range: >30 Optimum: >100

PINUS PATULA

Climatic requirements:

Mean annual temperature (in °C):	Range: 13-25	Optimum: 15-20
Mean annual rainfall (in mm) :	Range: 800-2,500	Optimum: 1,600-2,200
Mean number of dry months per year (P=<50 mm) :	Range: 1-8	Optimum: 1-4

Edaphic requirements:

Soil type	: Grows best on soils of medium to fine texture, less well on sandy or calcareous soils and poorly on stony soils. Does not grow on soils with gleyic, vertic or sodic characteristics or on saline soils.
Soil drainage (FAO soil drainage classes)	: Range: moderately well to somewhat excessively Optimum: well
Soil depth (in cm)	: Range: >30 Optimum: >100

APPENDIX XIV: RULES FOR LAND RESOURCES DATA ENTRY IN LRDB

Data are entered as codes. Decoded descriptions appear in LRDB reports and overviews. The identification numbers of land characteristics below are identical to numbers on the data entry screens and dictionary numbers in LRDB.

1. Land unit: A single number or a capital letter (for miscellaneous land units), e.g.: 153 or M .

1a. Land mapping unit: Consists of one land unit (see 1. above) for homogeneous land mapping units, or of two land units for complex land mapping units, e.g. 153 or 153/34 .

2. Soil unit: e.g.: A1f1 .

2a. Soil mapping unit: Consists of one soil unit (see 2. above) for homogeneous soil mapping units, or of two soil units for complex soil mapping units, e.g. A1f1 or A1f1/X2e3 .

3. Agro-climatic zone: A single number without parentheses, e.g. 45 . Each agro-climatic zone code stands for a combination of classes of agro-climatic characteristics (see 41-48. below). The code is taken from the national list of agro-climatic zones.

4. Study area:

CODE	DESCRIPTION
BLADD	Blantyre ADD
KADD	Kasungu ADD
KRADD	Karonga ADD
LADD	Lilongwe ADD
LWADD	Liwonde ADD
MZADD	Mzuzu ADD
NADD	Ngabu ADD
SLADD	Salima ADD

5. Area: Total area in hectares rounded-off to fifties, e.g. 8,550 . If a land unit is a constituent of a complex land mapping unit, the area is derived by multiplication by 0.7 for a dominant unit and by 0.3 for a sub-dominant unit.

6. Distribution, District(s): In terms of administrative district(s); with "north", "south", "east", "west" or "central" added if location can be specified. A maximum of three districts and a maximum of two specified locations (e.g. north and east) within a district may be given, for example BL, N, E .

CODE	DESCRIPTION
BL	Blantyre
CK	Chikwawa
CR	Chiradzulu
CT	Chitipa
DE	Dedza
DO	Dowa
KR	Karonga
KS	Kasungu
LI	Lilongwe
MA	Mangochi

CODE	DESCRIPTION
MC	Machinga
MJ	Mchinji
MU	Mulanje
MW	Mwanza
MZ	Mzimba
NB	Nkatha Bay
NE	Ntcheu
NI	Ntchisi
NK	Nkhotakota
NS	Nsanje

CODE	DESCRIPTION
RU	Rumphi
SA	Salima
TH	Thyolo
ZO	Zomba
C	Central
E	East
N	North
S	South
W	West

7. Distribution, Agro-ecological zone(s): Coding is used according to the legends of the Agro-ecological Zone Maps of the ADDs. Up to three zones may be given, in sequence of importance (area occupied). See pages 155 - 157.

8. Present land use and vegetation: Coding is used according to the Legend of the Present Land-use and Vegetation Map. A maximum of three land use and/or vegetation types may be given, in sequence of importance (area occupied).

CODE	DESCRIPTION
A1	Rainfed cultivation: maize, pulses, groundnuts, cassava
A2	" " : maize, pulses, groundnuts, cotton, etc.
A3	" " : maize, sorghum, pulses, cotton
A4	" " : maize, pulses, finger millet, etc.
A5	" " : maize, pulses, cotton, groundnuts, millet
A6	" " : maize, pulses, cassava, fruits, tea
A7	" " : maize, tobacco, soya beans sunflower, etc
A8	" " : sorghum, bulrush millet, maize, etc.
A9	" " : tea with forest plantations, etc.
A10	" " : tobacco, maize, (coffee)
A11	" " : coffee, maize, pulses (Irish potatos)
A12	" " : maize, pulses, groundnuts, finger millet
A13	" " : cassava, maize, banana (groundnuts, millet)
A14	" " : tobacco, maize
A15	" " : rubber, tea, macademia (coffee)
A16	" " : tung
A17	" " : maize, pulses, tobacco, groundnuts
A18	" " : maize, pulses, Irish potato, groundnuts
B1	Wetland cultivation: rice
C1	Dimba cultivation : vegetables, sweet potato, maize, etc.
D1	Irrigated cultivation: sugarcane
D2	" " : rice, maize
D3	" " : cashew
D4	" " : rice (maize, pulses)

(continued)

(continuation)

CODE	DESCRIPTION
E1	Montane grassland with forest remnants
E2	Dry grassland (secondary, cleared from wooded land)
E3	Seasonally wet grassland of floodplains
E4	Seasonally wet grassland associated with upland drainage systems
E5	Severely degraded/ eroded grassland/scrub
F1	Plantation forest: Pinus spp.
F2	Plantation forest: Eucalyptus spp.
F3	Plantation forest: mixed species
G1	Evergreen forest
G2	Semi-evergreen woodland (B. spiciformis + Erythrophloeum
G3	Moist Brachystegia woodland (B. spiciformis predominant)
G4	Brachystegia plateau woodland (B. taxifolia and B. glaucesens)
G5	Brachystegia plateau woodland (Julbernardia paniculata prominent
G6	Brachystegia hill woodland (J. globiflora often prominent)
G7	Brachystegia escarpment woodland (J. globiflora and B. boehmii)
G8	Mopane woodland (Colophospermum mopane)
G9	Terminalia woodland savanna (T. sericea)
G10	Woodland savanna of fertile plateau areas (Combretum, Acacia)
G11	Open plateau savanna (Erythrina, Cussonia, Croton, Dombeya)
G12	Savannas of fertile lowlands (Sclerocarya, Adansonia, Cordyla)
G13	Mixed low altitude tree savanna (Combretum, Diplorhynchus, etc.)
G14	Plateau thicket (Combretum, Commiphora, Euphorbia)
G15	Lowland thicket (Pterocarpus lucens often prominent)
G16	Recent regrowth of undifferentiated woody vegetation
G17	Vegetation of sands
M	Marshes
R	Bare or sparsely vegetated rock outcrops
W	Open water
Z	Built-up areas

9. <u>Dominant vegetation type (Veg for ALES)</u>: Only one vegetation type is entered and only if more than 50 percent of the unit concerned is covered with vegetation (i.e. not cultivated). Otherwise "N" for "not applicable" is entered. Codes are taken from the following list:

CODE	DESCRIPTION	CODE LU&V LEGEND
N	not applicable	others
MG	montane grassland	E1
DG	dry grassland	E2
WG	wet grassland	E3, E4
EG	degraded or eroded grassland	E5
FC	forest and closed canopy woodland	G1
OW	open canopy woodland	G2, G3, G4, G5, G6, G7, G8
WS	woodland savanna	G9, G10, G11, G12
TS	tree savanna	G13
T	thicket	G14, G15, G16

CODING OF AGRO-ECOLOGICAL ZONES.

CODE	DESCRIPTION Agro-ecological zone
KE	The entire Karonga Escarpment region
KL	The entire Karonga Lakeshore Plain region
BU1	Balaka Plains
CHP	The entire Chitipa Plain region
CP1	Chilwa & Chiuta Marshes
CP2	Chilwa Bottomlands
CP3	Phalombe Uplands
CP4	Chilwa & Chiuta Lowlands
CP5	Thuchila Plain
CP6	West Chilwa & Chiuta Footslopes
CP7	East Phalombe Plain & East Mulanje Footslopes
KE1	Karonga Escarpment (East)
KE2	Kilupula Hills
KE3	Karonga Escarpment (Centre)
KE4	Mwenemisuku Highlands
KH1	Kameme-Songwe Valley
KH2	Kameme Plain
KH3	Kameme Hills
KL1	Karonga Lakeshore Plain (Centre)
KL2	Karonga Lakeshore Plain (South + North)
KL3	Songwe Valley
KL4	Wasambo-Kyungu Lowlands
KP1	Luwelezi Plain
KP2	Nkhamenya Plain
LH1	Livingstonia Hills
LH2	Nchenachena Hills
LS1	Elephant & Ndinde Marshes
LS2	Makande Plain
LS3	Therere Plain
LS4	Lower Shire & Mwanza Footslopes
LU1	Lengwe Uplands
LU2	Chambuluka Uplands
LU3	Mwabvi Uplands
MH1	Majete Escarpment
MH2	Mkurumadzi Escarpment
MH3	Mwanza Uplands
MH4	Neno Uplands
MH5	Kirk Range
ML1	Mangochi Lakeshore Plain
ML2	Makanjila Lakeshore Plain
ML3	Nkhunguni Hills
MM1	Mount Mulanje Footslopes
MM2	Mount Mulanje
MP1	Makanjila Plain
MS1	Middle Shire Valley
MS2	Lisungwe Valley
NE1	Makanjila Escarpment
NE2	Namizimu Escarpment
NE3	Mangochi Hills
NH1	Natandwe Escarpment

(continued)

(continuation)

CODE	Descriotion of Agro-Ecological Zone
NH2	Lulwe-Chididi Highlands
NL1	Timbiri-Malenga Lakeshore Plain
NL2	Nkhata Bay Lakeshore Plain
NL3	Likoma & Chizumulu Islands
NP1	North Namwera Plain
NP2	South Namwera Plain
NTP	The entire Nthalire Plains and Hills region
NYH	The entire Nyika Hills and Escarpments region
PH1	Chingombe & Mbavi Hills
PH2	Phirilongwe Hills
RP1	Lower South Rukuru & Kasitu Valleys
RP2	Nkhamanga Plain
RP3	Vwaza Plain & Chiriwate Hills
RP4	Kapiritendele, Kanyawazi & Mulimapi Hills
RV1	Lower Ruo Valley
RV2	Luchenza Plain
RV3	South Mulanje Plain
SH1	Chikwawa Escarpment
SH2	Chileka & Mikolongwe Uplands
SH3	Blantyre-Thondwe Highlands
SH4	North Machinga Hills & Zomba Escarpment
SH5	Thyolo Escarpment & Nswadzi Valley
SH6	Limbe-Bvumbwe Highlands
SH7	Thyolo Highlands
SH8	Zomba Mountain
US1	Upper Shire Valley
US2	Rivi Rivi Valley & Upper Shire Footslopes
US3	Lisanjali Plain
US4	Linthipe-Lisanjali Footslopes
VE1	North Viphya Escarpment
VE2	Central Viphya Escarpment
VE3	South Viphya Escarpment
VM1	South Viphya Foothills
VM2	Rupashe Plateau
VM3	Champhila Hills
VM4	West Viphya Foothills
VM5	Central Viphya Mountains
VM6	Uzumara-Chimaliro Mountains
CHP1	Mwabulambya Plain
CHP2	Chitipa Plain
CHP3	Chikombwi Hills
CHP4	Mafinga Hills
MIH1	Misuku Hills
MIP1	Euthini-Embangweni Plain
MIP2	Emcisweni Plain
MIP3	Upper South Rukuru Plain
MIP4	Mzimba Hills
MUP1	Ezondweni-Ekwendeni Plains
MUP2	Mzuzu Plain
NKE1	Dwangwa Hills
NKE2	North Nkhotakota Escarpment
NTP1	Nthalire Plain

(continued)

(continuation)

CODE	Description of Agro-Ecological Zones
NTP2	Nthalire Hills
NTP3	Mwenewenya Hills
NYH1	Nyika Escarpment
NYH2	Nyika Hills
NYH3	Nyika Hills and Escarpment
NYP1	Nyika Plateau
NYP2	South Nyika Plateau
BWV3	Golomoti Footslopes
NF1	Ntcheu Foothills
NF2	Ntcheu Footslopes
DOH1	South Dowa Hills
DE1	Lower Dedza escarpment
DE2	Upper Dedza escarpment
KP7	South and West Kasungu Plain
LP1	North-east Lilongwe Plain
LP2	Central Lilongwe Plain
LP3	West and South Lilongwe Plain
DH1	Dedza Uplands
DH2	Dedza Hills
UB1	Upper Bua Plain
DR1	Dzalanyama Footslopes
DR2	Dzalanyama Hills
NTH1	Ntcheu Uplands
NTH2	Ntcheu Escarpment
KP4	Lisasadzi Plain
MJH2	Mchinji Foothills
UB2	Kochilira-Kazyozyo Plain
LP4	Mponela Plain
CMH	Chimaliro Ridge
KP5	Mtunthama Plain
KP3	Dwangwa Plain
LP5	West Ntchisi Plain
DOH3	Dow-Ntchisi Ridge
DOH2	South and East Dowa Hills
NKL1	Dwangwa and Chia Lowlands
SL1	Salima Lowland Plain
NKL2	Nkhotakota Lowlands
BWV2	Bwanje Lowlands
SL2	Mwadzama Lowland Plain
BWV1	Bwanje Bottomlands
SL3	Salima Foothills
SL4	Senga Bay Raised Beach
NKE3	Upper Bua Hills
NKE7	Mwansambo Foothills
NKE4	Dwambazi hills
NKE5	Nkhotakota Foothills
NKE8	Mwadzama Hills
NKE6	Lower Bua Hills

10 Landform: Up to a maximum of three different landforms may be listed:

CODE	DESCRIPTION
AF	alluvial fans
AP	alluvial plains
B	bottomlands
BL	badlands
BR	beach ridges
D	depressions
DA	dambos
DE	dissected escarpments
DF	dissected footslopes
DH	dissected hills
DHS	dissected hillsides
DMS	dissected mountain sides
DP	dissected plateaux
DR	dissected ridges
DU	dissected uplands
E	escarpments
F	footslopes
FP	floodplains
I	inselbergs
HS	hillsides
L	lakes
LE	levees
LH	low hills

CODE	DESCRIPTION
LP	lowland plains
LMP	lake margin plains
M	marshes
MM	marsh margins
MS	mountain sides
OD	old dunes
OP	outwash plains
P	plains
PL	plateaux
R	rock outcrops
RI	ridges
RD	recent dunes
RDF	ridges in footslopes
RI	rivers
RU	ridges in uplands
U	uplands
UI	uplands with inselbergs
V	valley sides
VU	valleys in uplands
RT	river terraces
H	hills

11. Dominant slope class: Only one slope class (in %) can be given. On the data entry screen the code appears automatically, and is copie from the slope class element in the soil unit code:

CODE	DESCRIPTION (in %)
1	0-2 (flat to almost flat)
2	2-6 (gently sloping)
3	6-13 (sloping)
4	13-25 (moderately steep)
5	25-55 (steep)
6	>55 (very steep)
	miscellaneous

12. Altitude range (m asl): Range is given, rounded off to tens or hundreds (whichever applicable); no other conventions. For example, 900-1600.

13. Present erosion:

CODE	DESCRIPTION
N	nonee
SL	slight
SLM	slight to moderate
M	moderate
MSE	moderate to severe
SE	severe

14. Parent material: Only one parent material can be indicated:

CODE	DESCRIPTION
AC	colluvial deposits
AF	fluvial deposits
AFC	fluvial and colluvial deposits
AFL	fluvial and lacustrine deposits
AL	lacustrine deposits
BB	mafic igneous rocks (basalt)
BP	mafic igneous rocks (metapyroxenite or peridotite)
DCF	mixed coarse to fine-grained sedimentary rocks
DMF	medium- to fine-grained sedimentary rocks (shale, mudstone)
DM	medium-grained sedimentary rocks (marl, shale or mudstone)
S	coarse grained sedimentary rocks (sandstone)
XG	intermediate metamorphic rocks (gneiss or granulite)
XS	intermediate igneous rocks (syenite)
XQ	felsic igneous rocks (granite)
Z	aeolian deposits

15. Soil description: Brief description of soil in terms of soil depth, soil drainage, soil colour, generalized profile texture, general fertility status, pH and special characteristics if present. The general fertility status of the soil is derived from CEC, N, P and K - see page 160. For example, deep, moderately well to well drained, greyish brown, fine textured soils of low chemical fertility; slightly saline; pH (0-50 cm) 4.0-5.5.

GENERAL CHEMICAL FERTILITY AS A FUNCTION OF CEC, N, P AND K.
N, P, K; sequence is unspecified

CEC	==- (1) or ===	==+ or =-+ or =--	--- or =++	--+	+++ or -++
<5	very low	very low	very low	low	low
5-10	very low	low	moderate	moderate	high
>10	low	moderate	moderate	moderate	high

(1) "=" stands for "very low"
"-" stands for "low"
"+" stands for "high to very high"

16. Classification, soil group: Only one soil group may be given. On the data entry screen the code is entered automatically, and copied from the soil group element in the soil unit code:

CODE	DESCRIPTION	CODE	DESCRIPTION
a	arenic	m	mopanic
c	calcaric	p	paralithic
d	dystric-fersialic	r	dystric-ferralic
e	eutric-fersialic	s	salic
f	fluvic	v	vertic
g	gleyic	x	eutric-ferralic
u	lithic		miscellaneous

17. Classification, soil family: The name of only one soil family will be given (local names); no codes are provided.

18. Classification, FAO (1988): A maximum of two FAO soil units and phase (FAO, 1988) may be given. for example, GLE, IN .

CODE	DESCRIPTION
AC	Acrisols
ACF	Ferric Acrisols
ACG	Gleyic Acrisols
ACH	Haplic Acrisols
ACP	Plinthic Acrisols
ACU	Humic Acrisols
AL	Alisols
ALF	Ferric Alisols
ALG	Gleyic Alisols
ALH	Haplic Alisols
ALJ	Stagnic Alisols
ALP	Plinthic Alisols
ALU	Humic Alisols
AR	Arenosols
ARA	Albic Arenosols
ARB	Cambic Arenosols
ARC	Calcaric Arenosols
ARG	Gleyic Arenosols
ARH	Haplic Arenosols
ARL	Luvic Arenosols
ARO	Ferralic Arenosols
CL	Calcisols
CLH	Haplic Calcisols
CLL	Luvic Calcisols
CLP	Petric Calcisols
CM	Cambisols
CMC	Calcaric Cambisols
CMD	Dystric Cambisols
CME	Eutric Cambisols
CMG	Gleyic Cambisols
CMO	Ferralic Cambisols
CMU	Humic Cambisols
CMV	Vertic Cambisols
CMX	Chromic Cambisols
FL	Fluvisols
FLC	Calcaric Fluvisols
FLD	Dystric Fluvisols
FLE	Eutric Fluvisols
FLM	Mollic Fluvisols
FLS	Salic Fluvisols
FLU	Umbric Fluvisols
FR	Ferralsols
FRG	Geric Ferralsols
FRH	Haplic Ferralsols
FRP	Plinthic Ferralsol
FRR	Rhodic Ferralsols
FRU	Humic Ferralsols
FRX	Xanthic Ferralsols

CODE	DESCRIPTION
GL	Gleysols
GLD	Dystric Gleysols
GLE	Eutric Gleysols
GLK	Calcic Gleysols
GLM	Mollic Gleysols
GLU	Umbric Gleysols
HS	Histosols
HSF	Fibric Histosols
HSL	Folic Histosols
HSS	Terric Histosols
LP	Leptosols
LPD	Dystric Leptosols
LPE	Eutric Leptosols
LPK	Rendzic Leptosols
LPM	Mollic Leptosols
LPQ	Lithic Leptosols
LPU	Umbric Leptosols
LV	Luvisols
LVA	Albic Luvisols
LVF	Ferric Luvisols
LVG	Gleyic Luvisols
LVH	Haplic Luvisols
LVJ	Stagnic Luvisols
LVK	Calcic Luvisols
LVX	Chromic Luvisols
LVV	Vertic Luvisols
LX	Lixisols
LXA	Albic Lixisols
LXF	Ferric Lixisols
LXG	Gleyic Lixisols
LXH	Haplic Lixisols
LXJ	Stagnic Lixisols
LXP	Plinthic Lixisols
NT	Nitisols
NTH	Haplic Nitisols
NTR	Rhodic Nitisols
NTU	Humic Nitisols
PH	Phaeozems
PHC	Calcaric Phaeozems
PHG	Gleyic Phaeozems
PHH	Haplic Phaeozems
PHJ	Stagnic Phaeozems
PHL	Luvic Phaeozems
PL	Planosols
PLD	Dystric Planosols
PLE	Eutric Planosols
PLM	Mollic Planosols
PLU	Umbric Planosols

CODE	DESCRIPTION
PT	Plinthosols
PTA	Albic Plinthosols
PTD	Dystric Plinthosols
PTE	Eutric Plinthosols
PTU	Humic Plinthosols
RG	Regosols
RGC	Calcaric Regosols
RGD	Dystric Regosols
RGE	Eutric Regosols
RGU	Umbric Regosols
RGY	Gypsic Regosols
SC	Solonchaks
SCG	Gleyic Solonchaks
SCH	Haplic Solonchaks
SCK	Calcic Solonchaks
SCM	Mollic Solonchaks
SCN	Sodic Solonchaks
SN	Solonetz
SNG	Gleyic Solonetz
SNH	Haplic Solonetz
SNJ	Stagnic Solonetz
SNK	Calcic Solonetz
SNM	Mollic Solonetz
VR	Vertisols
VRD	Dystric Vertisols
VRE	Eutric Vertisols
VRK	Calcic Vertisols

PHASES

CODE	DESCRIPTION
DU	Duripan
FR	Fragipan
GI	Gilgai
IN	Inundic
LI	Lithic
PF	Petroferric
PH	Phreatic
PL	Placic
RU	Rudic
SA	Salic
SK	Skeletic
SO	Sodic
TK	Takyric

19. Effective soil depth: Only one depth class (in cm) may be given:

CODE	DESCRIPTION (in cm)
1	0-30 (very shallow)
2	30-50 (shallow)
3	50-100 (moderately deep)
4	100-150 (deep)
5	>150 (very deep)

20. Depth limiting factor: Only one factor can be given; "N" is used for "none":

CODE	DESCRIPTION
N	none
GS	>70 % stones
HR	hard rock
I	ironstone
RR	rotten rock

21. Colour subsoil: Only one colour may be given:

CODE	DESCRIPTION	CODE	DESCRIPTION
B	brown	LB	light brown
BG	brownish grey	LBG	light brownish grey
BL	black	LG	light grey
DB	dark brown	R	red
DG	dark grey	RB	reddish brown
DRB	dark reddish brown	SB	strong brown
DYB	dark yellowish brown	V	variable
G	grey	VDB	very dark brown
GB	greyish brown	VDG	very dark grey
		YB	yellowish brown

22. Surface stoniness and rockiness: Only one class (in %) can be given:

CODE	DESCRIPTION (in %)
1	<1 (non-stony and non-rocky)
2	1-15 (stony and/or fairly rocky)
3	>15 (very stony and/or rocky)

23. Particle size, topsoil (0-30 cm), detailed: Twelve classes are used. A texture range can be indicated if necessery; "variable" can also be used. If more than 40% rock and mineral fragments occur, "SK" for "skeletal" is added. For example, SCL-SC, SK.

CODE	DESCRIPTION
C	clay
CL	clay loam
L	loam
LS	loamy sand
S	sand
SC	sandy clay
SCL	sandy clay loam
S1	

CODE	DESCRIPTION
SIC	silty clayy
SICL	silty clay loam
SIL	silt loam
SL	sandy loam
V	variable
SK	skeletal

24. Particle size, topsoil (0-30 cm), generalized (as legend of Soils and Physiography Map): The twelve texture classes of section 23. above are generalized using standard FAO definitions; "variable" can also be used. "SK" for "skeletal" can be added but only to single texture classes.

CODE	DESCRIPTION
C	coarse
CM	coarse to medium
M	medium
MF	medium to fine
F	fine
V	variable
SK	skeletal

25. Tex-t (= Texture topsoil; for ALES): The twelve texture classes are generalized into two classes:

CODE	DESCRIPTION
C	coarse
MF	medium to fine

26. Particle size, subsoil (>30 cm), detailed: Same as 23. above.

27. Particle size, subsoil (>30 cm), generalized (as legend of Soils and Physiography Map): Same as 24. above.

28. Tex-p (= Texture profile; for ALES): A weighted average is made of the texture component of 23. and 26. above and generalized into two classes, which are the same as in 25. above.

29. Rmf (= Rock and mineral fragments profile; for ALES): A weighted average is made of coarse fragments in the topsoil and in the subsoil ("skeletal" in 23. and 26. above) and indicated here in two classes:

CODE	DESCRIPTION (in %)
NSK	<40 % (non-skeletal)
SK	>40 % (skeletal)

30. Soil drainage class: Only one of the following classes can be given:

CODE	DESCRIPTION
V	very poor
VP	very poor to poor
P	poor
PI	poor to imperfect
I	imperfect
IM	imperfect to moderately well
M	moderately well
MW	moderately well to well
W	well
WS	well to somewhat excessive
S	somewhat excessive
SE	somewhat excessive to excessive
E	excessive

31. Dr (= Median soil drainage class; for ALES): The median is inferred from the soil drainage class range given in 30. above. The codes used here are the same as in 30., but only single classes may be given here; e.g., V but not VP .

32. Frequency of flooding: Only one class can be given:

CODE	DESCRIPTION
N	none
NE	none to exceptional
E	exceptional
F	frequent

33. Ponding: Only one class can be given:

CODE	DESCRIPTION
N	none
SL	slight
SLM	slight to moderate
M	moderate
MSE	moderate to severe
SE	severe

34. Soil reaction (pH) (0-50 cm): A pH range is given, indicated by two pH values rounded off to zero or 0.5 and separated by a hyphen. The lowest value that can be used is 3.5 and the highest is 8.5; one extra class - "8.5-9.9" - is provided for strongly alkaline conditions. E.g., 4.0-5.5 or 6.5-7.0 .

35. PH (= Median soil reaction; for ALES): The median soil reaction class is derived from 34. above. Only one class is given here:

CODE	DESCRIPTION
3.5	3.5-4.0
4.0	4.0-4.5
4.5	4.5-5.0
5.0	5.0-5.5
5.5	5.5-6.0
6.0	6.0-6.5
6.5	6.5-7.0
7.0	7.0-7.5
7.5	7.5-8.0
8.0	8.0-8.5
8.5	8.5-9.9

36. Salinity (0-50 cm): Only one class (in mmhos/cm) can be given:

CODE	DESCRIPTION (in mmhos/cm)
1	0-2 (non saline)
2	2-4 (slightly saline)
3	4-8 (moderately saline)

37. Cation exchange capacity (0-50 cm): Only one class (in me/100 g soil) can be given:

CODE	DESCRIPTION (in me/100g)
1	<5 (very low)
2	5-10 (low)
3	>10 (medium to very high)

38. Nitrogen (0-50 cm): Only one class (in %) can be given:

CODE	DESCRIPTION (in %)
1	<0.08 (very low)
2	0.08-0.12 (low)
3	>0.12 (medium to very high)

39. Phosphorus (0-50 cm): Only one class (in ppm) can be given:

CODE	DESCRIPTION (in ppm)
1	<6 (very low)
2	6-18 (low)
3	>18 (medium to very high)

40. Potassium (0-50 cm): Only one class (in me/100 g soil) can be given:

CODE	DESCRIPTION (in me/100g)
1	<0.1 (very low)
2	0.1-0.2 (low)
3	>0.2 (medium to very high)

41. LGP (days): (1)

CODE	DESCRIPTION
1	105-120
2	120-135
3	135-150
4	150-165
5	165-180
6	180-195
7	195-210
8	210-225
9	225-240
10	240-270
11	270-300
12	300-330

42. P/PET: (2)

CODE	DESCRIPTION
1	0.8-1.0
2	1.0-1.3
3	>1.3

43. T-GP (°): (3)

CODE	DESCRIPTION
6	12.5-15.0
7	15.0-17.5
8	17.5-20.0
9	20.0-22.5
10	22.5-25.0
11	25.0-27.5
12	27.5-30.0

44. P-an (mm): (4)

CODE	DESCRIPTION
1	600-800
2	800-1200
3	1200-1600
4	1600-2000
5	>2000

45. DM (months): (5)

CODE	DESCRIPTION
1	1-2
2	3-4
3	5-6
4	7-8

46. T-an (°C): (6)

CODE	DESCRIPTION
6	12.5-15.0
7	15.0-17.5
8	17.5-20.0
9	20.0-22.5
10	22.5-25.0
11	25.0-27.5

47. T-min (°C): (7)

CODE	DESCRIPTION
1	0.0-2.5
2	2.5-5.0
3	5.0-7.5
4	7.5-10.0
5	10.0-12.5
6	12.5-15.0
7	15.0-17.5

48. T-EGP (°C): (8)

CODE	DESCRIPTION
6	12.5-15.0
7	15.0-17.5
8	17.5-20.0
9	20.0-22.5
10	22.5-25.0
11	25.0-27.5
12	27.5-30.0

(1) Reference length of growing period
(2) Quality of moisture supply
(3) Mean temperature during the LGP
(4) Mean annual precipitation
(5) Mean number of dry months/year
(6) Mean annual temperature
(7) Mean minimum temp. coolest month
(8) Mean temperature during end LGP

APPENDIX XV: LAND SUITABILITY INVENTORY - AN EXAMPLE OF A SUITABILITY MATRIX

Brief explanation of matrices

Explanation of land suitability classes:

S1 - Highly suitable

S2 - Moderately suitable

S3 - Marginally suitable

N - Not suitable

S1/2, S2/3 and S3/N. These classes are used to show intermediate land suitabilities.

Land suitability subclasses. Lower-case letter suffixes are added to the suitability classes S1/2, S2, S2/3, S3, S3/N and N. They indicate the type of limitation to the given land use. If more than three types of limitation occur, only the three most important ones are indicated. The suffixes used are:

- c: temperature
- e: Erosion hazard
- f: Flooding hazard
- k: Soil workability
- m: Moisture regime
- n: Nutrient availability
- r: Rooting conditions
- s: Soil requirements
- t: nutrient retention capacity
- w: Oxygen availability
- x: Toxicity/acidity

(continued)

LAND SUITABILITY MATRIX   Model: Improved traditional management (ITM)   Study Area: MZADD
first part

Land Unit	Soil Unit	AC ZN	Area (ha)	CASHEW	CASSAVA L	CASSAVA S	CITRUS	COFFEE ARABICA	COTTON	COWPEA	FINGER MILLET	GROUND NUTS-L	GROUND NUTS-S	IRISH POTATO	MAIZE L	MAIZE S	PEAS. BEANS-L	PEAS. BEANS-S	PIGEON PEA	SORGHUM	SOYBEAN	SUN FLOWER	TEA	TOBACCO AFC	TOBACCO FC	WHEAT
1020	A2x1	(58)	700	S3/Nc	S3m	Nm	S3m	S3/Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2mt	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1021		(61)	4,100	Nc	S3cm	Ncm	S3/Nm	Nm	Nc	S3c	S3c	S2/3c	Nc	S2c	S2mt	S3c	S2x	S3c	S3c	S3c	S3c	S2cx	Nm	S2/3c	S2ct	S2ctx
1022		(73)	2,000	Nc	S3cm	Nc	S3/Nm	Nm	Nc	S3c	S3c	S2/3c	Nc	S2c	S2t	S3c	S2x	S3c	S3c	S3c	S3c	S2cx	Nm	S2/3c	S2ct	S2ctx
1023	A2x2	(30)	4,700	S3/Nc	S3m	Nm	Nm	Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2/3m	S2ct	S2/3m	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1024		(57)	3,200	Nc	S3cm	Nm	S3/Nm	Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2mt	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1025		(58)	3,400	S3/Nc	S3m	Nm	S3m	S3/Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2mt	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1026		(61)	3,200	Nc	S3cm	Ncm	S3/Nm	Nm	Nc	S3c	S3c	S2/3c	Nc	S2c	S2mt	S3c	S2x	S3c	S3c	S3c	S3c	S2cx	Nm	S2/3c	S2ct	S2ctx
1027		(72)	1,900	Nc	S3cm	S3cm	S2cmx	S3m	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2t	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	S3c	S2t	S2t	S3c
1028		(137)	4,000	S3/Nc	S3m	Nm	Nm	Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2mt	S2ct	S2mx	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1029	A2x3	(21)	5,700	S3/Nc	S3m	Nm	Nm	Nm	S3c	S2cmt	S2cmt	S2mt	S2/3c	S3c	S3/Nm	S2/3mt	S3/Nm	S2/3m	S2ct	S2t	S2/3m	S2t	Nm	S2/3mt	S2/3mt	S3c
1030		(30)	6,200	S3/Nc	S3m	Nm	Nm	Nm	S3c	S2ct	S2ct	S2t	S2/3c	S3c	S2/3mt	S2/3t	S2/3m	S2ct	S2ct	S2t	S2ct	S2t	Nm	S2/3t	S2/3t	S3c
1031		(31)	3,250	Nc	S3cm	Nm	Nm	Nm	S3c	S2ct	S2ct	S2t	S2/3c	S3c	S2/3mt	S2/3t	S2/3m	S2ct	S2ct	S2t	S2ct	S2t	Nm	S2/3t	S2/3t	S3c
1032		(57)	4,900	Nc	S3cm	Nm	S3/Nm	Nm	S3c	S2ct	S2ct	S2t	S2/3c	S3c	S2/3t	S2/3t	S2t	S2ct	S2ct	S2t	S2ct	S2t	Nm	S2/3t	S2/3t	S3c
1033		(138)	8,500	S3/Nc	S3m	Nm	S3/Nm	Nm	S3c	S2ct	S2ct	S2t	S2/3c	S3c	S2/3t	S2/3t	S2t	S2ct	S2ct	S2t	S2ct	S2t	Nm	S2/3t	S2/3t	S3c
1034	A3f5	(58)	700	S1/2mt	S3m	Nm	S3m	S3/Nm	S2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S2mt	S2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	Nm	S2t	S2t	S2t
1035		(73)	2,800	S2/3m	S3m	S3m	S3/Nm	Nm	S2mt	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S2t	S2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	Nm	S2t	S2t	S2t
1036		(81)	350	S1/2t	S3m	S3m	S2m	S3m	S2mt	S1/2t	S1/2t	S1/2t	S2m	S1/2t	S2t	S2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S3x	S2t	S2t	S2t
1037		(92)	500	S1/2mt	S3m	S3m	S3m	S3/Nm	S2mt	S1/2t	S1/2t	S1/2t	S2m	S1/2t	S2t	S2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	Nm	S2t	S2t	S2t
1038		(95)	700	S1/2t	S3m	S3m	S2m	S3m	S2mt	S1/2t	S1/2t	S1/2t	S2m	S1/2t	S2t	S2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S1/2t	S3x	S2t	S2t	S2t
1039	A3f6	(30)	900	S3/Nc	S3m	Nm	Nm	Nm	S3c	S2c	S2c	S1/2t	S2/3c	S3c	S2/3m	S2ct	S2/3m	S2c	S2c	S1/2ct	S2c	S1/2t	Nm	S2t	S2t	S3c
1040		(73)	450	Nc	S3cm	Nc	S3/Nm	Nm	Nc	S3c	S3c	S2/3c	Nc	S2c	S2t	S3c	S1/2et	S3c	S3c	S3c	S3c	S2ce	Nm	S2/3c	S2cet	S2ct
1041		(99)	300	S2c	S3/Ne	S3/Ne	S2cm	S3cm	S3/Ne	S3e	S3/Ne	S3e	S3e	Nc	S3e	S3e	S3e	S3e	S3/Ne	S3/Ne	S3e	S3/Ne	Nc	S3/Ne	S3/Ne	Nc
1042	A3x1	(30)	3,200	S3/Nc	S3m	Nm	Nm	Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2/3m	S2ct	S2/3m	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1043		(70)	450	S3/Nc	S3m	S3cm	S3m	S3/Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2t	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1044		(88)	1,250	Nc	S3cm	S3cm	S2cmx	S3m	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2t	S2ct	S2x	S2cx	S2c	S1/2cet	S2cx	S2x	S3c	S2t	S2t	S3c
1045	D1x1	(58)	800	S3/Nc	S3m	Nm	S3m	S3/Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2mt	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1046	D2u1	(58)	350	Nr	Nr	Nmr	Nr	Nmr	Nr	S2/3r	S2/3r	S3r	S3r	S3cr	S3r	S3r	S2/3r	S2/3r	S3/Nr	S3r	S3r	S3/Nr	Nmr	Nr	Nr	S3cr
1047	D2x2	(58)	1,900	S3/Nc	S3m	Nm	S3m	S3/Nm	S3c	S2cx	S2c	S2x	S2/3c	S3c	S2mt	S2ct	S2x	S2cx	S2c	S1/2ct	S2cx	S2x	Nm	S2t	S2t	S3c
1048		(106)	200	Nc	S3cm	S3c	S2cmx	S3m	S3c	S2cx	S2cm	S2x	S2/3c	S3c	S2t	S2ct	S2x	S2cmx	S2c	S2m	S2cx	S2mx	S3c	S2mt	S2mt	S3c
1049	D2x3	(67)	950	S2ctx	S3x	S3x	S3x	S3cx	S3x	S3x	S2tx	S3x	S3x	Nc	S2/3t	S2/3t	S3x	S3x	S2tx	S2tx	S3x	S3x	Nc	S2/3t	S2/3t	Nc
1050		(100)	2,400	S2/3x	S3x	S2cmx	S3x	S3cx	S3x	S3x	S2mtx	S3x	S3x	Nc	S2/3t	S2/3t	S3x	S3x	S2tx	S2mtx	S3x	S3x	Nc	S2/3t	S2/3t	Nc
1051		(101)	4,750	S2ctx	S3x	S2cmx	S3x	S3cx	S3x	S3x	S2mtx	S3x	S3x	Nc	S2/3t	S2/3t	S3x	S3x	S2tx	S2mtx	S3x	S3x	Nc	S2/3t	S2/3t	Nc

NOTE: L = Long cycle varieties; S = Short season varieties.
See also Table of cultivars in the main text.

LIMITING FACTORS:
c - temperature regime
e - erosion hazard
f - flooding hazard
k - soil workability
m - moisture regime
r - rooting conditions
t - nutrient retention capacity
w - oxygen availabiltiy
x - toxicity/acidity

APPENDIX XVI: GLOSSARY

Critical value: a value of a diagnostic factor (q.v.) which forms the boundary between suitability rating classes.

Crop requirements: the land use requirements (q.v.) specifically related to an individual crop.

Diagnostic factor: a variable, which may be a land quality, a land characteristic or a function of several land characteristics, that has an understood influence on the output from, or the required inputs to, a specified kind of land use, and which serves as a basis for assessing the suitability of a given type of land for that use. For every diagnostic factor there will be a critical value (q.v.) or set of critical values which are used to define suitability class limits.

Factor rating: a set of critical values (q.v.) which indicate how well a land use requirement is satisfied by the particular condition of the corresponding land quality.

Note: suitability rating refers to the land use requirement for a land quality: when this rating is combined with the value of that land quality possessed by a given land unit, it becomes a land suitability rating , q.v.

Inputs: the material inputs (e.g., seed, fertilizers, chemical sprays) and other inputs (e.g. labour hours) applied to the use of land (cf. levels of inputs, outputs).

Kind of land use: this term refers to either a major kind of land use or a land utilization type (q.v.), whichever is applicable; where the meaning is clear it is abbreviated to "kind of use" or simply "use".

Land: an area of the earth's surface, the characteristics of which embrace all reasonably stable or predictably cyclic attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man.

Land characteristic: an attribute of land that can be measured or estimated, and which can be employed as a means of describing land qualities or distinguishing between land units of differing suitabilities for use.

Land quality: a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use.

Land suitability: the fitness of a given type of land for a specified kind of land use.

Land suitability classification: an appraisal and grouping, or the process of appraisal and grouping, of specific types of land in terms of their absolute or relative suitability for a specific kind of use.

Land suitability rating: the partial suitability of a land unit for a land utilization type, based on one land quality or a partial set of land qualities. Land suitability ratings are combined to give a land suitability class (cf. note on suitability rating).

Land unit: an area of land possessing specified land qualities and land characteristics, which can be demarcated on a map.

Land use requirement: the conditions of land necessary or desirable for the succesful and sustained practice of a given land utilization type (cf. crop requirements, management requirements).

Land use type: the same as land utilization type.

Matching: the process of comparing land use requirements with the land qualities of land units.

Land utilization type: a kind of land use described or defined in a degree of detail greater than that of a major kind of land use (q.v.). In the context of rainfed agriculture, a land utilization type refers to a crop, crop combination or cropping system with a specified technical and socioeconomic setting.

Land suitability category: a level within a land suitability classification. Three catagories of land suitability are recognized:

Land suitability order: a grouping of land according to whether it is suitable or not suitable for a specified kind of use.

Land suitability class: a subdivision of a land suitability order serving to distinguish types of land which differ in degree of suitability.

Land suitability subclass: a subdivision of a land suitability class serving to distinguish types of land having the same degree of suitability but differing in the nature of the limitations which determine the suitability class.

Levels of inputs: a means of differentiating farming systems in generalized terms according to inputs and technology used. Two levels of inputs have been recognized:

Low inputs: no significant use of purchased inputs such as artificial fertilizers, improved seeds,pesticides or machinery - traditional farming.

Intermediate inputs: methods practised by farmers who follow the advice of agricultural extension services but who have limited technical knowledge and/or capital resources; improved agricultural techniques; improved seeds; inputs adequate to increase yields but not to achieve absolute maximum yields or maximum economic return; some fertilizers and chemical weed or pest control. This level is equivalent to improved traditional farming.

High inputs: methods based on advanced technology and high capital resources; fertilizers at levels of maximum economic return; chemical weed and pest control at advanced technical levels; modern methods of mechanization are employed to maximize yields or economic return. This level can be found on some estates in Malawi.

Limitation: a land quality, or land characteristic which adversely affects the potential of land for a specified kind of use.

Major land improvement: a large non-recurrent input in land improvement which causes a substantial and reasonably permanent (i.e. lasting in excess of about 10 years) change in the suitability of the land, and which cannot normally be financed or executed by an individual farmer or other land user (cf. minor land improvement).

Major kind of land use: a major subdivision of rural land use, such as rainfed agriculture, wetland rice cultivation, irrigated agriculture, forestry, recreation, etc.

Minor land improvement: a land improvement which has relatively small effects on the suitability of land, or is non-permanent, or which normally lies within the capacity of an individual farmer or other land user (cf. major land improvement).

Outputs: the products (for rainfed agriculture: crops), services (e.g. water supply, recreational facilities), or other benefits (e.g. wildlife conservation) resulting from the use of the land.

Quantitative land suitability classification: a land suitability classification in which the distinctions between classes are defined in common numerical terms, usually economic, which permit objective comparison between classes relating to different kinds of land use.

Qualitative land suitability classification: a land suitability classification in which the distinctions between classes are made in terms which do not meet the requirements of a quantitative land suitability classification (q.v.).

Sustained use: continuing use of land without severe or permanent deterioration in the resources of the land.

Two-stage approach: a land evaluation methodology in which a first approximation of land suitability is made on the basis of physical criteria, and in which economic and social analysis is carried out as a second stage on the land use alternatives which appear most promising on the basis of physical evaluation.

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