World Soil Resources Reports 65

EIGHTH MEETING OF THE EAST AND SOUTHERN AFRICAN SUB-COMMITTEE FOR SOIL CORRELATION AND LAND EVALUATION

Harare, Zimbabwe, 9-13 October 1989

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Rome 1990

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M-53
ISBN 92-5-102993-8

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1. INTRODUCTION

The East and Southern African Sub-committee for Soil Correlation and Land Evaluation was set up by FAO in 1974 following a recommendation of the 7th FAO Regional Conference for Africa (Libreville 1972). The Sub-committee which comprises all member countries of the sub-region, meets once every two years to discuss matters related to soil survey, classification, land evaluation and management. This Eighth session in Harare falls within that context.

The meeting took place in the Conference Room of the Ambassador Hotel in Harare, and was officially opened by the Director of the Department of Research and Specialist Services, Mr. Fenner. The FAO Representative in Zimbabwe, Mr. C.R. MacCulloch, welcomed the participants. In attendance were invited officials from the host country (Zimbabwe), supporting agencies, seven participating countries and observers.

In his opening speech, Mr. Fenner called for a closer working relationship among soil scientists of the Region, hence the need for a regular meeting every two years. He also pointed out that if the ultimate goal is to attain self-sufficiency in food supply, participating countries must be able to exchange research experiences on the management of various types of soils within the Region, as no country can do it all alone.

Mr. MacCulloch, in his welcoming address said that lack of moisture affects land productivity and that natural climatic changes resulting in severe drought have threatened many African countries with serious food deficits affecting millions of people and animals. Support for increased food production can be given through improving soil moisture storage capacity.

The delegate of Zimbabwe, Mr. C.W. Kanyanda, was elected Chairman of the meeting, while Messrs P. Banda of Malawi, S. Wokabi of Kenya and H. Makhooane of Lesotho were elected Vice-Chairman, and first and second rapporteurs respectively.

The papers presented by the participants dealt with the theme of the meeting, which was "Rating of the land quality of moisture availability: a country appraisal".

A three day field trip took the participants to Chiredzi and Chisumbanji, where 8 soil profiles were described and classified, and to the Mushandike irrigation scheme, situated 20 km south of Masvingo town.

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3. PROGRAMME

Monday, 9 October 1989

09.00 - 09.30	Opening ceremony
	. Welcome address by FAO Representative in Zimbabwe. . Opening address by the Director of Research and Specialist Services
10.00 - 10.20	Election of officers
	Adoption of the Agenda
10.20 - 12.30	**Agenda Item No. 1:** Rating of land qualities - moisture availability: country appraisal
10.20 - 10.45	. Paper by the delegate of Zimbabwe
10.45 - 11.10	. Paper by the delegate of Kenya
11.10 - 11.35	. Paper by the delegate of Ethiopia
11.35 - 12.30	Discussions
12.30 - 14.00	Lunch break
14.00 - 17.00	**Agenda Item No. 1** (continued)
14.00 - 14.25	. Paper by the delegate of Lesotho
14.25 - 14.50	. Paper by the delegate of Malawi
14.50 - 15.15	. Paper by the delegate of Botswana
15.45 - 17.00	Discussions

Tuesday, 10 October 1989

08.00 - 13.00	Agenda Item No. 1 (continued)
08.00 - 08.25	. Paper by the delegate of Zambia
08.25 - 08.50	. Paper by the delegate of Tanzania
08.50 - 09.40	. Paper by the observers
10.00 - 11.00	Discussions
11.00 - 13.00	Paper by the observers
	Discussions
13.00 - 14.30	Lunch break
14.30 - 17.00	Committee on recommendations
18.00 - 20.00	Cocktail

Wednesday, 11 October 1989	**Agenda Item No. 2:** Field trip
08.00 - 17.00	Harare - Chiredzi
	. Visit to soil correlation sites Nos. 1 to 4 . Night at Chiredzi
Thursday, 12 October 1989	**Agenda item No. 2** (continued)
08.00 - 17.00	Chiredzi - Chisumbanje:
	. Soil correlation sites Nos. 5 to 8 . 5 and 6 under irrigation conditions . 7 and 8 under rainfed conditions
17.00 - 18.30	Adoption of recommendations
	Closing session
	Night at Chiredzi
Friday, 13 October 1989	
07.00 - 16.30	Chisumbanje - Masvingo - Harare
	. Visit to Irrigation Scheme of Masvingo
16.30	Arrival in Harare

4. OPENING CEREMONY

4.1 Welcome Address by Mr. C.R. MacCulloch, FAO Representative in Zimbabwe

Mr. Chairman, Honourable Minister, Dear Participants, Ladies and Gentlemen,

It is indeed a pleasant duty and a great pleasure to be associated with the opening ceremony of the Eighth meeting of the East and Southern African Sub-comittee for Soil Correlation and Land Evaluation.

On behalf of FAO and on my own behalf, I would like to express our sincere gratitude to the Government and people of the Republic of Zimbabwe for kindly agreeing to host this meeting. Particular thanks go to the Chemistry and Soil Research Institute of the Department of Research and Specialist Services which for some time now has been working to make the meeting a success and I am sure that, looking at your schedule, this will pay off by the positive results we expect from your deliberations.

I would also like to convey my sincere appreciation to our resource persons who, in spite of their commitments, have gone beyond the normal call of duty to prepare background papers for your deliberations.

Distinguished participants, ladies and gentlemen, discussions on the land quality of moisture availability will be the main preoccupation of your present meeting : and quite rightly so, when we consider that lack of moisture affects land productivity and that natural climatic changes resulting in severe drought have threatened many African countries with serious food deficit affecting millions of people and animals. Therefore the most crucial area which requires our attention and support for increased food production is the development of methods for improving the soil moisture storage capacity. Other production inputs such as fertilizers and pesticides, yielding varieties, etc., are also necessary.

But when assessing the soil moisture capacity, your investigation should not only be limited to the soil/land qualities, you should also consider the management practices. In fact, some of the management practices such as inter-cropping and minimum tillage influence soil moisture storage indirectly through their effect on water intake and reduced evaporation. These practices also increase the efficiency of the stored moisture for crop use in rainfed agriculture. Also of importance is the microtopography which can often lead to micro-climatic differences affecting significantly the actual evapotranspiration by the crop.

Mr. Chairman, having said this, I shall now turn to the problems of farming under rainfed conditions. From experience we know that farming under these conditions has become increasingly risky and thus resorting to irrigation is an obvious solution. It is my hope therefore that this meeting, while addressing itself to land qualities moisture availability, will also examine how best some problems associated with the supply of soil moisture through irrigation, can be overcome.

Mr. Chairman, I am pleased to note that you have included in your programme a field excursion to Chiredzi and Chisumbanje, where you will in many cases be treated to the challenges of agriculture under rainfed conditions and the enormity of the task in water harvesting.

Mr. Chairman, Honourable Minister, distinguished participants, without taking too much of your time, I would like once again on behalf of FAO to wish you all the best in your deliberations.

Thank you very much.

4.2 Address by Mr. Penner, Director of the Department of Research and Specialist Services

As the Director of the Department of Research and Specialist Services, it also gives me great pleasure to welcome you all to Zimbabwe. It may be the hottest time of the year, but being Jacaranda time this must be a compensation to those of you who in the context of this meeting raise their heads to a more upright position.

But let us get to the root of the matter. Why do you meet regularly every two years? On the broad front, this is easy to answer. Your continued activities lay the foundation for good working relationships between soil scientists in the Region. So do many other meetings of agricultural scientists afford this opportunity, but what is different about this meeting and you, the participants?

Soil classification and land evaluation are very specific and specialized disciplines, and many agricultural researchers believe you to be a very small cog in the vast complicated machine of agricultural production.

Before I became an administrator and manager, I was a soil chemist and crop nutritionist. I therefore cannot, and do not, underrate your importance. No country can be an island onto itself! To progress we must be able to transfer agrotechnology between countries. We must be able to exchange research experiences on the management of various soil types within the region, as no one country can do it all, if the ultimate goal is to attain self-sufficiency in food supply. To do this we must know what each of us means when we describe the basic unit of agricultural productivity, the soil. A colleague of mine, a very eminent soil scientist here in Zimbabwe, classified our soils into sands and red soils; and we may laugh, but most of us who have worked here for many years know exactly the point being made. Would anyone from outside our borders? The answer in the negative goes without saying! We must be able to correlate through the nomenclature the soils of the Region.

But names are not enough. They must also describe the properties inherent and what can be done with them, and we also must agree on these matters. And the specific themes of past meetings have done just that. In 1983 in the Sudan, the properties, management and classification of Vertisols were discussed in detail; in 1985 in Lesotho "problem soils" were discussed. Not as grand a theme as the previous one, or even the following meeting, but the English language tends to underestimate the importance of any problem. In Botswana in 1987 you discussed land evaluation for rainfed agriculture and during the discussions you found it diffcult to rate moisture availability through lack of guidelines. In fact one was unable to describe precisely what is the ideal available moisture requirement for crop growth.

I note from the programme this meeting attempts to answer this question; what a difficult goal, particularly as your deliberations are crop specific, and when one considers the wide range of climatic situations that occur within the region. To anyone here it is obvious that, lower the available water capacity of a given soil, the shorter the period over which any crop can stay alive in the absence of rainfall becomes less or the rainfall itself becomes less reliable. I therefore wish you well in your attempts to define and measure those soil parameters that determine the ability of a soil, whether you call it a fine-grained sand, a Haplic Arenosol, or a coarse, siliceous, hyperthermic Typic Tropopsamment, to hold and store moisture.

It is now my privilege, on behalf of the Government of Zimbabwe and the Ministry of Lands, Agriculture and Rural Resettlement, to declare the 8th Session on Soil Correlation and Land Evaluation in East and Southern Africa officially open.

5. EXPRESSION OF THANKS AND RECOMMENDATIONS

Expression of Thanks

The participants of the eight session of the East and Southern African Sub-Committee for Soil Correlation and Land Evaluation,

Satisfied that the eight session of the Sub-Committee has provided a good forum for discussing land quality with respect to moisture availability towards increased crop production,

Convinced of the impact of such periodic meetings in enhancing exchange of experiences on soil survey, classification, evaluation and management,

Record their warm appreciation to FAO for its efforts aimed at promoting technical cooperation among the national institutions of the sub-region towards continuous support to the work of the Sub-Committee,

Express on behalf of FAO their deep sense of gratitude to the Government of Zimbabwe for hosting the meeting and for the facilities provided; to the Governments of Angola, Botswana, Ethiopia, Kenya, Lesotho, Malawi, Madagascar, Mozambique, Sudan, Swaziland, Tanzania, Uganda and Zambia for their confidence in the work of the sub-committee; to the Winand Staring Centre (The Netherlands) for the continuous interest and cooperation accorded to the Sub-committee; to the Chemistry and Soil Research Institute of the Department of Research and Specialist Services (Zimbabwe) for the preparation of the session and field tours, and to those who contributed in various ways to the success of the meeting.

Recommendations

The participants

Being aware that the natural climatic variations resulting in severe drought threatened many African countries with serious deficits in food production,

Convinced that lack of moisture is a major constraint on land productivity in the region and that there is a need for development of methods for assessing and improving the utilization of the soil moisture storage capacity,

Recommend that:

1. Governments of the sub-region

   a. Promote internal cooperation and exchange of information relevant to moisture studies development between the different soil and agroclimatological agencies.

   b. Facilitate regional and international cooperation in agrotechnology transfer among countries of the sub-region and elsewhere.

2. National soil institutions:

   a. Pay greater attention in their programmes to the assessment of moisture availability year by year for optimum crop production.

   b. Use a quantitative moisture balance model, incorporating precipitation, evapotranspiration and soil moisture storage (models should be crop and soil specific).

c. Conduct further investigations to establish local values for certain parameters (for example effective rainfed groundwater contribution and initial moisture studies),

d. Test and verify the models in comparison with actual crop yields,

e. Develop soil moisture regime classification in collaboration with FAO and other agencies.

3. FAO

a. Assist member countries in their programmes for assessing and improving the utilization of the soil moisture storage capacity,

b. Produce guidelines on moisture balance modelling for moisture availability assessment, specifically for rainfed conditions,

c. Advise on software for computerized systems and on interfacing with programmes dealing with data bases, land evaluation and geographical information systems.

Next Meeting of the Sub-Committee

The Secretariat should explore the possibility of holding the ninth session of the Sub-Committee in Malawi.

The theme of the meeting will be: Computer assisted systems for processing soil data and for quantified land evaluation.

6. TECHNICAL PAPERS

6.1 ASSESSMENT OF AVAILABLE SOIL MOISTURE IN ZIMBABWE

by

C.W. Kanyanda, M. Moyo and B. Nyamwanza

INTRODUCTION

One of the limiting factors to agricultural production in Zimbabwe is the availability of soil moisture. This is particularly so in areas of low and unreliable rainfall. Over the years, investigations have been conducted to assess the effect of this land quality on crop production in the country. The most notable document on this subject is the Agro-ecological Survey of Southern Rhodesia (Vincent and Thomas) in which the country was divided into five natural regions which constitute broad areas of optimal land use capabilities based on climate. Natural Region I is where rainfall is high (>1000 mm) and reliable. At the bottom end, Natural Region V is where rainfall is low (<450 mm) and erratic for the reliable production of crops.

The most recent refinement of this document was by Hussein (1987) who used rainfall and temperature data to calculate length of growing seasons in Natural Regions III, IV and V. In a way this was an assessment of the available moisture.

Within each region potential use is determined by soil characteristics. Such soil parameters are, therefore, to be utilized to determine the ability and capacity of a particular soil to hold and store moisture. Thus the lower the available water capacity of any given soil, the shorter the period over which any crop can be sustained in the absence of rainfall.

CHARACTERISTICS AFFECTING AVAILABLE MOISTURE

The available water capacity of the soil depends on various soil parameters but consideration will be given to soil depth, soil texture, whether sand fraction is fine grained or coarse grained, and clay mineralogy.

Soil Depth

Soil depth with respect to moisture availability refers to the depth in a soil profile within which roots can easily penetrate in search of water for the development of crops. Rooting conditions are controlled by soil effective depth and ease of root penetration. The deeper the soil, the more water is retained and thus more of it is available for plant growth.

Six depth classes are recognized for general use. These are given in Table 1.

Table 1 DEPTH CLASSES

Depth Class	Depth (cm)
Deep	>150
Moderately deep	100 - 150
Moderately shallow	50 - 100
Shallow	40 - 50
Very shallow	25 - 40
Extremely shallow	<25

Soil Texture/Nature of Sand Fraction

The water that a soil can hold is influenced by soil texture within the rooting depth. Clayey soils hold more water than sandy soils. Figure 1 depicts moisture release curves for various textural classes of some Zimbabwean soils. This Figure shows that at any suction, clayey soils hold more water than sandier soils. Available data show that clay content has a good positive correlation with retained water, with increasing effect at higher suctions. With regard to available water, the fine sand fraction gives the best correlation, but lower correlation with retained water. Table 2 below shows a comparison of available moisture and retained moisture for various textural classes of some Zimbabwean soils.

Table 2 AVAILABLE AND RETAINED MOISTURE

Textural Class	Available Water (%)	Retained Water (%)
Clay	12.6	38.1
Sandy clay	10.9	32.0
Sandy clay loam	13.3	29.9
Sandy loam	14.0	24.7
Loamy sand	12.3	18.1
Sand	10.2	13.6

The effect of the nature of sand fraction is shown in Table 3.

Table 3 NATURE OF SAND FRACTION

Texture	Available Water (%)
Fine sandy loam	17.0
Medium sandy loam	14.8
Coarse sandy loam	11.5
Fine sandy loam	15.4
Medium sandy clay loam	14.7
Coarse sandy clay loam	10.3

The influence of the fine sand fraction on available moisture is more pronounced on lighter textured soils than on heavy textured soils. Thus for lighter textured soils, available moisture increases significantly with increase in the amount of the fine sand fraction whilst for heavier textured soils the increase is very gradual. This is shown in Figure 2.

Clay Mineralogy

Available moisture is also dependent on the type of clay. In Zimbabwe the classification system is to some extent based on mineralogy and this makes it easier to relate the available moisture to the classification.

In general, less weathered and leached soils have a higher available moisture content than those which are more weathered and leached. This is attributed mainly to the 2:1 lattice clay minerals in the less weathered and leached soils, to the 1:1 lattice clay minerals and sesquioxides in the more weathered and leached soils.

Table 4 below depicts this phenomenon where siallitic, fersiallitic and orthoferrallitic soils are compared: the degree of weathering and leaching increases from the siallitics to the orthoferrallitics. This is however only valid in heavier textured soils where there is a significant amount of clay.

Table 4 PERCENTAGE OF AVAILABLE WATER

Texture	AVAILABLE WATER %		
	Siallitic	Fersiallitic	Orthoferrallitic
Sandy clay loam	12-16	11-14	10
Sandy clay	14	12-14	11
Clay	13	12	11-12

CONCLUSION

The difference in the ability of soils to hold and store moisture has minimal effects on crop performance and distribution in regions receiving high and reliable rainfall but becomes more evident as rainfall decreases. Thus in Natural Region I and II farming systems are specialised, diversified and intensive. The average length of the growing season in these regions is 150 days and this is a measure of the time when the soil is able to supply the plant with required moisture to sustain growth.

On the other side of the scale, Natural Regions III to V, farming systems range from semi-intensive to extensive, respectively. Mean medium values of season length were found to be 131, 121 and 96 days for Natural Regions III, IV and V respectively (Hussein 1987).

In these regions soil characteristics become increasingly more important. Soils are generally shallow due to poor prevalent weathering and leaching conditions. Hence a deeper soil (more available moisture) will considerably increase the water available to crops, i.e. length of the growing season.

In Natural Region III, IV and V, deep, fine grained soils of medium textures are more suitable for dryland cropping assuming that field capacity is attained at one time or another during the season.

FIG. 1

MOISTURE RELEASE CURVES FOR VARIOUS TEXTURAL GROUPS

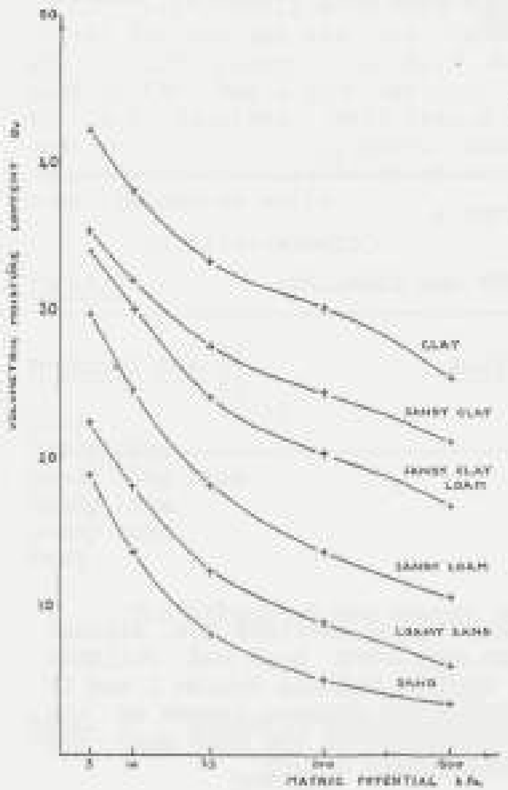
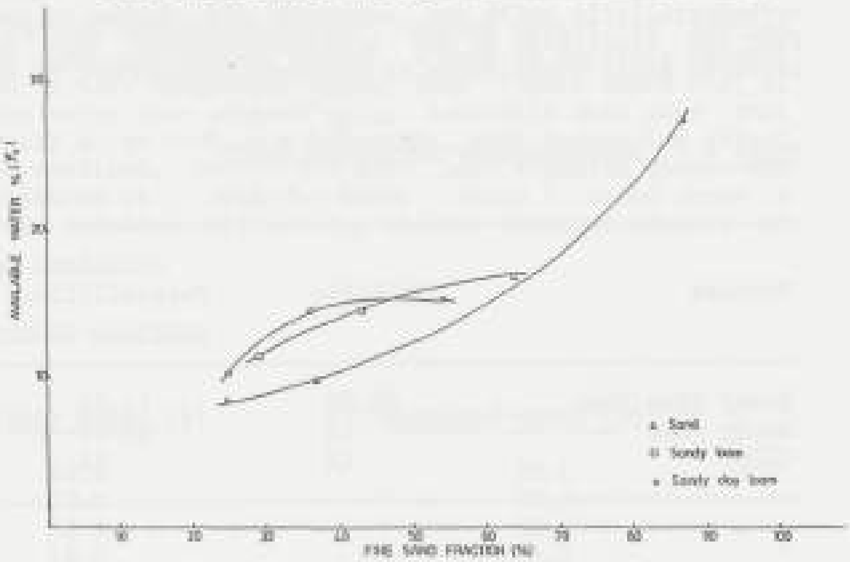


FIG 2 THE INFLUENCE OF THE FINE SAND FRACTION ON AVAILABLE WATER



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6.2 RATING OF AVAILABILITY OF SOIL MOISTURE - A KENYAN APPRAISAL

by

S.M. Wokabi, M.M. Gatahi and W.W. Aore

INTRODUCTION

A major constraint to agricultural production in Kenya, like in many other sub-Saharan countries, is availability of moisture. Only 20% of the total land surface in Kenya is suited for rainfed arable production while the remaining 80% is arid to semi-arid. Population pressure has necessitated increased utilization of semi-arid areas where availability of moisture becomes the single crucial factor limiting sustained productivity.

The rating of availability of moisture in Kenya has evolved over the years in accordance with our growing capacity to compile specific data on land resources, including climate, soils, vegetation on one hand and crop yields on the other. The rating of availability of moisture has thus evolved from broad generalization of moisture availability involving water balance calculations culminating in the use of crop moisture deficits as the rating criteria.

MOISTURE INDICES

Various moisture indices have been used in Kenya. Pratt and Gwynne (1966) used monthly rainfall and annual potential evaporation (Eo) to calculate the index of humidity and aridity, then subsequently a moisture index as shown in the equation below:

$$\text{Index of humidity (Ih)} = \frac{\text{monthly rainfall excesses}}{\text{annual Eo}} \times 100$$

$$\text{Index of aridity (Ia)} = \frac{\text{monthly rainfall deficits}}{\text{annual Eo}} \times 100$$

thus moisture index = $Ih - 0.6Ia$

Later this moisture index was modified to

$$Im = Ih - Ia \text{ or } Im = 100\ (P/PE - 1)$$

where Im = moisture index

P = average annual precipitation and

PE = annual average potential evapotranspiration

The resultant map of the Pratt, Greenway and Gwynne moisture index system appeared to be optimistic and was difficult to interpret vegetation in terms of the average annual water balance. Woodhead (1970) calculated an annual index of available water, through a water balance based on average monthly rainfall, average monthly evaporation and incorporated soil moisture storage capacity.

The soil moisture storage capacity was however estimated from a soil map of 1:3 million (Gethin Jones and Scott 1959). The soil moisture storage capacity estimate was however too generalized since the soil units were catenas. At that time, the water balance calculations were based on evaporation rather than potential evapotranspiration.

Braun (1977) defined the moisture index in terms of agro-climatic zones based on the ratio of rainfall (r) to potential evaporation (Eo) which appears to coincide with the vegetation zones of Kenya. The agro-climatic zones are presently used to indicate the general moisture availability zones at the national scale but fails to incorporate soil moisture storage which is deemed difficult to estimate from the soil map of Kenya at 1:1 000 000 (Sombroek et al. 1982). The agro-climatic zones map of Kenya and the boundary criteria are presented in Figure 1.

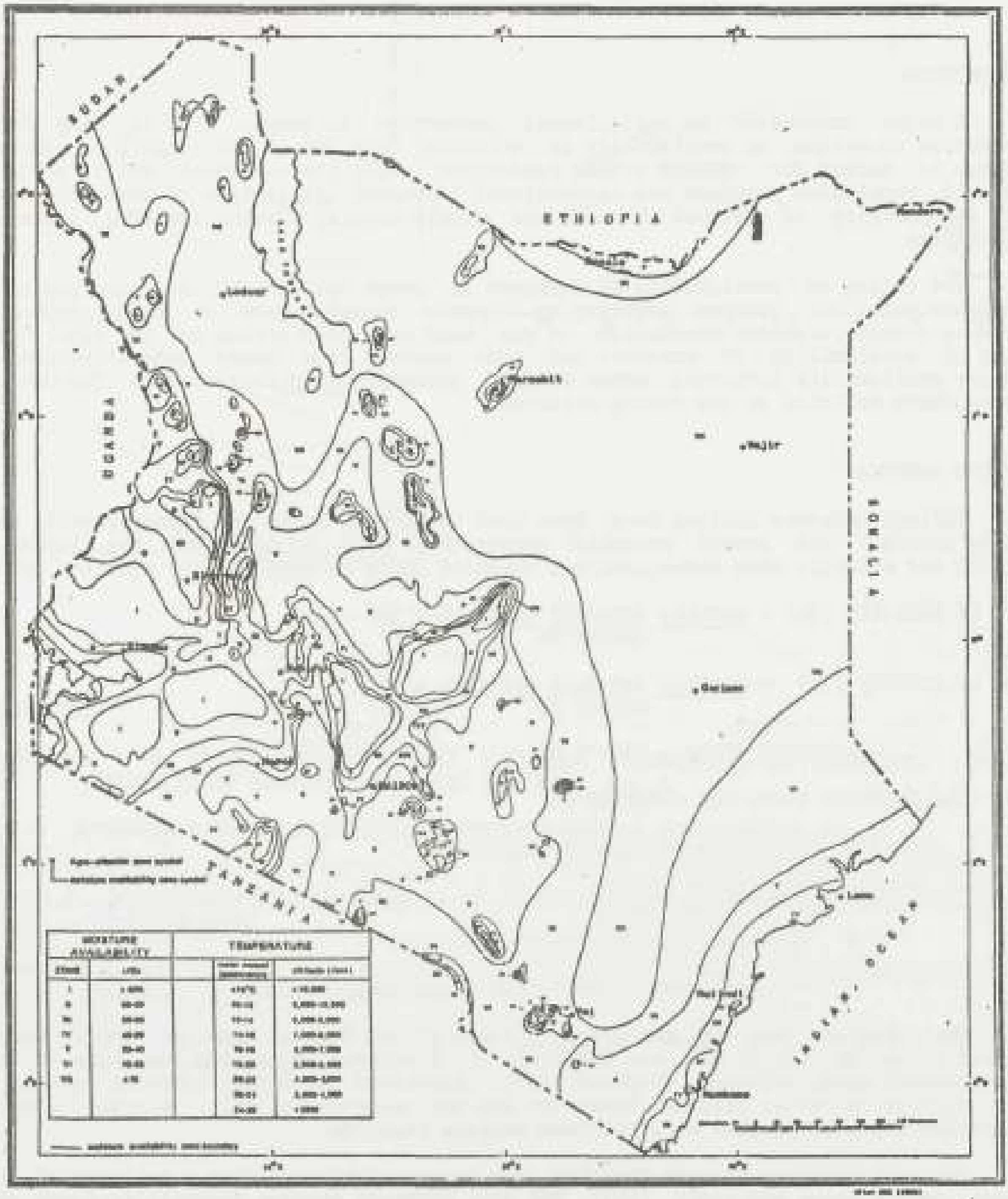

FIG. 1 AGRO-CLIMATIC ZONES OF KENYA

The r/Eo based moisture index of Braun (1977) is a simple but useful indicator of agricultural productivity on a national or regional level, however it falls short when the productivity of a specific area is considered.

Jaetzold et al. (1982) using the FAO Agro-ecological Zone Methodology (1978) delineated the agro-ecological zones of Kenya. The ecological zones are based on the probability that the temperature and water requirements of a crop will be fully met within an area.

This methodology takes into account the soil moisture storage, effective rainfall, rooting volume of the crop and a progressively changing crop coefficient through the several stages of crop development. The yield expectations (suitability ranking) of an area is given in terms of a probability (60%) that a given percentage of the optimum yield can be obtained. The ranking is as shown below:

Yield	% of optimum yield
Very good	80-100
Good	60-80
Fair	40-60
Poor	20-40
Very poor	0-20

The agro-ecological zone methodology has served its intended purposes well in terms of selection of the crops suitable for particular zones. The method is however based on the 1:1 000 000 Soil Map of Kenya (Sombroek et al. 1982); consequently, for larger scale of mapping, a methodology employing more specific data on soil moisture storage is necessary for evaluating the land quality availability of moisture.

A water balance approach using crop moisture deficits for rating availability of moisture for specific crops is presently being tested by the Kenya Soil Survey.

CRITERION FOR RATING AVAILABILITY OF MOISTURE

Since its inception, the Kenya Soil Survey has employed both agro-climatic zones and the soil moisture storage capacity for rating availability of moisture. The agro-climatic zones based on the ratio r/Eo, has been used broadly and qualitatively to indicate areas of differing moisture availability. The higher the ratio, the higher the available moisture. At the second level, soil moisture storage capacity is used to rate the availability of moisture per individual soil mapping unit. The total readily available moisture (TRAM), taken as moisture content at pF 2.3 minus moisture content at pF 3:7, is used as the criteria for rating soil available moisture storage capacity.

The total available moisture storage capacity integrated over the rooting depth of the soil is rated according to Table 1 (Braun and Van de Weg 1977).

Table 1 RATING OF TOTAL READILY AVAILABLE MOISTURE

	Rating	TRAM (mm)
1.	Very high	160-200
2.	High	120-160
3.	Moderate	80-120
4.	Low	40
5.	Very low	<40

Graphical correlations between total readily available moisture and clay content were used to estimate the available moisture where actual determinations were not available. These graphical correlations were tabulated for various textures and soil depths, as shown in Table 2.

The use of agro-climatic zones and total readily available moisture storage capacity has some limitations. First, quantification of availability moisture is not possible since the actual moisture content is not taken into account. Secondly, the graphical correlations used to estimate available moisture storage capacity was based on one soil characteristic (clay) within a limited geographical extent. Given these limitations, the Kenya Soil Survey is presently using a water balance approach which takes into consideration rainfall, soil moisture storage capacity, rooting depth and crop water requirements to calculate moisture deficits. The moisture deficits are employed as criteria for rating the land quality availability of moisture.

Table 2 RATING OF READILY AVAILABLE MOISTURE (mm) FOR VARIOUS TEXTURES AND DEPTHS

Soil depth (cm)	Textural class				
	LS	SL	SCL	SC	C
25	8	10	14	20	28
50	15	20	28	40	55
80	24	32	44	64	88
120	36	48	66	96	132
150	45	60	83	120	165
180	54	72	99	144	198

LS = Loamy sand; SL = Sandy loam; SCL = Sandy clay loam; SC = Sandy clay; C = Clay

(Source: Braun and Van de Weg 1977).

Moisture Deficit Approach

This method is both soil and crop specific. It involves the calculation of moisture deficits experienced by a crop during a selected period and subsequently uses the deficits to rate availability of moisture. Rainfall, rooting depth, soil moisture storage capacity and crop water requirements are all considered in these calculations.

a. **Determination of available moisture storage capacity**

The readily available moisture storage capacity (RAM) viz. the difference between moisture content at pF 2.3 and pF 3.7, and total available moisture (TAM) viz. the difference between moisture content pF 2.3 and pF 4.2 was determined for approximately 300 soil samples from all parts of the country. The determined moisture storage capacities were then regressed against the soil characteristics vide clay, silt, sand, carbon and bulk density. The resultant regression equations (i) and (ii) were used to estimate RAM and TAM where actual data was not available.

i. $RAM = 44.423-14.385X_1-0.24X_2-0.172X_3-0.097X_4-0.08X_5$
multiple R = 0.657

ii. $TAM = 17.846-12.735X_1 + 0.027X_2 \times 0.067X_3 \times 0.245X_4 - 0.363X_5$
multiple R = 0.685

where X_1 = bulk density; X_2 = percent clay; X_3 = percent sand; X_4 = percent silt and X_5 = percent carbon.

b. **Crop water requirements**

Penman Eo and crop coefficients of selected periods were used to estimate crop water requirements. For maize, Kc values used were 0.3, 0.7, 1.05 and 0.8 for initial, development, mid-season and late season respectively (Doorenbos and Kassam 1979). For coconut, Kc values ranging from 0.3 to 1.0 and cashew nut 0.5 - 0.85 (Gatahi 1983).

c. **Moisture deficit calculations**

Moisture deficits were calculated according to the equation

$$MD = P + SMS - Etc$$

where

MD = moisture deficit over selected periods;
P = rainfall for selected periods
SMS = soil moisture storage
Etc = crop evapotranspiration

Moisture deficits were calculated per decade during the various growth stages for maize. For coconut and cashew nuts, monthly moisture deficits were calculated. Cumulative moisture deficits of selected periods were regressed against yields. The regression equation obtained for maize was of the form:

$$Y = 5.64 - 0.257X \qquad (r^2 = 0.618)$$

where

Y = yield (tons/ha)
X = cumulative moisture deficit

The regression equation relating to copra yield (Y) to moisture deficits during 29 and 24 months (X_1 and X_2) preceding the year of harvest respectively are:

$$Y = 218.89-0.049X_1 \ (r^2 = 0.562), \text{ and}$$
$$Y = 221 - 0.058X2^1 \ (r^2 = 0.581)$$

The regression equation between cashew yield (Y) and August-December moisture deficit (X) is:

$$Y = 261 + 0.645X \ (r^2 = 0.593)$$

d. **Rating of availability of moisture using moisture deficit method**

Moisture deficits experienced by coconuts 24 months preceding harvest was found to be significantly correlated to copra yields and was therefore used to rate availability of moisture according to Table 3.

Table 3 RATING OF AVAILABILITY OF MOISTURE FOR COCONUT

Class	Range of moisture deficits (mm)
1	0 - 570
2	571 - 1140
3	1141 - 1700
4	1701 - 2200
5	>2200

Moisture deficits experienced by cashew nuts during the August-December period were also significantly correlated to yields. The rating criteria for availability of moisture is given in Table 4.

Table 4 RATING OF AVAILABILITY OF MOISTURE FOR CASHEW NUTS

Class	Range of average moisture deficits (mm)
1	<160
2	161 - 320
3	321 - 470
4	471 - 625
5	>625

The study for maize is still in progress and no conclusive ratings for availability of moisture have been established to date.

CONCLUSION

Difficulties have been experienced in rating availability of moisture using simple moisture indices. More elaborate approaches, for example, agro-ecological zones, are suited for delineating land use zones on regional and national scales. The moisture deficit approach is both crop and soil specific, furthermore it can be used to predict crop yields once significant relationships are established. It is therefore suitable for large scale resource maps.

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6.3 RATING OF LAND QUALITIES: MOISTURE AVAILABILITY

A COUNTRY APPRAISAL - ETHIOPIA

by

Frikru Abebe

SUMMARY

The moisture availability rating as part of a computerized Land Evaluation System to prepare semi-detailed land use plans at a scale of 1:50 000 is presented with special emphasis on the highlands of Ethiopia with minor reference to rainfed agriculture.

It is part of a land evaluation methodology developed during Phase II of the Land Use Planning Project of the Land Use Planning and Regulatory Department. The method of assessing moisture availability and diagnostic land characteristics of features considered necessary for estimating and rating soil moisture availability viz. climate [decadal or monthly precipitation values (mm), decadal or monthly PET-values (mm)], soil [depth of topsoil and subsoil (cm), texture of topsoil and subsoil, bulk density of topsoil and subsoil (g/cc), organic matter content of topsoil (%), permeability class of least permeable horizon, ground water table depth (cm), relative topographic situation], crops [crop-specific rooting depth (cm), crop coefficient Ko, available soil moisture depletion fraction (p) of crop] are outlined. Conclusions emanating from the discussions are also presented.

INTRODUCTION

With global and regional change in climatic pattern and a trend of grading towards drier conditions moisture availability most often becomes the most critical factor determining crop production. The mostly bimodal rainfall pattern in the Ethiopian highlands also shows considerable variation on the onset and duration of the rainy seasons thus causing substantial changes in cropping seasons and patterns over relatively short distances. Droughts usually occur at alarming frequencies with catastrophic consequences. Assessment and rating of moisture availability for land use planning purposes, therefore, become extremely essential in Ethiopia because soil moisture is perhaps the most important factor which limits crop growth and development.

Crops are affected by moisture availability through the effects of moisture stress on growth, and the possible death of the crop through drought.

Moisture stress occurs when soil water in the rooting zone falls substantially below field capacity. Either vegetative growth may suffer or fruiting may be affected. The moisture level at which stress effects first become apparent varies considerably between crops, e.g. vegetables need relatively continuous wet soils, whereas cotton and sorghum can deplete soil water much further before stress effects occur.

The severity of the effects of moisture stress varies according to the development stage of the crop.

Moisture availability is affected by climate, soil, landforms and hydrology. The initial determinant is the ratio between rainfall and potential evapotranspiration. Climatically determined moisture deficiency is modified by soil moisture storage, being lower for sandy and/or shallow soils and higher for deep loams or well structured clays. Further modifications are caused by valley-floor situations receiving run-off, by seepage sites or by the presence of ground water within rooting range.

The purpose of this paper is to highlight the major features of the model for assessing of moisture availability which involves calculation of crop specific LGP's based on available soil moisture and the rating of land quality: moisture availability for land use requirements.

1. ASSESSMENT OF MOISTURE AVAILABILITY

1.1 Soil Moisture Balance Model

The present assessment model for moisture availability determines the period at which moisture content in the soil is sufficient to permit crop growth. It gives a calculation of the moisture available to a specified crop (S_{10}) under defined soil, climatic and hydrological conditions for each ten day period (decade) of the year.

In its simplest form the soil moisture balance model reads:

$$S10 = So + \frac{Peff10 + gw10 - ETa10}{D} \qquad (1)$$

Where S10 = available soil moisture at the end of the decade (mm/m)

So = available soil moisture at the start of the decade = S10 or the preceding decade (mm/m)

D = crop specific rooting depth or soil depth (effective rooting depth) or depth of the ground water table during the growing season, whichever is shallower (m)

Peff10 = effective precipitation during the decade (mm)

gw10 = ground water contribution during the decade (mm)

ETa10 = actual evapotranspiration during the decade (mm)

Soil moisture availability in a defined decade consequently should fulfill the following condition if the decade is to be considered part of the growing period for a specific crop:

$$S10 \quad 1/3\ (1-P)\ Sa \qquad (2)$$

Where S10 = available soil moisture at the end of decade (mm/m)

P = soil moisture depletion fraction (readily available soil moisture fraction)

1-P = not readily available soil moisture fraction

Sa = total available soil moisture (mm/m) for a given soil

The principal equation (2) is applied to the crop specific rooting depth.

The soil moisture balance of equation (1) can be rewritten in detail as follows:

$$S10 = So + \frac{Ci \times Cp \times P10 + gw10 - Kw \times Kc \times Ko \times PET}{D} \qquad (3)$$

Where S10 = Available soil moisture at the end of the decade (mm/m)

So = Available soil moisture at the start of the decade (mm/m)

Ci = rainfall intensity coefficient

Cp = Permeability and available soil moisture content coefficient

P10 = Precipitation during the decade (mm)

gw10 = ground water contribution during the decade (mm)

Kw = restricted soil moisture supply coefficient

Kc = Crop coefficient

PET = Potential evapotranspiration during the decade (mm).

D = Crop-specific rooting depth or soil depth (effective rooting depth) or depth of ground water table during the growing season, whichever is shallower (m)

The determination of the various parameters of soil moisture balance model is briefly outlined below:

a. Effective decadal precipitation, mm (P10) :

It is derived from monthly values by linear interpolation. In case of a deficient data base for monthly precipitation values, this data can be generated using a model developed within the Land Use Planning and Regulatory Department. Thus P10 is obtained either by measuring, generating or interpolation.

b. Ground water contribution during the decade, mm (gw10) :

Very detailed experiments are required to determine the ground water contribution under field conditions. Therefore in the moisture balance model a standardized contribution of 10 mm per decade is assumed, if the conditions in Table 1 are met.

Table 1 COMBINATION OF GROUND WATER - LEVEL AND TEXTURE CLASSES ENABLING STANDARDIZED GROUND WATER CONTRIBUTION (10 mm/decade) AT SPECIFIED ROOTING DEPTHS

Crop-specific rooting depth (cm)	Ground water level (cm)	Texture class
any	<50	any
<50	50 - 100	finer than sand
<50	100 - 150	only sandy loam
50 - 100	50 - 100	any
50 - 100	100 - 150	finer than sand
50 - 100	150 - 300	only sandy loam
100 - 150	50 - 100	any
100 - 150	100 - 150	any
100 - 150	150 - 300	finer than sand

In all other cases no ground water contribution is assumed.

c. Actual evapotranspiration during the decade, mm (ETa10)

The decadal potential evapotranspiration data is derived by linear interpolation from the monthly values. If the latter is scarce or deficient either rough estimates should be made or based on deficient data, more complete data sets should be generated using a model developed within LUPRD.

d. **Crop specific rooting depth, m (D)**

The rooting depth from which crops extract moisture is considered as the soil depth or the depth of the ground water table during the growing season whichever is shallower.

e. **Available soil moisture at the start of the decade, mm/m (So)**

For the calculation of S10 of the first decade (S0) of the year, it has been arbitrarily defined as being equal to 0.2 cm since So is assumed to be 20% of the total available soil moisture.

1.2 Length of Growing Period and Assessment of Moisture Availability

The parameters calculated above allow the determination of the length of the growing periods. For each decade of the year it has to be decided if the available soil moisture (S10) does support crop growth (humid decade) or does not permit crop growth (dry decade). In order to be considered humid the available soil moisture (S10) has to meet the conditions given in equation (2).

$$S10 \geq 1/3\ (1-P)\ Sa$$

with S10 and Sa expressed in mm/m rooting depth.

Equation (2) in principle refers to the limiting depth (generally the crop-specific rooting depth). However, at the start of the rainy season, it is applied only to the upper 30cm of the soil. For this layer a standardized total moisture availability of 20 mm has been assumed for all soils. As long as the S10 for this upper 30 cm (S10u) is <15 mm equation (2) is applied to this layer. When S10u $\geq$ 15 mm, it is assumed that the entire rooting depth is sufficiently moistened and equation (2) is applied to the limiting depth.

After all decades are assessed in this way the length of the growing periods occurring in the year can be calculated. The calculation differs for annual crops and perennial crops.

The perennial crops include coffee, tea, banana, citrus, sugarcane, pineapples, sisal, cassava, grape and ensete. All the remaining crops are annuals. In the case of annual crops each sequence of humid decade is added up, however, without considering an interruption of one dry decade. Generally it will be found that several growing periods of varying duration occur. In the Ethiopian highlands a bimodal rainfall pattern is predominant, but monomodal rainfall patterns do occur as well. Moreover the two rainy seasons 'Belg' and 'Kremt' may merge to one long season. Therefore only the one or two longest growing periods are taken into consideration. Although not always coinciding with the traditional rainy seasons Belg and Kremt, the two longest growing periods will be characterized as Belg and Kremt to avoid lengthy characterizations.

In the case of perennial crops, the length of the growing period is determined by adding up all humid decades throughout the whole year irrespective of the duration of the dry spells in between.

Both for the annual and perennial crops the calculation of the period is carried out on a year by year basis. From the number of years data available or generated, it is possible to calculate the mean value of the growing period together with its standard deviation.

The final assessment of the moisture availability is carried out by comparing the calculated length of the growing period (LGP) at a certain confidence limit with the requirements of the crop, i.e. with the growing cycle duration required by the specific crop.

The length of the growing period will vary according to the confidence limit applied. The above described assessment model will result in a mean value for the LGP, i.e. confidence limit of 50%. For agricultural planning purposes this confidence limit is inadequate. The confidence limits of 75% (3 out of 4 years) or 80% (4 out of 5 years) have a much higher predictive value.

Based on the calculated mean LGP - range for other confidence limits, assuming a Gauss distribution can be determined using the following equation:

$$LGPn = LGP50 \underline{+ c} \ SD$$

Where LGPn = Length of growing period for confidence limit n (days)

LGP50 = mean length of growing period (days)

c = Coefficient determined by confidence limit (see below)

SD = Standard deviation (days)

The values of c for various confidence limits are as follows:

Confidence limit (n)	Coefficient (c)
50%	0
66%	0.43
75%	0.675
80%	0.842
90%	1.282

The above equation will result in a range of the LGP values, which does occur at a certain confidence limit. The highest and the lowest LGP values of this range are matched separately with the requirements of the crop. The lowest of the factor ratings is selected as the final one for the land quality moisture availability.

2. SURVEY OF DIAGNOSTIC LAND CHARACTERISTICS

Most of the climate and soil related diagnostic characteristics are routinely collected during field surveys. Others, like bulk density, organic matter content and permeability, can be estimated in the field but should be backed up by laboratory analyses (bulk density, organic matter) or field tests (permeability) on representative soils.

The crop specific information required is reasonably well documented for common crops or should be estimated for less well known crops such as niger seed, ensete, etc.

3. LAND USE REQUIREMENTS AND RATING OF MOISTURE AVAILABILITY

Each crop can only achieve optimum yield when its growth cycle (from germination to crop maturity) fits comfortably within the growing period, i.e. the crop must be allowed to proceed unimpeded through its various development stages. However, a situation in which the growing period becomes shorter than the growth cycle required by a particular crop does not necessarily render the crop unsuitable for cultivation but may result in a reduction in yield or quality of the crop since the time available for yield forming activities is curtailed.

Similarly yield losses or quality reducing effects can occur when the LGP is much longer than the LGP cycle.

For each crop an LGP range is defined in such a way as to permit optimum growth conditions and consequently result in a factor rating of S1 = highly suitable. Shorter as well as longer LGP values result in yield decreases and thus in lower factor ratings. In Tables 2 and 3 these LGP ratings are indicated for each crop. As input-management levels influence the optimum LGP ranges, two sets of factor ratings have been defined. A matter that complicates the determination of the optimum length of the growing period for a specific crop is that its growth cycle is temperature dependent. Under colder conditions, a crop needs a longer period to reach full maturity. For the Ethiopian highlands this implies that the higher the altitude a crop is grown, the longer the optimum length of growing period.

For several tropical crops this fact is not relevant, because they do not resist the colder tempertures of higher altitudes. However, for temperate crops or highland varieties of originally tropical crops (e.g., maize and sorghum) altitude strongly influences the growth cycle of the crops.

It has been assumed that the optimal length of growing period remains constant for all crops at altitudes below 1 800 m (mean annual temperature >20°C). In Tables 2 and 3 the length of the growing period that corresponds to the five factor ratings refers to this altitude.

The increase of the length of the growing period with an increase in altitude of 100 meters that corresponds to each crop has been determined (a linear correlation was assumed). As can be seen from Table 4, this correlation for the lower limits of the LGP-ranges (too short LGP) differs from that for the upper limits of the LGP (too long LGP). Apart from wheat and barley, this correlation is not influenced by input-management levels.

Once the LGP is obtained for the appropriate land units from the zonation of the study area either by analysis of rainfall and potential evapotranspiration data, or from the map of the growing period zones of Ethiopia, the next step will be to match the dependable LGP (80% reliable LGP) with the crop requirements for minimum LGP in Tables 2, 3 and 4, and assign a land suitability subrating. If the subrating for minimum LGP is S4 or N, match the median LGP with the requirements. If the subrating for median LGP is S3 or better, upgrade the 75% (or 80%) reliability subrating by one class (i.e. S4 to S3, or N to S4). Finally match the median LGP against the crop requirements for maximum LGP in Tables 2, 3 and 4 and assign a subrating accordingly. The final rating of moisture availability is the most limiting (the worst) of the subratings for the minimum LGP and the maximum LGP.

CONCLUSION

i. Because the land quality moisture availability is assessed on the basis of the length of the growing period for rating purposes, it conveniently allows the assessment, at the same time, of constraints due not only to excessively long growing periods but also moisture availability due to growing periods which are too short.

ii. Though complex, the moisture balance model used to assess soil moisture availability and rating is more accurate than any other available methods and models.

iii. The model used to assess soil moisture availability must be continually verified and validated in the field.

Table 2 FACTOR RATING FOR LGP REQUIREMENTS OF CROPS PRODUCED AT LOW AND INTERMEDIATE INPUT MANAGEMENT LEVEL

Crop	Factor rating	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Very marginally suitable S4	Not suitable N
Sorghum		100 - 240	90 - 100 240 - 270	80 - 90 270 - 285	75 - 80 285 - 310	< 75 days >310 "
Maize		100 - 255	90 - 100 255 - 300	80 - 90 300 - 345	75 - 80 345 - 365	< 75 "
Rice (Upland)		200 - 365	170 - 200	150 - 170	100 - 160	<100 "
Wheat		115 - 240	100 - 115 240 - 265	90 - 100 265 - 285	80 - 90 285 - 310	< 80 " >310 "
Barley		105 - 240	90 - 105 240 - 265	80 - 90 260 - 285	75 - 80 285 - 310	< 75 " >310 "
Teff		95 - 230	80 - 95 230 - 255	70 - 80 255 - 295	65 - 70 295 - 350	< 65 " >350 "
Oats		105 - 240	90 - 105 240 - 265	80 - 90 265 - 285	75 - 80 285 - 310	< 75 " >310 "
Fieldpeas		95 - 265	75 - 95 265 - 305	70 - 75 305 - 340	60 - 75 340 - 365	< 60 "
Haricotbeans		95 - 265	75 - 95	70 - 75 305 - 340	60 - 75 340 - 365	< 60 "
Horsebeans		96 - 265	75 - 95	70 - 75	60 - 70	< 60 "
Chickpeas		95 - 265	75 - 95 265 - 315	70 - 75 315 - 350	60 - 70 350 - 365	< 80 "
Lentils		95 - 265	75 - 95 265 - 315	70 - 75 315 - 350	60 - 70 350 - 365	< 80 "
Vetch		95 - 265	75 - 95 265 - 315	70 - 75 315 - 350	60 - 70 350 - 365	< 60 "
Soyabeans		100 - 245	85 - 100 245 - 295	65 - 85 295 - 330	60 - 75 330 - 365	< 65 "
Coffee		240 - 300	220 - 240 300 - 345	200 - 220 345 - 365	180 - 200	<180 "
Tea		240 - 365	210 - 240	195 - 210	180 - 195	<180 "
Banana		355 - 365	340 - 355	310 - 340	285 - 310	<285 "
Citrus		240 - 365	210 - 240	195 - 210	180 - 195	<180 "
Sugarcane		315 - 365	265 - 315	230 - 265	195 - 230	<195 "
Pepper		150 - 270	130 - 150 270 - 300	110 - 130 300 - 330	90 - 110 330 - 365	< 90 "

Table 2 (Contd.)

Crop	Factor rating	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Very marginally suitable S4	Not suitable N
Shallot		160 - 365	145 - 160	130 - 145	100 - 130	<100 "
Tomato		130 - 270	110 - 130 270 - 300	100 - 110 300 - 330	90 - 100 330 - 365	< 90 "
White potato		120 - 255	100 - 120 255 - 285	85 - 100 285 - 315	70 - 85 315 - 340	< 70 " >340 "
Sweet potato		120 - 315	105 - 120 315 - 345	95 - 105 345 - 365	80 - 95	< 80 "
Cabbage		140 - 365	120 - 140	100 - 120	90 - 100	< 90 "
Pineapple		360 - 365	330 - 360	315 - 330	300 - 315	<300 "
Sisal		270 - 365	240 - 270	225 - 240	210 - 225	<210 "
Niger seed		120 - 150	110 - 120 150 - 210	100 - 110 210 - 240	90 - 100 240 - 270	< 90 " >270 "
Sesame		135 - 195	120 - 135 195 - 210	90 - 120 210 - 240	75 - 90 240 - 270	< 75 " >270 "
Sunflower		140 - 210	120 - 140 210 - 240	90 - 120 240 - 300	75 - 90 300 - 330	< 75 " >350 "
Safflower		150 - 240 240 - 300	135 - 150 240 - 300	120 - 135	90 - 120	< 90 "
Flax (linseed)		130 - 240	110 - 130 240 - 270	90 - 110 270 - 300	80 - 90 300 - 330	< 80 " >330 "
Tobacco		180 - 240	140 - 160 240 - 270	100 - 140 270 - 300	90 - 100 300 - 330	< 90 " >330 "
Cassava		364 - 365	300 - 364	270 - 300	210 - 270	<210 "
Cotton		140 - 235	130 - 140 235 - 280	120 - 130 280 - 310	100 - 120 310 - 340	<100 " >340 "
Groundnut		140 - 255	125 - 140 255 - 300	110 - 125 300 - 345	90 - 110 345 - 365	< 90 "
Pearl millet		80 - 215	70 - 80 215 - 235	60 - 70 235 - 270	55 - 600 270 - 290	< 55 " 290 "
Finger millet		90 - 100	80 - 90 100 - 120	70 - 80 120 - 365	60 - 70	< 60 "
Grape		180 - 270	150 - 180 270 - 300	120 - 150 300 - 330	100 - 120 330 - 365	<100 "

Table 3 FACTOR RATING FOR LGP-REQUIREMENT OF CROPS PRODUCED AT HIGH INPUT-MANAGEMENT LEVEL

Crop / Factor rating	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Very marginally suitable S4	Not suitable N
Sorghum	100 - 240	90 - 100 240 - 270	80 - 90 270 - 290	75 - 80 290 - 310	< 75 days >310 "
Maize	100 - 265	90 - 100 265 - 310	80 - 90 310 - 355	75 - 80 355 - 365	< 75 "
Rice (upland)	200 - 365	170 - 200	150 - 170	100 - 150	<100 "
Wheat	115 - 230	100 - 115 230 - 265	90 - 100 265 - 290	80 - 90 290 - 305	< 80 " >305 "
Barley	105 - 230	90 - 105 230 - 265	80 - 90 265 - 290	75 - 80 290 - 305	< 75 " >305 "
Teff	95 - 240	80 - 90 240 - 255	70 - 80 255 - 300	65 - 70 300 - 320	< 65 " >320 "
Oats	105 - 230	90 - 105 230 - 265	80 - 90 265 - 290	75 - 80 290 - 305	< 75 " >305 "
Fieldpeas	95 - 215	75 - 95 215 - 270	70 - 75 270 - 315	60 - 70 315 - 365	< 60 "
Haricotbean	95 - 215	75 - 95 215 - 270	70 - 75 270 - 315	60 - 70 315 - 365	< 60 "
Horsebeans	95 - 215	75 - 95 215 - 270	70 - 75 270 - 315	60 - 70 315 - 365	< 60 "
Chickenpeas	95 - 255	75 - 95 255 - 290	70 - 75 290 - 325	60 - 70 325 - 365	< 60 "
Lentils	95 - 255	75 - 95 255 - 290	70 - 75 290 - 325	60 - 70 325 - 365	< 60 "
Vetch	95 - 255	75 - 95 255 - 290	70 - 75 290 - 325	60 - 70 325 - 385	< 60 "
Soyabeans	100 - 225	85 - 100 225 - 280	75 - 85 280 - 325	65 - 75 325 - 385	< 65 "
Coffee	240 - 300	220 - 240 300 - 345	200 - 220 345 - 365	180 - 200	<180 "
Tea	240 - 365	210 - 240	195 - 210	180 - 195	<180 "
Banana	355 - 365	340 - 355	310 - 340	285 - 310	<285 "
Citrus	240 - 365	210 - 240	195 - 210	180 - 195	<180 "
Sugarcane	315 - 365	285 - 315	230 - 265	195 - 230	<195 "
Pepper	150 - 270	130 - 150 270 - 300	110 - 130 300 - 330	90 - 110 330 - 365	< 90 "

Table 3 (Contd.)

Crop	Factor rating	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Very marginally suitable S4	Not suitable N
Shallot		160 - 365	145 - 160	130 - 145	100 - 130	<100 days
Tomato		130 - 270	110 - 130 270 - 300	100 - 110 300 - 330	90 - 100 330 - 365	< 90 "
White potato		120 - 255	100 - 120 255 - 285	85 - 100 285 - 315	70 - 85 315 - 340	< 70 " >340 "
Sweet potato		120 - 300	105 - 120 300 - 350	95 - 105 350 - 365	80 - 95	< 80 "
Cabbage		140 - 365	120 - 140	100 - 120	90 - 100	< 90 "
Pineapple		360 - 365	330 - 360	315 - 330	300 - 315	<300 "
Sisal		270 - 365	240 - 270	225 - 240	210 - 225	<210 "
Niger seed		120 - 150	110 - 120 150 - 210	100 - 110 210 - 240	90 - 100 240 - 270	< 90 " >270 "
Sesame		135 - 195	120 - 135 195 - 210	90 - 120 210 - 240	75 - 90 240 - 270	< 75 " >270 "
Sunflower		140 - 210	120 - 140 210 - 240	90 - 120 240 - 300	75 - 90 300 - 330	< 75 " >330 "
Safflower		150 - 240	135 - 150 240 - 300	120 - 135 300 - 365	90 - 120	< 90 "
Flax (linseed)		130 - 240	110 - 130 240 - 270	90 - 110 270 - 300	80 - 90 300 - 330	< 80 " >330 "
Tobacco		160 - 240	140 - 160 240 - 270	100 - 140 270 - 300	90 - 100 300 - 330	< 90 " >330 "
Cassava		300 - 365	270 - 300	210 - 270	150 - 210	>150 "
Cotton		140 - 235	130 - 140 235 - 280	120 - 130 280 - 315	100 - 120 315 - 350	<100 " >350 "
Groundnut		104 - 255	125 - 140 255 - 300	110 - 125 300 - 345	90 - 110 345 - 365	< 90 "
Pearl millet		80 - 220	70 - 80 220 - 225	60 - 70 255 - 275	55 - 60 270 - 300	< 55 " >300 "
Finger millet		90 - 100	80 - 90 100 - 120	70 - 80 120 - 365	60 - 70	< 60 "
Grape		180 - 270	150 - 180 270 - 300	120 - 150 300 - 330	100 - 120 330 - 365	<100 "

Table 4. ALTITUDE DEPENDENT INCREASE OF LGP REQUIREMENT OF CROPS FOR ALTITUDE ABOVE 1 800 m (APPLICATION TO ALL INPUT MANAGEMENT LEVELS)*

Sorghum	Short LGP	:	18 days/100m	long LGP	:	9 days/100m
Maize	Short LGP	:	18 days/100m	long LGP	:	8 days/100m
Rice (paddy)	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Rice (upland)	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Wheat	Short LGP	:	7 days/100m	long LGP	:	4 days/100m
Barley	Short LGP	:	7 days/100m	long LGP	:	4 days/100m
Teff	Short LGP	:	7 days/100m	long LGP	:	4 days/100m
Oats	Short LGP	:	7 days/100m	long LGP	:	4 days/100m
Field peas	Short LGP	:	7 days/100m	long LGP	:	4 days/100m
Haricotbeans	Short LGP	:	5 days/100m	long LGP	:	0 days/100m
Horsebeans	Short LGP	:	5 days/100m	long LGP	:	0 days/100m
Chickpeas	Short LGP	:	5 days/100m	long LGP	:	0 days/100m
Lentils	Short LGP	:	5 days/100m	long LGP	:	0 days/100m
Vetch	Short LGP	:	5 days/100m	long LGP	:	0 days/100m
Soyabeans	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Coffee	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Tea	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Banana	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Citrus	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Sugarcane	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Pepper	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Shallot	Short LGP	:	2 days/100m	long LGP	:	0 days/100m
Tomato	Short LGP	:	2 days/100m	long LGP	:	0 days/100m
White potato	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Sweet potato	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Cabbage	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Pineapple	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Sisal	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Niger seed	Short LGP	:	2 days/100m	long LGP	:	0 days/100m
Sesame	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Sunflower	Short LGP	:	4 days/100m	long LGP	:	0 days/100m
Safflower	Short LGP	:	3 days/100m	long LGP	:	0 days/100m
Flax (linseed)	Short LGP	:	2 days/100m	long LGP	:	0 days/100m
Tobacco	Short LGP	:	3 days/100m	long LGP	:	0 days/100m
Cassava	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Cotton	Short LGP	:	0 days/100m	long LGP	:	0 days/100m
Groundnut	Short LGP	:	6 days/100m	long LGP	:	0 days/100m
Pearl millet	Short LGP	:	10 days/100m	long LGP	:	6 days/100m
Finger millet	Short LGP	:	10 days/100m	long LGP	:	6 days/100m
Grape	Short LGP	:	20 days/100m	long LGP	:	0 days/100m

* only for low and intermediate input management levels; for high input-management level 2 days/100 m.

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6.4 RATING OF LAND QUALITIES: MOISTURE AVAILABILITY

A COUNTRY APPRAISAL - LESOTHO

by

Habofanoe Makhooane

ABSTRACT

This paper briefly describes land evaluation projects which have been executed in Lesotho, especially with respect to the rating of land quality as regards moisture availability. It is to be noted that the initial effort at land evaluation was undertaken in 1968 by Bawden & Carrol. This effort did very little in addressing climatic effects on land use practices. Most of the projects concerned aspects dealing with topography, soils and vegetation.

A subsequent effort in 1979 by the Soil Conservation Division of the Ministry of Agriculture (MOA) also dealt in very general terms with the effects of climate on land utilization. This effort mainly involved the evaluation of such soil characteristics as internal drainage, nutrient availability, nutrient retention, effective depth, erodibility and ease of cultivation without specifically addressing the climatic effects on moisture availability.

F.R. Berding, in his assessment of climatic zones of Lesotho in 1984, under the Institute of Land Use Planning of MOA, produced a document based on separate analysis of climatic factors and geomorphological units. This assessment addressed the length of the growing season which in Lesotho depends upon the period of available moisture and upon the frost free period. The beginning of the growing season has been defined as the point when rainfall exceeds 0.5 Potential Evapotranspiration, using the Penman method. This occurs in October in most agricultural areas in Lesotho. The growing season runs up to April. Although the crops reach maturity in March, the moisture availability up to April is regarded as important since winter crops such as winter wheat and peas will make use of this moisture.

The rainy season is used as an approximation of the start of the growing season. This growing season is taken as the first day of the first week of the rainy season provided that frost will not occur after that day at the 79% and 90% probability levels, and also the first week is close to the point when rainfall exceeds 0.5 PET (Penman). If frost occurs at the probability levels indicated above after the first day of the first week of the rainy season, the day after the last frost date is taken as the beginning of the growing period.

The soil series listed in Table 1 were selected on the basis of their extent and as the most used for crop production in Lesotho. Leribe, Khabo and Sephula soils are found mainly in the lowlands. Machache and Sefikeng occur in the foothills, while Thabana and Pusi occur mainly in the mountains.

The climatic assessment was not done for specific locations of these soil series but rather for general areas where they occur.

Table 1 EIGHT MAJOR SOIL SERIES OF LESOTHO AND THEIR CLASSIFICATION

Soil Series	Soil Taxonomy	FAO Classification
Leribe	Fine, mixed, mesic, Cumulic Hapludoll	Ferric Luvisol
Rama	Fine-loamy, siliceous thermic, Ultic Paleustalf	Ferric Luvisol Plinthic Luvisol
Thabana	Very fine, montmorillonitic, mesic, Typic Pelludert	Pellic Vertisol
Khabo	Fine-loamy, mixed thermic, Pachic Argiustoll	Luvic Phaeozem
Machache	Fine, mixed, mesic, Mollic Hapludalf	Chromic Luvisol
Sefikeng	Fine, halloysitic, mesic, Mollic Paleudalf	Humic/Ferric Acrisol
Fusi	Fine, mixed, mesic, Cumulic Hapludoll	Haplic Phaeozem
Sephula	Fine, mixed, thermic Albaquic Paleustalf	Solodic Planosol

Table 2 PHYSICAL CHARACTERISTICS OF MAJOR SOIL SERIES IN LESOTHO

Soil Series	Surface Texture	Internal Drainage	Permeability	AWC cm/cm
Leribe	L	Well	Moderate	0.16-0.18
Rama	VFSL	Mod. well	Moderate	0.13-0.17
Thabana	SiC	Moderate	Very slow	0.10-0.14
Khabo	SCL	Well	Mod. slow	0.15-0.16
Machache	C	Well	Mod. slow	0.16-0.18
Sefikeng	CL	Well	Moderate	0.16-0.18
Fusi	C	Well	Mod. slow	0.15-0.18
Sephula	VFSL	Mod. well too poorly	Slow	0.16-0.18

The physical properties of the major soil series which have bearing on soil water are shown in Table 2. Although the assessment was not meant to make a direct comparison among different soils, these properties will mean that some soils have an advantage over others in terms of crop moisture availability for given moisture conditions. Two characteristics have been determined for assessment of moisture availability.

1. Length of growing period

2. Total rainfall during growing season (October-March.

There are periods when dry spells are experienced during the growing season in Lesotho. It is during these periods that soils with good moisture retention properties give better crop protection against drought than those with not so good moisture retention properties.

To evaluate rainfall characteristics of different areas for crops it became necessary to consider the decrease of Potential Evapotranspiration with increasing elevation. The October-March PET totals for the 9 available stations are shown in Table 3.

Table 3 POTENTIAL EVAPOTRANSPIRATION

Station	Elevation	PET (Penman) Oct.-March	Average Rainfall Oct.-March(mm)	% PET
Maseru	1510m	822mm	541	66
Mohale's Hoek	1620m	820mm	553	67
Leribe	1670m	761mm	655	86
Butha-Buthe	1680m	709mm	620	87
Teyateyaneng	1690m	739mm	638	87
Quthing	1740m	790mm	584	74
Thaba-Tseka	2150m	658mm	455	69
Mokhotlong	2250m	734mm	480	65
Oxbow	2650m	553mm	911	165

In Figure 1 the October-March PET values are plotted against the evaluations as shown in Table 3. A drawn eye-fitted line indicates an average decrease of about 50 mm (PET) for every 300 mm increase in elevation. This means that in any average lowland area at 1 600 m the total PET (Penman) during October-March will be roughly 50 mm higher than an average foothill area at 1 900 m and roughly 100 m higher than an average lowland area at 2 200 m. All this suggests that if for a specific crop, the probability of October-March rainfall exceeding 500 mm is considered in the lowlands it may be necessary to consider only 450 mm in the foothills and only 400 mm in the lower mountains in order not to under-evaluate available rainfall at higher elevations.

The analysis made above shows the effect of climate at different locations as regards the actual available moisture during the growing season on the major soil series in Lesotho. This of course is influenced by the particular ability of the soil to retain moisture as shown in Table 2.

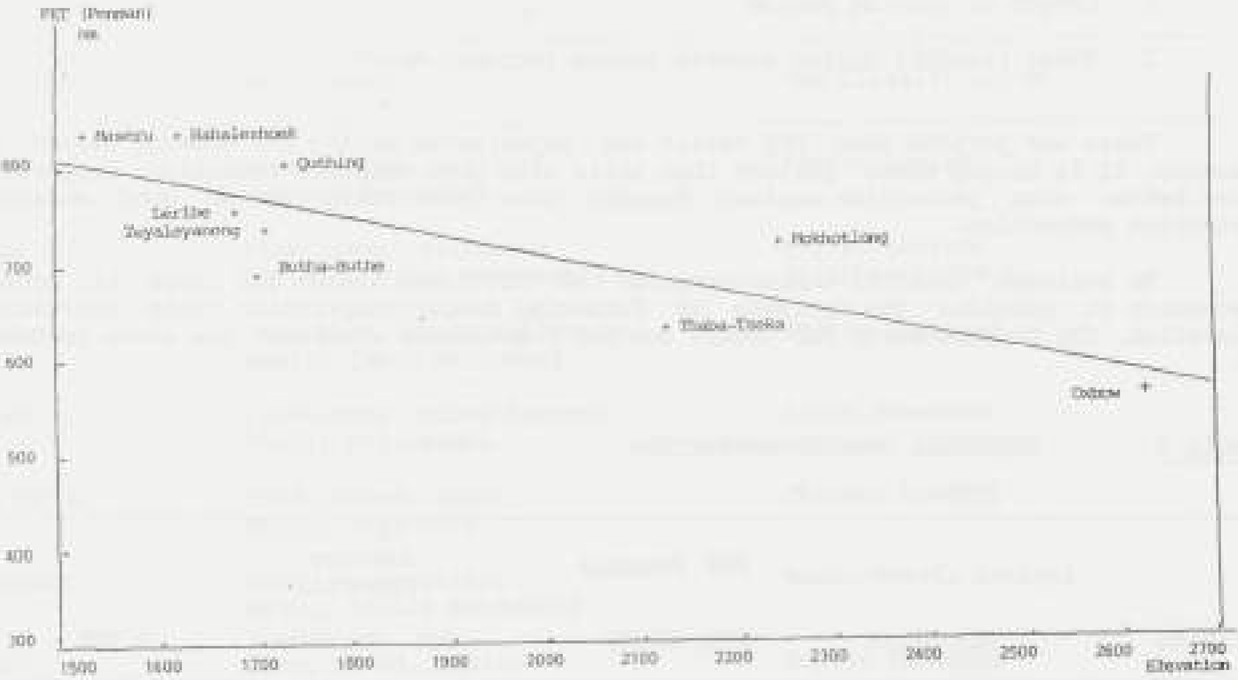

Fig. 1 Correlation of PET Penman with elevation (October-March)

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6.5 SUITABILITY RATING FOR MOISTURE AVAILABILITY

THE MODEL USED BY THE LAND RESOURCE EVALUATION PROJECT IN MALAWI

by

P. Banda

INTRODUCTION

Over the last two years, the Land Resources Evaluation Project (MLW/85/011) has developed land evaluation guidelines for rainfed cropping (Eschweiler 1988), forestry and extensive grazing in Malawi. The guidelines are primarily developed for land evaluation at reconnaissance and semi-detailed levels. They are based on the FAO Framework for Land Evaluation (1976) and designed to fit the Automated Land Evaluation System (ALES), designed by Cornell University (Rossiter et al. 1988). The model for rainfed arable farming includes submodels for ten land qualities. The submodel for moisture availability is the most complicated of the ten.

NATURE AND EFFECTS OF MOISTURE AVAILABILITY

Crops are affected by moisture availability through the effects of moisture stress on growth and possible death of the crop through drought. Moisture stress occurs when soil water in the rooting zone falls substantially below field capacity. However, crops vary considerably in their response to moisture stress and therefore the moisture level at which stress effects first become apparent, varies between crops (FAO 1983). When soil moisture falls below wilting point for more than a certain period, which varies from crop to crop, it will eventually cause the death of the crop. The most likely period for complete crop failure through drought is during emergence and establishment, i.e. before a deep rooting system has been established.

DIAGNOSTIC LAND CHARACTERISTICS

Moisture availability is one of the most difficult land qualities to assess as many land characteristics play roles, either directly or indirectly. From all the characteristics involved, rainfall (P) and potential evapotranspiration (PET) are the most important, although there are exceptional situations where other characteristics take over (e.g. land with high groundwater table or flooding, very steep and/or rocky land). Therefore, moisture availability is determined first from climatic characteristics and then modified through the combined effects of physiographic and edaphic characteristics. The selection of parameters is not only influenced by their relevance to the assessment of moisture availability but also by the availability of data. For example soil texture would not have been included as a diagnostic land characteristic if data were available on available moisture holding capacity of relevant types of soils.

The following land characteristics are used in the assessment of moisture availability:

CLIMATIC CHARACTERISTICS

- Precipitation (P): rainfall at monthly intervals
- Potential evapotranspiration (PET) (modified Penman): at monthly intervals
- Physiographic characteristics
- Slope angle (5 classes: 0-2, 2-6, 6-13, 13-25, >25%)
- Position in landscape (2 classes: water shedding and water receiving)

SOIL CHARACTERISTICS

- Soil classification (choice of 2: vertic/mopanic or other groups)
- Content of stones and gravel (2 classes: <40% or >40%)
- Topsoil texture (2 classes: coarse or medium-fine)
- Mean texture soil profile up to a depth of 150 cm (2 classes: coarse or medium-fine)
- Effective depth (3 classes: <50, 50-100, >100 cm)
- Occurrence of surface crusting: (2 classes: none-slight and moderate-severe)

Moisture availability can only be assessed for specific crops or groups of crops. Important in this respect are the rooting characteristics of the various crops and their ability to survive periods of moisture stress.

CROPS CHARACTERISTICS.

- Optimal rooting depth (3 classes: <50, 50-150, >150 cm)
- Drought resistance (3 classes: low, moderate, high)

ASSESSMENT

1. For a certain land unit, determine the Length of Growing Period (LGP): i.e. the period in days when moisture supply exceeds half potential evapotranspiration (P >0.5 PET), including the time required to evapotranspire 100 mm moisture assumed to be stored in the soil.

2. With the use of Table 1, match LGP with the requirements of a specific crop and determine LGP factor rating. The ratings are based on the agro-climatically attainable yield of a specific crop.

For topo-locations which receive not only moisture directly from rainfall but also through seepage and/or from runoff (e.g. lower footslopes, bottomlands, depressions, floodplains), the suitability rating for the LGP (Table 1) is taken as the final suitability rating for moisture availability for shallow and moderately deep rooting crops. For deep rooting crops (e.g. coffee, citrus, cashew, tea, and cotton), evaluated for very deep soil, this suitability rating is upgraded by one class.

For topo-locations which only receive moisture directly from rainfall, further adjustments are made for runoff, available waterholding capacity, moisture quality during the growing period (P/PET ratio) and crop drought resistance.

3. Estimate run-off as a function of slope, topsoil texture, soil classification and crusting as shown in Table 2.

4. To estimate the Available Water Holding Capacity (AWHC), the "actual rooting depth" has to be known. The "actual rooting depth" not only depends on soil depth, but also on the rooting characteristics of individual crops. Crops which do not root very deeply are unable to extract moisture stored in the lower subsoil. Therefore, shallow rooting crops (i.e. Irish potato, Phaseolus bean and cowpea), if evaluated for deep soils, are given ratings as for shallow soils. Crops which roots are very deep, extracting moisture from a depth of 150cm or more (e.g. coffee, citrus, cashew, tea, cotton), score very highly if evaluated for very deep soils. Estimate actual rooting depth as a function of soil depth and crop rooting characteristics as shown in Table 3.

5. Estimate AWHC as a function of actual rooting depth and particle size as shown in Table 4.

6. The factor rating found for LGP (Table 1) is now adjusted for the combined effect of runoff and AWHC of the soil as shown in Table 5. Adjustments are shown in whole (1.0) or half (0.5) suitability classes, e.g. a score of +1.0 means an adjustment from s2 to s1; a score of -0.5 an adjustment from s2 to s2/s3.

7. A further adjustment is for the "quality of the moisture supply" during the growing period and for the ability of crops to withstand moisture stress (i.e. drought). The ratio P/PET is used to express the quality of moisture supply during the growing period:

- low quality of moisture supply (P/PET <1): rainfall does not fully meet potential evapotranspiration and a slight to moderate moisture stress is created for crops throughout the growing period

- moderate quality of moisture supply (P/PET 1-1.3): short periods of slight to moderate moisture stress are likely to occur during the growing period. (Although this situation corresponds with a "normal" type of growing period, the "humid" period (i.e. P> PET) is likely to be of short duration and soil moisture storage is often not achieved to its full capacity)

- high quality of moisture supply (P/PET > 1.3): no moisture stress during the growing period.

Low to moderate moisture supply during the growing period normally occurs in areas with a short LGP (i.e. <165 days). Generally the shorter the LGP, the more pronounced the risk of having droughts. Table 6 gives the combined effect of various P/PET ratios and different classes of drought resistance of crops. The number of classes are shown by which the LGP factor rating is further adjusted after the first adjustment for increased run-off and limited AWHC. Adjustments in this case are only downwards, e.g. from s2 to s3.

QUANTIFICATION OF MOISTURE AVAILABILITY

The result of the assessment of moisture availability is expressed in the suitability sub-ratings (or sub-classes) s1, s2, s3 and n. Half, or intermediate classes are also distinguished, expressed as s1/2, s2/3 and s3/n respectively. These sub-ratings can be quantified in two ways:

i. in number of days that moisture is actually available for the growth of a certain crop. Table 1 gives the correlation between suitability sub-rating and length of growing period

ii. in maximum attainable yield. Assuming moisture availability is the only limiting land quality, the sub-rating for moisture availability is also the final overall land suitability class (i.e. s1, s2, s3 and n correlate with S1, S2, S3 and N). Overall land suitability classes (S1, S2, S3 and N) for a certain land use type have been correlated with maximum attainable yield for that land use type.

ACKNOWLEDGEMENTS

The presentation of this paper has been made possible with assistance from the Land Resource Evaluation Project (Ministry of Agriculture/UNDP/FAO, MLW/85/011) and with kind permission of the Department of Agricultural Research and the Malawi Government.

The paper is based on the work of Messrs J.A. Eschweiler, S. Paris and J.H. Venema, FAO experts of the Land Research Evaluation Project.

Table 1 SUITABILITY RATING FOR LGP REQUIREMENTS AND DROUGHT RESISTANCE FOR VARIOUS CROPS

CROP	LENGTH OF GROWING PERIOD (in days) 105-120	120-135	135-150	150-165	165-180	180-195	195 210	210-225	225 240	240-255	255-270	270-285	285-300	300-315	315-330	330-345	345-360	DROUGHT RESISTANCE
maize																		
(highland)	n	s3	s3	s2	s2	s2	s2	s1	s1	s1	s1	s1	s2	s2	s2	s3	s3	low
(lowland)	s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s2	s3	s3	s3	s3	s3	s3	low
sorghum	s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	n	n	n	n	n	moderate
wheat	s3	s2	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	s3	n	n	n	n	low
bulrush millet	s2	s2	s2	s1	s1	s1	s2	s2	s3	n	n	n	n	n	n	n	n	high
sunflower	s3	s2	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	s3	s3	s3	s3	n	moderate
soyabean	s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s2	s3	s3	n	n	n	n	low
groundnut																		
(highland)	n	n	s3	s2	s1	s1	s1	s1	s1	s2	s2	s3	s3	n	n	n	n	moderate
(lowland)	s3	s2	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	n	n	n	n	n	moderate
phaseolus bean	s3	s2	s2	s1	s1	s1	s1	s2	s2	s3	s3	s3	s3	s3	n	n	n	low
cowpea	s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s2	s3	s3	n	n	n	n	moderate
pigeon pea	s3	s2	s2	s1	s1	s1	s1	s1	s1	s2	s2	s3	s3	n	n	n	n	moderate
cassava	n	n	s3	s3	s3	s2	s2	s1	s1	s1	s1	s1	s1	s1	s1	s2	s2	high
irish potato	s3	s2	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	n	n	n	n	n	low
cotton	s2	s1	s1	s1	s1	s2	s2	s2	s3	s3	s3	s3	n	n	n	n	n	moderate
tobacco	n	s3	s2	s1	s1	s1	s1	s2	s2	s3	n	n	n	n	n	n	n	low
tea	n	n	n	n	n	n	s3	s3	s2	s2	s2	s1	s1	s1	s1	s1	s1	low
arabica coffee	n	n	n	n	n	n	s3	s2	s2	s1	s1	s1	s2	s2	s3	s3	s3	low
citrus	n	n	n	s3	s3	s2	s2	s2	s1	s1	s1	s1	s1	s2	s2	s3	s3	low
cashew	n	s3	s2	s1	s1	s1	s1	s2	s2	s3	s3	n	n	n	n	n	n	high
guar bean	s2	s2	s1	s1	s1	s1	s2	s2	s3	n	n	n	n	n	n	n	n	high

Table 2 RUN-OFF AS A FUNCTION OF (TOP) SOIL CHARACTERISTICS AND SLOPE

Characteristics Topsoil (0-50cm)	Slope (%)				
	<2	2-6	6-13	13-25	>25
Coarse texture	low	low	low	mod.	mod.
Medium or fine texture, moderate or high permeability (*) and none-slight crusting	low	low	mod.	high	high
(a) medium or fine texture with moderate-severe crusting or (b) medium or fine texture with low or very low permeability(*)	mod.	mod.	high	high	high

(*) the "mopanic" (high bulk density) and "vertic" soil groups of Malawi.

Note: upgrade one class in case of good soil/water conservation management.

Table 3 ACTUAL ROOTING DEPTH AS A FUNCTION OF SOIL DEPTH AND CROP ROOTING CHARACTERISTICS

Crop rooting characteristics	Soil Depth (cm) (*)			
	<50	50-100	100-150	>150
Shallow rooting crops	shallow	shallow	shallow	shallow
(moderately) deep rooting crops	shallow	mod. deep	deep	deep
Very deep rooting crops	shallow	mod. deep	deep	very deep

(*) depth to impermeable layer or layer with 80% coarse mineral fragments

Table 4 AVAILABLE WATERHOLDING CAPACITY AS A FUNCTION OF ACTUAL ROOTING DEPTH AND PARTICLE SIZE SOIL PROFILE

Particle size (*)	Actual rooting depth			
	shallow	mod. deep	deep	very deep
coarse texture with >40% coarse mineral fragments	low	low	low	medium
(a) coarse texture with <40% coarse mineral fragments or (b) medium or fine texture with >40% coarse mineral fragments	low	low	medium	high
medium or fine texture with <40% coarse mineral fragments	low	medium	high	very high

(*) average over upper 150 cm, or less if soil depth is less.

Table 5 ADJUSTMENTS TO LGP RATING FOR EFFECT OF RUN-OFF AND AVAILABLE WATERHOLDING CAPACITY

AWHC	Run-off		
	low	moderate	high
low	-0.5	-0.5	-1.0
medium	0	-0.5	-1.0
high	0	0	-0.5
very high	+1.0	+0.5	0

Table 6 ADJUSTMENT OF LGP FACTOR RATING FOR COMBINED EFFECT OF P/PET RATIO AND DROUGHT RESISTANCE OF CROPS

Crop drought resistance (see Table 1)	P/PET ratio		
	<1.0	1.0-1.3	>1.3
low	-1.0	-0.5	0
moderate	-0.5	0	0
high	0	0	0

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6.6 RATING OF LAND QUALITIES: MOISTURE AVAILABILITY

A COUNTRY APPRAISAL - BOTSWANA

by

T.D.Mafoko

INTRODUCTION

The development of a land evaluation system in Botswana started in 1981 in the context of the Soil Mapping and Advisory Services Project (BOT/80/003). These first rather ad hoc approaches were formulated by Venema, Eldridge and Remmelzwaal. In 1984 Venema and Rhebergen published a first version of this system in which the land quality "availability moisture" was based on the agroecological zone approach (FAO 1978), in which a simple water balance based on the rainfall in a mean year, lead to the calculation of length of available growing period. This approach proved less than satisfactory on a country scale. In 1984, Rhebergen introduced a system of climatic zones based on frequencies of efficiently long growing periods. This system was later refined by Dambe (1987).

To take into account soil characteristics in the evaluation of moisture availability, Rhebergen (1988) proposed a system of correction factors that started from a basic figure indicating the available water holding capacity of the soil and evaluated numerous characteristics, e.g. texture, soil depth, stoniness, bulk-density, infiltration rate, site characteristics and agroclimatic zone in which the soil was found.

Moisture Availability (m)

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.

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 required to evaporate as 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.

It should be noted that the potential evapotranspiration was calculated using the Penman method with constants reflecting local conditions (S.M.E.C. 1987).

The agro-climatic zones are the basis for the determination of the moisture availability rating for dryland farming.

2. <u>Water Retention Characteristics</u>

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 20 mm rainfall, while a crop on a dry clay soil will not respond to a 20 mm rainfall.

3. <u>Lateral Movement of Water in the Soil</u>

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. <u>Downward Movement of Water in the Soil</u>

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 function of plant rooting characteristics (shallow rooting plants vs. deep rooting plants). An important soil characteristic is the available water holding capacity.

5. <u>Effective rooting depth</u>

The effective rooting depth is influenced to a large extent by 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, abrupt textural change and sedimentary stratification.

PROCEDURE

i. determine the available water holding capacity (AWHC) according to Table 1

ii. correct AWHC for infiltration rate

iii. read moisture availability rating combining AWHC/infiltration rating and climatic zone and correct if necessary for site characteristics using Table 2

iv. give final rating after texture correction if applicable using Table 3

Table 1 AVAILABLE WATER HOLDING CAPACITY RATING ESTIMATED FROM TEXTURE, SOIL DEPTH AND STONINESS

Texture	Effective rooting depth (cm)				Stoniness (%)		
(Average 0-100cm or less if soil depth is less)	10-25	25-50	50-75	75	(average 0-100cm less if soil depth is less)		
					20	20-50	50-90
Coarse sand, sand	X				6	6	6
		X			6	6	6
			X		5	6	6
				X	5	5	6
Very find sand, fine and fine medium sand (7% clay), loamy coarse sand, loamy sand	X				6	6	6
		X			5	5	6
			X		4	5	5
				X	4	4	5
Loamy very find sand, loamy sand, coarse sandy loam and sandy loam with 18% clay and >65% sand fine sand (>7% clay)	X				6	6	6
		X			5	5	5-6
			X		4	4	5
			X	3	4	4	
Very fine sandy loam, fine sandy loam, (coarse) sandy loam with >18% clay or <65% sand, sandy clay loam, sandy clay, loam, silt loam, silt, non-vertic clay, vertic clay with >60% clay	X				5	5-6	6
		X			4	5	5
			X		3	4	4
				X	2	3	4
Fine sandy clay loam, fine sandy clay, silty clay, clay loam, silty clay loam, vertic clay with <60% clay	X				5	5	6
		X			3-4	4	5
			X		2	3	4
				X	1	2	3-4

Shove up texture column one step if high bulk density is found over a depth of last 25 cm within 75 cm 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 2 MOISTURE AVAILABILITY RATINGS ESTIMATED FROM CLIMATIC ZONES. AVAILABILITY WATER HOLDING CAPACITY (AWHC) AND SITE CHARACTERISTICS

climatic zone		AWHC	moisture availability rating			
			normal site	water receiving site		water shedding site
				seasonal	permanent	
IbI	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
Ib2	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
Ic2	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 Gomare	1	3	1-2	1	4
		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
Id3	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
Ie3	Gaborone	1	3	1-2	1	4
		2	3	1-2	1	4
		3	4	2-3	1-2	5
		4	4	3-4	2-3	5
		5	5	3-4	2-3	6
		6	6	4-5	3-4	6
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

Table 2 (contd.)

climatic zone	AWHC	moisture availability rating			
		normal site	water receiving site		water shedding site
			seasonal	permanent	
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 3.

Table 3 ESTABLISHMENT OF FINAL MOISTURE AVAILABILITY RATING APPLYING A TEXTURE CORRECTION

Texture (unless covered by at least 30cm of sand to sandy loam)	Rating Ib1, Ib2, Ic2, 2c2		Final rating climatic zone others
montmorillonitic sandy clay	1	2	3
to clay, fine sandy clay,	2	3	4
fine sandy clayloam, silt	3	4	5
loam, silt, silty clayloam, clay-	4	5	6
loam, silty clay	5	6	6

moisture availability rating

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

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6.7 MOISTURE AVAILABILITY AS A LAND QUALITY AN APPRAISAL FOR ZAMBIA

by

D.J. Banda

ABSTRACT

Moisture availability is perhaps the single most important factor influencing agricultural activity in Zambia. Not only are certain crops grown in particular parts of the country but they can also only be grown during specific periods of the year. Although it is usually modified by such other factors as soil characteristics, landforms and hydrology, moisture availability is largely dependent on climatic parameters. International classifications divide Zambia into three soil moisture regimes. The major part (85.1%) of the country has Typic Tropustic moisture regime while the remaining 11.5 and 2.0% have Aquic and Aridic Tropustic moisture regimes, respectively. Approximately 1.4% of the country is occupied by lakes. These regimes have different moisture characteristics. A land evaluation system being developed for Zambia has shown varying moisture availability ratings of these regimes for crop production. The Typic Tropustic regime is more suitable and has the widest range of suitable crops. The Aridic Tropustic moisture regime has serious drought hazards and the range of crops is limited. On the other hand the Aquic moisture regime has excess moisture with the resultant depletion of oxygen and suitable crops are mostly limited to paddy rice.

INTRODUCTION

To a greater extent Zambia agriculture is dependent on the natural moisture availability. A careful study and appraisal of moisture availability in the country is obviously one of the major steps in the national drive for increased agricultural productivity. However, to carry out this appraisal it is perhaps best, in the absence of extensive data, to go by soil moisture regimes. Classifications by the Soil Survey Staff (1987) and proposals by van Wambeke (1982) proposed three distinct soil moisture regimes in Zambia: the Aquic, Typic Tropustic and Aridic Tropustic. These have different moisture characteristics. A semi-quantified land evaluation system for rainfed agriculture in Zambia (Veldkamp 1987b) shows that suitability of these regimes for crop production varies widely. This paper is, therefore, a brief outline of the distribution and extent of the different soil moisture regimes. Moisture availability in these regimes is also rated for some selected common Zambia crops.

SOIL MOISTURE REGIMES OF ZAMBIA

Figure 1 shows the distribution and extent of the different moisture regimes in Zambia. Three major soil moisture regimes: Aquic, Typic Tropustic and Aridic Tropustic, are identifiable.

Aquic Soil Moisture Regime

This constitutes about 11.5% (8.6 million hectares) of the total area of Zambia. it mostly occurs in major dambos and zones of subsidence, some of which have since been filled with river alluvium to form the famous floodplains. Topography in these areas is generally very flat, perhaps this is the reason why some of the areas are popularly referred to as 'flats'. Geographically, these areas show a particular concentration towards the northern parts of the country, of annual rainfall totals exceeding 1 000 mm.

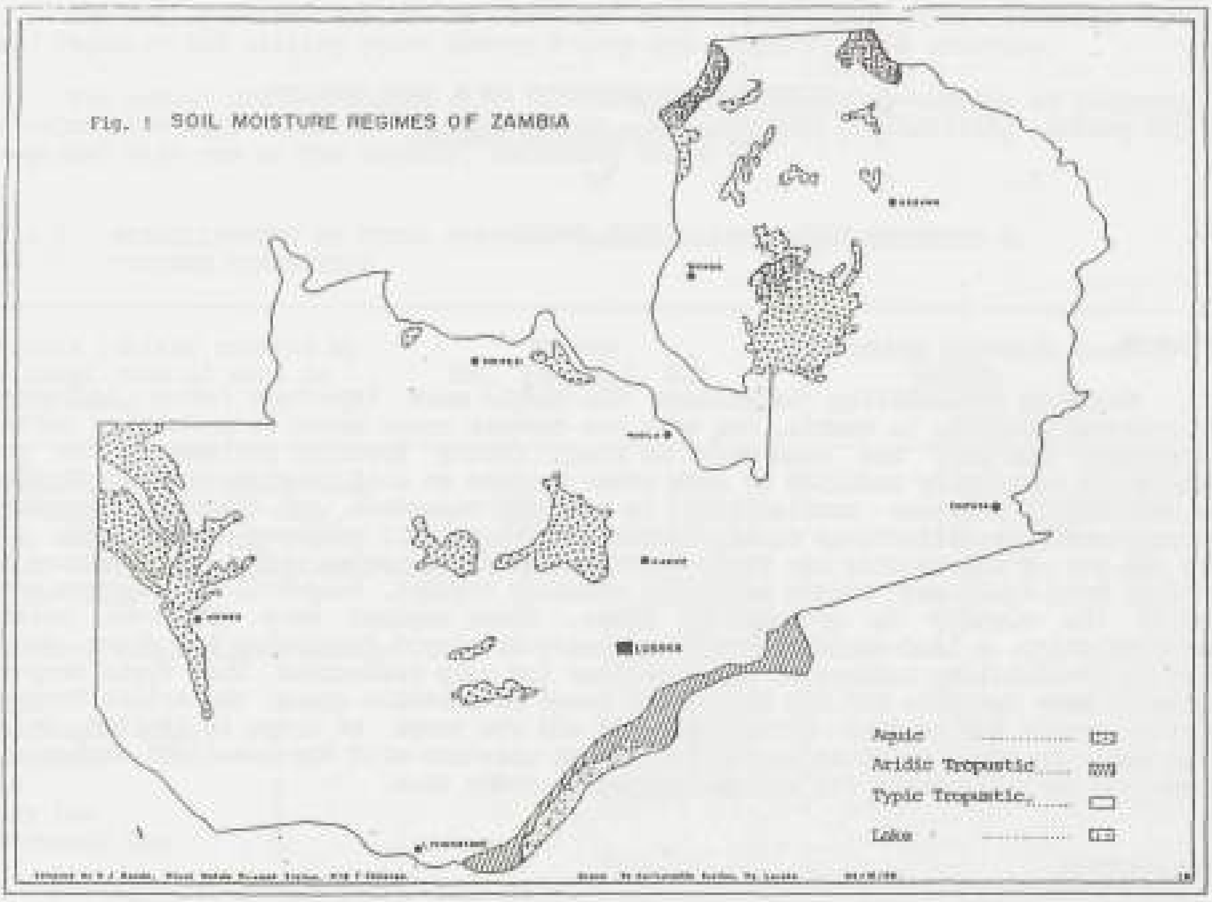

Fig. 1 SOIL MOISTURE REGIMES OF ZAMBIA

Soils are mostly young alluvial with variable textures, ranging from silts through loams to coarse sands. Moisture conditions range from moist to very wet in some parts within 1 m from the surface and the water table is entirely at the surface for the most part of the rainy season. Colours are also variable but tend to range from light gray to reddish yellow (Munsell N-5Y-10YR). The topsoil is often very rich inorganic matter and even becomes peaty in some cases. Soil reaction is generally medium to very strongly acid.

Length of the growing season ranges from 90-200 days, increasing northwards (Veldkamp, 1987a). Dry season frosts are characteristic, especially towards the south.

Typic Tropustic Moisture Regime

This is the most extensive moisture regime in the country. It occupies approximately 85.1% (64.1 million hectares) of the total area of Zambia, covering much of the central and northern parts. In this moisture range, the moisture control section is partly or completely moist between 180 and 270 days when soil temperature at a depth of 50 cm is more than 8°C (Van Wambeke 1982).

Soils are very variable but are medium to highly leached often with very low pH levels. Length of growing season varies from 100-200 days. Within the growing season there may be up to ten-day dry (30 mm rainfall) periods. Mild upland frosts could be expected for 1-2 days in July. The temperature regime is mostly Isohyperthermic.

Aridic Tropustic Moisture Regime

The Aridic Tropustic moisture range occurs exclusively in the Gwembe Valley in the southern part of the country. It occupies about 1.5 million hectares (2%). The moisture control section is partly or completely moist for only up to 180 consecutive days when the soil temperature at 50 cm is more than 8°C (Van Wambeke 1982).

Soils are mostly derived from calcareous sandstones and mudstones of the Karroo sedimentaries. Not much is known about the nature of these soils but recent surveys have indicated that a considerable number of them belong to the highly sodic Typic Natrustalfs (Banda 1988). This area is relatively drier and has been more susceptible to repeated crop failures due to moisture stress than the rest of the country. Length of growing season ranges from 80-110 days and may contain as many as 5 or more ten-day dry periods with rainfall less than 30 mm (Veldkamp 1987a). The soil temperature regime is Megathermic/Isomegathermic with rare upland frost.

MOISTURE AVAILABILITY RATING IN ZAMBIA

The work of Bunyolo **et al.** (1982) represents the first attempt to characterize and rate moisture availability in Zambia. Other than the annual rainfall, this work mostly considered the total available moisture and hinderances to root development. Moisture availability is largely dependent on climatic factors, mostly the balance between rainfall and the potential evapotranspiration. This is, however, most often modified by local environmental factors including soil characteristics, landforms and hydrology. A land evaluation system (Veldkamp 1987b) being developed for Zambia considers some of these factors in assessing moisture availability. Although most of the procedural details of this system are outside the scope of this paper, its major features are, however, outlined.

The system is based on the FAO (1983) guidelines. It considers a total of 21 land qualities among which is moisture availability. These are subdivided into some 79 sub-qualities. Furthermore, the system recognizes that moisture availability can either be restricted or excessive, in which case crop growth is limited due to moisture stress or oxygen depletion, respectively. Moisture availability, therefore, appears in five sub-qualities, viz excess rainfall, shortage in total minimum rainfall, length of growing season, waterlogging problems and general drought hazard.

Excess Rainfall

This mainly concerns excess rainfall during the rainy season which largely corresponds with the main growing season. Some crops are more sensitive to excess moisture than others. The northern parts of Zambia receive rainfall almost more than double the amount in the South. Severity of constraints formed by this sub-quality, therefore varies from North to South. The total annual rainfall data are directly used in rating this sub-quality.

Shortage in total minimum rainfall

This deals mainly with the effective rainfall derived from the annual total rainfall (70% probability). Corrections are made for the available water holding capacity as well as soil drainage class. It is downgraded for lower available water holding capacities on well drained soils.

Unfavourable length of growing season

The balance between precipitation and potential evapotranspiration is considered. The growing season starts when precipitation exceeds half potential evapotranspiration and ends when the reverse is true plus the time taken to deplete the soil moisture reserve. The length of growing season indicates the possible shortness of a cultivation season which may affect the later stages of crop growth as well as the final crop performance. This period shortens from the northern to the southern parts of the country where annual variations become even higher.

In the rating, corrections are made for the available water holding capacity, soil depth, gravel content and ground water influence within the upper 1 m. Downgrading is undertaken for low available water holding capacities, shallow soil depths, and high gravel content when there is no groundwater influence within the upper 1 m.

General drought hazards

This evaluates the general hazard of drought as well as consistent occurrences of droughty periods within the growing season. The number of dry (rainfall 30 mm) ten-day periods is used in the rating. Corrections are made for available water holding capacity of the soil, soil depth, gravel content and groundwater influence.

The hazard of droughts for most crops becomes pronounced in the South with low rainfall and shorter growing seasons. This corresponds with areas with the Aridic Tropustic soil moisture regime.

Waterlogging Problems

This sub-quality concerns the saturation of the topsoil with water during a period in which oxygen becomes depleted. Rating involves the actual physical observation of the period during which the top 0-25cm of the soil becomes waterlogged. The period may range from a few hours to more than a month. The longer the period the lower is the grading. These conditions are common in swampy areas with Aquic moisture regimes.

CONSTRAINT CLASSES

In the evaluation, each land quality forms a constraint, the severity of which varies. Before arriving at a constraint class, the basic rating is first determined during which various correction factors are considered (see Veldkamp 1987b for details). In all, five constraint classes are distinguished.

1a	-	none
1b	-	slight
2	-	moderate
3	-	severe
4	-	very severe

The most limiting constraint determines the final suitability class for a particular crop at a particular input level. With this evaluation system the different moisture regimes have been rated for moisture availability and following are the constraint classes for some selected common Zambian crops:

Table 1. CONSTRAINT CLASSES IN AQUIC MOISTURE REGIME

CROP	CONSTRAINT CLASSES					
	BE	WW	BM	LG	YD	MLC
Bulrush millet	3	4	1a	1a	1a	WW/BE
Maize	1b	4	1a	1a	1a	WW
Sorghum	2	4	1a	1a	1a	WW
Sunflower	1b	4	1a	1a	1a	WW
Soybeans	1b	4	1a	1a	1a	WW
Cotton	1b	4	1a	1a	1a	WW

Table 2: CONSTRAINT CLASSES IN TYPIC TROPUSTIC

CROP	MOISTURE REGIME					
	BE	WW	BM	LG	YD	MLC
Bulrush millet	2	1a	1a	1a	1a	BE
Maize	1a	1a	1a	1a	1a	-
Sorghum	1b	1a	1a	1a	1a	BE
Sunflower	1a	1a	1a	1a	1a	-
Soybeans	1a	1a	1a	1a	1a	-
Cotton	1a	1a	1a	1a	1a	-

Table 3 CONSTRAINT CLASSES IN ARIDIC TROPUSTIC MOISTURE CLASSES

CROP	CONSTRAINT CLASSES					
	BE	WW	BM	LG	YD	MLC
Bulrush	1a	1a	1a	1a	1a	-
Maize	1a	1a	3	1b	3	BM/YD
Sorghum	1a	1a	1a	1a	1a	-
Sunflower	1a	1a	3	1a	2	BM/YD
Soybeans	1a	1a	4	1a	2	"
Cotton	1a	1a	1a	1a	2	YD

Symbols:

BE - Excess Rainfall

BM - Shortage in total minimum rainfall

LG - Unfavourable length of growing season

YD - General drought hazard

WW - Waterlogging problems

MLC - Most limiting constraint (Sub-quality).

In the ratings, the following assumptions have been made:

a. Medium available water holding capacities (100-150 mm/m)
b. Soils are deep (1m or more)
c. No gravel within 1m depth.
d. Crop production is exclusively rainfed and at high input level (Veldkamp 1987b).

It is observed in the above results that different moisture regimes differ quite widely in their suitability for crop production. The Typic Tropustic moisture regime is more suitable for production of a wider range of both traditional and commercial crops. The high rainfall levels in the northern parts of this moisture regime are however somewhat limiting for production of sorghum and bulrush millet. The Aquic moisture regime has very severe waterlogging problems limiting production of most crops, except perhaps wetland rice varieties. The Aridic Tropustic moisture regime experiences severe to very severe shortages in total minimum rainfall as well as drought hazards. Only the drought resistant bulrush millet and sorghum are suitable for production in these areas. The range of crops in this moisture regime can only be increased with the provision of irrigation.

CONCLUSION

Three soil moisture regimes (Aquic, Typic Tropustic and Ardic Tropustic) occur, their boundaries approximately coincide with those of the country's rainfall belts. With regard to moisture availability, these zones have been shown to vary in their suitability for production of different crops. Thus while the general drought hazards and shortages in total minimum rainfall severely limit the production of maize, sunflower and soybeans in the drier South, these crops are highly suited for extensive cultivation in the North. In the South, the most suitable crops are bulrush millet, sorghum and cotton. Waterlogging problems in areas with Aquic soil moisture regime constitute very severe constraints for the production of most crops except, perhaps, paddy rice.

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6.8 RATING OF LAND QUALITIES: MOISTURE AVAILABILITY

A COUNTRY APPRAISAL - TANZANIA

by

S.E. Mugogo

INTRODUCTION

Tanzania is situated in the Eastern part of Africa, between 1° - 12° South and 29° - 41° East. It has an area of about 1 million km² of which roughly 90% is land and the rest is water. Tanzania has a population of 25 million people of which 90% are engaged in subsistence rainfed agriculture. Water availability is the major limiting factor to crop production since only 20% of the country receives more than 750 mm of the annual rainfall with a 90% probability. Even in many of the higher rainfall areas, the variability of rainfall in space and time is so great that the assessment of water availability for crop based on climate parameters forms an important part of land suitability evaluation.

Land quality is a complex attribute of the land with a distinct and individual influence on the suitability of land for a specific kind of use (FAO 1976).

Moisture availability: this land quality refers to the availability of moisture for plant growth as determined by water supply (rainfall), and water storage capacity of the soil and water out-take by evapotranspiration.

CHARACTERISTICS AFFECTING MOISTURE AVAILABILITY

Moisture availability is a function of the climate, soil physical condition and topography. Water, to be supplied by the soil to the plants is either stored in the root zone or rises by upward flow from the water table or the unsaturated subsoil to the root zone. Moisture availability is therefore defined as the amount of water which can be supplied to a crop in a well defined dry year when the moisture supply capacity is most limiting.

"Available water" is defined as water held between pressing the potential of 1/3 bar (33 KPa) (field capacity) and (1 500 K.Pa) 15 bar (wilting point). Values (in mm water) are accumulated for the depth of rooting.

Moisture availability: as indicated elsewhere, land quality is determined by climate, soil and topographic factors. Climatic factors which influence moisture availability include rainfall and evapotranspiration. Water is a key factor in the development of Tanzania and clearly, therefore, rainfall together with evaporation are the most important climatic elements.

Rainfall

Rainfall to a large extent determines the length of the growing period. The total amount of rainfall per year and its distribution in time and space greatly influences agriculture. In Tanzania there are 5 rainfall belts (<500 mm; 500-800 mm; 800-1 000 mm, 1 000-1 500 mm; and >1 500 mm mean annual rainfall per annum). The seasonal rainfall distribution in particular greatly influences agricultural practices.

There are three modes of rainfall distribution : Monomodal, bimodal and transitional. The mode of rainfall distribution determines the type of growing period. The distinction between "monomodal" and "bimodal" rainfall regimes is made on the basis of the occurrence of one or two rainfall peaks per year. Therefore in areas with a monomodal and transitional mode of rainfall there is one growing period and in a bimodal pattern of rainfall there are usually two growing periods per year. Single growing periods are usually suited for annual crops because the growing period is concentrated. In contrast, double growing periods are usually better suited for perennial crops. The separation of single from double growing period areas is based on the following criteria:

- a separation is only necessary if the secondary growing season is sufficiently long and reliable to influence agriculture

- the dry period between the two growing periods should be of such intensity that in most years soil moisture storage cannot compensate for inadequate rainfall and therefore cultivation of rainfed annuals is virtually excluded. In general it can be pointed out that rainfall is more reliable in areas with a monomodal pattern of rainfall than in areas with a bimodal pattern of rainfall.

Another very important aspect of climate to be considered in land evaluation is rainfall variability. This factor affects crop production in two ways:

- The time and duration of the growing season may vary considerably;

- Short term dry spells may occur within the growing season. The first situation implies that in years with timely and long growing periods, crop growth conditions in respect of moisture availability may be excellent and result in bumper harvests. Years with untimely and too short growing periods, drought and crop failures may occur even in areas with high average rainfall. This high variability rainfall makes planning of agricultural operations, particularly planting of crops, extremely difficult.

  Short term dry spells within the growing season are short rainless periods up to a few weeks in duration, which may interrupt crop growth and reduce yields. Their impact in yields depends on their timing and the drought tolerance of the particular crop.

  In areas with pronounced rainfall variability, a growing period that is based on average rainfall data has little practical meaning, because the growing period may vary greatly from year to year. In such areas the use of average data tends to mask extremes of moisture deficiencies and leads in general to an overestimation of the growing period and moisture availability. It becomes essential to analyse the variation of the growing periods by means of the total rainfall record rather than the average data and to derive likely conditions of moisture availability.

Rainfall intensity, duration and frequency

The foregoing rainfall characteristics are of great importance in assessing both **soil erosion and effective rainfall**. The latter refers to the rainfall that enters the soil and remains within the root zone. High rainfall intensity results in thunderstorms with an intensity that exceeds the threshold level at which rainfall becomes erosive. Moreover large storms of high intensity will result in considerable water losses by surface runoff and by deep percolation beyond the rooting zone, thus reducing the effective rainfall.

The soil factors which should be taken into account include particle-size distribution, bulk density, moisture retention and effective depth. These factors affect the inherent capacity of soils to store moisture within a given depth (the available waterholding capacity or AWC, expressed in mm/m).

There have been many studies carried out in Tanzania to determine moisture availability. However, two such studies warrant discussion since the results emanating from them are widely used at the moment at the national level.

The first such study was undertaken in the early seventies, when an attempt was made to establish agro-ecological zones in Tanzania. The first map had 19 agro-ecological zones based on parent material, total annual rainfall, rainfall pattern and total rainy days. The first revision in 1977 increased the number of zones to 30 and was based on temperature (as an indicator of evapotranspiration), total annual rainfall and soil parent materials. During the life of the NSS Project, a good deal of information on these parameters was collected and processed. Based on that information, a third revision was undertaken and in that edition a total of 20 agro-ecological zones based on parameters given in Table 1 were identified.

The Ecological zone map and the "Fertilizer recommendations related to ecological zones in Tanzania" (Samki **et al.** 1982) have been published as a technical document of the National Soil Service.

Another more recent study on agro-ecological zones was carried out in the late seventies and early eighties. Elements taken into consideration in this study include climate, physiography, soils, vegetation/land use and tsetse occurrence. These are the main physical factors that influence the potential and constraints to crop and livestock production. The main climatic factors specified by the agro-ecological zones map are temperature regime and the growing period. Moisture availability has been assessed by means of the growing period concept. In this study a concept of the "dependable growing period" was established. A "dependable growing period" is defined as the minimum period with sufficient moisture for crop production in 4 years out of 5. For example, a dependable growing period of 5 months implies that in 4 years out of 5 the growing period can be expected to be equal or longer than 5 months, and in 1 year out of 5 to be shorter. The working definition for dependable growing period adopted is "a period in which the actual evapotranspiration equals or exceeds half the potential evapotranspiration and whose duration is likely to be equalled or exceeded in four years out of five". A number of growing period key characteristics, particularly the duration and the onset date of the dependable growing period and their variability were estimated and mapped in "thirty moisture zones" that are fairly homogenous in their growing characteristics. The land quality "moisture availability" on the basis of the limitations is rated as follows:

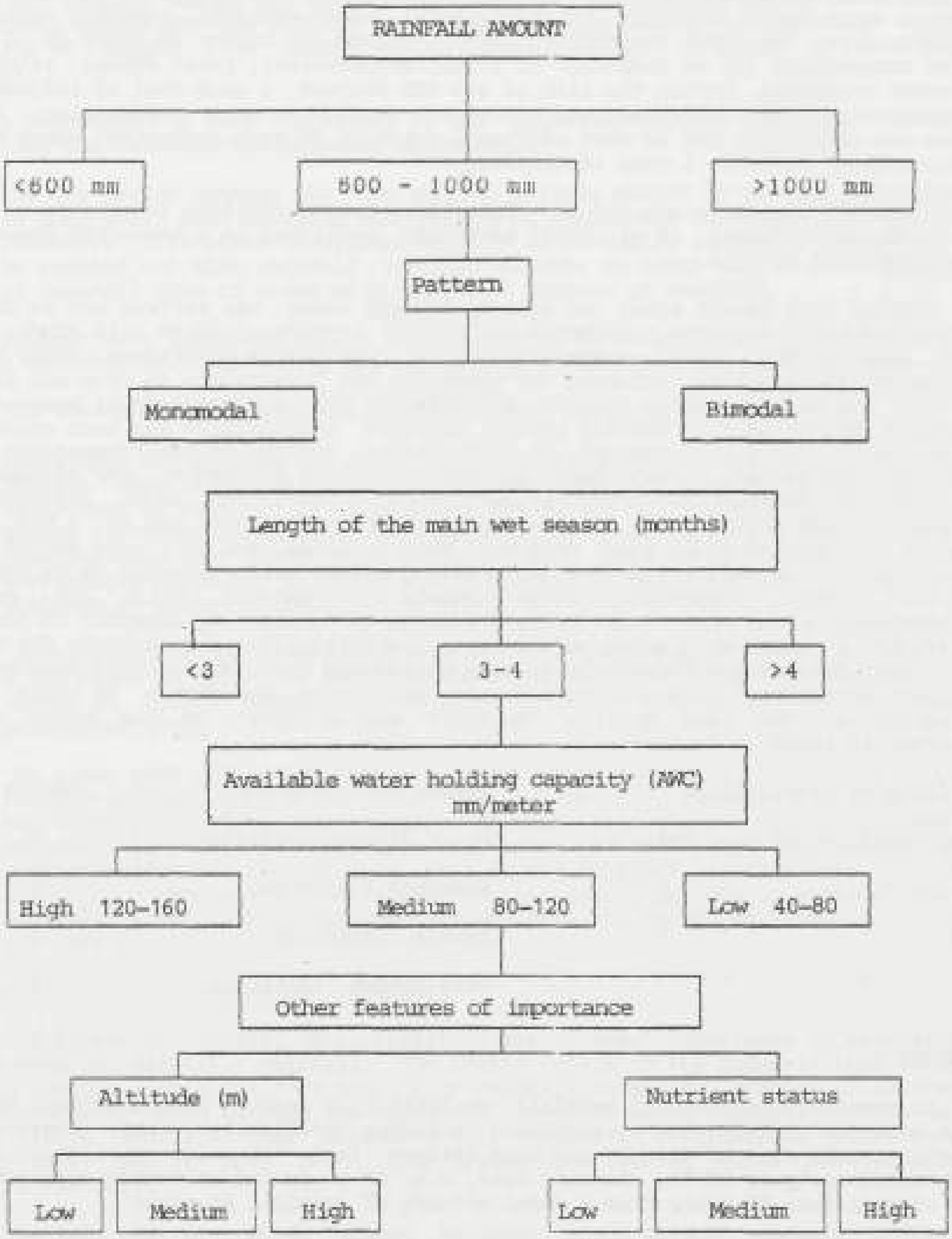
Probability of crop failure				Degree of limitation	Rating
0-10% probability of crop failure				No or slight limitation	1
11-20%	"	"	"	Moderate limitation	2
21-40%	"	"	"	Severe limitation	3
>40%	"	"	"	Very severe limitation	4

CONCLUSION

In areas with pronounced rainfall variability a growing period concept based on average data is likely to overestimate moisture availability and, therefore, to underestimate the risk of drought and crop failure. It is therefore necessary to make a more detailed analysis of the climatic data, e.g. on a pentad or decade approach over a period of more than 20 years from a denal network of rainfall stations.

Owing to the complexity of soil patterns within land units and the scarcity of actual laboratory determinations of AWC in Tanzania, most of the previous works are based on estimates only. It is important to carry out further studies on the soil properties that affect rainfall acceptance, moisture retention and moisture availability, studies that at present are very scanty in Tanzania.

TABLE 1 PARAMETERS FOR THE DELINEATION OF AGRO-ECOLOGICAL ZONES IN TANZANIA



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6.9 RATING OF LAND QUALITY: MOISTURE AVAILABILITY

A COUNTRY APPRAISAL - SUDAN

by

Abdulla Hassan Hag

1. INTRODUCTION

The capacity of soils to absorb and retain water may provide valuable information as to the amount that can be stored at a given time as a reservoir from which plants may draw their water needs. An initial determinant to moisture availability is the soil water balance. This balance is an interplay between amount of water - rainfall or irrigation - infiltration, run-off, drainage and evapotranspiration. These attributes of the physical environment have been studied and various soil water constants have been defined and used as indices for soil water holding capacity and plant available water.

Moisture availability as a land quality is an expression of the way in which the relevant land characteristics of the physical environment interact to meet the water requirement of a specific kind of land use.

Rating of land quality is determined by the degree or severity of the limitations that land characteristics may impose on land use.

2. AVAILABLE WATER CAPACITY

Available water capacity (AWC) is determined by soil physical characteristics, such as texture, structure and soil depth. AWC is usually an estimate from the difference between water content at field capacity (FC), and water content at permanent wilting point (PWP). The accuracy of the estimation of AWC is therefore dependent upon the reliability of estimates made for FC and PWP.

2.1 Field Capacity Concept

Field capacity is defined as the amount of water held by the soil after excess gravitational water has drained away and the rate of downward movement of water has materially decreased - two to three days after irrigation. However, the moisture held by the soil at 0.33 bar has been found to be closely correlated with field capacity for many soils. In soils with extremely low permeability and under humid climate, it is difficult to evaluate the upper limit of available water according to the procedure defined by field capacity. Under such conditions the upper limit of AWC is specified by the true equilibrium water content (Peters 1965). For irrigated Gezira Vertisols, it has been demonstrated by Farbrother (1972-86), that calculation of AWC is only of practical value when the saturation capacity is used to define the upper limit of AWC.

2.2 Permanent Wilting Point Concept (PWP)

The permanent wilting point is defined as the water content of the soil when plants growing on that soil are reduced to a permanent wilt condition from which plants cannot recover in an approximately saturated atmosphere. The 15-bar moisture content has been found to be closely correlated with permanent wilting point (Richards and Weaver 1943).

2.3 Determination of AWC

AWC is usually estimated by the difference in moisture held by a soil sample when subjected to a pressure of 0.33 bar and 15 bar.

$$Pw = f - w$$

Pw = AWC in weight percent

f = percent moisture at 0.33 bar

w = percent moisture at 15 bar

Bulk density at 0.33 bar is used to convert moisture percent from weight basis to volume basis. Total amount of AWC in a soil profile is estimated by introducing a depth factor.

$$AWC/100\ cm = \frac{Pw \times b^{0.3} \times d}{100} = cm$$

$b^{0.3}$ = bulk density at 0.3 bar

d = depth in cm

Since AWC is determined on fine soil less than 2mm, correction for the presence of coarse fractions greater than 2 mm may be necessary.

$$F = 1 - \frac{cb}{100B}$$

F = correction factor for fractions greater than 2 mm diameter
b = bulk density of dry soil
c = weight percent of coarse fractions
B = bulk density of coarse fractions

In soils with a high shrink swell ratio, the bulk density changes with a change in moisture content. To correct this uncertainty, Arlidge (1975), introduced the term "mean moisture bulk density (b^m)".

$$b^m = 1/2 \left(\frac{b + b^{0.3}}{2} + b^{0.3}\right)$$

The corrected formula will be:

$$AWC - 100\ cm = \frac{Pw \times b^m \times d}{100} .F\ cm$$

2.4 Rating of AWC

Rating of AWC aims at expressing the anticipated influence of the various factors in the physical environment. However, it is generally assumed that for optimum plant growth, AWC of Class I land should be more than 150 mm in the 120 cm soil depth, whereas AWC for Class II should be more than 100 mm and more than 75 mm for Class III soils.

Rating of AWC may be based on one or more of the relevant elements in the physical environment.

Agro-climatic rating of AWC

Under rainfall conditions, AWC is determined by rainfall/evapotranspiration ratio. The intensity and frequency of rainfall as well as the duration of the rainy season are important factors to consider.

Climatically defined AWC may be modified by other elements in the physical environment, i.e. texture or shallowness of the soil.

Moisture availability under a specific agro-climatic zone is assessed by the moisture surplus attained when precipitation exceeds potential evapotranspiration, i.e. humid period (P PET). The duration of the humid period, defined by specific confidence limit - 75 or 90%, probability, magnitude of the moisture surplus, determines the appropriate rating of an agro-climatic zone. Table 1 gives an appropriate AWC rating in the different agro-climatic zones in Sudan (Van der Kevie 1976). The legend for the agro-climatic zones is given in Table 2.

Table 1 MOISTURE AVAILABILITY IN AGRO-CLIMATIC ZONES

Rating	Climatic Moisture Regime	AWC (cm)	
		Top-Soil 0-30 cm	Sub-Soil 30-120 cm
1	M_1, M_2, M_3, M_4, and H_2	> 4	> 12
2	M_1, M_2, M_3, M_4, and H_2 H_1, and S_1	> 3 > 4	> 12 > 12
3	M_1, M_2, M_3, M_4, and H_2 H_1, and S_1, A_1, and A_2	>2 >3 >4	> 6 > 9 >12
4	M_1, M_2, M_3, M_4 and H_2 H_1, and S_1 A_1, and A2 A3, and D	> 1 > 2 > 3 > 4	> 3 > 6 > 9 >12

The monsoon climate in Sudan stands a better chance of being potentially qualified as Class I agro-climatic environment. This agro-climatic zone is characterized by an annual rainfall that exceeds 44% of the potential evapotranspiration more than two humid months, a growing season of 5-11 months when rainfall exceeds half the potential evapotranspiration.

However, climate rating of AWC is subject to modifications imposed by elements in the physical environment, i.e. texture, infiltration and topography. For example, in very dry climates (Arid and semi-desert), the AWC rating is to be upgraded one level in case of receiving sites. In humid climates, water shedding sites are downgraded one level, etc.

Table 2 LEGEND OF AGRO-CLIMATIC ZONE IN SUDAN

Symbol	Climatic Zone	Humid Month	Dry Month	Growing Season	Average annual rainfall (mm)	Mean max. Temp. in hottest months	Mean max. Temp. in coldest Months	Diagnostic Characteristics
A1.1	Arid, summer rain warm winter	0	10 - 11	1 - 2	225 - 400	40 - 42	13 - 17	Rw = 0.5 - 1.0 Ew $Tc < 13$
A1.2	Arid, summer rain, cool winter	0	10 - 11	1 - 2	225 - 400	40 - 42	8 - 13	Rw = 0.5 - 1.0 Ew $Tc < 13$
A2	Arid, winter rain	0	10 - 11	1 - 2	225 - 600	40 - 42	13 - 20	Rw = 0.5 - 1.0 Ew
A3	Arid, no marked seasons	0	8 - 9	3 - 4	550 - 750	37 - 38	18 - 20	Rw = 0.5 - 1.0 Ew
S1.1	Semi-arid, summer rain, warm winter	1	9	3	400 - 750	39 - 40	13 - 17	$Rw > 1.0$ Ew $Tc > 13$, Ew
S1.2	Semi-arid, summer rain, cool winter	1 - 2	9	3	300 - 600	35 - 39	8 - 13	$Rw > 1.0$ Ew $Tc < 13$
M1.1	Dry monsoon, long dry season, warm winter	3 - 5	5 - 7	5 - 7	750 - 1000	36 - 41	17 - 20	$Rw > 0.44$ E Ln = 0.1-0.0 2 E
M1.2	Dry monsoon, long dry season, cool winter	3 - 4	7	5	600 - 850	38 - 39	5 - 13	$R > 0.44$ E Ln = 0.1-1.0.2 E
M2	Dry monsoon, medium Dry season	2 - 3	4 - 6	6 - 8	850 - 1000	36 - 38	18 - 21	$R > 0.44$ E $Ln < 0.1$ E
M3	Wet monsoon, medium wet season	5 - 7	3 - 5	7 - 9	950 - 1400	34 - 39	12 - 20	$R > 0.44$ E $Ln > 0.1$ E
M4	Wet monsoon, long wet season	7 - 8	1 - 2	10 - 11	1200 - 1600	34 - 35	14 - 19	$R > 0.44$ E $Ln > 0.2$ E
H1	Highland, short wet season, warm summer	3	7	5	600 - 1000	36 - 39	6 - 8	$Ln > 0.2$ E $Tc < 8$
H2	Highland, medium wet season, cool winter	5 - 6	3 - 4	8 - 9	1000 - 1600	23 - 33	10 - 17	$Tw < 33.5$

Notes

Occasional occurrence of night-frost in M1.2, H1.

Rw = average rainfall in wettest month in mm.

R = average annual rainfall in mm.

Ew = average potential evapotranspiration in wet test (Penman) in mm.

E = average annual potential evapotranspiration (Penman) in mm.

Ln = leaching rainfall (surplus of rainfall over potential evapotranspiration in humid months)

Tc = mean maximum temperature of coldest month in °C

Tw = mean maximum temperature of hottest month in °C

humid month = month in which rainfall >potential evapotranspiration

dry month = month in which rainfall >1/2 potential evapotranspiration

growing season = 12 minus number of dry months.

In rating land qualities, limitations associated with AWC are identified by a subclass symbol. Soils having low AWC get a climatic limitation C at subclass level; if it is due to low rainfall, a moisture limitation (m) at the subclass level; if it is a sandy soil, a subclass depth (d) limitation and if it is a shallow soil, e.g. S3VC, S3m, S3d.

2.5 Prediction of AWC

AWC may be predicted from textural classes as shown in Table 3.

It can be seen in Table 3 that the loams and the clays stand a better chance of being qualified as a potential Class I land. But soils in the same texture class may have different amounts of water, depending on the presence of fractions greater than 2mm diameter. Gravelly clays are inferior to find sand.

Table 3 ESTIMATION OF AVAILABLE WATER CAPACITY

AWC in cm. Soil depth (cm)		Textural class	Max.Vol. % coarse fraction allowed if soil is deep (weighted average	Min. soil depth allowed if there are no coarse fragments (For AWC of Subsoil	
3 - 30	30-120			Hard	Soft
		Sandy clay loam and loam	5	120	100
		Clay loam, sandy clay,	15	105	85
>4	>12	Clay	30	90	75
		Sandy loam, sandy clay loam	5	120	100
3 -4	9 -12	Loam	20	105	85
		Clay loam and sandy clay	35	90	70
		Clay	50	75	55
		Loamy sand	5	120	100
		Sandy loam	20	105	85
2 - 3	6 - 9	Sandy clay loam and loam	40	90	70
		Clay loam and sandy clay	50	75	55
		Clay	65	60	40
		Fine sand	5	120	100
		Loamy sand	20	105	85
1 - 3	3 - 6	Sandy loam	40	90	70
		Sandy clay loam and loam	50	75	55
		Clay loam and sandy clay	65	60	45
		Clay	75	50	40

AWC of soil may be predicted from other parameters. Abedine (1968) reported a significant correlation between ESP and AWC in Gezira Vertisols.

Fig. 1 The correlation is expressed by the equation

$$AWC\ \% = 16.7 + ESP \times 0.233$$

Similar correlations were established for some of the Australian Vertisols, e.g. Shaw and Yule 1978, Mullins 1981 and Williams et al. 1983.

2.6 Measurements of AWC

2.6.1 Laboratory Measurements

The upper and lower limits of AWC as measured on soil samples subjected to a moisture potential of -0.33 and -15 bar are shown in Table 4a for samples from Gezira Research Station (GRS), and in Table 4b for samples from the Dinder-Kenana area to the south of the Gezira.

Table 4a MEASURED VALUE OF AWC - GRS

Soil Type	Depth (cm)	Water retention(wt%) -0.33 bar	-15 bar	AWC Wt %	AWC cm
Typic Chrom-ustert	0 - 20	36	20	16	3.74
	20 - 50	38	21	17	6.38
	50 - 85	46	22	24	11.34
	85 - 120	44	22	22	10.86
					32.32
Entic Chrom-uster	0 - 10	42	23	19	2.22
	10 - 35	45	23	22	6.88
	35 - 65	45	23	22	8.25
	65 - 95	47	26	21	8.06
	95 - 120	48	26	22	7.43
					32.84

Table 4b MEASURED VALUE OF AWC - DINDER-KENANA PLAIN

Soil Type	Depth (cm)	Water retention(wt%) -0.33 bar	-15 bar	AWC Wt %	AWC cm
Typic Pell-ustert	0 - 15	46.0	29.8	16.2	2.84
	15 - 30	46.1	30.7	15.4	2.89
	30 - 60	44.2	32.5	11.7	4.74
	60 - 90	48.5	33.1	15.4	6.51
	90 - 120	48.8	33.5	15.3	6.61
					23.56
Entic Pell-ustert	0 - 15	46.4	27.3	17.10	3.00
	15 - 30	43.2	30.2	13.00	4.88
	30 - 60	44.9	31.4	13.50	5.06
	60 - 90	45.8	32.0	13.80	5.30
	90 - 120	48.6	32.3	16.30	6.60
					24.84

Gezira soils have higher AWC compared with Dinder/Kenana soils. Possibly this may be due to the high ESP levels in Gezira soils. This is in conformity with what has been suggested by Abedine (1968). The AWC in both soils increases progressively with depth. Vertisols are usually rated high in AWC and particularly so because the high storage capacity in the subsoil is more than 200 mm in the 50-120 zone in a Typic Chromustert from Gezira Research Station Farm. The distribution pattern is seen in Fig. 2.

2.6.2 Field Measurement of AWC

Available water holding capacity is an important soil property that needs to be determined in the field under conditions appropriate to its application. Field measurements are met with many problems. Apart from these, the concept of field capacity as is generally conceived does not hold true for Gezira Vertisols. Permeability at saturation in Gezira clay is so low that the FC concept based on free drainage is positively misleading. Calculations of AWC in Gezira clay can only be of practical value when saturation capacity is used to define the upper limits of AWC (Farbrother 1972).

The degree of the physical compaction due to the stresses created by the weight of over burden depressed hydraulic conductivity is virtually zero in the subsoil layer below 50 cm in the Gezira clay profile (Abedine 1971).

Initial water recharge via cracks in these high shrink/swell clays is an important contributing factor in the moisture distribution pattern of the Gezira clay.

2.6.2.1 Measurement of AWC under rains

The soil moisture distribution pattern in a fallow plot in the Gezira Research Farm (GRF) immediately after rains amounting to 100 mm during mid-August (1971) when total rainfall received during that period amounted to about 260 mm (Farbrother 1972-73), is shown in Table 5 and Fig. 3.

Table 5 SOIL MOISTURE DISTRIBUTION PATTERN UNDER RAINS

Soil Depth (cm)	Bulk density gm/cm^3	Moisture percent Wt basis					Rain recharge(mm)	AWC CM
		before rains	after rains	water recharge	PWP	AWC		
0-20	1.14	15.1	47.4	32.3	20.0	27.4	7.4	6.3
20-40	1.16	18.5	42.6	24.1	20.5	22.1	5.6	5.1
40-60	1.23	17.9	34.8	16.9	20.9	13.9	4.2	3.4
60-80	1.31	21.9	29.5	7.6	21.6	7.9	2.0	2.1
80-100	1.46	21.9	24.8	2.9	21.5	3.3	0.9	1.0

Rain water recharge was very high in the 0-60 cm zone, amounting to 172 mm, and sharply decreased with depth to practically nill in the 80-100 cm zone and below. The moisture distribution pattern displayed in Fig. 3 was opposite to that given by estimating AWC from soil samples (Fig. 2). Obviously assessment of AWC from soil samples is practically misleading when used in Gezira Vertisols.

2.6.2.2 Measurement of AWC under irrigation

Under irrigation, with the physical behaviour of the Gezira clay per se, the field capacity concept is being replaced by what can be described as post irrigation state, where the upper limit of available water is defined by the static equilibrium water content of saturated soil in the presence of such an amount of free standing water in the furrow after completion of watering (Farbrother 1972-78). This is to say, sampling to commence one day after completion of watering.

Fig. 1 ESP AVAILABLE MOISTURE DETERMINED AS MOISTURE RETAINED AT 1/3 BAR MOISTURE RETAINED AT 15 BARS

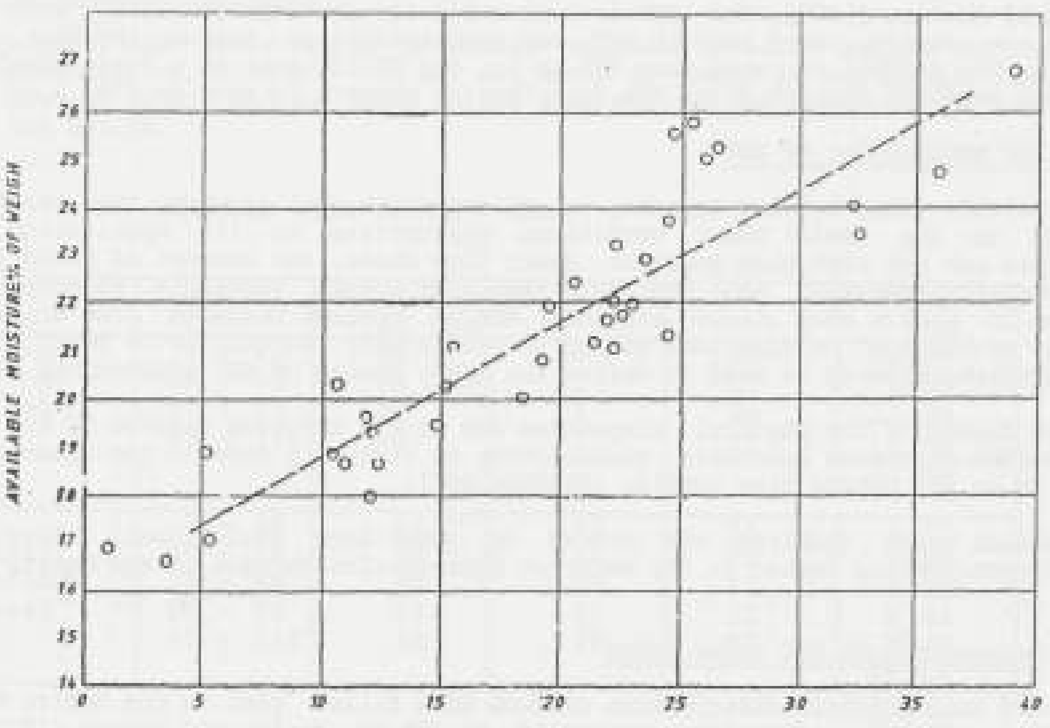
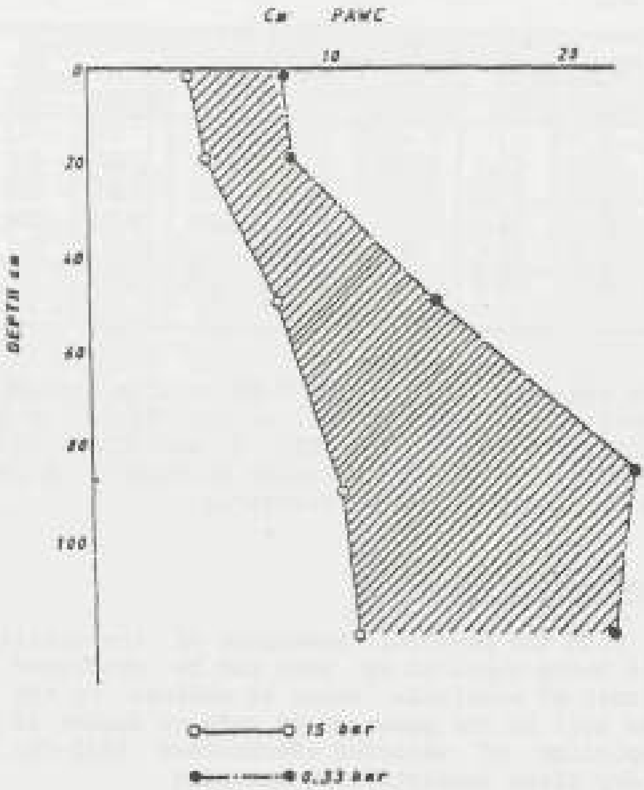


Fig.2 MOISTURE DISTRIBUTION PATTERN
GEZIRA SAMPLES



In the Vertisols in general, with high shrink-swell ratio, initial water research depends on the volume of cracks, i.e. drier soil is expected to have a higher initial water intake; with the physical constraints recognized in the Gezira Vertisols, three options in irrigation water management systems may be cited.

a. Irrigation on slightly dry soil: long irrigation intervals, i.e. 14-21 days intervals practised in Gezira. PAWC to be assessed three days after completion of watering.

b. Irrigation on slightly moist soil: irrigation intervals 10-7 days. PAWC to be assessed three days after completion of watering.

c. Start with system (a) above. PAWC assessed at the post irrigation state, i.e. one day after completion of watering.

The distribution pattern of PAWC is the same for the three systems of water management, i.e. surface maximum and sharp fall with depth. The total amount of PAWC is highest in system (c), moderate in system (a) and relatively low in system (b) (Tables 6a, b and c).

Table 6a SOIL MOISTURE CONTENT AFTER IRRIGATION OF INITIALLY DRY SOIL

Depth (cm)	% moisture wt basis				A W C cm
	P W P	before irrigation	3 days after irrigation	A W C	
0 - 20	20.0	18.0	38.5	18.5	4.2
20 - 40	20.6	24.0	35.5	14.9	3.5
40 - 60	21.4	25.0	29.5	8.1	2.0
60 - 80	22.4	23.5	28.5	6.1	1.7
80 - 100	22.4	23.0	27.5	5.1	1.5
					12.9

Table 6b SOIL MOISTURE CONTENT AFTER IRRIGATION OF INITIALLY MOIST SOIL

Depth (cm)	% moisture wt basis				A W C cm
	P W P	before irrigation	3 days after irrigation	A W C	
0 - 20	20.0	28.5	42.0	22.0	5.0
20 - 40	20.5	31.0	33.0	13.5	3.2
40 - 60	22.3	27.0	28.5	6.2	1.6
60 - 80	23.0	25.0	24.6	1.6	0.4
80 - 100	23.0	23.5	24.5	1.5	0.4
					10.6

Table 6c   POST IRRIGATION STATE OF SOIL MOISTURE

Depth (cm)	% moisture wt basis			A W C cm
	P W P	Post irrigation	A W C	
0 - 20	20.0	47.5	27.5	6.2
20 - 40	20.6	36.0	15.4	3.6
40 - 60	21.4	30.0	8.6	2.2
60 - 80	22.4	28.5	6.1	1.7
80 - 100	22.4	27.0	4.6	1.3
				15.0

However, Vertisols are generally rated as very good and good in PAWC mainly because of the general belief that they are deep and have high water holding capacity in the subsoil. The Gezira Vertisols under irrigation do not have more than 3.0 cm of PAWC in the subsoil below 60 cm. The moisture status in the subsoil layers below 100 cm is permanently at the wilting point. It is to be noted that Gezira Vertisols with less than 3.0 cm of plant available water in the subsoil can hardly be rated better than a Class III or Class IV land. PAWC in a 60 cm deep Vertisol from Gezira can reasonably satisfy the requirements of evapotranspiration at the average rate of 5 mm/day for 14 to 21 days without subjecting the plants to any moisture stress.

Fig. 3   MOISTURE DISTRIBUTION PATTERN UNDER RAIN CONDITIONS

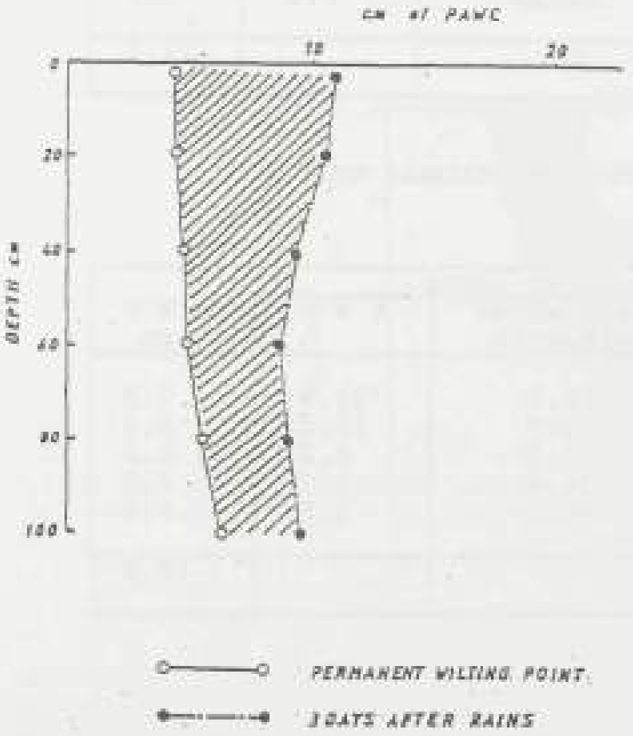
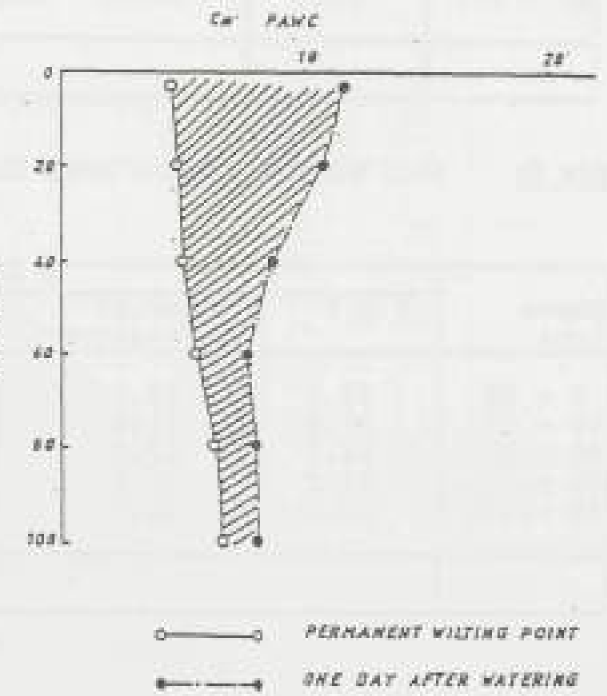


Fig. 4   MOISTURE DISTRIBUTION PATTERN POST WATERING STATE



CONCLUSION

PAWC in subsoil layers of Vertisols needs critical reevaluation. The stress of the weight of the over burden reduces the hydraulic conductivity in the subsoil layers to practically zero.

Measurements of PAWC in the laboratory gave misleading results.

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6.10 A METHODOLOGY FOR THE CALCULATION OF ANTICIPATED RAINFED CROP YIELDS

by

F.O. Nachtergaele and P.V. De Wit

1. INTRODUCTION

1.1 Objective

The objective of this paper is to propose a methodology for calculating anticipated yields of rainfed crops on the basis of climatic and soil factors and to indicate areas for further research in order to improve the basis of the socio-economic analysis and in the end serve as an aid to land use planning.

The approach is quantitative, which is a must since the results are to be used in economic analysis and land use planning. It is also computerized, which is necessary when dealing with a huge amount of data and rather complex formulae simulating crop growth and yield responses to soil and water stress conditions.

The methodology has been introduced recently in Botswana although it has been tested in other parts of Africa and Asia and calibration of the results obtained is an ongoing exercise. Previous land evaluation approaches in the country were qualitative (Eldridge 1978, Rhebergen 1988) and aimed at the evaluation of reconnaissance scale soil and climatic maps for rainfed agriculture. The present method is scale independent and is able to identify physical constraints to arable farming and hence contributes to the finding of appropriate remedies which will result in increased agricultural production in the country.

1.2 Methodology

The methodology employed is explained in general terms in Section 2 and schematically presented in Figure 1.

The approach takes as a starting point the radiation limited yield which in fact is the crop - time - and site-specific maximum obtainable yield under ideal conditions of temperature, water, nutrient availability and optimum management and input levels. This maximum yield is reduced in a multiplicative function, taking into account specific temperature conditions, water stress and non-correctable soil properties, to obtain an anticipated optimum rainfed yield of the crop (variety) studied. Input levels and their effect on correctable soil characteristics are considered in the calculation of the anticipated land-determined yield.

Emphasis has been put on crop yield reduction as a result of water stress. In a semi-arid country like Botswana, the variability of traditional crop yield and planted area is more than 80%, accounted for by the degree to which the water requirements of crops has been satisfied by rainfall (Vossen 1989).

2. METHODOLOGY

2.1 Radiation Limited Yield

The maximum yield (Ym) is defined by FAO (1979) as the harvested yield of a high producing variety, well adapted to the given growing environment, including the time available to reach maturity under conditions where water, nutrients, pests and diseases do not limit yield. Climatic factors which determine Ym are mainly radiation and crop specific characteristics.

Maximum yields can be calculated for different climatic conditions. During the last decade, several computer programmes have been developed to calculate Ym for a wide

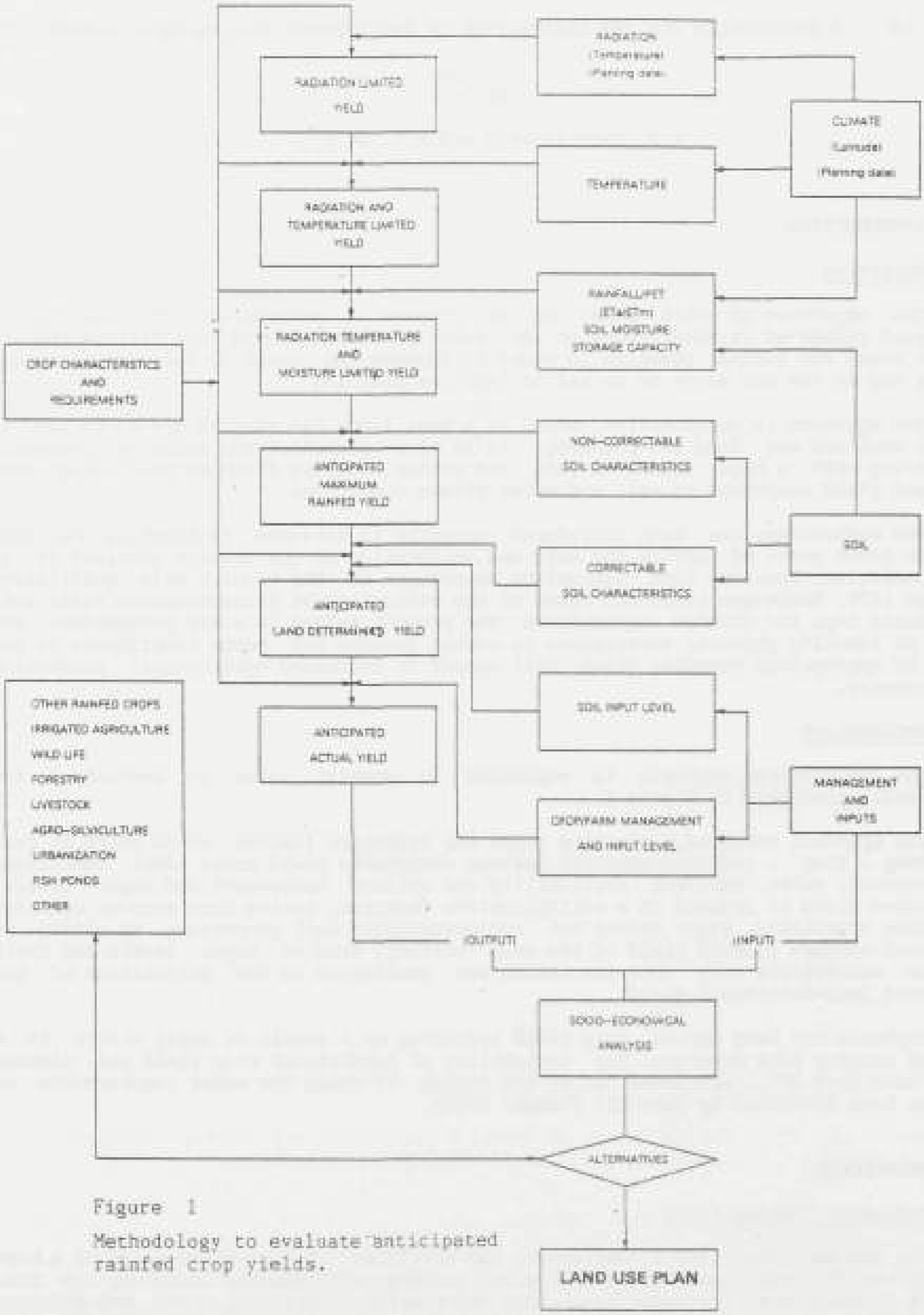

Figure 1

Methodology to evaluate anticipated rainfed crop yields.

range of crops. Nearly all of these models are based on the concepts of De Wit (1965). Two of the most well known methods are the WOFOST model (Van Keulen and Wolf 1986) developed at the University of Wageningen, and the Agro-ecological zones approach, developed by Kassam (1977).

The latter approach can be summarised for standard conditions (when the maximum leaf gross dry matter production rate equals 20 kg CH_2O per hectare, per hour) by the following equation:

$$Ym = Hi \times K \times (0.36 \times (F \times bo + (1-F) \times bc)) / (1/N + 0.25 \times Ct) \quad (1)$$

wherein:

- Ym = the maximum yield
- Hi = the harvest index and equals the fraction of the biomass production that has economic importance
- K = a correction factor related to the maximum leaf area index (LAI) reached during growth
- F = the fraction of the time of day when the sky is overcast (derived from radiation or sunshine or cloudiness data)
- bo = the maximum gross biomass production when the sky is completely overcast (which in turn is a function of the latitude and the time of the year)
- bc = as bo but when the sky is clear. Note that bo and bc can be derived from published tables (Goudriaan 1977)
- N = the number of days the crops need to reach maturity
- C_t = a correction factor for temperature based on the mean day temperature of the growing period and the type of crop

Note that the foregoing equation has only been developed for annual crops; for perennials, maximum yield data are to be obtained from the literature.

2.2 Temperature Index

In the calculation of the maximum yield, temperature is only considered in its effect on the gross dry matter production. However, its direct effect on yield through specific temperature conditions in the different growth stages of the crop is not taken into account, while the general temperature environment for the crop is considered ideal (or near ideal).

Hence an additional evaluation of the temperature factor is required, specifically with regard to frost and night temperatures. The temperature index is of particular importance in non-tropical climates where its influence can be greater than the influence of the water availability (Nachtergaele 1985a). To evaluate the temperature constraints, mean (normal) values are used, as generally, temperature variations from year to year are small when compared to variations in rainfall. A probability approach is suggested, however, in tropical highlands and non-tropical climates. The methodology is based on the parametric approach wherein the most limiting temperature factor is given a rating on a scale of 0 to 100.

Basic information on specific crop requirements with regard to temperature can be obtained from existing literature for a total of about 100 crops, e.g. Sys (1985), Nachtergaele (1985a, 1988) and De Wit (1989).

2.3 The Moisture Limited Yield

2.3.1 Introduction

Water deficits in crops and the resulting water stress on the plant have an effect on crop evaporation and crop yield.

Water stress in the plant can be quantified by the rate of actual evapotranspiration (ETa) in relation to the rate of maximum evapotranspiration (ETm).

When crop water requirements are fully met from available water supply then ETa equals ETm; when water supply is insufficient, ETa ETm.

When the full crop water requirements are not met, water deficit in the plant can develop to a point where crop growth and yield are affected. The manner in which water deficit affects crop growth and yield varies with the crop species and crop growth period.

The effect of plant water stress on yield decrease can be quantified by comparing the relative evapotranspiration (ETa/ETm) and the relative yield losses (Ya/Ym) through the equation :

$$1 - \frac{Ya}{Ym} = ky \left(1 - \frac{ETa}{ETm} \right) \qquad (2)$$

where Ya = actual harvested yield

Ym = maximum harvested yield

ky = yield response factor

ETa = actual evapotranspiration

ETm = maximum evapotranspiration

Water deficit of a given magnitude may occur during any one of the individual growth periods or may occur continuously over the total growing period. For the individual growth period, the decrease in yields due to water deficit is relatively small for the vegetation and ripening period and relatively large for the flowering and yield formation period.

The yield response factors for most crops are derived on the assumption that the relationship between relative yield and relative evapotranspiration deficit is linear and is valid for water deficits up to 50%. The values of ky were based on an analysis of experimental field data covering a wide range of growing conditions.

The proposed methodology of assessing moisture in direct relation to yield/yield reduction involves calculations with respect to: maximum yield (Ym) (see Section 2.1), maximum crop evapotranspiration and actual crop evapotranspiration.

2.3.2 Maximum Crop Evapotranspiration

The ETo is considered to be the evapotranspiration of a standard or reference crop, and is calculated with the Penman formula adapted to Botswana conditions (SMEC 1989; Vossen 1989). Empirically determined crop coefficients (kc) are used to relate ETo to the maximum evapotranspiration of the crop (ETo). Crop coefficients are specific of the crop and the crop developed stage. The crop coefficient at the initial crop development stage (kco), is determined as a function of the frequency of rain within the decade and the value of ETo at the time of planting (FAO 1977).

For each ten day period during the crop growing cycle, kc and ETc values are calculated by a computer programme. Note that ETm = ETc = kc x ETo.

2.3.3 Actual Crop Evapotranspiration

The next stage in the programme is the calculation of the actual crop evapotranspiration by means of a simple water balance.

Taking into account the maximum soil moisture storage (which can be set at the beginning of the programme), the input (rainfall) and the output (crop evapotranspiration) of water and the increase of the total available water as the rooting depth increases, the soil water balance for each ten day period is calculated based on equations worked out by FAO (1979) and Joshua (1986).

The reserve built up in the previous decade (ST(L-1)) is set at the start of the growing period at the full amount of rain fallen in the decade before planting. The programme only runs growing cycles after an amount of 30 mm of rainfall has been obtained in a given decade. The purpose is to stimulate the requirement of sowing/planting in a moist soil.

The soil moisture reserve can never exceed the maximum soil moisture storage capacity and excess rain is assumed to drain freely by gravity.

The model does not take into account contributions of groundwater or flooding; as such it is only applicable to free drained soils, not subject to flooding. Note that the WOFOST model (Van Keulen and Wolf 1986) provides an alternative evaluation procedure when the groundwater table is considered important (not discussed here).

When the soil moisture storage decreases, the crop evapotranspiration will remain at its maximum level as long as a fraction of p of the total available soil water (Sa.D) is not depleted. The actual crop evapotranspiration (ETa) then equals the maximum crop evapotranspiration (ETc). The fraction p is determined as a function of the crop type and ETc.

When the soil moisture storage falls below the critical value (1-p) x Sa.D, then the actual crop evapotranspiration ETa will become less than ETc. The depletion of the available soil water, once a fraction p is consumed, is proportional to the actual available soil moisture content relative to the fraction (1-P) of the total available moisture.

Practically the ETa for a ten day period can be calculated as the difference between the initial moisture reserve (MRi) and the final moisture reserve (MRf) of that decade.

MRi equals the available water storage of the previous decade and the effective rainfall of the considered decade.

The calculation of MRf is based on the equation of Rijtema and Aboukhaled (1975).

$$\frac{d\,(St.D)}{d\,(t)} = \frac{St.D}{(1-p)Sa.D} \times ETc \quad (3) \qquad (3)$$

Where St.D = available soil water at time t over the root depth.

P = crop depletion factor

Sa.D = total available soil water over the root depth

The possible solutions of this equation are presented in Appendix 1. For each considered planting date the programme calculates ETa and ETc data throughout the growing cycle of the crop. An example is given in Table 1.

2.3.4 Determination of the Moisture Stress Index

When ETa is less than ETc, waterstress will adversely affect crop growth and will ultimately reduce crop yield. The effect of waterstress on the development of the crop depends on the crop species and variety, the intensity of the moisture stress and on the development stage in which the stress occurs. The yield response factor (ky) expresses the sensitivity of the crop to moisture stress in each specific development stage.

$$ky = (1-ya/Ym)/(1-ETa/ETm) \qquad (4)$$

Table 1 WATERBALANCE FOR A SOIL WITH AWHC OF 60 mm UNDER SORGHUM IN SELEBI PHIKWE

decade	ETo (mm)	kc	ETc (mm)	P	D (cm)	R (mm)	RE (mm)	MRi (mm)	MRf (mm)	Eta (mm)
Nov 2	64	0.58	37	0.71	23	56	24	65	28	37
Nov 3	59	0.58	34	0.74	43	25	13	41	7	34
Dec 1	60	0.65	39	0.69	67	76	35	42	5	37
Dec 2	64	0.80	51	0.60	87	13	10	15	1	14
Dec 3	60	0.93	56	0.57	97	35	26	27	2	25
Jan 1	62	1.0	62	0.54	100	41	31	33	3	30
Jan 2	65	1.0	65	0.52	100	65	47	50	6	44
Jan 3	59	1.0	59	0.56	100	91	58	64	12	52
Feb 1	53	1.0	53	0.59	100	41	29	41	5	36
Feb 2	55	0.91	50	0.61	100	102	49	54	10	44
Feb 3	51	0.76	39	0.70	100	26	18	28	3	25
Mar 1	54	0.59	32	0.75	100	16	11	14	1	13

ETo : Penman evapotranspiration
kc : crop coefficient
ETm : maximum crop evapotranspiration
P : depletion factor
D : rooting depth
R : rainfall
RE : effective rainfall
MRi : initial moisture reserve
MRf : final moisture reserve
ETa : actual crop evapotranspiration

ky values for a wide range of crops are presented by FAO (1979). From the equation the relative yield reduction due to moisture stress can be calculated in each development stage as follows:

$$Ya/Ym = 1 - ky(1-ETa/ETm) \quad (5)$$

Finally a relative yield reduction (Ya/Ym) or moisture stress index (Iw) for the whole crop cycle can be obtained by the multiplication of the relevant reduction factors.

An example of the output is given in Table 2.

Table 2 DETERMINATION OF THE YIELD REDUCTION OF SORGHUM DUE TO MOISTURE STRESS ON A SOIL WITH AWHC OF 60 mm IN SELEBI PHIKWE

Individual growth periods	duration ind. growth periods days	1-ETa/ ETm	ky	Ya/Ym (%)	Ym (kg/ha)	Ya (kg/ha)
Establishment	20	0	-	100		
Vegetative	30	0.48	0.20	90		
Flowering	20	0.39	0.55	79		
Yield formation	40	0.22	0.45	90		
Ripening	10	0.59	0.20	88		
Total growth period	120			56	6233	3490

Planting decade : 2 November 1974

2.3.5 Remarks

Several remarks can be made about this methodology, some of them are directly related to a wider use of the proposed approach.

a. Water stress, although generally related to water deficit, should also take into account excessive rain during sensitive stages of crop development which directly affects harvest and/or post harvest losses. The present model does not reflect this effect, but it is suggested that the parametric approach should be utilised for this purpose. For instance, for cotton the ideal condition should be less than 5 rainy days during the ripening month (average index : 100), while more than 10 rainy days should be considered marginal in the ripening month (average index : 52).

b. Doorenbos et al. (FAO 1979) discuss the kc and ky factors for 26 crops. kc factors are however known for many more crops. On the other hand no ky factors have been given for this expanded list. Two ways to widen the application of the approach are suggested here:

- When the kc values are known, but ky values are unpublished, one can replace the moisture stress index by Effective Rain/ETc over the whole growing period. The latter factor showed a highly significant correlation with the ETa/ETc ratio in Botswana.

- When no kc or ky values are known, which is the case of many perennials, it is suggested that the parametric approach should be used (Biot et al. 1984; Nachtergaele 1988).

c. Note that the programme runs through each suitable planting date for the whole period where rainfall data are available (see Table 3). A final evaluation of the average yield reduction should be based on a probability analysis. Several assumptions can be made, by considering that at this stage high management levels are assumed, the average of the maximum yield obtainable each year can be calculated. Other possibilities are:

- To take a fixed planting month (e.g. December in Botswana) and average the highest decade potential within this month only.

- To take the actual planting date if data are available.

Table 3 ANTICIPATED YIELD (% OF RADIATION LIMITED YIELD) OF SORGHUM UNDER RAINFED CULTIVATION AT SELEBI PHIKWE (BOTSWANA)

Decade Growing Season	Oct 1	Oct 2	Oct 3	Nov 1	Nov 2	Nov 3	Dec 1	Dec 2	Dec 3	Jan 1	Jan 2	Jan 3	Feb 1	Feb 2	Feb 3	Mar 1	Mar 2
1974/75	–	–	–	–	56	55	–	44	–	31	26	24	21	17	15	–	–
75/76	–	–	–	–	–	–	–	–	27	26	–	–	–	19	–	–	–
76/77	–	–	–	–	44	–	–	–	–	32	–	–	–	10	9	–	7
77/78	61	–	–	–	–	–	–	–	26	20	17	16	14	–	–	–	–
78/79	–	–	–	–	23	–	–	–	–	–	–	–	11	–	–	–	–
79/80	–	–	–	–	–	–	–	27	–	–	14	–	10	–	7	9	–
80/81	–	–	–	–	–	–	37	–	29	–	25	–	20	19	–	–	11
81/82	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
82/83	–	–	24	–	–	–	19	27	–	–	–	21	–	–	10	–	–
83/84	–	–	–	–	–	15	–	–	21	–	–	25	–	–	–	–	–
84/85	–	–	–	–	31	–	19	–	–	–	11	8	8	–	–	–	–
85/86	–	–	–	14	12	–	–	–	–	–	27	–	–	–	–	–	–
86/87	–	–	–	–	–	–	–	–	–	–	–	9	–	–	–	–	–

Available water holding capacity of the considered soil - 60 mm

d. kc factors are established for optimal planting densities under high management. In reality the leaf area index of the crops cultivated under a traditional cultivation system is less than the optimal value, so that ETc values are rather overestimated. A correction of kc factors can be considered.

e. Actual evapotranspiration is calculated for each decade. If there is a severe water stress period, ETa can equal very low values near to zero. If such an event occurs during several consecutive decades, there is a possibility that the crop may die although the programme will still indicate a low corresponding actual yield. A threshold value for the maximum acceptable length of such dryspell periods (in function of ETa) should be proposed for each crop development stage.

2.4 The Soil Capability Index

A fixed number of soil characteristics are matched with specific crop requirements in a parametric approach in which each characteristic receives a rating on a scale of zero to one hundred.

The considered soil characteristics are the following: depth, organic carbon content, base saturation percentage, calcium carbonate content, salinity, sodicity, structure, the drainage class, the slope percentage, the flood risk and the CEC.

All these characteristics are generally determined during routine soil surveys. In Botswana such data are stored in a computerized soil data bank that at the moment contains more than 2000 soil profiles with analytical data and site characteristics.

Depending on the crop, the depth to which soil characteristics are taken into account varies in order to simulate the optimum rooting depth of each crop. For instance, for groundnuts only the top 75 cm is considered; for coconut, soil characteristics up to 150 cm have to be determined.

The final soil index is obtained by multiplying the individual ratings (divided by 100) which is in the range between 0 to 100.

2.5 Correctable and Uncorrectable Soil Factors

Theoretically every soil factor can be influenced in such a way that it approaches the ideal conditions for the specific land utilization type under consideration. The general land use that is discussed in this paper is rainfed agriculture, hence soil properties that require water management measures are considered to be uncorrectable for this type of agriculture. This concerns, in particular, drainage, when the soil is too permeable and has high salinity content. The effect of water harvesting techniques is not considered at this stage as their design normally goes beyond farm level.

The correction of the other soil properties through adequate soil management would theoretically result in a parametric rating of one hundred for each of these characteristics. To simulate more realistically the input effect, three levels of soil inputs are recognized and arbitrary improvements of the soil property rating can be given.

Taking into account the present rules, three soil indices can now be calculated, one for each input level.

2.6 The Anticipated Land-determined Yield

As explained in the general introduction the anticipated land-determined yield calculated by the present model is based on a multiplicity approach and assumes that the parametric index is equivalent to a percentage potentiality of each factor (temperature, soil), while the water stress model calculates the yield reduction due to moisture deficiencies. The starting point of the calculation is the radiation limited yield which is in fact the maximum obtainable yield for the site and crop under study.

This reasoning can be expressed in the following equation:

$$YA(I) = Ym \times It \times Iw \times Is(I) \quad (6)$$

wherein:

YA(I) = the anticipated land determined yield at a given input level

Ym = the radiation limited yield (section 2.1)

It = the temperature factor

Iw = the moisture stress factor (section 2.3)

Is(I) = the soil index as a function of the input level I (sections 2.4 and 2.5)

I = can be low, moderate or high

The validity of equation 6 has been tested as a whole or in parts by several authors for specific crops in a variety of countries and production situations. Biot et al. (1984) and De Baveye (1986) found statistically significant linear correlations with the actual yield of sugarcane in Malaysia; Cools and Bruggeman (1984) reported highly significant correlations with paddy rice yields in on-farm studies in Laos; Embrechts (1978) reported significant correlations between the soil index and cacao production in Cameroon; Nachtergaele (1985a) correlated soil and climate indices with actual production of winter wheat, olives and white potatoes in Northern Algeria; Bruggeman and Nachtergaele (1986) found statistically highly significant correlations between anticipated and actual production of sugarcane, maize and paddy rice in Laos, Thailand and Vietnam; Nachtergaele (1988) and Gibbs (1988) reported good correlation between this methodology and anticipated yields based on agricultural experience in Tanzania for a wide range of crops.

2.7 Preliminary Results in Botswana

This methodology was introduced in Botswana early in 1989 and some time had to be spent to install and refine the methods of the authors cited in the introduction. In addition to the soil databank which existed, a climatic databank had to be set up and links had to be made between these databases and the computerized programmes in order to be able to calculate the soil and moisture stress indices.

The collection of actual yield figures has only recently been started with emphasis on farm research obtained yields both for reliability and for consistency of information. Agricultural statistics are notoriously rather unreliable and difficult to link with specific soil and climatic conditions as they are generally presented for administrative units. The approach of Bruggeman and Nachtergaele (1986) which deals with this kind of matching has not been tested yet in Botswana.

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Appendix 1

Calculation of actual evapotranspiration (ETa)

In calculating actual evapotranspiration (ETa), it is assumed that actual evapotranspiration is equal to maximum evapotranspiration until the fraction (p) of the total available soil water (Sa) over the root depth (D) has been depleted. For a given crop, ETa is determined by the evaporative demand of the air when available soil water does not restrict evapotranspiration. Beyond the depletion of the fraction (p) of total available soil water (Sa.D), ETa will fall below Etm and ETa will depend on the remaining soil water and on Etm (see Fig. A.1). Under these assumptions the following relationships hold (Rijtema and Aboukhaled 1975):

$$ETa = ETc - \frac{d\,St.D}{dt} \quad \text{where } St.D > (1-p)Sa.D \qquad (1)$$

$$ETa = \frac{St.D}{(1-p)Sa.D} \times ETc = \frac{-d\,-St.D}{dt} \quad \text{where } St.D < (1-p)Sa.D \qquad (2)$$

where : SA.D = total available soil water over the root depth
St.D = available soil water at time t over the root depth
p = depletion factor of the crop

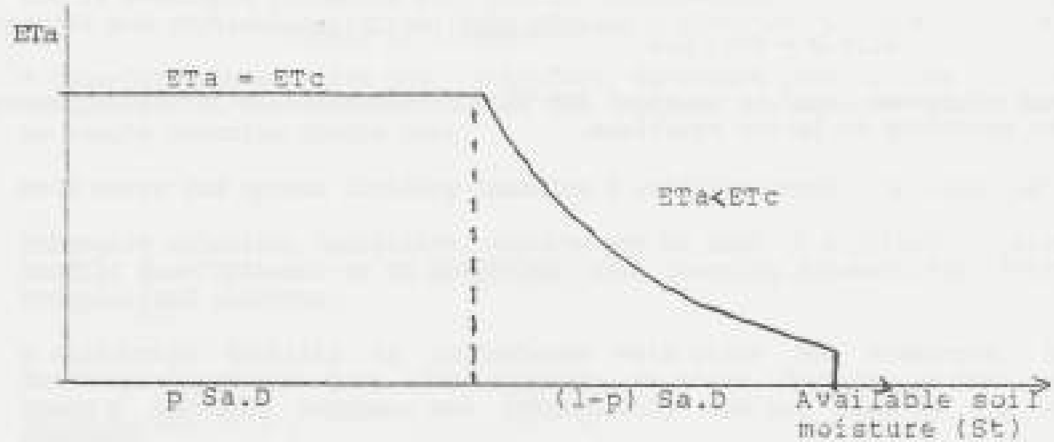

Fig. A.1 The assumed evolution of the actual crop evapotranspiration with a changing available soil moisture reserve

The ETa value for a decade equals the difference between the initial available soil water of that decade (St1.D or MRi) and the final available soil water (St10.D or MRf).

The available soil water at the beginning of the decade is the sum of the effective rainfall of that decade and the available soil water at the end of the previous decade.

The calculation of the available soil water at the end of the considered decade is obtained by integration of differential equations.

For practical reasons three different situations have to be considered:

a. $St1.D > (1-p)Sa.D$ and $\frac{St1.D - (1-p)Sa.D}{Etc(decade)} > 1$

or in other words St1.D is high enough to allow maximum crop evapotranspiration during the entire decade.

Under these conditions :

$$St10.D = St1.D - ETc(decade) \qquad (3)$$

b. $St1.D>(1.p)Sa.D$ and $\frac{St1.D - (1-p)Sa.D}{ETc(decade)} < 1$

These conditions imply that during a certain number of days (10-t) ETa equals ETc, but that after (10-t) days ETa is smaller than ETc, and this for a period of t days.

Thus :

$$St10.D = (1-p)Sa.D.e^{-ETc(decade).t/10(1-p)Sa.D} \qquad (4)$$

c. $St1.D<(1-p)Sa.D$

or the initial available moisture reserve never allows maximum crop evapotranspiration.

Under these conditions, integration of equation 2 gives :

$$St10.D = St1.D.e^{-ETc(decade)/(1-p)Sa.D} \qquad (5)$$

The computer programme used in project BOT/85/011 calculates St10.D and consequently Eta(decade) according to latter equations.

6.11 FAO/ISRIC SOIL DATA BASE

by

Erik Van Waveren

INTRODUCTION

The FAO/ISRIC Soil Database (SDB) is a user-friendly micro-computer Program to store, organize and manipulate soil data of different climatic regions and geographical environments. SDB is developed for the Soil Resources, Management and Conservation Service of the Land and Water Development Division of FAO.

SDB is a modification of the Botswana Soil Database (Van Waveren 1988). A large part of SDB is, conceptually, based on the ISRIC Soil Information System (ISIS), which accomodates the soil monolith collection of the International Soil Reference and Information Centre (Van Waveren and Bos 1988).

SYSTEM OVERVIEW

SDB is developed to handle soil profile information, including field information and chemical and physical analytical data. The main features of the system are:

A menu-based interactive user interface. On-screen instructions and help screens assist the user in running SDB. Options are selected and started by simply pressing single keys.

Data entry and update facility includes a validity control on coded data.

Extensive selection facilities. Results may be sent to a printer (tables, profile descriptions) or to diskfiles, thus creating datasets for further computerized analyses.

A read/write facility to communicate with other SDB databases. This facility allows the user, for instance, to enter directly in the field using a portable computer and subsequently add the data to the main database.

A flexible coding system module, which can be adapted to local conditions.

The databases are protected against operational errors and power failures.

SDB is a stand-alone program and does not need a supporting database management system. The program code is written in the dBASE programming language and later compiled with Clipper (Nantucket 1987). The datafiles have a dBASE format and consequently can be used directly in dBASE, as well as in any other application programme that reads dBASE files, such as, statistical packages, word processors, expert systems (ALES), geographical information systems.

Also, the datafiles can be transformed into ASCII (text) files with a simple dBASE command.

SDB CODING SYSTEM

To facilitate effective database management the descriptive field data need to be stored in a coded format. Storage of coded data reduces the size of the databases and, equally important, it standardizes the descriptive data and thus allows for selection, comparison and validity control.

A coding system gives the classification and class codes of all the variable (attributes) that are for the soil description. For example:

Variable (attribute)	Classification (code and related term
Landform	PL plain
	VA valley
	etc....
Cutans (abundance)	F few
	C common
	M many

The coding system module forms an integral part of SDB and comprises a number of conversion tables. A conversion table contains the classification of a single variable. For instance the conversion table for Cutans-abundance may look like:

O nil

F few

C Common

M Many

Obviously, it is extremely difficult to design a coding system that is universally applicable and meets the requirements of all potential users. Therefore, SDB contains a flexible coding system module which allows the user to make the necessary modifications in order to describe specific soil characteristics effectively. More precisely:

a. The classification of variables and the related class codes can be changed.

b. The standard sets of site, horizon and analytical variables can be extended by defining an additional number of 'blank' site and analytical variables.

These operations are done interactively and do not require any modifications to be made in the software.

SDB comes with a default coding system which is intended to serve as a basis for further development. It follows the FAO Guidelines for Soil Profile Description (FAO 1977) and has been updated according to the first draft of the Revised FAO Guidelines (March 1989).

OUTPUTS AND APPLICATIONS (A FEW EXAMPLES)

a. Soil Surveys:

Output: SDB generates reports in standard formats, such as soil profile descriptions and tables with analytical data.

SDB creates sets of systematically and uniformly described soil profiles which enable proper quality control and comparison.

SDB allows for grouping or differentiation of soil profiles/units on soil characteristics other than those used in soil classification. This may be very useful for legend construction, validation and inventory of soil units.

b. In Land Evaluation

Traditionally, the interpretation of a soil unit is based on a representative soil profile which more or less characterizes the unit. The soil database enables the evaluator to use a different approach: First the soil profiles are evaluated and the generalization (grouping of point data into units) is done afterwards. In other words "Calculate first, generalize later" instead of "Generalize first, calculate later" (see Bouma 1989). The main advantages are :

- The land evaluation procedures become more precise and basically scale independent
- Validation of the evaluation procedures will be easier.

Both factors are extremely important for the development of a (semi-) quantitative and computerize land evaluation system.

Figure 1 is added in order to illustrate the position of SDB in a computerized land evaluation system. The flow diagram visualizes the data input structure of the system, which is presently developed in the Yemen Arab Republic. Soil data derived from various sources are transferred into the standard format (according to the coding system) and stored in the soil database.

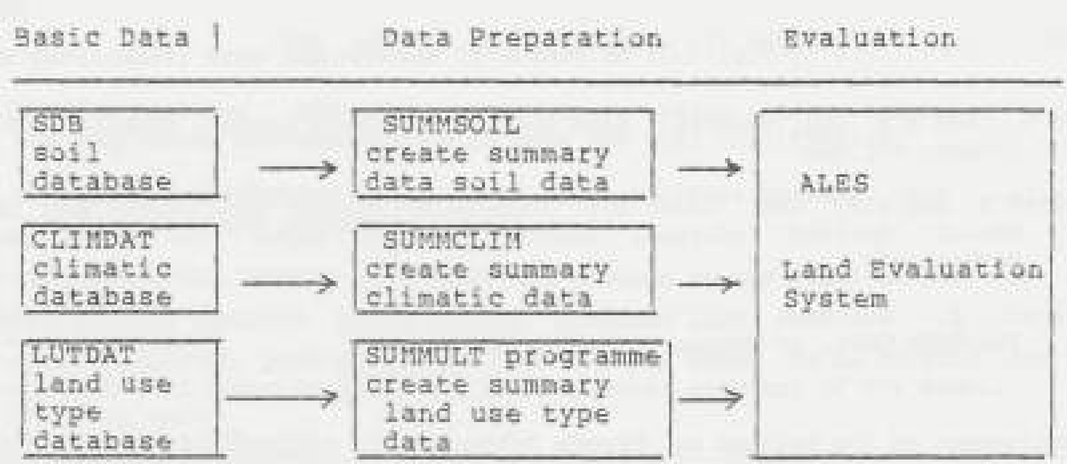

Fig. 1 Data input/preparation for land evaluation in the Yemen Arab Republic.

A computer program extracts relevant field and analytical information from the soil database, recalculates the profile information for standard depth intervals, and stores the data into a file.

This datafile provides the information on land characteristics for a computerized land evaluation system, which is developed with ALES (Rossiter and Van Wambeke 1989).

The information on climate and land use types is stored in separate databases.

SYSTEM REQUIREMENTS

SDB runs on IBM (compatible) XT, AT and PS/2 micro computer with at least 512kb of RAM and a harddisk. For small amounts of data, a harddisk is not essential. A 720 kb diskette is sufficient to store the SDB system files and information on approximately 30-40 profiles.

FURTHER INFORMATION

A complete description of SDB is given in the SDB User Manual. To obtain the SDB package please write to: Chief, AGLS, FAO, Via delle Terme di Caracalla, 00100, Rome, Italy.

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7. SUMMARY OF THE DISCUSSIONS

Availability of moisture is one of the most important land qualities affecting crop production in Eastern and Southern Africa. It was observed, however, during the meeting that less attention was paid to this crucial area by most member countries in their programmes, hence the need to develop efficient and suitable methodology for assessing and rating it. Definition of this quality is essential both as a part of overall land evaluation and also to predict the importance of interannual fluctuation in moisture availability on crop production.

As a result of the present meeting it was suggested that:

1. The year by year variation in moisture availability should be taken into account

   This is of particular importance in predicting the incidence of drought and evaluating its potential impact on production. Neither of these assessments can be carried out using average data. Year by year analysis should be presented in terms of probability, and the number of years analysed should preferably be sufficient to that required for analysis of confidence limits.

2. A moisture balance model should be used, incorporating precipitation, evapotranspiration (PET) and soil moisture storage

   Soil moisture balance should preferably be carried out for 10 day or 5 day periods, using actual precipitation data and PET values interpolated from monthly figures. If daily rainfall figures are not available monthly values can be used although assessment will be less accurate.

3. Models should be crop and soil specific

   Moisture balance model should take account of the specific moisture uptake abilities and yield responses of individual crops and the moisture retention characteristics of particular soils.

4. Further investigation of various parameters used in the model should be carried out

   In particular, more information is needed on such factors as:

   - correction for effective rainfall, taking into account intensity, run-off/run-on characteristics of site and soil infiltration;

   - assessing contribution of groundwater to moisture balance, particularly under residual moisture cropping;

   - estimating the initial soil moisture content at the start of the crop growing season;

   - what additional soil physical determination needs to be carried out in the field or the laboratory, to assure reasonable accuracy of the model.

5. Testing and verification of the model should be carried out by comparison with actual crop yields

   The output of the moisture balance modelling may be expressed either quantitatively, as a yield relative to that which could be achieved when moisture is not limiting, or qualitatively as a land suitability rating. In both cases results should be verified with actual yields, preferably those obtained under controlled conditions on research stations. If agreement is poor, modification of some of the parameters used in the model may be necessary.

6. **Spatial variation in moisture availability should be investigated**

Actual field measurements have often revealed large variations in soil moisture content within short distances. Attempts should be made to assess the level of variation within mapping units or on individual farms.

7. **Classification of soil moisture regimes should be further developed**

Soil moisture regimes are particularly valuable for classification and correlation purposes and existing classifications need to be expanded to improve definitions for tropical and subtropical conditions.

8. FIELD TRIP GUIDE

GENERAL

The field excursion was from Harare to Chiredzi, via Masvingo, a distance of about 500 km. Two days were allocated for this trip. On the first day, 4 profiles were visited between Harare and Masvingo. Participants spent the night in Chiredzi. On the second day, another 4 profiles were visited in the Chiredzi area. On the third day, participants travelled back to Harare and en route visited Mushandike Irrigation Scheme in Masvingo.

PROFILE 1

Profile 1 is located in Beatrice, about 55 km south of Harare. Beatrice is a commercial farming area in Natural Region II, which is suitable for intensive crop production supported by livestock.

Climate

The table below depicts climate data for the Beatrice site.

Month	Rainfall	Temperature M.D. Max. oC	Temperature M.D. Min. oC	PET (mm)
Jul	0.2	23.0	4.9	76
Aug	1.6	25.6	6.7	100
Sept	5.2	28.9	10.2	129
Oct	31.1	30.8	13.8	159
Nov	100.7	28.9	15.9	134
Dec	169.1	27.9	16.8	127
Jan	173.5	27.9	16.9	125
Feb	157.1	27.6	16.6	106
Mar	83.5	27.8	15.0	114
Apr	44.5	27.1	12.7	91
May	6.3	25.1	8.4	78
Jun	3.1	22.8	5.3	59
Year	275.9	26.9	11.9	108

Beatrice is at an elevation of about 1 300 m above sea level with a mean annual rainfall of 776 mm (CV% of 32) and a mean annual temperature of 19.4°C. Since Natural Region II is defined by climatic conditions that favour crop and animal production, it is the region in which soil characteristics find their fullest agricultural expression. The range of crops, the level of productivity and the degree of intensification of animal production made possible by the favourable climate, provide scope for choosing systems of farming that utilize in the fullest measure the varying potential and peculiarities of the soils.

Soils in the area are derived from basaltic metavolcanics which give rise to dark reddish brown clay loams to clays.

Soils are inherently fertile and are suitable for large scale crop production which can be maintained at high yield levels by suitable systems of rotation and management. In the area, farming systems are dictated chiefly by the necessity for maintaining soil organic matter. The soils respond to a restoration period under fertilized grass. Pastures are playing an important part in the farming systems of the area resulting in material cash returns through the integration of animals.

Crop Production in the Area

While maize is the main crop, numerous side crops (winter wheat, beans, soyabeans, sunflower) also play important roles in the cropping programmes. Apart from their value as potential cash crops, they can provide valuable residues for feeding livestock as an addition to crops grown specifically for this purpose.

Dairy Production

Intensive dairy production of whole as well as industrial milk is also important in the area. Production is based on yield in summer and feeding on pastures in winter together with complete supplementation with concentrates throughout the year. In addition to these main lines of animal production, there are associated profitable supplementary enterprises of sheep and pig production.

PROFILE 2

Profile 2 is in the Featherstone area. Climatic data for Chivu, about 35 km to the south, have been used to represent this area.

Month	Rainfall (mm)	Temperature M.D. Max. oC	M.D. Min. oC	PET (mm)
Jul	1	20.3	5.9	90
Aug	3	23.0	7.4	111
Sept	7	26.5	10.0	161
Oct	38	28.3	13.0	184
Nov	99	26.8	14.4	144
Dec	161	26.1	15.1	133
Jan	172	26.2	15.4	133
Feb	119	25.9	15.0	111
Mar	72	25.9	13.8	118
Apr	27	24.8	12.0	96
May	6	22.8	8.8	80
Jun	5	20.4	6.5	65
Year	710	24.7	11.4	119

Featherstone lies at an elevation of 1 410 m in Natural Region III, with an annual rainfall of about 710 mm, and a mean annual temperature of 18.1°C.

Much of the rainfall is accounted for by infrequent heavy falls and the region is also subject to fairly severe mid season dry spells. The liability of the region to these drought spells, together with the lower effective rainfall, reduce the reliability of crop production and intensive systems of farming based on cash cropping alone, are therefore impracticable. In addition, crops with long growing periods are excluded; this is illustrated in the table below which shows the safety of growing crops with different requirements. Number of seasons out of twenty in which crops of various growing-season requirements can be produced satisfactorily (calculated from rainfall figures).

Growing-season requirements

	150 days	130 days	110 days	90 days	90 days
Chivu	3	7	12	17	20

Crop varieties grown in this region must therefore be early maturing and drought resistant.

In Natural Region III, the reduced efficiency and the unreliability of rainfall limit crop production both in range and potential yield. Emphasis shifts more towards semi-intensive systems based on livestock assisted by crop production, particularly on soils of high available moisture potential. Thus soil characteristics that affect the water holding capacity assume greater importance than in Natural Region II where soil fertility is more paramount.

Although there is a fairly wide range of soils in the area, the profile depicts fine grained sands on Triassic sandstones with imperfectly drained subsoils. The area is virtually treeless and gently undulating. On these soils, cropping potential is limited due to low fertility and wetness. Cropping potential is best directed to the production of fodder crops to support semi-intensive livestock production with sideline cash crop production.

Livestock production should be based on the highest possible production from the veld in summer and production should continue into winter on a semi-intensive plan by supplementary feeding. Small flocks of sheep are a useful sideline.

The area has a high percentage of ploughable land but little good land. Thus large areas can be cultivated to supply the crop requirements of the system. Millet serves well for silage purposes.

The poor sandy nature of the soils requires that they should not be subjected to continuous cropping and rotations should include periods of rest under grass leys, fertilized at moderate levels. The planted pastures in addition to assisting soil stabilization will provide suitable grazing area for livestock development.

PROFILES 3 AND 4

Climatic data for Makaholi

Month	Rainfall (mm)	Temperature M.D. Max. oC	Temperature M.D., Min. oC	PET (mm)
Jul	1	21.1	6.2	68
Aug	2	23.9	8.4	102
Sept	5	27.2	10.9	139
Oct	23	28.6	14.2	164
Nov	88	27.9	15.5	138
Dec	154	27.6	16.6	138
Jan	144	27.9	16.8	140
Feb	128	27.0	16.1	113
Mar	68	26.4	15.0	111
Apr	26	25.1	12.8	93
May	6	23.2	9.3	73
Jun	5	20.8	6.6	60
Year	650	75.6	12.4	112

Makaholi Experimental Station lies about 30 km north of Masvingo town at an elevation of 1 200 m. The area is subject to periodic seasonal droughts and severe dry spells during the rainy season. Thus, although mean annual rainfall is 600-700 mm, in normal years, 331 mm was recorded in 1972/73. The risk of drought makes cash cropping uneconomical on soils of low water holding capacity that require appreciable expenditure on soil improvement. Farming systems on a limited scale for drought resistant crops and fodder crops in support of semi-extensive beef production are best suited to this area.

Soils in the area are derived from granite which is mainly of the sheet or dwala type. Because of this type of parent material, vertical drainage to depth does not occur and surplus water moves laterally through the solum to drainage lines. Due to impeded drainage the soils become waterlogged during the rainy season; consequently the products released by chemical weathering remain within the solum for considerable periods. At the same time, due to anaerobic conditions, iron in the soil is reduced by bacterial action to soluble ferrous forms. These two factors lead to destabilization of the clay fraction which is then removed from the solum by drainage. The result is a leached very sandy soil (Profile 3). On higher ground/coastal positions, the soils are brown (7.5YR colours) and analysis shows that these soils contain more free iron. These factors suggest that the soils have developed under conditions of relatively good drainage. However, the presence of lateritic gravel in the lower portion of the solum may indicate that these soils have suffered from hydromorphy (Profile 4).

The area is in Natural Region IV which is suited to a semi-intensive farming system. The suitable farming system should not only be in accord with natural factors as well as based on livestock production but also should be intensified to some extent by the growing of drought resistant fodder crops.

PROFILES 5 TO 7

Climatic data for Buffalo Range

Month	Rainfall (mm)	Temperature M.D. Max. oC	M.D. Min. oC	PET (mm)
Jul	3	25.5	8.7	79
Aug	8	27.7	10.8	115
Sept	16	30.7	13.6	160
Oct	34	31.8	16.9	182
Nov	78	32.2	18.9	169
Dec	90	32.7	19.9	170
Jan	119	32.9	20.3	171
Feb	129	31.2	19.7	131
Mar	81	30.5	18.5	127
Apr	29	29.0	15.9	95
May	15	27.4	11.7	77
Jun	3	25.0	9.2	66
Year	605	29.7	15.3	129

Profiles 5 to 7 are represented by climatic data for Buffalo Range. This is the major sugar producing area in Zimbabwe. The low veld is typified as a region where the soil-moisture season, although variable, is generally very limited. The soils are, therefore, much shallower and less weathered with high base saturation and reserves of weatherable minerals.

Profiles 5 and 6 at Hippo Valley Estates are under irrigated sugarcane. The soils are mainly derived from gneiss and these generally give rise to a range of contact soils with those derived from basalt. A feature to note is the development of perched water tables in some of the profiles caused by almost 24 years of irrigation.

Profile 7, Chiredzi Research Station, is also derived from mafic paragneiss. The soils are reddish brown sandy clay loams over redder sandy clays and sometimes over clays. These in turn overlie weathering gneiss and there is generally a horizon of mixed soil-like material and weathering rock of variable thickness. This intermediate horizon often contributes very materially both to the available water capacity of the soil and to its inherent fertility.

Climatic data for Chisumbanje

Month	Rainfall (mm)	Temperature M.D. Max. oC	M.N. Min. oC	PET (mm)
Jul	2.6	25.4	8.0	119
Aug	4.3	27.6	10.3	160
Sept	4.3	30.7	13.1	219
Oct	24.6	32.0	16.8	256
Nov	63.0	32.0	18.7	234
Dec	95.3	32.0	19.4	221
Jan	104.1	32.0	19.8	213
Feb	82.4	30.9	19.3	163
Mar	52.0	30.6	18.0	177
Apr	17.0	29.3	15.3	143
May	7.9	27.5	11.2	122
Jun	5.9	25.2	8.6	101
Year	463.4	29.6	14.9	177

This data is for the period 1960-1976.

The area served by Chisumbanje is the largest single tract of relatively deep basalt-derived soils in Zimbabwe. The soils, in the main, consist of grey to black self churning clays characterised by loose granular surface horizons of varying thickness which take up water very readily. This surface horizon overlies a less permeable subsoil.

Profiles 5 to 8 lie within Natural Region IV where climatic factors completely dominate the natural land use. Rainfall is low and erratic and farming has to be based on the utilisation of the veld alone. Extensive cattle farming and game ranching is the only sound farming system. However, irrigated agriculture has completely transformed this natural disadvantage of the area. Large scale irrigation development has expanded and is served by a number of research stations in the area.

Grid Reference:	TO-731-785	Map No: :	1830-84
Profile No:	102/DD/89	Pedon No :	1
Author:	Moyo, M.	Date:	11.9.89

Location: Inyondo A Farm Beatrice

Elevation: 1300 m

Rainfall: 776 mm

Landscape: Form Pediment
Shape Flat or almost flat

Slope: Position Middleslope
Percent 2
Aspect 270 degrees

Erosion: Severity Nil/slight
Type Sheet

Capping: Nil

Surface features: Stones Nil
Outcrops Occasional
Cracks Fine (0-5 mm)

Physiognomic class: Cleared land

Disturbance class: Old fallow

Effective depth: 105 cm

Natural region: IIB

Classification: Zimbabwe group: 4 - Siallitic
family: E - Igneous & Metamorphic - excluding basalts

FAO/Unesco: Chromic Luvisol

USDA Soil Taxonomy: Very fine clay mixed isothermic Lithic Rhodustalf

Land use: Maize (7 t/ha), potatoes (1.5 t/ha) and Kikuyu grass as pasture (40 t of dry matter per year). Dairy farm.

Description

0 - 18 cm — Dark reddish brown (2.5YR 3/4d) dark reddish brown (2.5YR 3/4m); clay loam; dry, hard, moist, firm, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; few fine Fe/Mn stains; numerous fine roots; few angular small stones (quartz); gradual smooth boundary; 18cm thick; pH 6.2.

18 - 42 cm — Dark reddish brown (2.5YR 3/4d) dark reddish brown (2.5YR 3/4m) clay loam; moist friable, plastic, sticky consistence; moderate fine subangular blocky structure; good permeability; well drained; few medium Fe/Mn stains; fairly numerous fine roots; many angular coarse gravel (quartz); clear wavy boundary, 24cm thick; pH 6.5.

42 - 105 cm — Hard and soft weathering rock. Good permeability; well drained; few fine roots.

Comments — Exotic syringa trees provide shelter for grazing cattle. Horizon 3 has soil-like material (s,l,m), hard and soft weathering rock. There are inclusions of weathering rock in horizon 2. Horizon 3 was not sampled.

<u>Analysis:</u> Profile 102/DD/89 Pedon Number 1

Depth(cm)	0 - 18	18 - 42	42 - 105*
Lab No	Y1171	Y1172	Y1173
DM%	94.8	94.5	
Texture	C	C	
Clay %	53	65	
Silt %	16	16	
Fine sand %	21	13	
Medium sand %	5	3	
Coarse sand %	4	3	
Gravel %	2	13	
pH (CaCl2)	6.2	6.5	
Carbonates %			
EX Ca (me %)	10.8	14.0	
EX Na (me %)	7.9	10.8	
EX K (me %)	0.17	0.18	
TEB (me %)	18.9	25.1	
CEC (me%)	22.7	26.6	
Base sat %	83	94	
E/C	42.6	40.7	
S/C	35.5	38.4	
ESP	0.4	0.3	
EKP	0.8	0.7	

* Not sampled

Grid Reference:	TO_775_311	Map No:	1830-D2
Profile No:	99/DD/89	Pedon No:	2
Author:	Moyo, M.	Date:	16.8.89

Location: Donkerhoek Farm Featherstone

Elevation: 1410 m

Rainfall: 750 mm

Landscape: Form Pediplain
Shape Flat or almost flat

Slope: Position Upperslope
Percent 2
Aspect 240 degrees

Erosion: Severity Nil/slight
Type Sheet

Capping: Nil
Surface features: Stones Nil
Outcrops Nil
Cracks Nil

Physiognomic class: Cleared land

Mean tree height: 6-8 m

Mean grass height: 25-75 cm

Disturbance class: Old fallow

Principal species: Paricura

Effective depth: 161 cm

Natural region: III

Classification: Zimbabwe group: 5 - Fersiallitic
family: M - Sandstones
Series: Featherstone 5M.3

FAO/Unesco: Eutric Regosol

USDA Soil Taxonomy: Sandy mixed isothermic Typic Quartzipsamment.

Land use: Dairy farm. The farm produces 1 425 litres of milk per day. Grasses are grown for cattle feed.

Description

0 - 25 cm Pale brown (10YR 6/3d) brown (10YR 5/3m) fine grained sand; dry loose, moist loose, non plastic, non sticky consistence; apedal structure; rapid permeability; very well drained; very numerous very fine roots; no stones; clear smooth boundary; 25 cm thick; pH 4.9

25 - 74 cm Very pale brown (10YR 7/3 d), light yellowish brown (10YR 6/4 m); fine grained sand; few very fine faint brownish yellow (10YR 6/6) mottles; dry loose, moist, loose, non plastic, non sticky consistence; apedal structure; rapid permeability; moderately well drained; numerous very fine roots; no stones; abrupt smooth boundary; 49 cm thick; pH 4.7

74 - 96 cm Light yellowish brown (5.5Y 6/4), fine grained sandy loam; common very fine distinct red (2.5YR 4/8) mottles; moist firm; slightly plastic, slightly sticky consistence; massive structure; good permeability; poorly drained; common medium Fe stains; few very fine roots; no stones; gradual smooth boundary; 22cm thick; pH 4.6

96 - 161 cm Red (2.5YR 4/8 m), fine grained sandy loam; many medium prominent light grey (5Y 6/1) and brownish yellow (10YR 6/6) mottles; moist, friable, slightly plastic, slightly sticky consistence; massive structure; good permeability; poorly drained; common medium Fe stains; few very fine roots; no stones; pH 4.5

Analysis: Profile 99-DD89 Pedon Number 2

Depth (cm)	0 - 20	27 - 72	76 - 94	98 - 160
Lab No	Y1031	Y1032	Y1033	Y1034
DM %	99.7	99.8	99.8	99.7
Texture	fS	fS	fSaCL	fSaCL
Gravel %	0	0	0	0
Coarse sand %	1	1	2	1
Medium sand %	11	10	9	7
Fine sand %	85	87	67	68
Silt %	2	1	2	2
Clay %	1	1	21	21
pH (CaCl2)	4.9	4.7	4.6	4.5
Carbonated %				
EX Ca (me %)	0.6	1.2	1.2	1.1
EX Mg (me %)	0.1	0.0	2.2	1.9
EX Na (me %)	0.00	0.02	0.04	0.04
EX K (me %)	0.18	0.08	0.28	0.18
TEB (me %)	0.8	1.7	3.7	3.3
CEC (me %)	1.6	1.2	6.3	5.9
Base Sat %	51	100	59	56
E/C	160.0	240.0	29.5	27.6
S/C	82.0	240.0	17.5	15.4
ESP	0.0	1.7	0.6	0.7
EKP	11.3	6.7	4.5	3.1

Grid Reference:	TO-678-046	Map No:	1930-DA
Profile No:	101/DD/89	Pedon No:	3
Author:	Moyo, M.	Date:	17.8.89

Location: Makoholi Experimental Station CPU

Elevation: 1180 m

Rainfall: 650 m

Landscape: Form — Pediplain
Shape — Gently undulating

Slope: Position — Upperslope
Percent — 2
Aspect — 260 degrees

Erosion: Severity — Nil/slight
Type — Sheet

Capping — Nil
Surface features: Stones — Nil
Outcrops — Nil
Cracks — Nil

Physiognomic class: Cleared land

Mean grass height: 25 cm

Disturbance class: Cultivated/recent fallow

Effective region: 168 cm

Natural region: IV

Classification: Zimbabwe group — 5 - Fersiallitic
family — G - Granites
series — Makoholi 5G.3

FAO/Unesco: Haplic Arenosol

USDA Soil Taxonomy: Sandy mixed thermic Ustic Quartzipsamment.

Land use: Cleared not planted.
Trial plots for the Agronomy Institute of the Department of Research and Specialist Services. This land has been under cultivation since 1965 and is used mainly for experiments on maize, pearl millet and sorghum. Lime is applied every 3 to 4 years. Manure is also applied to improve the structure of the soil. The soil is inherently infertile and therefore nitrogen, phosphorus and sulphur fertilizers have to be applied. With proper management, the following yields can be easily attained: 5 t/ha of maize, 2.5 t/ha of pearl millet and 1 t/ha of sorghum. Soya beans are grown under irrigation and a yield of 3 t/ha is expected. New crops like cassava and bambara groundnut have recently been introduced.

Description

0 - 35 cm	Yellowish brown (10YR 5/4m) coarse grained sand; moist, loose; non plastic, non sticky consistence; apedal structure; rapid permeability; very well drained; fairly numerous fine roots; no stones; clear smooth boundary; 35cm thick; pH 5.0
35 - 74 cm	Brownish yellow (10YR 6/6m), coarse grained sand; moist, loose; non plastic, non sticky consistence; apedal structure; rapid permeability; very well drained; fairly numerous fine roots; no stones; abrupt wavy boundary; 39 cm thick; pH 4.5
74 - 168 cm	Excessively rapid permeability; moderately well drained; fairly numerous fine roots; loosely packed angular small stones and angular coarse gravel (quartz);
Comments	Horizon 3 has lateritic quartz stones which start at 105 cm at the other face.

Analysis: Profile 101-DD-89 Pedon Number 3

Depth (cm)	0 - 30	37 - 72
Lab No	Y1039	Y1040
DM %	99.9	99.8
Texture	cS	cS
Gravel %	1	2
Coarse sand %	25	29
Medium sand %	34	32
Fine sand %	34	31
Silt %	5	4
Clay %	2	4
pH (CaCl2)	5.0	4.5
Carbonates %		
EX Ca (me %)	0.7	1.0
EX Na (me %)	0.2	0.0
EX K (me %)	1.101 0.02	
TEB (me %)	1.1	1.0
CEC (me %)	1.4	1.0
Base Sat %	76	100
E/C	70.0	25.0
S/C	55.0	25.0
ESP	4.3	2.0
EKP	7.1	2.0

Grid Reference:	TP-657-112	Map No:	1930-D4
Profile No:	100/DD/89	Pedon No:	4
Author:	Moyo, M.	Date:	17.8.89

Location: Makoholi Experimental Station, Drewton Farm

Elevation: 1 240 m

Rainfall: 650 mm

Landscape: Form Pediplain
Shape Gently undulating

Slope: Position Scarp
Aspect 90°

Erosion: Severity Nil/slight
Type Sheet

Capping: Nil
Surface features: Stones Nil
Outcrops Nil
Cracks Nil

Physiognomic class Cleared land

Mean grass height: 25 cm

Disturbance class: Old fallow

Effective depth: 176 cm

Natural region: IV

Classification: Zimbabwe group 6 - Paraferrallitic
family G - Granites
series Makohli 6G.2

FAO/Unesco: Haplic Lixisol

USDA Soil Taxonomy: Fine loamy mixed Thermic Typic Kandiustalf.

Land use: Flue cured tobacco has been grown on this land till mid 1960's, after which it became a ranching area until 1979. From 1979 to date maize trials are being conducted and yield averages of 6.5 t/ha have been obtained.

Description

0 - 25 cm Dark brown (10YR 3/3m) coarse grained loamy, sand; moist very friable, non plastic, non sticky consistence; apedal structure; rapid permeability; very well drained; numerous fine roots; no stones, clear smooth boundary, 25 cm thick; pH 5.3.

25 - 80 cm Strong brown (7.5YR 5/8m) medium grained sandy clay loam; moist friable, slightly plastic, sticky consistence; weak very fine subangular blocky structure; good permeability; well drained few fine roots; occasional angular fine gravel (quartz); diffuse boundary; 55 cm thick, pH 5.6

80 - 127 cm	Strong brown (7.5YR 5/6m) medium grained sandy clay loam; moist friable, slightly plastic, sticky consistence; weak very fine subangular blocky structure; good permeability; well drained; few fine Fe stains; few fine roots; occasional angular fine gravel (quartz); clear smooth boundary; 47cm thick; pH 5.9.
127 - 176 cm	Moist, loose consistence; apedal structure; excessively rapid permeability; very well drained; common fine Fe stains; few fine roots; loosely packed angular coarse gravel and angular fine gravel (quartz).
Comments:	Horizon 4 has lateritic quartz gravels and few stones. Horizon 3 & 4 have inactive clay.

Analysis: Profile 100-DD-89 Pedon Number 4

Depth (cm)	0 - 20	25 - 80	80 - 127
Lab No	Y1035	Y1036	Y1037
DM %	99.7	99.5	99.4
Texture	mLs	mSaCL	mSaCL
Gravel %	2	2	5
Coarse sand %	14	14	14
Medium sand %	32	30	26
Fine sand %	43	29	33
Silt %	5	6	5
Clay %	6	21	22
pH (CaCl2)	5.3	5.6	5.9
Carbonates %			
EX Ca(me %)	1.1	1.8	1.8
EX Mg(me %)	0.3	0.4	0.4
EX Na(me %)	0.02	0.10	0.08
EX K (me %)	0.24	0.24	0.18
TEB (me %)	1.6	2.5	2.4
CEC (me %)	1.6	2.8	2.4
Base sat %	100	90	100
E/C	26.7	13.2	10.7
S/C	26.7	11.9	10.7
ESP	1.3	3.6	3.4
EKP	15.0	8.7	7.7

Grid Reference:	ZZ-000-000	Map No:	2131 B1
Profile No:	1/KK/89	Pedon No:	5
Author:	Garikayi, A.O.D.	Date:	13.9.89

Location: Hippo Valley Estate Section 1 Field 9C

Elevation: 450 m

Rainfall: 590 mm

Landscape: Interfluve

Slope: Position Crest
Aspect 0°

Effective depth: 40 cm

Natural region: V

Classification: Zimbabwe group: 4 - Siallitic
family: PE - Intermediate paragneiss
series: Chiredzi 4PE.1

FAO/Unesco: The existence of a Mollic A horizon was debated at this site in the absence of % C analysis. Tentatively the Cambic B horizon was used as a criteria for classification: Chromic Cambisol.

USDA Soil Taxonomy: Fine loamy mixed hyperthermic typic. In the absence of mollic epipedon, it is classified as fine loamy mixed hyperthermic Reptic Lithic Haplustoll.

Land use: The land has been under irrigated sugar cane for the past 16 years. Potassium and nitrogen fertilizers are applied but leaching of the latter is a major problem. Phosphorus fertilizers are not used as the nutrient is not deficient in these soils. Sugar cane yield is 153 t/ha (12.8 t/ha per month).

Description

0 - 11 cm: Yellowish red (5YR 4/6d) dark reddish brown (4YR 2/4 m); coarse grained sandy loam: dry, slightly hard consistence; moderate medium subangular blocky structure; good permeability; well drained; numerous roots; few angular coarse gravel (parent material); gradual smooth boundary; 11cm thick; pH 5.0

11 - 27 cm: Reddish brown (5YR 4/4 d) dark reddish brown (5YR 2/4 m) coarse grained sandy loam; dry, slightly hard consistence; weak medium subangular blocky structure; good permeability; well drained; fairly numerous roots; common (parent material); clear wavy boundary; 16 cm thick; pH 5.2

27 - 85 cm: Occasional roots; Horizon of hard and soft weathering gneiss. 75% of matrix consists of weathering gravels and gneiss.

NB. Profile form is altered by ridge and furrow topography hence effective depth varies from 27 to 55cm.

Analysis : Profile 1/KK/89 Pedon No. 5

Depth (cm)	0 - 11	11 - 27
Lab No	Y1193	Y1194
DM %	97.3	96.7
Texture	mSal	cSal
Clay %	17	19
Silt	7	6
Fine sand %	37	30
Medium sand %	22	22
Coarse sand %	17	23
Gravel %	17	44
pH (CaCl2)	5.0	5.2
Carbonates %		
EX Ca (me %)	4.9	4.2
EX mg (me %)	2.0	2.8
EX Na (me %)	0.12	0.19
EX K (me %)	0.31	0.16
TEB (me %)	7.4	7.3
CEC (me %)	9.1	8.8
Base sat %	81	83
E/C	54.0	45.3
S/C	43.6	37.5
ESP	1.3	2.2
EKP	3.4	1.9

Grid Reference:		ZZ-000-000	Map No:	2131-B1
Profile No:		2/KK/89	Pedon No:	6
Author:		Garikayi, A.O.D.	Date:	14.9.89
Location:		Hippo Valley Estates Section 7 Field 7B		
Elevation:		450 m		
Rainfall:		590 mm		
Physiognomic class:		Cleared land		
Disturbance class:		Cultivated/recent fallow		
Depth to watertable:		68 cm		
Water clarity:		Clear		
Effective depth:		68 cm		
Natural region:		V		
Classification:	Zimbabwe group	4 - Siallitic		
	family	PE - Mafic Paragneiss intergrade		
	series	Chiredzi 4PE.2 integrade (integrade referring to influence of other parent materials possibly sandstone)		
	FAO/Unesco	Gleyi-Chromic Luvisol		
	USDA Soil Taxonomy	Fine loamy mixed hyperthermic Aquic Palustalf.		

Land Use: Irrigated sugar cane with yield of 10 t/ha per month and about 13% sugar content. Surface irrigation is used and is about to be 70 - 80% efficient. There is little response to potash. 40 kg P_2O_5 and 150 N are applied for hectare. The scheme lies within Natural Region V where the rainfall is low (about 350 mm effective rainfall).

Description

0 - 17 cm	Dark reddish brown (5YR 3/3m), coarse grained sandy loam; moist friable consistence; moderate medium subangular blocky structure; good permeability; well drained; numerous fine roots; no stones; diffuse boundary; 17 cm thick; pH 6.4
17 - 31 cm	Dark reddish brown (5YR 3/3m); coarse grained sandy clay loam; moist friable consistence; moderate medium subangular blocky structure; good permeability; well drained; numerous fine roots; no stones; clear smooth boundary; 14cm thick; pH 7.1
31 - 43 cm	Dark brown (7.5YR 4/4m), coarse grained sandy clay; few, very fine faint yellowish brown (10YR 5/4) mottles; moist firm consistence; weak fine subangular blocky structure; good permeability; moderately well drained; fairly numerous medium roots; no stones; diffuse boundary; 12cm thick; pH 7.2
43 - 68 cm	Dark brown (7.5YR 4/4m); coarse grained sandy clay; few very fine faint yellowish brown (10YR 5/4) mottles; moist firm consistence; weak fine subangular blocky structure; good permeability; moderately well drained; fairly numerous medium roots; no stones; diffuse boundary; 12 cm thick; pH 7.2
68 - 130 cm	Water table

Comments: Horizon 4 has poor drainage (approximately 24yrs of irrigation). Water table at 68 cm is a limitation for effective depth. Horizon 3 has slight drainage problems due to fluctuating water table.

Analysis : Profile 2/KK/89; Pedon Number 6

Reference				
Depth (cm)	0 - 15	17 - 31	31 - 43	45 - 60
Lab No.	Y1195	Y1196	Y1197	Y1198
DM %	97.5	97.4	96.1	95.1
Texture	cSaCL	cSaCL	cSaCL	cSaC
Clay %	20	26	34	38
Silt %	7	6	6	6
Fine sand %	22	22	16	15
Medium sand %	31	28	23	22
Course sand %	20	19	22	19
Gravel %	3		2	
pH (CaCl2)	6.4	7.1	7.2	6.5
Carbonates %				
EX Ca (me%)	7.1	7.6	8.2	5.5
EX Mg (me %)	2.6	3.8	5.4	4.0
EX Na (me %)	0.76	0.66	0.85	0.50
EX K (me %)	0.19	0.09	0.12	3.58
TEB (me %)	10.6	11.3	13.6	13.5
CEC (me %)	11.6	11.3	13.6	14.7
Base sat %	91	100	100	92
E/C	58.4	43.8	39.6	38.3
S/C	53.1	43.8	39.6	35.2
ESP	6.6	5.8	6.3	3.4
EKP	1.6	0.8	0.9	24.3

Profile No.:		UM-518-755	Pedon No.: 7
		Date:	13/6/87
Location:		Chiredzi Research Station Trial Plots	
Elevation:		430 m	
Mean Annual Rainfall:		600 mm	
Site:		Middle slope position (2% slope)	
Parent material:		Paragneiss	
Erosion:		Nil/slight	
Land capability Classification:		Class II	
Classification:	Zimbabwe group:	4 (Siallitic)	
	family:	PE (mafic paragneiss)	
	series:	Triangle 4 PE.2	
	FAO/Unesco:	Chromic Luvisol	
	USDA Soil Taxonomy:	At this site the presence of a Mollic A horizon was debated in the absence of % C results. As a result two classifications were given as follows:	

a) with Mollic A horizon - fine loamy mixed isothermic Placic Aquistoll. The presence of a mollic is possible from local experience.

b) without Mollic A horizon - fine loamy mixed isothermic Typic Rhodustalf.

Land use: Experimental site for water harvesting in Natural Region V. Crops are grown in the furrows which can hold up to 30% of the precipitation. Increases in yield average 25 - 30% and can be up to 100% in dry years. An oxen-drawn ridger has been designed and will soon be available to communal farmers. The crops grown include sorghum, maize and cotton.

Ridging has proven to be a big 'hint' to farmers in the area and with the newly designed ox-drawn implement it is expected that more farmers will go for the ridge/furrow farming system.

Description

0 - 30 cm — Dark reddish brown (mixed 5YR 3/4 d, 3/4 m and 5YR 3/3 d, 3/2 m due to cultivation); medium sandy clay loam; dry, slightly hard consistence; weak medium subangular blocky structure breaking to fine crumbs; good permeability and well drained; few roots; clear wavy boundary; 30 cm thick; pH 7.1.

30 - 60 cm — Dark reddish brown (5YR 3/4d, 3/3 m), medium sandy clay; dry hard consistence; strong medium subangular blocky structure; few manganese stains; soil mass fizzes with HCl; good permeability and well drained; few roots; diffuse boundary; 30 cm thick; pH 6.1.

60 - 86 cm — Dark reddish brown (5YR 3/4 d, 3/3 m); medium sandy clay; dry, very hard consistence; strong coarse subangular blocky structure; few manganese stains; soil mass fizzes with HCl; slightly restricted

permeability and well drained; occasional roots; clear smooth boundary; 26 cm thick; pH 6.2.

86 - 110 cm Saprolithic material with occasional roots which fizzes vigorously with HCl; 24 cm thick; pH 6.5

Analysis: Profile UM-518-755 Pedon Number 7

Depth (cm)	0 - 20	45 - 55	70 - 80	95 - 105
Lab. No.	V0823	V0824	V0825	V0826
DM %	97.8	96.8	96.6	95.6
Texture	mSaCL	mSaC	cSaC	cSaL
Gravel %	O	O	O	O
Coarse sand %	14	12	9	45
Medium sand %	25	19	13	19
Fine sand %	30	24	29	17
Silt %	9	8	8	7
Clay %	22	38	41	12
pH (CaCl2)	7.1	6.1	6.2	6.5
Org. carb. %	0.59	0.84	0.44	0.18
EX Ca(me %)	10.4	10.2	16.2	18.5
EX Mg (me %)	2.6	3.7	4.4	4.1
EX Na (ME %)	0.08	0.21	0.31	0.25
EX K (me %)	0.92	0.31	0.21	0.21
TEB (me %)	14.0	14.4	21.1	23.0
CEC (me %)	19.2	16.8	21.5	25.9
Base Sat %	73	86	98	89
E/C	87.4	44.7	49.6	215.7
S/C	63.6	38.2	48.7	191.7
ESP	0.4	1.2	1.5	1.0
PKP	4.8	1.8	1.0	0.8

Grid Reference:	ZZ-000-000	Map No:	2032 03
Profile No.:	3/KK/89	Pedon No.:	8
Author:	Garikayi, A.O.D.	Date:	20.11.87

Location: Chisumbanje

Elevation: 400 m

Rainfall: 400 mm

Landscape: Pediplain; flat or almost flat

Natural region: V

Classification:	Zimbabwe group	3 (Vertisol)
	family	B (derived from Basalt)
	series	Chisumbanje 3 B.2
	FAO/Unesco	Eutric Vertisol
	USDA/Soil Taxonomy	Hyperthermic montmorillonitic Typic Palustalf

Land use: Trials on irrigated and rainfed early maturing varieties of maize and cotton. Under rainfed conditions the crops are grown in furrows and this increases yield by 25-50%. Response to potash fertilizers is negative but there is response to phosphorus. Zinc deficiency is a problem in these soils. This applies mainly under rainfed conditions.

Description:

0 - 10 cm: Dark grey (10YR 4/1 d), very dark grey (10YR 3/1 m), clay; dry very hard, moist very firm, very plastic, very sticky consistence; moderate, medium, angular blocky structure; slightly restricted permeability; well drained; fairly numerous, fine roots; clear smooth boundary; 10 cm thick; pH 7.5.

10 - 29 cm: Dark grey (10YR 4/1 d), very dark grey (10YR 3/1 m), clay; dry very hard, moist very firm, very plastic, very sticky consistence; moderate, medium angular blocky structure; moderately restricted permeability; moderately well drained; fairly numerous medium roots; few slickensides; gradual smooth boundary; 19 cm thick; pH 7.6.

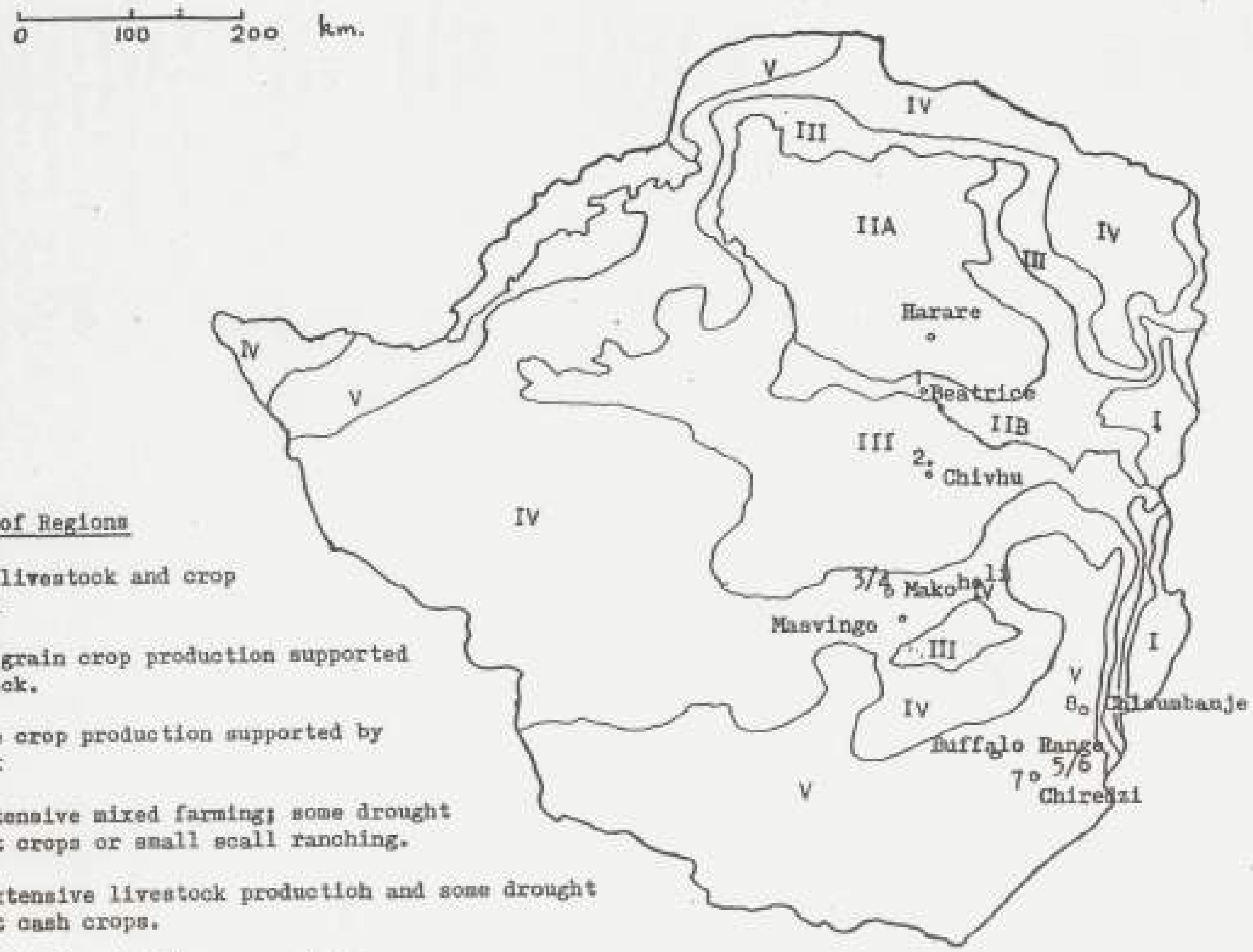
29 - 49 cm: Very dark grey (10YR 3/1 m), clay; dry very hard, moist very firm, very plastic, very sticky consistence; moderate coarse angular blocky structure; moderately restricted permeability; moderately well drained; common medium $CaCO_3$ concentrations; fairly numerous fine roots: few pressure faces; diffuse boundary; 20 cm thick; pH 7.7.

49 - 87 cm: Very dark grey (10YR 3/1 m), clay; dry extremely hard, moist very firm, very plastic; very sticky consistence; strong medium angular blocky structure; moderately restricted permeability; moderately well drained; common medium $CaCO_3$ concentrations; few fine roots; common slickensides; gradual smooth boundary; 38 cm thick; pH 7.8

87 - 128 cm: Very dark grey (10YR 3/1 m), clay; moist very firm, plastic, very sticky consistence; moderate medium angular blocky structure; moderately restricted permeability; well drained; few very fine roots; common slickensides; 41 cm thick; pH 7.8.

Comments: Horizon 1 is Ap and has surface mulch poorly developed. Horizon 2 has some pressure faces. Horizon 3 has few small slickensides. Cracks are about 1 cm wide throughout the solum.

NATURAL REGIONS OF ZIMBABWE AND PROFILE SITES (1 - 8)



Brief Outline of Regions

I. Intensive livestock and crop production

II. Intensive grain crop production supported by livestock.

IIB. Intensive crop production supported by livestock

III. Semi- Intensive mixed farming; some drought resistant crops or small scall ranching.

IV. Semi - extensive livestock productioh and some drought resistant cash crops.

V. Extensive beef production : ranching.

WORLD SOIL RESOURCES REPORTS

1. Report of the First Meeting of the Advisory Panel on the Soil Map of the World, Rome, 19-23 June 1961.**
2. Report of the First Meeting on Soil Survey, Correlation and Interpretation for Latin America, Rio de Janeiro, Brazil, 28-31 May 1962**
3. Report of the First Soil Correlation Seminar for Europe, Moscow, USSR, 16-28 July 1962.**
4. Report of the First Soil Correlation Seminar for South and Central Asia, Tashkent, Uzbekistan, USSR, 14 September-2 October 1962.**
5. Report of the Fourth Session of the Working Party on Soil Classification and Survey (Subcommission on Land and Water Use of the European Commission on Agriculture), Lisbon, Portugal, 6-10 March 1963.**
6. Report of the Second Meeting of the Advisory Panel on the Soil Map of the World, Rome, 9-11 July 1963.**
7. Report of the Second Soil Correlation Seminar for Europe, Bucharest, Romania, 29 July-6 August 1963.**
8. Report of the Third Meeting of the Advisory Panel on the Soil Map of the World, Paris, 3 January 1964.**
9. Adequacy of Soil Studies in Paraguay, Bolivia and Peru, November-December 1963.**
10. Report of the Soil of Bolivia, January 1964.**
11. Report of the Soils of Paraguay, January 1964.**
12. Preliminary Definition, Legend and Correlation Table for the Soil Map of the World, Rome, August 1964.**
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M-53/T [illegible]
ISBN [illegible]