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Soil Mapping and Advisory Services

Botswana

# A SYSTEM OF LAND EVALUATION FOR ARABLE FARMING IN BOTSWANA

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# A SYSTEM OF LAND EVALUATION FOR ARABLE FARMING IN BOTSWANA

by

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Gaborone, 1988

## Preface

The present guidelines for land evaluation for arable farming in Botswana are the result of a long and repetitive process of defining, testing and redefining.

The development of the system started in 1981 in the context of the Soil Mapping and Advisory Services Project BOT/80/003. The first rather ad hoc approaches were formulated by Venema, Eldridge and Remmelzwaal.

From 1982 to 1983 responsibility for land evaluation and the development of the system remained with Venema. The first draft was completed October 1983 (Venema and Rhebergen) and issued the following year by FAO, Rome as a field document. In the estimation of the for Botswana critical land quality 'availability of moisture', the agro-ecological zones approach was followed, using monthly means of rainfall (of the mean year) for determining the growing period.

This approach proved not satisfactory and the first draft (1983/84) has not been used. Rhebergen, who assumed responsibility for land evaluation from 1984, introduced a system of climatic zones based on frequencies of sufficiently long growing periods (Venema and Rhebergen, 2nd draft, unpublished). This system was applied in the draft report on the soils of the central distrcit (Remmelzwaal, 1984).

In the third draft (Venema and Rhebergen, 1985) only minor changes were made as compared to the second draft. After a testing period a fourth and final draft was completed in 1987, incorporating a new version of the agro-ecological zones system. The calculations were carried out by the meteorological department at Gaborone using 10-day periods on an annual basis. Data of the synoptic stations and rainfall data of about 50 other stations were analysed. An adapted evaporation formula was applied to reflect local conditions. In this draft a number of other land quality determinations were changed.

This seems a long period to develop a land evaluation system. However, the developing of new approaches and concepts is time consuming and the inclusion of some basic testing is essential for achieving sound correlations of land qualities with suitability classes.

The introduction of important changes and major improvements by Rhebergen since 1984, justifies a change of authorship. This system, together with other basic data systems, constitutes an essential element in the evaluation of land in Botswana.

A. Remmelzwaal
Team leader

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# INTRODUCTION

The system of land evaluation as presented here is part of a soil mapping programme, which started in 1981 (Soil Mapping and Advisory Service, UNDP/FAO BOT 80/003, Ministry of Agriculture). Interpretation of the collected soil data should be carried out in a systematic way to obtain consistent and comparable information on the land suitability for various types of land use in different parts of the country.

In this report a system is described to evaluate land for arable farming. Systems for other major kinds of land use (e.g. grazing and forestry) could be developed along the same lines.

The present system of land evaluation is not the first one to be developed for Botswana. Siderius (1970) developed a Land Capability Classification for both dryland farming and irrigated land use, following a system developed by the United States Department of Agriculture. This classification was modified (Soil Survey Section, undated) and applied for traditional dryland farming in north-eastern Botswana (Venema, 1980) and south-eastern Botswana (Eldridge, unpublished maps). Mitchell (1976) used a system developed for Zimbabwe to classify irrigable land along the main rivers of eastern Botswana.

Following the recommendations of the 4th Eastern African Soil Correlation and Land Evaluation meeting (Arusha, 1980) it was decided to adopt the FAO Framework for Land Evaluation (FAO, 1976). The concepts and general procedures are described in chapter 1.

Chapter 2 gives the guidelines for land evaluation for arable farming in Botswana. This part includes many 'critical values' which are based on present knowledge of soil properties and their significance with respect to the production of various crops under various types of management. Proper validation of these values has to be carried out in the coming years, through correlation of S-classes with measured yields in farmers' fields. It is realized that as a result of this validation process some critical values will have to be changed in the future.

# 1 FRAMEWORK FOR LAND EVALUATION

## 1.1 LAND EVALUATION, FUNDAMENTAL PRINCIPLES

Land evaluation is concerned with the assessment of land performance when used for specified purposes. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use.

Certain principles are fundamental to the approach and methods employed in land evaluation. The following are considered to be the most important (FAO, 1976):

i. Land suitability is assessed and classified with respect to specified kinds of use (different kinds of landuse have different requirements).

ii. Evaluation requires a comparison of the benifits obtained and the imputs needed on different types of land.

iii. Suitability refers to use on a sustained basis

iv. Evaluation is made in terms relevant to the physical, economic and social context of the area concerned. (The present system is designed for Botswana and valid for this country under the present social, political and economic conditions).

## 1.2 BASIC CONCEPTS

Definitions of several of the most frequently used terms as in the FAO framework (FAO, 1976) are as follows:

**Land** comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use.

A **major kind of land use** is a major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, forestry.

A **land use type** is a kind of land use described or defined in a degree greater then that of a major kind of land use.

A **land characteristic** is an attribute of land that can be measured or estimated. Examples are slope angle, rainfall, soil texture. If land characteristics are employed directly in evaluation, problems arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not by the slope angle alone but by the interaction between slope angle, slope length, soil structure, infiltration rate and other characteristics. Therefore the comparison of land with land use should be carried out in terms of land qualities.

A **land quality** is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Examples are moisture availability, resistance to soil erosion, nutrient availability.

**Requirements of the land use** refer to the set of land qualities that determine the production and management conditions of a kind of land use.

**Limitations** areland qualities which adversely affect a kind of land use.

**Land improvements** are activities which cause benificial changes in the qualities of the land.

A **major land improvement** is a substantial and reasonably permanent improvement in the qualities of the land affecting a given use. Examples are: drainage of swamps, construction of dams.

A **minor land improvement** is one whih has either relatively small effects or is non-permanent or both, or within the capacity of individual farmers or other land users. Examples are: stone clearance, fencing, destumping, simple drainage works.

## 1.3 LAND SUITABILITY CLASSIFICATION

Four categories of decreasing generalization are recognized:

Orders
Classes
Subclasses
Units

**Orders**: There are two orders: S (Suitable)
N (Non-suitable)

**Classes**: In Botswana four classes are distinguished within order (S) and two classes within order (N):

S (Suitable): S1
S2
S3
S4

N (Non-suitable): N1
N2

The suitability classes are defined as follows:

**S1 highly suitable**: Land which is expected to be highly productive for the defined use. High returns amply justify required imputs. No significant limitations.

**S2 moderately suitable**: Land which is expected to be moderately productive for the defined use. Moderate returns justify required inputs. Limitations reduce crop yield 20-40% and/or increase recurrent costs for production and conservation.

**S3 marginally suitable**: Land which is expected to have a low productivity for the defined use. Yield benefits are just high enough to justify required inputs. Limitations reduce crop yield 40-60% and/or considerably increase costs for production and conservation.

**S4 very marginally suitable**: Land which is expected to have a very low productivity for the defined use. It is doubtful wether yield benifits alone justify required inputs. Severe limitations reduce crop yields with 60-80% and/or considerably increase cocts for production and conservation.

**N1 currently unsuitable land**: Land with very severe limitations, which at present cannot be corrected economically.

**N2 permanently unsuitable land**

Subdivision of the classes is as follows:

**Subclasses**: Land suitability subclasses reflect kinds of limitations. They are indicated by lower-case letters, symbolyzing the kind of limitation (e.g. subclass S2e: limitation caused by erosion)

The classes S1 and N2 have no subclasses.

**Units**: Land suitability units reflect small differences in production characteristics. Units are indicated by arabic numbers, following a hyphen (e.g. S2e-1).

Seasonal cultivation of land classed as S4 will not be profitable over a long period in terms of money. However, part of this land is used and will be used in the future, either permanently or periodically, for the following reasons:

a. In traditional dryland farming economic considerations do not play a role, or only a minor one. In this concept very low yields can be accepted.

b. In countries which have a highly erratic rainfall such as Botswana, some years have sufficient rainfall to produce an acceptable yield.

c. Considerations other than economic, such as employment and self-sufficiency, justify strongly reduced crop yields.

Current and Potential Suitability:

The current suitability refers to the suitability for a defined use of land in its present condition, without major improvements. Minor improvements which are common practice for the defined land use are included.

Potential suitability refers to the suitability for a defined use of land after specified major improvements have been completed. It isassumed that land evaluation is for current suitability for a defined use unless the contrary is stated clearly.

## 1.4 LAND EVALUATION PROCEDURES

The evaluation procedure includes four steps as follows:

1. Specification of areas to be evaluated and the kind(s) of land use which have to be considered.
2. Description of kind(s) of land use and identification of requirements of the use and limitations.
3. Description of land units and their qualities within the specified areas.
4. Estimation of benefits and inputs for each relevant combination of land use type and land unit, resulting in a land suitability classification. Benefits not only consists of produce, but also include benefits like the creation of employment.

Steps 2 and 3 should be taken simultaneously, the results of one influencing the other.

e.g. the identification of certain land qualities (step 3) may be reason to change the initial description of the land use type (step 1) and the requirements (step 2). On the other hand, the identification of certain requirements (step 2) will be reason to identify certain land qualities (step 3).
This process is called matching of land use with land.

# 2 GUIDELINES FOR LAND EVALUATION FOR ARABLE FARMING IN BOTSWANA

## 2.1 PROCEDURES

In section 1.4 the procedure of land evaluation has been described in general terms. Here follows a more specific description of the procedures as applied to arable farming in Botswana:

1. Specification of areas to be evaluated and the kind(s) of land use which have to be considered. As far as the latter is concerned, one or more of the land use types as described in section 2.3 can be identified. Relevant crops have to be specified.

2. Identification of the requirements of the relevant land use, including land use types and crops.

3. Description of the relevant land qualities and definition and mapping of land units. The basis for the land inventory will be a soil map. Superimposed on the soil map is all other relevant information (climate, topography, etc.). In many cases the boundaries of the soil mapping units and land mapping units will be the same, but the same soil mapping unit does not necessarily correspond with the same land mapping unit.

The process of matching land with land use (see chapter 1.4) has been provisionally done in a general way for arable farming in Botswana. It will not be possible to establish a definite list of land use types because social, economic, political and technical developments may take place that cannot be foreseen. Equally, it is not possible to produce soil maps, which include information on all relevant requirements of future land use. Both descriptions of land use and land inventory have to be reviewed periodically.

The country wide systematic soil survey, which is still in progress, is set up in such a way as to give information relevant to the land use types identified. The identification of relevant land use types is partly a result of knowledge gained by soil survey and the study of the climate. The result of the matching process is shown in section 2.3 (land use types) and section 2.5 (land qualities). Further matching will be necessary for detailed surveys, more specific descriptions of requirements, with the need of more detailed soil maps, climatic data, etc.

Land qualities have been rated (section 2.5), which means that critical limits have been established for each land quality which relate to the requirements of land use relevant to Botswana.

The following procedure will lead to the suitability classification of a land mapping unit:

a. determine the ratings for the individual land qualities (only those land qualities which are relevant to the land use under consideration);

b. establish a relationship between land quality ratings and suitability class by comparing requirements of specified land use and the ratings. This involves an estimation of inputs and benefits. A consideration of inputs and benefits will show that the weight given to a rating can vary from one land use type to the other and from one crop to another crop.
c. the lowest suitability class(es) of the land qualities considered determine(s) the final suitability class of a land unit.

The following example is given:

| land qualities relevant for land use X | rating for land unit Y | suitability class for land use X |
|---|---|---|
| (a) | 2 | S1 |
| (e) | 1 | S1 |
| (f) | 1 | S1 |
| (g) | 2 | S2 |
| (m) | 3 | S3 |
| (n) | 3 | S2 |
| (o) | 1 | S1 |
| (p) | 2 | S2 |
| (t) | 1 | S1 |
| (w) | 2 | S2 |

Land unit Y is classified as marginally suitable (subclass S3m) for land use X.

## 2.2 LAND SUITABILITY MAPPING

Land suitability maps are prepared at various scales, depending on the purpose of the survey. Large scale maps are made for farm planning purposes (e.g. irrigation farms); medium scale land suitability maps are meant for regional planning (CFDA's, Pandamatenga plains, etc.); small scale maps are intended for policy making at a national level, education, etc.

For each type of survey and for each land use type a relevant set of land qualities is selected. A systematic land suitability evaluation at scale 1:250.000 of areas covered by the systematic soil survey is carried out, with improved traditional dryland farming as the land use type and sorghum as a main crop.

The soil mapping units as shown on the soil maps, often consist of 2 or more soil units (either as an association or as a complex). It appears impracticle for cartographic reasons to evaluate all soil units and to map an association of land suitability (sub)classes. The number of characteristics would be too big (e.g. S3mn-S3m-S2mnot).

In Botswana conditions for dryland farming are generally poor, mainly due to the marginal climatic conditions. Often only the best part of a soil mapping unit offers some potential for dryland farming. For this reason only the soil unit with the highest suitability class will be mapped. In order to give an indication of the area covered by the mapped suitability class the letter S will be printed in three lettertypes:

| | | |
|---|---|---|
| bold capital | **S** : | area coverage per mapping unit 60-80% |
| capital | S : | area coverage per mapping unit 40-60% |
| lower case | s : | area coverage per mapping unit 20-40% |

It should be noted that generally 30% or less of the area of the soil mapping unit is covered by minor soil units, which are not mentioned in the soil association or complex.

## 2.3 Land Use Types

The following types of arable farming are considered to be relevant for Botswana, at present or in the near future:

Major land use: Arable farming

Land use types: Dryland farming

a. traditional
b. partly mechanized traditional
c. improved traditional
d. mechanized commercial

Irrigated farming

a. small scale
b. medium to large scale

Molapo farming

a. traditional
b. improved traditional

Descriptions of the land use types are given on the following pages. It is not possible to give a very precise definition of a land use type, as many "intergrades" exist (e.g. partly improved traditional farming).

The land evaluation system as proposed can also be used for other land types, unless unique requirements have to be considered. In that case the system may have to be expanded in terms of number of land qualities and/or land quality ratings.

Land use type: **Traditional Dryland Farming**

| | |
|---|---|
| Produce: | Sorghum, maize, beans (tepary bean, jugo bean and others), groundsnuts, cowpeas, millet, sunflower, cucurbit (various melons, pumpkins). |
| Yields: | 200 - 300 kg/ha (grain) |
| Market orientation: | Subsistance |
| Size of holding: | 2 - 20ha (mostly 4-6 ha). Total area planted depends on the availability of labour and draughtpower at the right time and on the amount and distribution of the rainfall. |
| Capital intensity: | Very low |
| Credit facilities: | None |
| Labour intensity: | Low |
| Farm power: | Oxen and/or donkeys |
| Technical knowledge: | Broadcasting, inter-cropping, little weeding, no fertilizer, little manure, shallow ploughing after first effective rain, continuous cultivation of same field (land may be fallow during years of low rainfall). |
| Infrastructure requirements: | None |
| Land tenure system: | Communal (land once allocated is practically owned the farmer but cannot be sold). |

Land use type: **Partly Mechanized Traditional Dryland Farming**

| | |
|---|---|
| Produce, yields: | See Traditional Dryland Farming |
| Market orientation: | Firstly subsistance; sale of surplus |
| Size of holding: | 10 to 40 ha, total area planted depends on amount and distribution of rain. |
| Capital intensity: | Variable |
| Credit facilities: | Government controlled and commercial banks |
| Labour intensity: | Very low |
| Farm power: | Tractor for ploughing (either owned or hired) |
| Technical knowledge: | Good knowledge of traditional farming practices |
| Management practices: | See Traditional Dryland Farming |
| Infrastructure requirements: | Fuel and mechanical skills/workshops should be available |
| Land tenure system: | Communal |

Land use type: **Improved Traditional Dryland Farming**

| | |
|---|---|
| Produce: | Sorghum, maize, millet, groundnuts, peas, beans, sunflower |
| Yields: | 500 - 600 kg/ha (grain) |
| Market orientation: | Firstly subsistance; sale of surplus |
| Size of holding: | 10 ha; total area planted depends on amount and distribution of rainfall |
| Capital intensity: | Moderate |
| Labour intensity: | Moderate |
| Credit facilities: | Government controlled institutions |
| Farm power: | Oxen, donkeys, mules |
| Technical knowledge: | Good knowledge of modern farming practices related to non-mechanized dryland farming |
| Management practices: | Winter ploughing, early planting, row planting, im proved seeds, modest use of fertilizer/manure, in secticides, use of planter and inter-row cultivator, contour ploughing, adequate crop protection against pests, proper storage of harvest. |
| Infrastructure requirements: | Advisory services; depots for sale of supllies (fertilizer, seeds) and storage of produce. |
| Land tenure system: | Communal |

Land use type: **Mechanized Commercial Dryland Farming**

| | |
|---|---|
| Produce: | Sorghum, maize, sunflower and other |
| Yields: | Variable |
| Market orientation: | Mainly commercial |
| Size of holding: | 50 - 500 ha |
| Capital intensity: | Moderate |
| Credit facilities: | Government controlled and commercial banks |
| Labour intensity: | Low |
| Farm power: | Engine |
| Technical knowledge: | Good knowledge of dryland farming and machinary |
| Management practices: | Main farm operations mechanized. Unlimited inputs as long as net return can be expected. |
| Infrastructure requirements: | Good access to markets or adequate storage facilities. Good access to supplies and mechanical skills/work-shops if not present on the farm. Adequate technical advise. |
| Land tenure system: | Communal, communal with long-term lease or freehold. |

Land use type: **Small Scale Irrigated Farming**

| | |
|---|---|
| Produce: | Vegetables, fruits, maize, sorghum and possibly fodder crops |
| Yields: | 5 - 8t/ha (grain) |
| Market orientation: | Commercial or as part of other farm activity (dairy, beef production) |
| Size of holding: | Less than 20 ha |
| Capital intensity: | Moderate to high |
| Credit facilities: | Government controlled and commercial banks |
| Labour intensity: | High in case of horticulture |
| Farm power: | Engine for pumping; hand, animal or engine for other farm operations |
| Technical knowledge: | Moderate to high |
| Management practices: | High inputs in terms of fertilizer, weeding, crop protection, seeds. Type of irrigation depends on topography of land, availability of water, crops, available capital, soil characteristics. |
| Source of water: | (sand) rivers, weirs, boreholes, open water (including small dams) |
| Infrastructure requirements: | Easy access to market essential in case of horticulture; advisory services should be available. |
| Land tenure system: | Freehold or communal |

Land use type: **Medium to Large Scale Irrigated Farming**

| | |
|---|---|
| Produce: | Food crops (including rice) and industrial crops |
| Yields: | 4 - 10 t/ha (grain) |
| Market orientation: | Commercial |
| Size of holding: | 20 - 200 ha |
| Capital intensity: | Moderate to high |
| Credit facilities: | Government controlled and commercial banks |
| Labour intensity: | Moderate to high |
| Farm power: | Engine |
| Technical knowledge: | High |
| Manangement practices: | Advanced irrigation techniques, unlimited inputs as long as net return is expected |
| Source of water: | Large weirs, dams, high-yielding boreholes, perennial rivers, swamps |
| Infrastructure requirements: | Easy access to markets or adequate storage facilities; easy access to agriculture expertise or on-the-farm skilled manager. Easy access to mechanical expertise/workshop or-on-the farm facilities. |
| Land tenure system: | Communal (long term lease) or freehold |

Land use type: **Traditional Molapo Farming**

Molapo farming is the cultivation of channels and floodplains ("melapo") immediately after the floods have receded (flood recession cultivation). Molapo farming is often practised in combination with dryland farming and communal grazing.

| | |
|---|---|
| Produce: | Maize, sorghum, water melon, pumpkin, groundnuts |
| Yields: | 0.6 - 1 t/ha (grain) |
| Market orientation: | Subsistance, occasional sale of surplus |
| Size of holding: | 2 - 10ha; area cultivated depends on availability of draughtpower, extent and time of flooding/flood recession and rainfall. |
| Capital intensity: | Very low |
| Credit facilities: | None |
| Labour intensity: | Low to moderate |
| Farm power: | Oxen, donkeys, mules; occasionally a tractor may be hired for ploughing |
| Technical knowledge: | Knowledge of traditional farming only |
| Management practices: | Location of fields may vary from year to year, depending on time and extent of flood, no fencing, very limited bunding to protect fields against flooding after planting; broadcasting; multicropping; no fertilizer. |
| Infrastructure requirements: | None |
| Land tenure system: | Communal |

Land use type: **Improved Traditional Molapo Farming**

| | |
|---|---|
| Produce: | Sorghum, maize, cucumbers and others |
| Yields: | 1,5 - 2,5 t/ha (grain) |
| Market orientation: | Subsistence and partly commercial |
| Size of holding: | 4 - 10 ha |
| Capital intensity: | Government institutions |
| Labour intensity: | Moderate to high |
| Farm power: | Mainly animal (oxen, donkeys, mules); occasionally a tractor may hired for ploughing. |
| Technical knowledge: | Good knowledge of modern farming practices |
| Management pratices: | Permanent cultivation of land protected by (fenced) bunds with inlet structure; improved seeds, mono-cropping, modest application of fertilizer or manure proper weeding; row planting. |
| Infrastructure | Adequate extension service; depots for supplies (seeds, fertilizer); adequate market/storage; bridges crossing channels. |
| Land tenure: | Communal |

## 2.4 AGRO-CLIMATIC ZONES

The differentiation of Botswana into agro-climatic zones is based on the variation in growing season lengths, the length of the humid period and on the number of dry days within the season.

Data of about 60 weather stations were processed by the meteorological department in Gaborone following the methodology of the FAO Agro-ecological Zones Project (FAO, 1978). The reader is referred to the report 'Agro-climatic zones in Botswana' (Dambe, 1987) for technical details.

The following definitions apply:

**growing season**: the length of the growing season is equal to the length of the growing period if one growing period occurs or equals the total length of the growing periods, when two or more growing periods occur plus the number of dry days.

**growing period**: the start of a growing period is assumed when precipitation exceeds half the potential evapotranspiration. The end of the period is assumed when precipitation falls below half potential evapotranspiration, plus a number of days to required to evaporate an assumed 100mm of soil moisture reserve when available.

**humid period**: the period during a growing period when precipitation exceeds full potential evapotranspiration.

**dry days**: days during the growing season when no soil moisture is available and rainfall is less than half the potential evapotranspiration.

In recent years both the Meteorological Department and the Department of Water Affairs have concluded that evaporation figures as given by Pike (1971) may be too low. A study of open water evaporation was initiated by the Department of Water Affairs and carried out by the Snowy Mountains Engineering Company (SMEC, 1987). In this study three approaches of the Penman formaula applied in Botswana were analysed and compared with reservoir water balance data. Recommended values for the constants in the formaula were presented (see appendix A) and applied in the growing period analyses.

Figure 1 shows the agro-climatic zones of Botswana. Sixteen zones are distinguished. The zones 2c-d3 and 3b-c3 can be considered as transitional areas, which are influenced by both the northern and (south)eastern weather systems.

The agro-climatic zones are the basis for the determination of the moisture availablity rating for dryland farming (section 2.5).

## 2.5 LAND QUALITIES AND RATINGS

The following land qualities are distinguished:

**edaphic and agro-climatic suitability**

(c) correct temperature regime, day length and air humidity
(d) soil drainability (irrigated arable farming only)
(f) absence of damaging floods
(g) adequacy of conditions for germination
(m) moisture availability
(n) nutrient availability
(o) oxygen availability in the rootzone
(q) availability of water of good quality (irrigated arable farming only)
(r) adequacy of foothold for roots
(t) absence of toxic substances

**management and conservation suitability**

(a) accessibility
(e) resistence to soil erosion
(p) absence of pests and diseases
(w) workability
(x) adequacy of topography
(y) adequacy of flooding (molapo farming only)
(z) land drainability

Each land quality is rated, using numbers (1-6). Although an increase in rating number generally corresponds with a decrease in suitability for all land use types, ratings are not the same as suitability classes. Different land use means different requirements and the weight given to each rating should be established separately for every land use type and for every crop (e.g. low oxygen availability in the rootzone is a severe limitation for maize but not for paddy rice).

The ratings or "critical limits" have been defined in such a way that they both reflect the range of conditions found in Botswana and are related to the requirements of the relevant land use types and crops.

### Land qualities relating to edaphic and agro-climatic suitability

#### (c) Correct temperature regime, day length and air humidity

With respect to air temperature the following characteristics will be considered:

1. Mean daily temperature: number of consecutive months with mean daily temperatures of respectively 10-15, 15-20, 20-25 and 25-30 degrees C.
2. Mean maximum daily temperatures: number of consecutive months with 20-25, 25-30 and 30-35 degrees C.

3. Occurence of frost in the growing season: number of months with the possibility of very light frost (0-2$^0$C), light frost (2-5$^0$C) and moderate frost (5-8$^0$C). It should be noted that large variations in minimum tem peratures can occur within very short distances depending on the topography.

Four ratings have been established:

1. Correct temperature regime, daylength and air humidity.
2. low possibility of extreme temperatures or temperature regime, daylength and/or air humidity not correct.
3. high possibility of extreme temperatures or temperature regime, daylength and/or air humidity not correct. Reduction of yield by approximately 50%.
4. temperature regime not correct. Yield insignificant under natural conditions and costs of improvements prohibitive.

**(d) adequacy of drainage conditions for irrigated farming**

The land use type 'irrigated farming' comprises different irrigation systems:

Surface irrigation - water is moved over the land in order to wet it. Several types can be distinguished: furrow irrigation, border strip irrigation, flooding from contour ditches, basin irrigation.

Sprinkler irrigation - water is pumped through distrubution pipes and applied to the land by means of sprinklers. Different types are in use:

conventional sprinkler systems:
- permanent with buried laterals and risers
- semi-permanent: the mains are permanent and the laterals with the sprinklers are portable
- portable: the mains and the laterals with the sprinklers are fully portable

mobile sprinkler systems: although many mobile sprinkler excist, the centre pivot is the most widely used system in Botswana. The area per circle varies from 5 to 100ha.

Localized irrigation presently not considered in the system as it is hardly applied in Botswana. When the need arises the specific requirements can be outlined.

To evaluate soil drainage conditions for irrigated farming some physical characteristics have to be considered.

a. minimum depth to the expected groundwater table:
A high groundwater table results in accumulation of salts and waterlogging in the rootzone. Hydrological investigations have to be conducted to predict future groundwater levels after implementation of the irrigation scheme.

b. available water holding capacity (AWHC):

The AWHC is an important factor in establishing the irrigation cycle and for the design of the system. The AWHC should not be inferred from the soil texture but measured in the laboratory (permanent wilting point and field capacity). For sandy soils it is preferable that field capacity is measured gravimetrically from a field sample, as lab measurements can easily lead to an underestimation of the AWHC.

c. basic infiltration rate (I.R.):

The basic infiltration rate of the topsoilrefers to the relatively constant rate which is established after 3 to 8 hours of infiltration. The various types of irrigation require different conditions. For surface irrigation the I.R. should neither be too fast nor too slow. In the case of sprinkler irrigation a distinction is made between (semi)permanent /portable and mobile (centre pivot) systems. With the first systems the application rate can be adjusted to the I.R. of the soil and the duration of the applicication can easily be varied. With the centre pivot systems a distinction is made between low pressure and medium to high pressure systems. A low pressure system (relatively low energy consumption) gives a high application rate and requires a high I.R. of the soil (e.g. a 100ha field with a sandy soil requires a peak application with an intensity of ca. 20cm/h at the end of the lateral). A high pressure system (relatively high energy consumption) gives a lower application rate, and can be used on soils with a lower I.R.. However, this systems is susceptible to direct evaporation losses under dry and windy conditions.

It should be noted that the infiltration rate varies with the soil moisture content. In a soil with a moisture content somewhere between field capacity and wilting point the infiltration rate is higher as compared to the basic infiltration rate, which is measured at field capacity and when cracks in the soil have closed.

d. hydraulic conductivity (permeability):

Impeded internal drainage (low hydraulic conductivity) results in accumulation of salts and waterlogging in the rootzone. High hydraulic conductivity results in loss of irrigation water. Hydraulic conductivity refers to the percolation rate of water through the least permeable layer within 1.5m. Presence of coarse elements (stoneline, silcrete, petrocalcic horizon, etc.) greatly reduces the permeability, and need careful attention when measuring the hydraulic conductivity.

Table 1 gives a general indication of the adequacy of drainage conditions for irrigated farming. It should not be used as a basis for the design of irrigation systems.

Table 1. Drainage criteria for irrigated farming.

| rating | min. depth to expected water-table (cm) | | AWHC mm/m | basic infiltration rate (cm/h) | | | | hydraulic conductivity (cm/h) |
|---|---|---|---|---|---|---|---|---|
| | texture | | | surface irr. (rice excluded) | sprinkler irrigation | | | |
| | | | | | (semi)permanent and portable | mobile (centre pivot) | | |
| | medium coarse | fine | | | | low press. | med-high press. | |
| 1 | >200 | >400 | >110 | 1-3.5 | >1 | >8 | >2 | 1-6 |
| 2 | 120-200 | 300-400 | 70-110 | 0.3-1 | 0.5-1 | 2-8 | 0.5-2 | 6-12 |
| | | | | 3.5-6 | | | | 0.5-1 |
| 3 | 75-120 | 200-300 | 40-70 | 0.1-0.3 | <0.5 | <2 | <0.5 | 0.2-0.5 |
| | | | | 6-12 | | | | >12 |
| 4 | <75 | <200 | <40 | <0.1 | | | | <0.2 |
| | | | | >12 | | | | |

**(f) absence of damaging floods**

Land quality (f) refers to the occurence of floods during the growing season which may damage crops and infrastructure. These floods occur along rivers during or shortly after periods of high rainfall.

Five ratings have been distinguished:

Table 2. Flooding factor rating

| rating | frequency of floods |
|---|---|
| 1 | less than once in 10 year |
| 2 | once every 5 - 10 years |
| 3 | once every 3 - 4 years |
| 4 | once every 2 years |
| 5 | every year |

**(g) adequacy of conditions for germination**

The main land characteristics which determine the conditions for germination in a moist subsoil are surface crusting, surface stones and gravel, and the sructure and consistence of the topsoil. Surface crusts are formed on some soils when heavy rain is followed by bright sunshine.

Three ratings have been established as follows:

Table 3. Germination factor rating

| rating | surface crust | surface gravel and stones | structure topsoil | consistence topsoil |
|---|---|---|---|---|
| 1 | none or thin and soft | 0-10% | single grain, crumb, granular; fine to medium blocky, prismatic or platy; weak (very) coarse blocky, prismatic or play | loose-hard (dry) loose-firm (moist) |
| 2 | thin and hard or thick and soft | 10-40% | massive, strongly coherent; moderate (very) coarse blocky, prismatic or platy | very hard (dry) very firm (moist) |
| 3 | thick and hard | >40% | strong (very) coarse prismatic or platy | extremely hard (dry) extremely firm (moist) |

**(m) moisture availability**

Moisture availability is, in general terms, determined by climate (rainfall and potential evapotranspiration), modified by topography (water shedding sites versus water receiving sites) and soil characteristics (infiltration, permeability, available water holding capacity).

1. Climate.

Of importance is the rainfall in relation to the potential evapotranspiration. See section 2.4.

2. Water retention characteristics.

Water retention characteristics (total available water, wilting point) of the soil determine how a crop will respond to rain. A crop on a dry sandy soil will respond to a 20mm rain shower, while a crop on a dry clay soil will not respond to a 20mm rain shower.

3. Lateral movement of surface and groundwater (runoff/seepage).

Within the soil, water may be lost or gained through lateral water movements. This is mainly a function of slope, slope position (site), infiltration rate, permeability and water holding capacity.

4. Downward movement of water in the soil.

Water can sink by gravity below a depth where it can be reached by plant roots. The amount of water lost through this process is very much a fuction of plant rooting characteristics (shallow rooting plants vs. deep rooting plants). An important soil characteristic is the available water holding capacity.

5. Effective rooting depth.

The effective rooting depth is influenced to a large extent the available water holding capacity. The rooting depth is restricted not only by shallow rock but also by the presence of a (petro)calcic horizon, an abrupt textural change and sedimentary stratification.

Procedure:

i. determine the available water holding capacity (AWHC) according to table 4
ii. correct AWHC for infiltration rate using table 6
iii. read moisture availability rating combining AWHC/infiltration rating AWHC/infiltration rating and climatic zone and correct if necessary for site characteristics using table 7
iv. give final rating after texture correction if applicable using table 8.

Table 4. Available water holding capacity rating estimated from texture, soil depth and stoniness

| texture (average 0-100cm or less if soil depth is less) | effective rooting depth (cm) | | | | stoniness (%) (average 0-100cm or less if soil depth is less) | | |
|---|---|---|---|---|---|---|---|
| | 10-25 | 25-50 | 50-75 | >75 | <20 | 20-50 | 50-90 |
| . | x | | | | 6 | 6 | 6 |
| coarse sand, sand | | x | | | 6 | 6 | 6 |
| . | | | x | | 5 | 6 | 6 |
| . | | | | x | 5 | 5 | 6 |
| . | x | | | | 6 | 6 | 6 |
| very fine sand, fine and fine me- | | x | | | 5 | 5 | 6 |
| dium sand (<7% clay), loamy coarse | | | x | | 4 | 5 | 5 |
| sand, loamy sand | | | | x | 4 | 4 | 5 |
| loamy very fine sand, loamy fine | x | | | | 6 | 6 | 6 |
| sand, coarse sandy loam and sandy | | x | | | 5 | 5 | 5-6 |
| loam with <18% clay and >65% sand, | | | x | | 4 | 4 | 5 |
| fine sand (>7% clay) | | | | x | 3 | 4 | 4 |
| very fine sandy loam, fine sandy | | | | | | | |
| loam, (coarse) sandy loam with >18% | x | | | | 5 | 5-6 | 6 |
| clay or <65% sand, sandy clay loam, | | x | | | 4 | 5 | 5 |
| sandy clay, loam, silt loam, silt, | | | x | | 3 | 4 | 4 |
| non-vertic clay, vertic clay with | | | | x | 2 | 3 | 4 |
| >60% clay | | | | | | | |
| fine sandy clayloam, fine sandy clay | x | | | | 5 | 5 | 6 |
| silty clay, clayloam, silty clay | | x | | | 3-4 | 4 | 5 |
| loam, vertic clay with <60% clay | | | x | | 2 | 3 | 4 |
| | | | | x | 1 | 2 | 3-4 |

move up texture column one step if high bulkdensity is found over a depth of at least 25cm within 75cm from the surface.

High bulk density is defined as follows:

| texture | high bulk density |
|---|---|
| coarse | > 1.8kg/dm3 |
| medium | > 1.75 |
| fine | > 1.7 |

Table 5. Correlation of rating and available water in mm per 100cm from the surface or less if the soil depth is less.

| Rating | available water |
|---|---|
| 1 | >160 |
| 2 | 110 - 160 |
| 3 | 70 - 110 |
| 4 | 40 - 70 |
| 5 | 20 - 40 |
| 6 | <20 |

Table 6. Correction of the AWHC with respect to the infiltration rate

| AWHC | infiltration rate (cm/h) | | |
|---|---|---|---|
| . | >2.5 | 0.5-2.5 | <0.5 |
| 1 | 1 | 2 | 3 |
| 2 | 2 | 3 | 4 |
| 3 | 3 | 4 | 5 |
| 4 | 4 | 5 | 6 |
| 5 | 5 | 6 | 6 |
| 6 | 6 | 6 | 6 |

With infiltration is meant here the entrance of water into unsaturated topsoil (o-25cm) and not the basic infiltration rate.

The infiltration rate is correlated with soil characteristics as follows:

>2.5cm/h: coarse textured soils, and medium textured soils if not massive, compacted, cemented or capped

0.5-2.5cm/h: medium textured soils if massive, compacted, cemented or capped and fine textured soils with less than 60% clay

<0.5cm/h: medium and fine textured soils with high exchangeable sodium and other fine textured soils with more than 60% clay

Table 7. Moisture availability ratings estimated from climatic zones, available water holding capacity (AWHC) and site characteristics.

| climatic zone | | AWHC | moisture availability rating | | | |
|---|---|---|---|---|---|---|
| | | | normal site | water receiving site | | water shedding site |
| | | | | seasonal | permanent | |
| 1b1 | Kasane | 1 | 2 | 1 | 1 | 3 |
| | | 2 | 2 | 1 | 1 | 3 |
| | | 3 | 2 | 1 | 1 | 3 |
| | | 4 | 3 | 1-2 | 1 | 4 |
| | | 5 | 3 | 1-2 | 1 | 4 |
| | | 6 | 4 | 2-3 | 1-2 | 5 |
| 1b2 | Shakawe | 1 | 2 | 1 | 1 | 3 |
| | | 2 | 2 | 1 | 1 | 3 |
| | | 3 | 3 | 1-2 | 1 | 4 |
| | | 4 | 3 | 1-2 | 1 | 4 |
| | | 5 | 4 | 2-3 | 1-2 | 5 |
| | | 6 | 4 | 2-3 | 1-2 | 5 |
| 1c2 | Tutume | 1 | 2 | 1 | 1 | 3 |
| | | 2 | 3 | 1-2 | 1 | 4 |
| | | 3 | 3 | 1-2 | 1 | 4 |
| | | 4 | 4 | 2-3 | 1-2 | 5 |
| | | 5 | 4 | 2-3 | 1-2 | 5 |
| | | 6 | 4 | 2-3 | 1-2 | 5 |
| 2c2 | Chizwina | 1 | 3 | 1-2 | 1 | 4 |
| | Gomare | 2 | 3 | 1-2 | 1 | 4 |
| | | 3 | 3 | 1-2 | 1 | 4 |
| | | 4 | 4 | 2-3 | 1-2 | 5 |
| | | 5 | 4 | 2-3 | 1-2 | 5 |
| | | 6 | 5 | 3-4 | 2-3 | 6 |
| 1d3 | Mahalapye | 1 | 3 | 1-2 | 1 | 4 |
| | | 2 | 3 | 1-2 | 1 | 4 |
| | | 3 | 4 | 2-3 | 1-2 | 5 |
| | | 4 | 4 | 2-3 | 1-2 | 5 |
| | | 5 | 4 | 2-3 | 1-2 | 5 |
| | | 6 | 5 | 3-4 | 2-3 | 6 |
| 1e3 | Gaborone | 1 | 3 | 1-2 | 1 | 4 |
| | | 2 | 3 | 1-2 | 1 | 4 |
| | | 3 | 4 | 2-3 | 1-2 | 5 |
| | | 4 | 4 | 2-3 | 1-2 | 5 |
| | | 5 | 5 | 3-4 | 2-3 | 6 |
| | | 6 | 6 | 4-5 | 3-4 | 6 |

| climatic zone | | AWHC | moisture availability rating | | | |
|---|---|---|---|---|---|---|
| | | | normal site | water receiving site | | water shedding site |
| | | | | seasonal | permanent | |
| 2c3 | Maun | 1 | 3 | 1-2 | 1 | 4 |
| | | 2 | 4 | 2-3 | 1-2 | 5 |
| | | 3 | 4 | 2-3 | 1-2 | 5 |
| | | 4 | 5 | 3-4 | 2-3 | 6 |
| | | 5 | 5 | 3-4 | 2-3 | 6 |
| | | 6 | 6 | 4-5 | 3-4 | 6 |
| 2c-d3 | Nata | 1 | 4 | 2-3 | | 5 |
| 2d3 | Serowe | 2 | 4 | 2-3 | | 5 |
| | | 3 | 4 | 2-3 | | 5 |
| | | 4 | 5 | 3-4 | | 6 |
| | | 5 | 5 | 3-4 | | 6 |
| | | 6 | 6 | 4-5 | | 6 |
| 3b3 | Jwaneng | 1 | 4 | 2-3 | | 5 |
| 3b4 | Tsetsebjwe | 2 | 4 | 2-3 | | 5 |
| | | 3 | 5 | 3-4 | | 6 |
| | | 4 | 5 | 3-4 | | 6 |
| | | 5 | 6 | 4-5 | | 6 |
| | | 6 | 6 | 4-5 | | 6 |
| 3b-c3 | Orapa | 1 | 4 | 2-3 | | 5 |
| 3c3 | Rakops | 2 | 5 | 3-4 | | 6 |
| | | 3 | 5 | 3-4 | | 6 |
| | | 4 | 6 | 4-5 | | 6 |
| | | 5 | 6 | 4-5 | | 6 |
| | | 6 | 6 | 4-5 | | 6 |
| 4b3 | Bobonong | 1 | 5 | 3-4 | | 6 |
| 4b4 | Tshane | 2 | 5 | 3-4 | | 6 |
| | | 3 | 5 | 3-4 | | 6 |
| | | 4 | 6 | 4-5 | | 6 |
| | | 5 | 6 | 6 | | 6 |
| | | 6 | 6 | 6 | | 6 |
| 5a4 | Tshabong | 1 | 5 | 3-4 | | 6 |
| | | 2 | 6 | 4-5 | | 6 |
| | | 3 | 6 | 4-5 | | 6 |
| | | 4 | 6 | 6 | | 6 |
| | | 5 | 6 | 6 | | 6 |
| | | 6 | 6 | 6 | | 6 |

Site characteristics:

permanent water receiving site: the permanent groundwater table is within 100cm from the surface seasonal water receiving site: seasonal high groundwater table or gain of moisture of more than 15% of annual rainfall

water shedding site: loss of at least 15% of annual rainfall; this applies mainly to upper slopes of more than 3%.

Soils with a high volume percentage of water at wilting point (fine textured soils) can dry out beyond wilting point during the winter season or during a summer dry spell.
Evaporation from the rootzone takes place from cracks in the soil (in montmorillonitic clayey soils) or from the surface through capillary rise of soil water.
The soil profile has to be recharged with water to a point somewhere between field capacity and wilting point before a crop can respond to the moisture. The actual growing season will therefore be considerably shorter as compared to the calculated agro-climatic growing season. The moisture availability rating may be downgraded with one or two classes following table 8.

Table 8. Establisment of final moisture availability rating applying a texture correction

| texture (unless covered by at least 30cm of sand to sandy loam) | rating | final rating climatic zone | |
|---|---|---|---|
| | | 1b1,1b2,1c2,2c2 | others |
| montmorillonitic sandy clay | 1 | 2 | 3 |
| to clay, fine sandy clay, | 2 | 3 | 4 |
| fine sandy clayloam, siltloam, | 3 | 4 | 5 |
| silt, silty clayloam, clay- | 4 | 5 | 6 |
| loam,silty clay | 5 | 6 | 6 |
| | 6 | 6 | 6 |

moisture availability rating

| | |
|---|---|
| high | 1 |
| moderately high | 2 |
| marginal | 3 |
| low | 4 |
| very low | 5 |
| extremely low | 6 |

## (n) nutrient availability

Nutrients considered here are calcium, magnesium, potassium, phosphorus and nitrogen. Since only insufficient data are available on nitrogen, organic carbon will be used as an indicator instead. Together with available nutrients, cation exchange capacity (CEC) and soil reaction are taken into account. Nutrient availability is considered for the top 25cm only.

Table 9 gives six chemical characteristics and their classes. The final rating gives a general indication on the fertility status of a certain soil, but does not provide a basis for fertilizer recommendations.

A more detailed study of the nutrient status is required when a survey on farm level is carried out. The surveyor should consider the following:

-nutrient imbalances (Ca/Mg, K/Mg)
-micro-nutrient deficiences
-nutrient retention (effective CEC)

Threshold values can be established after consultation with the Agricultural Research Department.

It should be noted that in gravelly soils the amounts of nutrients as given by the chemical analyses give an overestimation. When the amounts of available nutrients are given as parts per million (ppm) or as kg/ha the weight percentage of gravel should be considered and the amounts of available nutrients corrected accordingly.

There are four fertility ratings. The final rating can only be given after a correction is made for the pH.

The rating consists of three steps:

1. Score for each of the six characteristics (table 9) and determine total score.

Table 9: Chemical characteristics

| org.C % | score | P(Bray) ppm | score | CEC | score | me/100g soil exchangeable cations Ca | score | Mg | score | K | score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| >0.7 | 4 | >25 | 4 | >20 | 4 | | | | | | |
| 0.3-0.7 | 3 | 12-25 | 3 | 10-20 | 3 | >4 | 3 | >1 | 3 | >0.4 | 3 |
| 0.1-0.3 | 2 | 5-12 | 2 | 5-10 | 2 | 1-4 | 2 | 0.3-1 | 2 | 0.1-0.4 | 2 |
| <0.1 | 1 | <5 | 1 | <5 | 1 | <1 | 1 | <0.3 | 1 | <0.1 | 1 |

2. Adjust the score for pH (table 10).

Table 10: pH rating (topsoil 0-25cm)

| pH (water) | | score |
|---|---|---|
| >8.3 | very high | -6 |
| 7.5-8.3 | high | -3 |
| 5.5-7.5 | correct | 0 |
| 4.5-5.5 | low | -2 |
| <4.5 | very low | -4 |

3. Add scores of tables 9 and 10 and establish the final fertility rating

Table 11: fertility rating

| fertility rating | total score (9 +10) |
|---|---|
| 1 (high) | 19 - 21 |
| 2 (medium) | 13 - 18 |
| 3 (low) | 7 - 12 |
| 4 (very low) | 0 - 6 |

Soils which are known to be severely deficient in one or more micronutrients should be downgraded one or two classes depending on the kind of deficiency (e.g. boron deficiency vs. zink deficiency, boron is more difficult to rectify than zinc).

**(o) oxygen availability in the rootzone**

Oxygen availability in the soil is mainly a function of the drainage.

Five ratings are distinguished:

Table 12. Oxygen availability rating.

| rating | drainage class | ponding hazard (frequency) | | |
|---|---|---|---|---|
| . | | every 1-2 yrs | every 3-5 yrs | every 6-10 yrs |
| 1 | 3-6 | none | none | <1 day |
| 2 | 2-3 | none | <1 day | 1-7 days |
| 3 | 2 | <1 day | 1-7 days | 7-30 days |
| 4 | 1 | 1-7 days | 7-30 days | 30-60 days |
| 5 | 0 | 7-30 days | 30-60 days | >60 days |

**(q) availability of water of good quality (for irrigated farming)**

The availability of good quality is to be considered before a land suitability evaluation for irrigated farming is carried out. It is not necessary to give ratings for the amount of water; if there is not enough water the land use should be changed.

In general terms, the quality decreases with increasing salinity and increasing sodium, chloride, boron, nitrogen (in the form of NO3 or NO4) and bicarbonate content.

The reader is referred to FAO (1985) for guidelines for the evaluation of the quality of the water.

**(r) adequacy of foothold for roots**

One of the functions of soil is to provide foothold for plants. If there is not enough space in the soil for a plant to root, it will fall at some stage during its growth. Adequacy of foothold is a function of effective soil depth (i.e. part of the soil in which root growth is possible).

Five ratings have been established:

Table 13. Soil depth rating.

| rating | effective soil depth (cm) |
|---|---|
| 1 | >100 |
| 2 | 50-100 |
| 3 | 25- 50 |
| 4 | 10- 25 |
| 5 | <10 |

**(t) absence of toxic substances**

A substance is toxic when its presence in the soil is the cause of reduced yield. Substances like salts (certain chlorides, sulphates and carbonates causing high salinity), sodium and calcium carbonate occur in high concentrations in some soils and can be toxic. High concentrations of sodium create adverse physical consitions in the soil (clay dispersion). In sandy soils high ESP levels can be tolerated as the small amounts of (dispersed) clay have little negative effect. In Vertisols dispersion tests have to be carried out before a rating for the ESP can be given. It has been reported that an ESP of 15 or more has little adverse effects.
Land quality (t) is rated separately for:

1. salinity
2. sodicity
3. calcium carbonate/gypsum

Table 14. salinity rating

| rating | electrical conductivity (mS/cm at 25 C) | |
|---|---|---|
| . | topsoil (0-50cm) | subsoil (50-100cm) |
| 1 | <2 | <4 |
| 2 | 2-4 | 4-8 |
| 3 | 4-8 | 8-15 |
| 4 | 8-15 | 15-25 |
| 5 | >15 | >25 |

Table 15. sodicity rating

| rating | exchangeable sodium % (ESP) | |
|---|---|---|
| | topsoil (0-50) | subsoil (50-100cm) |
| 1 | <3 | <6 |
| 2 | 3-6 | 6-10 |
| 3 | 6-10 | 10-20 |
| 4 | 10-20 | 20-40 |
| 5 | >20 | >40 |

Table 16. calcium carbonate and gypsum rating

| rating | CaCO3 % | | gypsum % |
|---|---|---|---|
| . | 0-50cm | 50-100cm | 0-50cm |
| 1 | <8 | <15 | <0.5 |
| 2 | 8-15 | 15-30 | 0.5-2 |
| 3 | 15-30 | 30-50 | 2-5 |
| 4 | 30-50 | >50 | 5-20 |
| 5 | >50 | | >20 |

## Land qualities relating to management and conservation suitability

### (a) accessibility

The following elements are of importance:

1. Access of farmer and implements to the land: distance, quality of roads and possibility for improvements.

2. Distance and quality of (rail)roads between the farm and a suitable market for sale of produce.

3. Distance and quality of (rail)roads between the farm and a source of supplies (fertilizer, seeds) and services (agricultural extension).

Accessibility is difficult to quantify, as many land characteristics related to it change rapidly (infrastructure). Also facts other than land characteristics play an important role (cost of fuel).

Accessibility is one of the first land qualities to be considered, if an area is to be evaluated for land use other than subsistence farming. It can be assessed qualitatively (common sense). Accessibility should be studied in relation to the land use type.

Four ratings have been distinguished:

| rating | accessibility |
|---|---|
| 1 | good access |
| 2 | somewhat limited access |
| 3 | limited access |
| 4 | poor access |

### (e) resistance to soil erosion

At present only a qualitative approach to assess the erosion hazard can be adopted, as some of the necessary data for a quantitative approach such as the USLE or the SLEMSA model are not available.

Resistance of land to soil erosion will be assessed separately for the agents water and wind. Ratings will be given for each, the lowest rating being the final one.

**water erosion**

Erosion by falling and running rainwater depends on many factors, like rainfall erosivity, soil erodibility, vegetation or crop cover, slope percentage and slope length, infiltration rate and conservation measures.

Land quality (e) refers to the ability of the land, not protected by vegetation or conservation measures, to withstand the eroding force of falling and running rainwater of a certain intensity and amount as is typical for that land.

In Botswana rainfall erosivity increases with annual rainfall (van der Poel, 1980). It is therefore necessary to make a distinction between the various climatic zones.

The resistance of the soil is mainly a function of texture, structure, organic matter content and soil depth. Important land characteristics with respect to quantity and velocity of runoff are slope length, percentage and infiltration rate.

The rating for resistance to soil erosion by water is determined in three steps (tables 17, 18 and 19).

1. Determine the 'soil resistance factor' by scoring for percentage silt, percentage organic matter, structure and soil depth respectively and determine the total score (see table 17).

Table 17. Soil resistance factor (topsoil properties)

| % silt* | score | organic* carbon | score | structure* | score | soil depth | score |
|---|---|---|---|---|---|---|---|
| <15 | 1 | >1 | 1 | strong | 1 | deep to very deep | 1 |
| 15-30 | 3 | 0.3-1 | 2 | moderate | 2 | mod. deep | 2 |
| >30 | 5 | <0.3 | 3 | weak-none | 3 | very shallow to shallow | 3 |

* topsoil 0-25cm

| total score | soil resistance |
|---|---|
| 4-7 | high |
| 8-10 | moderate |
| 11-14 | low |

2. Determine the 'slope factor' (see table 18)

Table 18. Slope factor

| slope length (m) | slope % 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | vl | vl | l | l | l | l | m | m | m | m | h |
| 250 | vl | l | l | l | m | m | m | h | h | h | vh |
| 600 | l | l | l | m | m | h | h | vh | vh | vh | vh |
| >1000 | l | l | m | m | h | h | vh | vh | vh | vh | vh |

vl=very low; l=low; m=moderate; h=high; vh=very high

3. Establish the final rating through table 19. The rating between the brackets() is for climatic zones 4b3,4b4 and 5a4 (see figure 1).

Table 19. Resistance to soil erosion by water

| slope factor | infiltration cm/h* >2.5 | 0.5-2.5 | <0.5 | soil resistance factor high | moderate | low |
|---|---|---|---|---|---|---|
| | x | | | 1(1) | 1(1) | 1(1) |
| very low | | x | | 1(1) | 1(1) | 2(1) |
| | | | x | 1(1) | 2(1) | 2(2) |
| | x | | | 1(1) | 2(1) | 2(2) |
| low | | x | | 2(1) | 2(2) | 3(2) |
| | | | x | 2(2) | 3(2) | 3(3) |
| | x | | | 2(2) | 3(2) | 3(3) |
| moderate | | x | | 3(2) | 3(3) | 4(3) |
| | | | x | 3(3) | 4(3) | 4(4) |
| | x | | | 3(3) | 4(3) | 4(4) |
| high | | x | | 4(3) | 4(4) | 5(4) |
| | | | x | 4(4) | 5(4) | 5(5) |
| | x | | | 4(4) | 5(4) | 5(5) |
| very high | | x | | 5(4) | 5(5) | 5(5) |
| | | | x | 5(5) | 5(5) | 5(5) |

* infiltration = entrance of water into unsaturated topsoil

The infiltration rate is correlated with soil characteristics as follows:

>2.5cm/h: coarse textured soils, and medium textured soils if not massive compacted, cemented or capped.

0.5-2.5cm/h: medium textured soils if massive, compacted,cemented or capped and fine textured soils with less than 60% clay
<0.5cm/h: medium and fine textured soils with high exchangeable sodium and other fine textured soils with more than 60% clay

| rating | resistance to water erosion |
|---|---|
| 1 | very high |
| 2 | high |
| 3 | moderate |
| 4 | low |
| 5 | very low |

**Wind erosion**

Erosion by wind depends on climatic factors (windspeed, rainfall in relation to evapotranspiration), topographic factors ("roughness" of surface), soil erodibility (determined by by structure and consistence of the topsoil, soil texture, calcium-carbonate content), vegetation and conservation measures. All these factors have to be considered if wind erosion is to be assessed at farm level.

On a regional level the most important land characteristic determining the resistance to soil erosion of cleared land by wind are rainfall in relation to evaporation (climatic zones) and soil erodibility.

Four ratings have been established, determined in two steps:

1. Determine soil resistance to wind erosion with the aid of the following table:

Table 20. Resistance to wind erosion

| | structure, consistence, cementation topsoil (o-30cm) | | |
|---|---|---|---|
| texture | strong structure or (very) hard consistence or cemented | moderate-weak structure or sl.hard cons. | loose |
| clay, sandy clay, sandy clayloam | very high | high | moderate |
| silt, silty clay, very fine sandy loam, sandy loam, coarse sandy loam | high | moderate | moderate |
| silty clayloam, clayloam, loamy very fine sand, loamy (coarse) sand, fine sandy loam | high | moderate | low |
| siltloam, loam, very fine sand, (coarse) sand, loamy fine sand | moderate | low | low |
| fine and medium fine sand | moderate | low | very low |

2. Determine final rating with the aid of table 21.

Table 21. Wind erosion rating.

| climatic zone | soil resistance to wind erosion | | | | |
|---|---|---|---|---|---|
| | very high | high | moderate | low | very low |
| 1b1, 1b2, 1c2, 2c2, 1d3, 1e3 | 1 | 1 | 2 | 2 | 3 |
| 2c3, 2c-d3, 2d3, 3b3, 3b-c3, 3c3, 3b4 | 1 | 2 | 2 | 2 | 3 |
| 4b3, 4b4, 5a4 | 2 | 2 | 3 | 3 | 4 |

| rating | resistance to wind erosion |
|---|---|
| 1 | very high |
| 2 | high |
| 3 | moderate |
| 4 | low |

### (p) absence of pests and diseases

Pests include various types of game, birds, rodents, insects and parasitic weeds. Various types of diseases are caused by fungi, bacteria and viruses.

The absence of most pests is difficult to quantify, because of their great variety and often quick changes in distribution and intensity. This in contrast with parasitic weeds and many diseases which slowly build up in cultivated land and which may be very persistent.

Areas infested with parasitic weeds have a rating 3 (see below) for susceptible crops (e.g. Striga and sorghum).

Four ratings have been distinguished:

1. potential damage by pests and diseases limited and/or easy to control by individual farmers.
2. potential damage considerable; moderate input in the form of labour (weeding, bird scaring) needed;
3. potential damage high; moderate input in the form of (costly) materials (fencing, insecticides, herbicides) or very high input in the form of labour needed;

4. potential damage very high; very high input in the form of materials and/ or paid labour needed.

**(w) workability of the land**

The ease with which the soil can be cultivated is mainly a function of soil consistence, stoniness, and rockiness. Ratings are given separately for animal traction (traditional farming) and engine powered traction (mechanized farming) (see tables 22 and 23).

Table 22. Workability for traditional farming

| rating | topsoil consistence | | | % gravel, stones, rocks in topsoil | | |
|---|---|---|---|---|---|---|
| | dry | moist | wet | gravel <7.5cm | stones >7.5cm | rocks |
| 1 | lo-sh | lo-fr | ns | <3 | <1 | <2 |
| 2 | h | fi | ss | 3-15 | 1-2 | 2-10 |
| 3 | vh | vfi | st | 15-30 | 2-5 | 10-25 |
| 4 | eh | efi | vs | >30 | >5 | >25 |

Soil consistency abbreviations:

| dry | moist | wet |
|---|---|---|
| lo = loose | lo = loose | ns = non sticky |
| h = hard | fr = friable | ss = slightly sticky |
| sh = slightly hard | fi = firm | st = sticky |
| vh = very hard | vfi= very firm | vs = very sticky |
| eh = extremely hard | efi= extremely firm | |

Table 23. Workability for mechanized or partly mechanized farming.

| rating | topsoil consistence | | | % gravel, stones, rocks in topsoil | | |
|---|---|---|---|---|---|---|
| | dry | moist | wet | gravel <7.5cm | stones >7.5cm | rocks |
| 1 | lo-sh | lo-fr | ns | <3 | <0.1 | <1 |
| 2 | h-vh | fi-vfi | ss | 3-15 | 0.1-1 | 1-2 |
| 3 | eh | efi | st | 15-30 | 1-3 | 2-10 |
| 4 | | | vs | >30 | >3 | >10 |

**(x1) adequacy of topography (for improved molapo farming)**

The main characteristics are the shape of basin (how long and how high should a bund be to protect a particular basin) and meso/micro topography within that basin.

The bund/molapo ratio will be applied, defined as:

$$\frac{\text{length x height bund(s)}}{\text{area molapo protected by bund(s)}}$$

Final rating for (x1) is established in three steps:

1. estimate bund/molapo ratio with aid of table 24.

Table 24. Bund/molapo ratio

| bund/molapo ratio | |
|---|---|
| low | <0.0004 |
| medium | 0.0004-0.001 |
| high | >0.001 |

2. estimate adequacy of topography with the aid of table 25.

Assume the molapo is flooded to a maximum depth of 1m and estimate % of area under water:

Table 25. Meso-topography

| meso-topography | area under water |
|---|---|
| low | >75% |
| moderate | 50-75 |
| high | <50 |

3. final rating is a combination of bund/molapo ratio and mesotopography as shown in table 26.

Table 26. Adequacy of topography for molapo farming.

| bund/molapo ratio (see table 24) | meso-topography (see table 25) | | |
|---|---|---|---|
| . | low | moderate | high |
| low | 1 | 1 | 2 |
| medium | 1 | 2 | 3 |
| high | 2 | 3 | 4 |

**(x2) adequacy of topography for gravity irrigation farming**

Important land characteristics are slope, slope complexity (expressed by possible field size) and microrelief.

Table 27. Adequacy of topography for gravity irrigation

| rating | slope % | possible field size (ha) | microrelief (cm) |
|---|---|---|---|
| 1 | 0.1-2.0 | >8 | <10 |
| 2 | 0.01-0.1 | 2-8 | 10-30 |
| . | 2.0-7.0 | | |
| 3 | <0.01 | <2 | >30 |
| . | >7.0 | | |

(modified after van der Kevie, 1976)

**(x3) adequacy of topography for mechanized commercial dryland and sprinkler irrigation farming**

One characteristic is considered: the area of land where similar management practices can be applied, expressed as the 'possible farm size'.

Table 28. Possible farm size.

| rating | possible farm size |
|---|---|
| 1 | adequate |
| 2 | marginal |
| 3 | not adequate |

**(y) adequacy of flooding (for molapo farming)**

Table 29. Adequacy of flooding for molapo farming.

| rating | frequency of floods lasting one to eight months; floods receding during period September-January |
|---|---|
| 1 | 9-10 out of 10 years |
| 2 | 7-8 out of 10 years |
| 3 | 5-6 out of 10 years |
| 4 | 2-4 out of 10 years |
| 5 | 1 out of 10 years |

**(z) land drainability**

This land quality is applicable when the infiltration rate is very low (<0.5cm/h, heavy clay soils).

Land drainability is related to slope and microrelief. Some slope is necessary for the design of (shallow) drainage systems. Microrelief, which includes the degree of gilgai, relates to the ponding hazard.

Table 30. Land drainability rating.

| rating | slope % | micro-relief degree of gilgay |
|---|---|---|
| 1 | >1 | non |
| 2 | 0.3-1 | slight to moderate |
| 3 | 0.1-0.3 | strong |
| 4 | <0.1 | |

## 2.6 CROP REQUIREMENTS AND LAND SUITABILITY RATINGS

Tables 31 and 32 indicate the crop requirements, the land quality ratings and the resulting land suitability classes for the six most important crops. The ratings are for improved traditional dryland farming and would be different for high input modern farming or irrigated farming.

Table 31. Some requirements of seven traditional crops.

| | requirements/tolerance | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| crop | mean temp. | | moisture | pH(H2O) | | nutrients | ponding | salinity | | sodicity | | calcium | |
| | opt. | range | (mm) | opt. | range | | tolerance | EC(mS/cm) | | ESP | | carbonate % | |
| | | | | | | | | opt. | proh. | opt. | proh. | opt. | proh. |
| sorghum | 20-30 | 18-35 | 450-650 | 5.5-7.0 | 5.2-8.2 | medium | limited | <5 | >10 | | | <25 | >80 |
| maize | 20-30 | 18-35 | 500-800 | 5.5-7.5 | 5.2-8.2 | high | very limited | <4 | >6 | <8 | >15 | <15 | >50 |
| millet | 25-30 | 18-35 | 200-400 | 5.5-7.5 | 5.2-8.2 | low | limited | <4 | >6 | | | <15 | >50 |
| sunflower | 18-25 | | 240-350 | 6.0-7.5 | | medium | | <4 | >8 | | | | |
| groundnuts | 22-28 | 18-33 | 400-600 | 5.3-6.6 | 4.8-7.5 | low | very limited | <3 | >8 | | | | |
| cowpeas | 25-28 | | 250-400 | | | low | | <2 | >8 | | | | |
| dolichos | 22-35 | | 200-700 | 5.5-7.0 | 4.5-8.0 | low | limited | | | | | | |

opt. = optimum
proh. = prohibitive

Table 32. Land quality ratings and suitability classes for six crops grown under improved traditional dryland farming.

edaphic and agro-climatic suitability

| land quality | rating | crops so | ma | mi | su | do | co |
|---|---|---|---|---|---|---|---|
| . | 1 | S1* | | | | | |
| (c) | 2 | S2* | | | | | |
| temp. | 3 | S3* | | | | | |
| . | 4 | S4* | | | | | |
| . | 1 | S1* | | | | | |
| (f) | 2 | S2* | | | | | |
| damaging | 3 | S3* | | | | | |
| floods | 4 | S4* | | | | | |
| . | 5 | N1-2* | | | | | |
| (g) | 1 | S1* | | | | | |
| germina- | 2 | S2 | S2 | S2-3 | S2 | S2 | S2 |
| tion | 3 | S3 | S3 | S4 | S3 | S3 | S3 |
| . | 1 | S1 | S2 | S1 | S1 | S1 | S1 |
| . | 2 | S2 | S3 | S1 | S2 | S1 | S1 |
| (m) | 3 | S3 | S4 | S2 | S3 | S2 | S2 |
| moisture | 4 | S4 | N2 | S3 | S4 | S2-3 | S3 |
| . | 5 | N2 | N2 | S4 | N2 | S3 | S4 |
| . | 6 | N2 | N2 | N2 | N2 | S4-N2 | N2 |
| . | 1 | S1* | | | | | |
| (n) | 2 | S1 | S2 | S1 | S1 | S1 | S1 |
| nutrients | 3 | S2 | S3 | S2 | S2 | S2 | S2 |
| | 4 | S3 | S4 | S3 | S3 | S3 | S3 |
| . | 1 | S1* | | | | | |
| (o) | 2 | S1 | S2-3 | S2 | S1 | S1 | S1 |
| oxygen | 3 | S2-3 | S4 | S3 | S2 | S2-3 | S2 |
| . | 4 | S4 | N1 | S4 | S4 | S4 | S4 |
| . | 5 | N1-2* | | | | | |
| . | 1 | S1* | | | | | |
| (r) | 2 | S1* | | | | | |
| foothold | 3 | S2* | | | | | |
| roots | 4 | S3-4* | | | | | |
| . | 5 | N2* | | | | | |
| . | 1 | S1* | | | | | |
| (t) | 2 | S2* | | | | | |
| salinity | 3 | S3 | S4 | S4 | S3 | S4 | S4 |
| . | 4 | S4 | N2 | N2 | S4 | N2 | N2 |
| . | 5 | N2* | | | | | |
| . | 1 | S1* | | | | | |
| (t) | 2 | S2 | S2-3 | S2 | S2 | S2 | S2 |
| sodicity | 3 | S3 | S4 | S3 | S3 | S3 | S3 |
| . | 4 | S4 | N2 | S4 | S4 | S4 | S4 |
| . | 5 | N2* | | | | | |
| . | 1 | S1* | | | | | |
| (t) | 2 | S1 | S2 | S2 | S2 | S2 | S2 |
| calcium | 3 | S2-3 | S3 | S3 | S3 | S3 | S3 |
| carbonate | 4 | S4* | | | | | |
| . | 5 | N2* | | | | | |

management and conservation suitability

| land quality | rating | crops so | ma | mi | su | do | co |
|---|---|---|---|---|---|---|---|
| . | 1 | S1* | | | | | |
| (a) | 2 | S1* | | | | | |
| access | 3 | S2* | | | | | |
| . | 4 | S3* | | | | | |
| . | 1 | S1* | | | | | |
| (e) | 2 | S2* | | | | | |
| erosion | 3 | S3* | | | | | |
| resist. | 4 | S4* | | | | | |
| . | 5 | N1* | | | | | |
| . | 1 | S1* | | | | | |
| (p) | 2 | S2* | | | | | |
| pests | 3 | S3-4* | | | | | |
| . | 4 | N1* | | | | | |
| . | 1 | S1* | | | | | |
| (w) | 2 | S2* | | | | | |
| worka- | 3 | S3* | | | | | |
| bility | 4 | S4-N2* | | | | | |

so=sorghum ma=maize mi=millet su=sunflower do= dolichos co=cowpea

* suitability class is the same for all six crops

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## APPENDIX A

The Penman formula as presented by Chidley and Pike (1970)

$$E_o = \frac{\Delta}{\Delta+\gamma} \cdot R_a (a_1 + a_2 \cdot n/N)(1-r) - \frac{\Delta}{\Delta+\gamma} \cdot \sigma T_a^4 (a_3 - a_4\sqrt{e_d}) \cdot (a_5 + a_6 \cdot n/N)$$

$$+ \frac{\gamma}{\Delta+\gamma} \cdot a_7 \cdot (a_8 + a_9 \cdot h)(a_{10} + a_{11} \cdot u) \cdot (e_a - e_d)$$

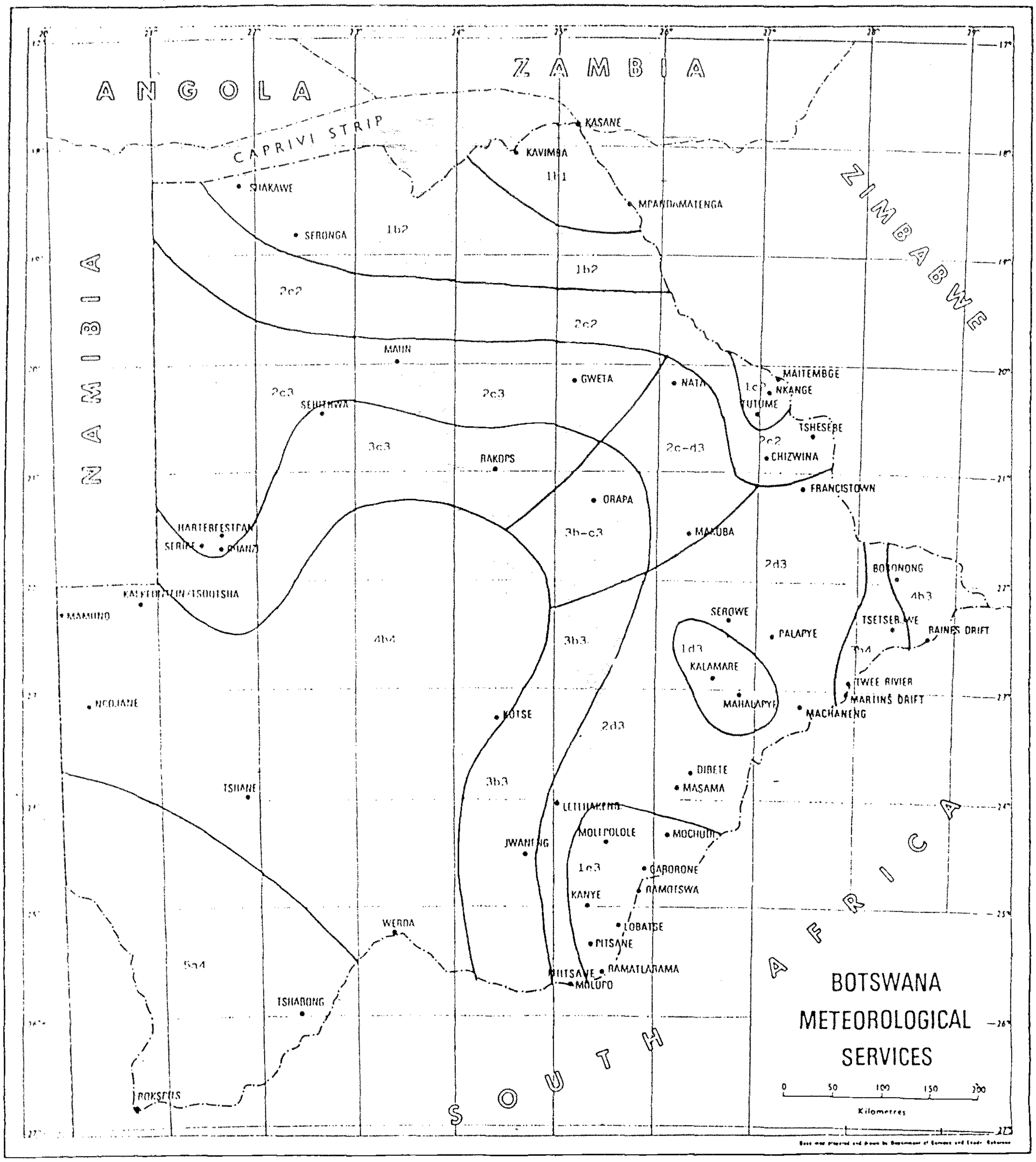
- $E_o$ = open water evaporation (mm.day$^{-1}$)
- $\Delta$ = slope of the saturation vapour pressure curve at mean air temperature (mb $^0C^{-1}$)
- $\gamma$ = constant of the wet and dry bulb psychrometer equation (mb $^0C^{-1}$)
- $R_a$ = theoretical incoming short wave radiation at the limit of the earth's outer atmosphere (mm of evaporation)
- $r$ = reflection coefficient or albedo
- $n$ = actual hours of sunshine
- $N$ = theoretical duration of sunshine
- $\sigma T_a^4$ = black body radiation at mean air temperature (mm of evaporation)
- $e_d$ = mean vapour pressure (mm.Hg)
- $e_a$ = saturation vapour pressure at mean air temperature (mm.Hg)
- $h$ = altitude
- $u$ = run of wind (miles.day$^{-1}$) ar 2 metres

Recommended coefficients in Penman's formula for Botswana
(source: S.M.E.C., 1987)

| coefficient | recommended value | Values used by others: Pike | Doorenbos/Pruitt | DMS |
|---|---|---|---|---|
| $a_1$ | 0.25 | 0.25 | 0.25 | 0.28 |
| $a_2$ | 0.50 | 0.50 | 0.50 | 0.49 |
| $a_3$ | 0.32 | 0.56 | 0.34 | 0.34 |
| $a_4$ | 0.042 | 0.080 | 0.044 | 0.044 |
| $a_5$ | 0.30 | 0.10 | 0.10 | 0.10 |
| $a_6$ | 0.70 | 0.90 | 0.90 | 0.90 |
| $a_7$ | 0.26 | 0.26 | 0.27 | 0.27 |
| $a_8$ | N.A. | 1.00 | ) adjusted by | ) adjusted by |
| | | | ) mult. by | ) mult. by |
| $a_9$ | N.A. | 0.00005 | ) P/P | ) P/P |
| $a_{10}$ | 0.5 | 1.00 | 1.00 | 0.50 |
| $a_{11}$ | 1/161 | 1/161 | 1/100 | 1/100 |
| C | N.A. | N.A. | variable | variable |
| r | 0.05 | 0.05 | 0.05 | 0.05 |

(N.A. - denotes not applicable)

FIGURE 1. AGRO-CLIMATIC ZONES OF BOTSWANA.




| length of season | | number of dry days within the season | length of humid period | |
|---|---|---|---|---|
| duration | frequency | | duration | frequency |
| (days) | (%) | | (days) | (%) |
| 1. 101-120 | 75-100 | a. 0-10 | 1. 41-60 | 75-100 |
| 2. 81-100 | 75-100 | b. 11-20 | 2. 20-40 | 50-74 |
| 3. 61-80 | 75-100 | c. 21-30 | 3. 20-40 | 25-49 |
| 4. 41-60 | 75-100 | d. 31-40 | 4. 20-40 | < 25 |
| 5. 41-60 | 50-74 | e. 41-50 | | |

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