# MSc Programme Soil and Water

# LAND USE SYSTEMS UNDER TRADITIONAL AGRICULTURE

# ANALYZED WITH PS123N/WOFOST AND ALES

# (With special reference to the Chuka-South area, Kenya)

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Not for publication

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Department of Soil Science and Geology

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# LAND USE SYSTEMS UNDER TRADITIONAL AGRICULTURE

# ANALYZED WITH PS123N/WOFOST AND ALES

(With special reference to the Chuka-South area, Kenya)

**MSc Thesis** 

# GETE ZELEKE E.

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July, 1993.

To: my mother Belaynesh Desta; my beloved wife, Muluadam Gedebe and my daughter, Yemisrach Gete.

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#### **CHAPTER 1**

## **INTRODUCTION**

#### 1.1 Overview

Land evaluation is the process of assessing suitability of a given land unit for a specified purpose under specified circumstances. It involves the interpretation of data on land form, soil, vegetation, climate and other aspects of land, in order to judge the comparative success of alternative land use systems in terms of the objective of the evaluation.

Land evaluation is concerned with the present performance of land. Frequently, however, one is confronted with changes in the use of land and in some cases changes in the land itself (FAO, 1976). Land use system(s) performance depends on many factors which change with time and location. Land evaluators have to cope with many different situations and objectives, so various kinds of evaluation are needed, from the very simple to the very complex.(for terms and definitions the reader is referred to the Framework for land evaluation, FAO soils bulletin 32, 1976).

In most developing countries especially in sub-saharan Africa, food production per capita, though growing, lags severely behind demand. Traditional farming methods are largely maintained inspite of the growing need for and pressure on agriculture land (Smaling, 1993). The yearly losses of precious soil, nutrients and other natural resources are significant which result in a low production level.

Losses have to be reduced to the minimum, if sustainable production is to be achieved. This clearly calls for appropriate land evaluation methods to further increased production from the land and to meet the needs of the growing population.

In this respect the Framework for Land Evaluation (FAO, 1976) has been useful to developing countries, even though the procedures described (qualitative land evaluation), involve data structuring, construction of rating tables (which by itself is a result of much generalization) and an extensive matching process. Besides, the many assumptions and generalizations, to simplify the dynamics of nature, make these procedures inaccurate, not free from bias.

In view of the many land use problems to be solved and the need to support land use planning at different scales fast and efficiently, land evaluation methods need to be further developed with a call for computerization and quantification.

Much has already been done in the development of computerized land evaluation systems. Examples are the Geographical Information and Land Evaluation System (GILES) which is used in land evaluation in the Ethiopian highlands, at scales of 1:50,000 and 1:250,000 (Bechtold, 1989); The Land Evaluation Computer System (LECS) developed for Indonesia (Wood & Dent, 1983); The Automated Land Evaluation System (ALES) which is capable to assess the physical and economic land suitability (Rossiter & Van Wambeke); The WOFOST crop simulation model (van Diepen, Rappoldt, Wolf & van Keulen, 1988); and PS123N quantified land evaluation system (Driessen, 1992). These are but some of the models and systems that were developed and some of them are still being steadily improved.

Quantified land-use systems analysis was defined by P.M Driessen, (1988), as a better tool for assessing the suitability of land and for signalling misuse of resources. He further elaborates that, in line with the dynamic nature of land use systems, quantified land evaluation procedures entail frequent updating of the values of all system-dependant (or 'state') variables. It follows that the resolution of the basic data which are processed, and the level of generalization of the functional relations which translate basic data into quantified land qualities and land use requirements, must tally with the dynamics of the system. However, complexity and massive data needs are serious limitations to the use of such systems.

If some of these limitations can be reduced to an acceptable level, combining quantified land evaluation and Automated systems seems to be a logical course to assist the rural development. The question to be answered at this stage is whether these systems can handle land use systems under traditional agriculture either by them selves or combined, and whether quantified land evaluation makes an essential contribution to rational planning of land use.

In line with the above, two comprehensive dynamic crop-growth models, namely WOFOST & PS123N, and ALES (Automated Land Evaluation System (qualitative)) were used for this study. The analyses were carried out using soil survey data from the Chuka-South area, Kenya. Twelve soil monoliths were selected, in a cross section from West to east, from the foot of Mount Kenya (which is wet and about 1700 m) to the dry lower eastern parts (800m).

The data bases required by the first two models were constructed after data aggregation and screening. Using these data, the applicability of the models was analyzed by comparing their results with reality.

An important aspect of the study was to find ways to exchange of information between the former two models and ALES. Important information on the area, such as moisture availability, reference yield and availability of oxygen for root growth, was deduced from PS123N results. These Land Use Requirements (LURs) were inputs in the ALES framework. A total of three land utilization types were evaluated, namely maize under traditional rainfed agriculture (MTA), maize under traditional rainfed agriculture but with biological soil conservation (MTC), and the same with physical soil conservation (MTP).

The study pays due attention to soil data analysis ('reasonable data gap fill methods'), model applicability and points of improvement, and to possible interactions between quantified and qualitative land evaluation procedures for better results.

The methodology developed in the study is believed worth testing in Ethiopian semi-highland agricultural areas.

#### 1.2 Research Questions and Justification

Developing countries at tropical and subtropical latitudes, have characteristically a large variety of factors (soil, climate, vegetation, etc.) that affect the timing and mode of cropping. Concurrently, farming is influenced by a variety of socio-economic factors. This complexity requires an integrated and realistic approach.

Realistic description of land use systems would have to be dynamic and consider biotechnical

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Realistic description of land use systems would have to be dynamic and consider biotechnical and socioeconomic processes in one integrated analysis. But in practice the complexity and massive data needs of evaluation models are prohibitive. It is possible to describe potential land suitability at a high level of simplification, but the production environment of the farmer is far more complex to be modelled, (Driessen, 1992).

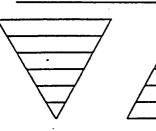
In the past few decades a need evolved for accessible, quantified and automated land evaluation systems but, as requirements varied quantification assumed many forms. Eventually, one is limited by data available, and it is both necessary to determine the minimum data requirements, and to develop flexible systems which can function at different levels of detail (Purnell, 1986).

Many authors understand that developing countries must be able to test, validate and calibrate the various evaluation models. But the paucity of detailed data on the resource variables is a recurrent problem (de Guenni, 1986).

Bouma (1986) when discussing the analysis of the land quality "available water" in relation to the scale of observation and applicability presents the following.

Relative areal applicability

Degree of information Methods of land use detail systems analysis



1.farmers experience
2.expert's judgement
3.calculations
4.simulation (simple)
5.simulation (complex)

- 6.simulation basic phenomena and processes

In line with the above the following research questions were addressed during the study:

1. Are the evaluation systems tested applicable for the environment under study ?

2.Is it possible to make information flow from one evaluation system to another ?

3. How detailed Should the basic data for acceptable results ?

4. To what extent do the results of the evaluation models tally with the farmers perception of reality ? and what is the degree of applicability ?

# 1.3 Objectives

The general objective of the study comprises:

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1. Evaluating the applicability of ALES, WOFOST and PS123N for land suitability assessment of selected crops under traditional agriculture.

2. Finding possible ways of information exchange between PS123N/WOFOST and ALES for better results.

3. Contributing to data aggregation and simplification, so that evaluation models and systems can be improved.

In particular it is investigated to what extent ALES can contribute to quantified land evaluation in areas with traditional farming systems. Besides, comparison of WOFOST with PS123N and with reality is a major objective.

From the study assessment of limitations adhering to the systems at this scale, and a strategy towards improvement is expected.

## 1.4. Literature review

### 1.4.1 Conceptual Framework

The Framework for Land Evaluation (FAO, 1976) defines land evaluation as the process of assessing the performance of land when used for specified purposes. Collection and interpretation of basic data on climate, soils, crops and other aspects of land in terms of the requirements of alternative land uses is part of this process.

Land evaluation was generalized according to (Driessen & Konijn, 1992) as an analysis of land suitability that combines a study of land (properties) with a study of land use requirements. Land suitability reflects the degree by which the compounded requirements of land use are met by the compounded properties of the land.

Different kinds of land are normally differently suited to various uses. Among the differences between land units are their physical attributes, such as soil characteristics, climate, terrain, and water resources. Lands also differ because of current and past land use, and by the social and economic context within which they are used.

Basically land evaluation aims to answer the following questions (FAO, 1976):

i) how is land presently managed, and what will happen if present practices remain unchanged?

ii) what possible improvements of management practises are feasible within the present use?

iii)what other uses of land are physically possible, economically and socially relevant, and which of these offer sustained production and benefits ?

For a sound judgment of which land use is feasible for a particular area, the evaluation process must answer most of the above questions. However, the land evaluation process does not determine the land use changes that are to be carried out by itself, but it rather provides a basis from which decisions on land use can be made. In other words, land evaluation is an input into land use planning.

#### 1.4.2 Basic principles of land evaluation

The framework for land evaluation (FAO, 1976) states six basic principles of land evaluation.

In brief these are as follows:

1. Land suitability is assessed and classified with respect to a specified kind of use. The principle recognizes the fact that different kinds of land use have different requirements.

2. Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. Suitability for different uses is assessed by comparing the required inputs with the benefits that can be obtained.

3.Land evaluation requires a multidisciplinary approach. Interactions between land uses is complex. Land properties vary in time and space, and land use is equally dynamic. Since land evaluation aims to study and understand these interactions, thorough knowledge of underlying processes is a precondition.

4. Evaluation considers the physical, economic and social context of land and land uses.

5. Suitability refers to production on a sustained basis. The aspects of environmental degradation should be taken into account when assessing suitability.

This does not mean that the environment should remain unchanged but the probable consequences of a changing environment should be assessed as accurately as possible and remain at acceptable levels.

6. Evaluation involves comparison of more than one kind of use. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several, alternatives.

## 1.4.3 Quantified land evaluation (general)

Quantified land evaluation (QLE) expresses land qualities and land utilization requirements as numerical values that depend on the momentary state of the entire land use system (Driessen, 1988, Juan & Guenni, 1986). Here, land qualities are so-called state variables of a land use system: quantifiable attributes of the system, that can be limiting factors and influence the behaviour of the system negatively. The crop and its biological interaction with its surroundings is described for limited intervals of time. The selection of the interval length is dictated by the dynamics of the land use system.

In QLE, results of point analyses must be interpreted and aggregated to represent an area of land. This adds an extra problem because it addresses the spatial variation of land qualities and land use requirements. A land unit is assumed to be an area possessing uniform land qualities and land characteristics (FAO, 1983). Therefore in analogy to the minimum temporal resolution, imposed by system dynamics, the basic data input must have a minimum spatial resolution, dictated by the scale and purpose of the evaluation (Beek, 1986, Driessen, 1988, 1992)

The suitability of the land unit is not only determined by the biophysical environment but also by the prevailing socio-economic conditions. The socio-economic context may be highly complex. In the past, much was done to develop systems that can estimate production potentials on the basis of reasonable assumptions so that acceptable results would be obtained with minimum effort.

## 1.4.3.1 WOFOST & PS123N

The crop growth simulation model of the centre for world food studies (WOFOST) and PS123N are quantified land evaluation systems that simulate crop growth of annuals at three levels of production abstractions, (1) potential production, (2) water-limited potential production and (3) nutrient-limited potential production. These hierarchical levels are also called "Production Situation, PS-1, PS-2 and PS-3" respectively, van Diepen and Driessen, (1986) and van Diepen, Wolf, Keulen & Rappoldt, (1988). Production situations are described rather than the actual production environment because the farmers environment, with its multitude of physical and socioeconomic limitations, is too complex to be handled in an integrated and quantified analysis. The analyses were simplified by assuming one or more amendable limitations eliminated or corrected.

Production situation 1 (PS-1) uses location, temperature, radiation and crop genetic characteristics to calculate the production potential of a crop provided that all other factors remain optimal. This is a level where only temperature and radiation can be growth limiting. Production situation 2 (PS-2) an additional land quality : "availability of moisture" might also be limiting. At this level, temperature, radiation and moisture are the growth limiting factors. Production situation 3 (PS-3) examines an additional land quality, nutrient availability.

These hierarchical levels of production possibilities are indeed important tools in quantified land evaluation. The models use spatial variables; combining spatial variability with temporal changes reveals the dynamic character of land-use systems. Therefore the dynamic aspects of physical properties and yield levels in the models are prominent (Veldkamp, 1987).

Production situation 1 (PS-1) specifies the absolute maximum production. PS-2 indicates how production can be affected by moisture deficit. Situation 3 may assist in analyzing crop nutrient requirements and levels of application, (see figure 1.1.).

The main difference between the PS123N and WOFOST lies in the allocation of assimilates to different organs of a crop and calculation of maintenance respiration. In PS123N, maintenance cost is calculated after the assimilates are distributed to the various organs, whereas in WOFOST maintenance respiration is calculated before the assimilate are redistribute.

Another difference is data use and aggregation. Though the main data requirement is roughly the same, data organization in PS123N is clear and the level of data aggregation is higher than in WOFOST. One prominent difference between the two models is that PS123N uses daily weather data whereas WOFOST uses average monthly values.

Neither system can be considered a full-fledged land evaluation system; both generate important input for it. Even though the generated results may be close to reality they have problems like other models. Main limitations are high data needs and the impossibility to catch all factors that pertain to management, (Driessen & Van Diepen, 1987)

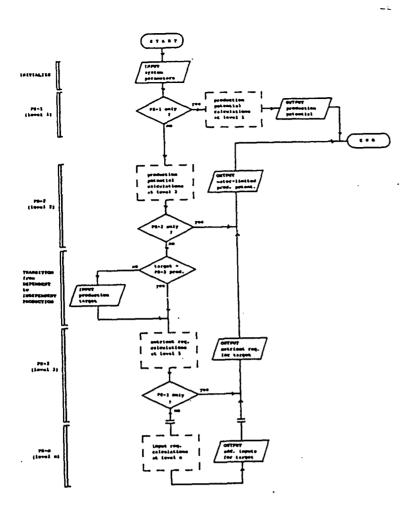


Figure 1.1 Relational diagram of production situations in PS123N. (adopted from lecture notes on land use systems analysis, Driessen, Konijn, 1992).

#### 1.4.4 Qualitative Land Evaluation

Qualitative Land Evaluation refers to systems which determine land suitability according to the framework of FAO (1976), i.e. by matching relevant land use requirements with the corresponding land qualities or land characteristics in a single land use system. Environmental factors are compared and ranked subjectively (Landon, 1991), based on expert knowledge, which is a drawback of the system. It expresses relative suitability in qualitative terms without quantification.

Generally it deals with selection of land utilization types that suit the physical socio-economic conditions of an area by determining land use requirements and identification of the corresponding land qualities or land characteristics. Qualitative systems express sufficiency by rating and finally matching rated land qualities and associated land use requirements to determine the comparative suitability of the land for the selected land utilization type.

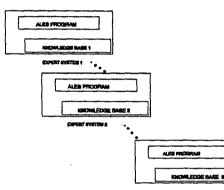
#### 1.4.4.1 Automated Land Evaluation System (ALES)

ALES is a computer program that allows land evaluators to build their own knowledge-based systems with which they can compute the physical and economic suitability of land mapping units in accordance with the FAO's framework for land evaluation (Rossiter and van Wambeke, 1990).

ALES itself is a framework within which it is possible to build one's own model of the local specific conditions. The relevance of the program varies with the evaluation models that are incorporated in it.

According to Rossiter, ALES is developed with the aim of allowing agricultural scientists to present natural resources data in a usable form to land use planners, and also to facilitate the analysis of data which in most countries are available but have remained underutilized (Rossiter, 1990).

ALES does not by it self contain any knowledge. In the terminology of knowledge-based systems it is a shell, which provides a reasoning mechanism and prompts the evaluator to express inferences using this mechanism. Thus it is a computerized realization of FAO's framework, and models within the system are computerized adaptations to suit the specific evaluation exercise, Rossiter, (1990).



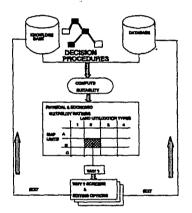


Figure 1.2 Relation between ALES program and models.

Figure 1.3. ALES program flow.

(both adopted from Soil use and management, volume 6, number 1, 1990)

The ALES programme has the following main components:

-a framework for knowledge base model construction using a set of decision trees.

-a framework for a data base to describe the area being evaluated.

-an inference mechanism to relate the above two, thereby computing the physical and economic suitability of a set of mapping units for a set of proposed land uses.

-an explanation facility that enables model builders to understand and fine-tune their models. -a consultation mode that enables a casual user to query the system about one land use at a time.

-a report generator that gives the evaluator options for presenting results.

#### CHAPTER 2

# Geographical environment of the study area

# 2.1 General

The Chuka-South area is located on the foot slopes of mount Kenya, stretching from west to east and bound by latitudes  $0^{\circ}15'$  S and  $0^{\circ}30'$  and by longitudes  $37^{\circ}30'$  E and  $38^{\circ}00'$ E.

Administratively, the area belongs to three districts, Embu, Meru and Kitui. The area is densely populated with an estimated 155-175 persons per  $\text{km}^2$  and a growth rate of about 4% (population census 1979). The population density is not uniform over the area; it is high in the eastern part (about 300-700 persons per  $\text{km}^2$ ), whereas the population density can be as low as 30 persons per  $\text{km}^2$  in the lower, drier western parts, (Meester & Legger (eds.), 1988, Jaetzold & Schmidt, 1983).

The altitude ranges from 2200 m in the north-west to about 500 m in the south-east. The drop in altitude of about 1800 m over 60 km causes a strong gradient in climate and hence in vegetation land use and living conditions.

The Chuka-South area is an extension of the typical agro-ecological profile of Mt. Kenya, from the cold and wet upper zones to the hot and dry lower zones in the Tana River Basin. The average annual rainfall reflects this contrast: more than 2200 mm per year at 2500 m altitude to less than 650 mm per year near the Tana River.

The upper north-western part is wet and steep; forest is the best land use (LHO). Down to the east, the Tea-Dairy Zone LH1 (Jaetzold & Schmidt, 1983) has still 1800 mm rainfall per year and permanent cropping is possible. In the lower Livestock-Millet Zone, LM5, rainfall during the agro-humic periods (i.e. the growing periods for annual crops) decreased rapidly over the past few years. The rainy period decreases very quickly from permanent cropping possibilities to 40-50 days at the driest sub-zone.

The Chuka-South area can be separated geologically into two halves: the volcanic western part and a basement-system in the eastern part.

The soils of lower ridges are derived from volcanic parent material, mainly consolidated pyroclastic rock, are very deep, permeable, uniform, red clays, almost irrespective of relief class. The soils of the volcanic plateaus are also derived from pyroclastic rock, but they are moderately deep to shallow and dominated by complexes of yellowish clay.

Land use on the volcanic soils (the western part) is forest, tea and dairy, coffee and maize, differentiated in zones according to altitude as mentioned above. The farms are mainly small holdings, traditional and sedentary.

The soils of the various land forms in the basement area are formed in granitoid gneiss, gneiss rich in ferromagnesium minerals and undifferentiated banded gneiss. Such soils are moderately deep to shallow (mainly Acrisols and Luvisols) are stony, yellowish red loams to clayloams, with substantial sealing, giving rise to lower infiltration rates. Run-off is much grater here and these soils are more liable to erosion. Erosion hazards are considerable in the area. Land uses in the basement area are cotton, maize, millet and extensive grazing. The farming type is mainly smallholder shifting cultivation and livestock farming.

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The fertility status of most soils is rather poor, mainly due to very low organic matter contents, low CEC levels and high leaching. Nutrient stress seems to be the major constraint in the wet volcanic parts, whereas in the dry basement area besides low nutrient availability, other factors like moisture availability and low erosion resistance are problematic, (for a detailed description of the area one is referred to the study by Meester & Legger, 1988 (eds); Bongers et al., 1986 (eds.)).

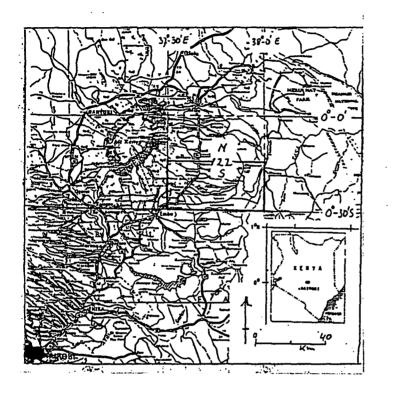


Figure 2.1. Location of the Chuka-South area

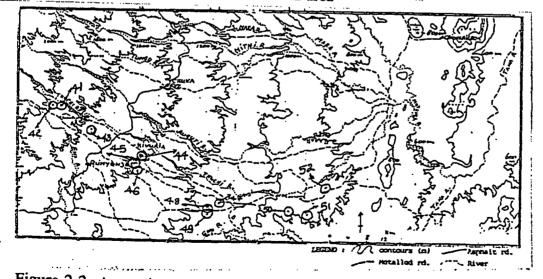


Figure 2.2. Approximate locations of soil monoliths.

#### **CHAPTER 3**

## Materials and Methods

#### 3.1. Climate Data Analysis

The two models need similar climate data for each study site, albeit in different formats. These data are believed to be available from meteorological stations. The need for complete data sets is one of the limitations of these models. This was disturbing in the in Chuka-South area. Since the models are very sensitive to location and altitude, using data from a climate station that is located far from the site is a source of error. The problem was solved by implementing different approaches, so that, the error incurred will be minimal.

### 3.1.1. Climate data for WOFOST

To run the WOFOST model the following climate data are required:

General station data (in this case site data were used) -name of meteorological station or site -latitude (°) -elevation (m) -empirical constants A & B -MARKOV constant

Average monthly data -minimum temperature (°C) -maximum temperature (°C) -radiation actually received (MJ.m<sup>-2</sup>.d<sup>-1</sup>) -vapour pressure (mbar)---- (either vapour pressure or relative -relative humidity (%) humidity data is needed) -wind speed (m.s<sup>-1</sup>) -rainfall(mm) -number of rainy days per month (d)

The basic climate data required were not fully available for each site. Most climate stations with a complete data set are far from the study area. There are some climate stations within the area but they have only few useful records. Therefore several alternatives were tried to fill the data gap. Though the alternatives are not also free from source errors, two data derivation systems were employed:

- calculation of data that can be found using standard calculation procedures based on location and elevation of the site;

- interpolation between weather maps and between nearby stations.

Five climate stations outside and inside the study area were selected. For the choice of climate stations nearness, the similarity of temperature Isohyets, sun hours (SUNH), and average annual EO were criteria used to select nearby stations and soil profile sites. Rainfall,

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maximum and minimum temperature, relative humidity or vapour pressure and wind speed were taken directly from nearby stations for each site.

The locations of climate stations and distances from each site are indicated in appendix G (or soil profile description)

The rest of the data except SUNH (sun shine hours) which were interpolated from data by Woodhead (1969), was calculated from FAO CROPWAT data. The program calculates radiation, potential evaporation and evapotranspiration using the original Penman (1948) method. (The complete calculated results are given in appendix D).

Where the distance between monoliths is small enough to cluster them, the climate variation was assumed to be insignificant. Nonetheless, calculations were done for all monoliths and the expected similarity proved correct. Therefore sites were grouped by the following criteria.

1. Similarity of agro-climatic zone (derived from agro-climatic map of Kenya, 1980).

2. Similarity of average potential evaporation and SUNH. In addition to the above source some information was borrowed from Woodhead, (1968).

3. Similarity of calculated actual radiation, EO and ETO.

# 3.1.2 Climate data for PS123N

This model use the same data items as WOFOST but the data must be daily values. Getting daily records in the area is not possible. Average monthly data were collected using the above methods, after which the data were converted to daily values by using a conversion programme (see appendix E).

Monolith	Locat		Altitude	Group	Representative
code	lat	long	(in m)	number	profile
EAK41	0°,21'15 S	37°,32'30 E	1710	- 1	EAK41
EAK42	0 <sup>°</sup> ,21'20 S	37°,32'10 E	1715		
EAK43	0°,22'50 S	37 <sup>°</sup> ,34'35 È	1550	2	EAK43
EAK44	0°,24'40 S	37°,37'40 E	1410	I	
EAK45	0°,24'50 S	37°,37'30 E	1380	- 3	EAK44
EAK46	0°,25'00 S	37°,37°25 E	1330 ———	l	
EAK47	0°,27'05 S	37 <sup>°</sup> ,42'00 E	1145	T	
EAK48	0°,27'05 S	37 <sup>°</sup> ,41'55 E	1142	- 4	EAK47
EAK49	0°,27'10 S	37°,41'51 E	1139 ———	l	
EAK50	0 <sup>°</sup> ,27'10 S	37 <sup>°</sup> ,46'20 E	855		
EAK51	0°,27'40 S	37°,47'25 E	855	- 5	EAK50
EAK52	0°,26'40 S	37°,48'20 E	845 —		

Table 3.1. Groups of soil monoliths

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Group	No Rain fall	Data type Temperature	Wind speed	RHA
1	Ruyenjes	Marienne	Embu.A	Marienne
2	Ruyenjes	Embu A.	Embu.A	Embu.A
3	Ruyenjes	Embu A.	Embu A.	Embu.A
4	Knuyombra	Kabodori	Kabodori	Kabodori
5	Kanuyombra	Kabodori	Kabodori	Kabodori

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Table 3.2 Climate stations from which data were taken for each group of profiles.

The calculated EO values were compared with values given by Woodhead (1968).

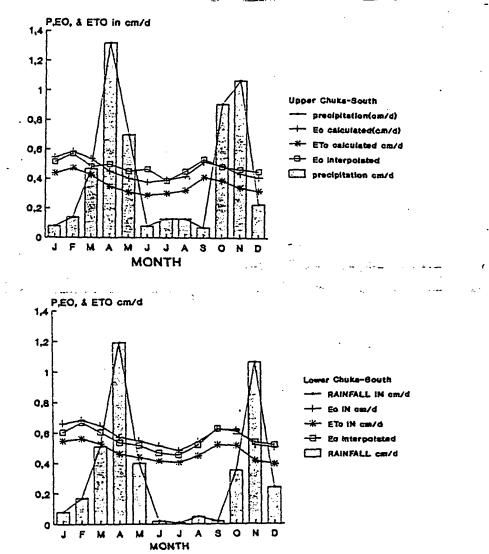


Figure 3.1. Calculated EO and ETO and interpolated EO for upper, middle and lower parts plotted together with rainfall data for Ruyenjes and Kanuyombra stations (upper and middle-lower parts respectively).

# 3.2 Soil Data Analysis

Soil data can be obtained from soil survey reports, standard tables and own measurements. For Chuka-South area the former two methods were used. The area was surveyed by the Training Project in Pedology (T.P.I.P) of the Agriculture University Wageningen, 1985-1986.

The soil survey data were stored in the International Soil Reference and Information Centre (ISRIC) data base system, ISIS. ISIS is a computerized soil data base developed for micro computers. It uses dBASEIII + and adheres to the FAO guidelines for soil profile description (1977), (see appendix G, profile description). Based on the information found in the data base, the required soil parameters were calculated or derived from standard tables. This tiresome task took considerable time and effort.

# 3.2.1 Soil Physical Parameters for PS123N

To run PS123N, the following soil and terrain data are needed.

-SMO	- total pore fraction (cm <sup>3</sup> cm <sup>-3</sup> )
-GAM	- texture specific constant (cm <sup>2</sup> )
-PSImax	- texture specific suction boundary (cm)
-KO	- saturated hydraulic conductivity (cm d <sup>-1</sup> )
-ALFA	- texture-specific geometry constant (cm <sup>-1</sup> )
-AK	- texture-specific empirical constant (cm <sup>-2.4</sup> d <sup>-1</sup> )
-SO	- reference sorptivity (cm d <sup>-0.5</sup> )
-Ktr	- hydraulic permeability of transmission zone (cm d <sup>-1</sup> )

These are all soil parameters that have to be estimated (by using texture-specific standard tables) or calculated (using various methods).

# 3.2.1.1. Limitations of texture-specific standard tables

Using texture-related parameter values posed two main problems:

The first of these is the definition of texture classes. U.S.D.A (Soil Survey staff, 1951) has eleven classes, FAO (1990) states eight particle size classes in the fine earth fraction, Rijtema (1969) published twenty texture classes, the Staring series (after Wösten, 1987) has eighteen classes, etc... The second problem is that different authors published different soil parameter values for similar texture classes.(see Appendix C).

The question arose whether so many texture classes are needed from land evaluation. To answer this question it was decided to use the various values in an evaluation exercise. The texture classes can then be judged by the results they give when a specific land utilization types are investigated, (personal communication P.M. Driessen, 1993).

Maize was chosen as a test crop and Kedung Salam (Indonesia) as a test site, because there was a complete data set of the area to run PS123N in the database of the model. U.S.D.A texture classes and soil parameter values suggested by Rijtema (1969), Rawls et al.(1982) and Carsel & Parish (1988) were used.

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The model was run three times for each texture class. The generated water-limited potential, plus or minus 20%, was plot in a graph.(see fig.4.3.). What was found is that, for the three cases, a number of texture classes gave the same result (with very little difference). Based on these findings, texture classes were aggregated to groups (see section 4.1.1.).

## 3.2.1.2 Alternative methods:

#### a. Calculations and regression analysis

SMO and ALPHA were calculated using existing equations (SMO) and transfer functions, based on statistical analysis (ALPHA).

-SMO - total pore space (cm<sup>3</sup> cm<sup>-3</sup>)

 $BD = W_t/V_t$ 

where

BD is bulk density (g cm<sup>-3</sup>)
Wt is dry soil sample weight (g)
Vt is sample volume (cm<sup>3</sup>)

In 'normal' soil, bulk density values lie between 0.9 and 1.5 g cm<sup>-3</sup>. The solid component, Vs, has a weight that is almost identical to Wt, because the weight a unit of soil air is negligible when compared with the weight of a similar unit of solid soil material. The weight of one volume unit of the solid component is the specific density (SD, expressed in g cm<sup>-3</sup>) of the soil material; it may be expressed as:

SD = Wt/Vt

Combination of the above two equations gives:

SMO = 1-BD/SDSD = 1/(0.38 + 0.57\*Cm)where

Cm is the organic carbon content of the matrix material (expressed in g  $g^{1}$ ). (for reference see Van Keulen et al, 1986, p 217-219).

-ALPHA - texture specific geometry constant  $(cm^{-1})$ 

This soil physical parameter was determined after transfer functions were established using linear regression analysis. For the purpose, the MYSTAT, statistics package was used. Rijtema and Rawls standard values were compared and Rawls values give good correlation. Two relations were found with different correlation coefficients, (see section 4.1.2). All other soil physical parameters, except KO which was adopted from Rawls (1982), were borrowed from Rijtema (1969).(see Appendix F).

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#### b. RETC (RETention Curve)

This is a computer programme developed by Van Genuchten et al. (1990) for describing the hydraulic properties of unsaturated soil. RETC is a descendent of the SOHYP code previously documented by Van Genuchten (1978). The programme uses the soil water descriptions by Brooks and Corey (1964), and Van Genuchten (1980), and pore-size distribution models of Burdine (1953) and Mualem (1976a) to predict unsaturated hydraulic conductivity functions.

Note that this programme was tested for its capacity to calculate soil physical parameters. However, I found out that the final value is always dependent on the first prediction or measurement. Hence the results are not used in this study.

### 3.2.2 Soil data for WOFOST

The following basic soil data are required by the WOFOST model:

-saturated hydraulic conductivity of the top and subsoil (cm  $d^{-1}$ )

-volumetric moisture content as a function of pF (cm<sup>3</sup> cm<sup>-3</sup>)

-log(conductivity as a function of pF (log(cm.d-1))

-chemical characteristics: pH(H2O), organic carbon (g/kg), P-Olsen (mg/kg), and exchangeable K (mmol/kg) (used only if nutrient calculations are required).

The two models were run with similar data so that it is possible to compare the results predicted.

To facilitate comparison most of the methods mentioned for PS123N were also used for WOFOST. Since, there is no accurately measured volumetric moisture content, equations were used (similar to those of PS123N water balance subroutine).

 $SMPSI = SMO*PSI^{-GAM*In(PSI)}$ 

where

SMPSI is volume fraction of moisture in soil with suction PSI (cm<sup>3</sup> cm<sup>-3</sup>).
SMO is total pore fraction (cm<sup>3</sup> cm<sup>-3</sup>)
GAM is texture-specific constant (cm<sup>-2</sup>)
PSI is matric suction of the rooted soil (cm) (see Driessen and Konijn, 1992).

The relation between matric suction and hydraulic conductivity reads: if  $PSI = \langle PSI_{max}$  then KPSI = KO\*exp(-ALPHA\*PSI) else KPSI = AK\*PSI<sup>a</sup> (Rijtema, 1965).

where

KPSI is hydraulic conductivity of soil with a matric suction of PSI (cm  $d^{-1}$ ) n is empirical constant: in practice n is close to 1.4 for all soil materials. (for the results see Appendix F.)

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## 3.3 Crop Data

In all cases crop data were present in the data base of the model. WOFOST provides only generic values, whereas PS123N, offers a variety-specific data set. The only thing done here is that a data set with generic values ( similar to WOFOST) was prepared for PS123N.

### 3.4 Data Analysis for ALES

ALES is an empty shell, that allows the expert to construct a data base for his local area, develop a model and determine physical and economic suitability.

#### 3.4.1 Model construction (development)

Land evaluation models for the study area were built in the following manner:

a) representative land utilization types were defined

b) the most important land use requirements were selected for each LUT.

c) important land characteristics were selected; some of these were derived from PS123N (WOFOST) simulation results and data analysis.

d) decision procedures were constructed to relate land use requirements to land characteristics e) physical and economic suitabilities were determined based on physical and economic information (using decision trees).

Considerable effort was given to inference of severity level ratings (the values were based on quantified evaluation results).

#### 3.4.1.1 Land utilization types

Maize under traditional agriculture (MTA), and maize under traditional agriculture with soil conservation (MTC & MTP), were the land utilization types examined. The latter two are the same apart from economical values of different soil conservation measures.

For each LUT, planning length, interest rate, annual and one-time inputs were determined. The optimum yield was determined by PS123N results. This is the yield per unit area that would be expected for a particular LUT (which includes management, input levels, socioeconomic aspects) assuming that all land qualities that affect yield have no limitation. This is considered as the attainable yield within the context of the area where the model is applied and not as biological maximum (Rossiter et al, 1988).

The optimum water-limited production potential (PS-2) as established with PS123N was taken as the reference yield. Since the area has a bimodal rainfall pattern, two cropping seasons are possible. The yield determined was assumed to be the yield obtained by an average farmer in an average year.

#### 3.4.1.2 Selection of land use requirements (LUR's)

The land use requirements are the main identifiers of the proposed land utilization types. It is possible to define many LUR's for each LUT, but, to keep the models to a reasonable size, it is important to limit the selected LUR's to those that cause clear differences in the performance of the land units considered. The selection of LUR's was based on their calculated and possible effects on the physical suitability of the land, potential production and cost of implementation. Five major LUR's were considered: -moisture availability -nutrient availability -erosion hazard -oxygen availability for root growth -foothold anchorage of roots Some of the land use requirements have multiple effects, e.g. erosion hazard affects physical suitability, yield and cost of production. They were all described and rated.

## a) moisture availability

Soil-water-plant relations involve complex processes that can not be handled with a simple model. In this study moisture availability was assessed using the results of PS-2 runs with PS123N. The water balance sub-routine of the model considers all processes that are take place during crop growth as much as possible.

The gap in production between PS-1 and PS-2 runs is attributed to water shortage. Therefore, the ratio of water limited production to potential production is thought to reflect the moisture condition of the soil.

A rating of the LUR was made and a severity level decision tree was built based on the ratio of PS-2/PS-1 production potentials.

## b) nutrient availability

This LUR was assessed by some basic parameter values, notably effective cation exchange capacity (ECEC), percent organic carbon (%C), annual average temperature (Tm), soil acidity (Sa), and soil basicity (Sb).

In the traditional land evaluation, nutrient availability is determined with a view to soil's cation exchange capacity. In many tropical soils, actual CEC is much less than measured CEC, determined at pH(H2O) 7.0. (see Appendix G, profile description).

Therefore, ECEC was taken as an indicator nutrient availability. A decision tree showing the severity level of the land use requirement was built using the possible interaction of the above basic parameters (land characteristics).

## c) erosion hazard

The susceptibility of an area to soil erosion is dependent on rainfall erosivity, slope, soil erodibility and management. Some of these can be rated semi-quantitatively; others are evaluated quantitatively on the basis of single soil properties. In this study, erosion hazard was estimated qualitatively by considering previous top soil erosion, slope angle, soil texture class and permeability. The decision tree has been built for this LUR was based on these factors.

## d) availability of oxygen to the roots

This LUR refers to the degree of soil aeration needed for adequate respiration of plant roots. Persistent waterlogging interferes with the supply of oxygen to the growing roots and this limitation is linked with the drainage class of the soil. The severity level decision tree considered the drainage condition of the soil and the average annual rainfall sum. During the

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actual data preparation for each site, the drainage condition (availability of oxygen ) was checked with PS-2 results of PS123N, and in some cases inference was made directly.

## e) foothold anchorage of roots

This LUR refers to the volume of soil space available for root growth. This can be limited by soil depth, coarse fragments, hardpans, toxic layers, bulk density and soil texture. Only soil depth were considered in the decision procedure.

# 3.4.1.3 Selection of land characteristics (LC's)

The selection of the land characteristics was based on the same principle as the selection of LUR's, it was considered whether the LC in question had an appreciable effect on the corresponding land quality or whether it varied over the set of land units under consideration. The land characteristics were translated to severity levels by considering corresponding land use requirements. In this study only existing data were used.

The definitions of classes and class limits for each land characteristic were based on Guidelines for soil profile description (FAO, 1977), Booker's Tropical Soil Manual (1991), Rating of land qualities in Kenya (Weeda & KSS, 1987), Personal communication (Legger and Kauffman) and own experience. Some LC's were inferred from simulation results; e.g. "estimation of moisture availability" is based on PS123N results.

## 3.4.1.4 Decision procedures

The heart of the ALES model is the set of decision procedures by which land suitability is assessed, (Rossiter et al., 1991). Three types of decision trees were constructed as follows: -For each land use requirement of each LUT;

-For proportional yield per output (to determine economic suitability);

-For overall physical suitability of each LUT.

Decision trees are hierarchical multi way keys in which the leaves are results (severity levels of land qualities), and the interior nodes of the tree are decision criteria (land characteristics values). These trees are constructed and they are traversed by the program to compute an evaluation using actual land data for each mapping unit (monoliths, in this case), (Rossiter, ALES user manual version 3, 1991).

## -Land use requirement severity level decision tree

The severity level of each LUR was inferred from single or combination of land characteristics values. If many factors must be considered then the decision tree become cumbersome, since it grows exponentially with the number of decision criteria. Therefore in this model, intermediate results were introduced in some decision trees of LUR's.

Figure 3.2. (in appendix A.), shows a severity level decision tree which allows the program to determine a value for the land quality 'nutrient availability' by considering single factor ratings for the land characteristics 'ECEC', 'mean annual temperature (Tm)', '%C', 'soil acidity (SA)' and 'soil basicity (SB)'. In this case ECEC can be considered as an intermediate value.

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The discriminant entities, namely, mean annual temperature (Tm), %C, soil acidity (Sa) and soil basicity(Sb) are introduced in the tree by > sign. This indicates at the severity level determined by the preceding land characteristics, the new LC's interject by > sign should be taken into consideration to determine the severity level of the LUR. A number preceded by an asterix (eg. \* 4) represents a final decision for a severity level of one branch of the tree. An equal sign followed by a number (eg. = 3), indicates the joining of the branch with another branch, both of them with the same severity level.

Table 3.3.Land qualities with corresponding dominant land characteristics

Land Quality	Land Characteristics
1. Moisture availability	a.PS123N relative yield
2. Nutrient availability	a.ECEC (effective cation exchange capacity)
	b.Mean annual temperature
	c.Organic carbon content (in %)
	d.Soil acidity
	e.Soil basicity
3. Erosion hazard	a. Previous erosion
	c.Slope angle
	d.Soil texture class groups
	e.Soil permeability (based on profile description)
4. Availability of oxygen	
in root zone	a.Soil drainage
	b.Average annual rainfall
5. Availability of foothold	-
for roots	a.Soil depth

# Physical suitability subclass decision tree

The physical suitability subclass of each land unit is determined from the set of single severity levels of its land qualities. The four physical suitability classes suggested by the FAO framework were used; complete suitable (S1), suitable (S2), marginally suitable (S3), and unsuitable (N). Within each class, subclasses designate the kind of the limitation(s) that placed the map unit in its class, for example 2AFH.

Land use requirements which are believed to have considerable impact on the physical suitability of the land, namely, erosion hazard, moisture availability, and nutrient availability were used in the decision tree (see figure 3.3. in appendix A.). In many cases nutrient availability is not considered a determining factor of physical suitability, but poor nutrient availability can be an indication of physical unsuitability.

Subclasses can be used as management groupings. For that matter, figure 3.3, shows the

physical suitability subclass decision tree for MTA, here the subclass '4MA/RE' might indicate land that is unsuitable because of high moisture stress 'MA' and risk of erosion 'RE'.

#### Proportional yield decision tree

The actual severity level of land qualities can be expressed by the proportion of the optimum (stress-free) yield that can be realised in a defined land-use system, i.e. by a defined land utilization type on the land unit under study. The standard procedure for prediction of yield proportion involves three model components, namely, "proportional yield" decision tree, a set of "proportion yield" factors and a set of limiting yield factors. In this model the former two were used. "Proportional yield" decision tree was built for each output. The severity levels of land qualities under consideration were used as diagnostic criteria in the decision tree. For each combination of severity levels, a proportional yield was specified, on a linear scale with intervals 0 to 1.

Figures 3.4.and 3.5.(in appendix A.), show a "proportional yield" decision tree for land utilization type MTA and MTC respectively. In the first case three LUR's were used to determine proportion of yield, namely, moisture availability, nutrient availability and erosion hazard. These were selected because they have considerable effect on crop yield in the study area. The signs and their meanings are the same as for the other tree except that a decimal number preceded by semi-colon represents an estimated proportional yield for the corresponding branch, (FAO, 1978, and some additional information were used from Jaetzold et.al. 1983).

In the second decision tree for land utilization type MTC, the LUR 'erosion hazard' was not considered. The reason is that in the definition of land utilization type MTC soil conservation was considered as a management factor, and soil erosion is assumed to be negligible.

#### 3.4.2 ALES data base

Data can be entered in the programme under two headings, soils as mapping unit specifications (mapping unit name, whether it is homogenous or compound and the total area it occupies in the survey area), and in data entry templates (which specify the land characteristics for which data are to be entered, and their order in the data entry form).

#### 3.4.2.1 Mapping unit specifications

The objective of this study was not to carry out a full-fledged land evaluation of the area, hence there was not much emphasis given to mapping units specification. Reference soil monoliths were considered representative for mapping units.

For this study twelve soil monoliths (mapping units) were selected. These stem from a west to east transect (wet to dry), to test the application of the model. For the sake of simplicity, they were assumed to represent homogenous mapping units. Note that all soil monoliths have the same site specifications as in PS123N & WOFOST.

#### 3.4.2.2 Data entry templates.

This part of the database allows the model builder to specify land characteristics for which data are to be entered, and their format. In this model two templates were defined (climatological & Kenya soil survey/ISRIC), to make groups of data. In the climatological template, the climate variables of soil monoliths were defined, whereas the second template accommodated only soil variables.

## 3.4.3 Economic evaluation

In ALES an economic evaluation follows the physical evaluation. Land that is rated as physically unsuitable will not be considered from the economic point of view. In this model economic parameters, namely, prices, optimum yields, and proportional yield information were collected and entered.

Two kinds of economic evaluation can be done by the program: discount cash analysis and gross margin analysis. The first of these considers the time value of money, and is appropriate for any plan in which cash flows in and out occur over a number of years. Gross margin analysis, on the other hand, is satisfactory for analyzing LUT's with no capital improvements only recurring costs and outputs (Rossiter et al., 1991)

## 3.4.3.1 Economic suitability classes

The importance of economic land suitability is to express the relative performance of mapping units for proposed land utilization types. In the model the net present value and gross margin were expressed by four suitability classes, corresponding to FAO classes S1, S2, S3, and N. To allow the program to perform this grouping, three economic suitability class limits were defined, i.e. values of currency per unit area (for cash flow analysis and gross margin analysis), to separate S1 from S2, S2 from S3 and S3 from N. These limits were defined based on the information of Jaetzold (1983).

#### **CHAPTER 4**

#### **RESULTS**

#### 4.1 Correlation test for the Penman method

Penman's method of EO and ETO calculation is widely used. The effect of rainfall on EO and ETO as predicted by the method was checked; it appears that there is little correlation during the rainy season but relatively good correlation in the dry period, and there is good correlation with radiation and sunshine duration. The prevalence of high cloud cover during the rainy season may be responsible. Figure 4.1., shows the above mentioned relation.

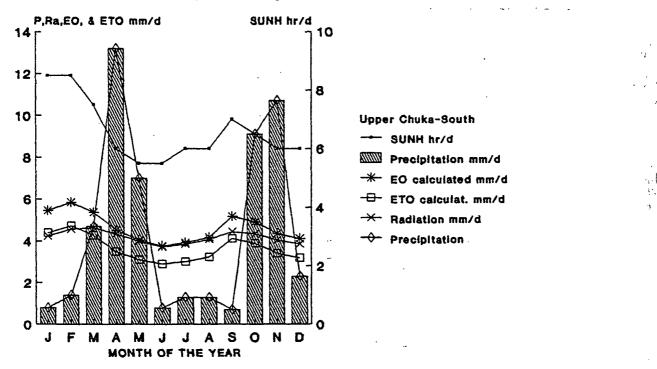


Figure 4.1 Effect of sunshine duration (SUNH), radiation (Ra), and Precipitation (P) on EO & ETO as predicted by the Penman method.

#### 4.2 Results of soil physical analyses

Soil physical parameters are important properties of soil. In the absence of measured field data, substitute values can be found in standard tables or can be calculated using transfer functions. However, the presence of different texture classes and standard values for the same texture class (see appendix C), complicates the use of texture-specific standard values.

#### 4.2.1 Texture-specific standard values and changes

Calculated water limited production potentials suggest that many texture classes can be aggregated to a small number of groups. Excluding extreme textures (i.e. more than 80% sand, silt or clay), five major texture groups were found (this needs further research).

Table 4.1. Calculated water-limited production potentials Arjuna maize for Kedung Salam, Indonesia, by USDA texture class, using soil parameter values of Rijtema (1969), Rawls et al.(1982) and Carsel et al.(1988). Germination was assumed on julian day #260.

Texture classes	Water-limit	ed Production	n potentials (in kg/ha)	
	Rijtema	Rawls	Carsel	
Loamy sand	2544	2567	2548	
Sandy loam	2501	2226	2214	
Loam	2616	2486	2483	
Silty loam	2106	1932	1851	
Silty clay loam	1762	1782	1750	
Silty clay	1858	2033	2205	
Sandy clay loam	1727	1 <b>9</b> 97	1816	
sandy/light clay	1426	1654	1442	
Clay loam	3430	3372	3500	
Clay	2795	2975	2741	

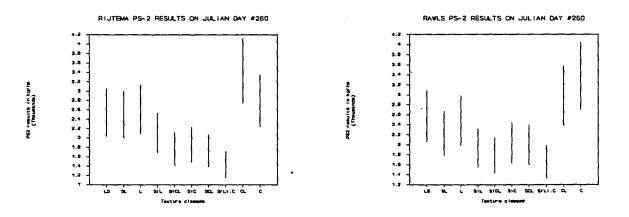


Figure 4.2. Calculated ranges in water-limited production potential of Arjuna maize for various texture classes using Rijtema & Rawls values.

Figure 4.2 shows that some of the texture classes give more or less similar results with very little difference. The texture classes were merged on the basis of their position in the soil texture class triangle, field properties and calculated production potentials. The combined

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classes and the calculated water-limited production potentials are presented in table 4.2. and on figure 4.3.

Table 4.2 Soil tex	tures aggregated	to five	groups
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Group No	General terms	Average Rijtema	-	• •	'ha) Group members
1	Sandy loam family	2422	2426	2415	loamy sand, sandy loam, loam
2	Silty loam				•
3	Silty clay family	1810	1858	1978	silty clay, silty cl/loam
4	Sandy clay family	1460	1826	1629	sandy/light clay, sandy cl/loam
5	Clay family	3013	3174	3122	clay, clay loam

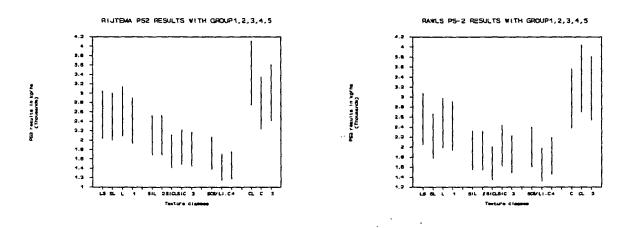


Figure 4.3. Texture classes and calculated water-limited production potentials  $(\pm 20\%)$  and their group value.

## 4.2.2 Results of pedotransfer functions

A number of soil physical characteristics, namely, SMO, ALPHA, SMPSI and KPSI, were estimated using pedotransfer functions.

#### -SMO, SMPSI and KPSI

SMO, SMPSI and KPSI were determined using relations suggested by Rijtema (1965) and Driessen (1986). The results were directly input in WOFOST's soil data base. PS123N has a subroutine to calculate these parameters (using the same relations). Since one of the

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intentions of the study was to compare the results of the two models, much effort was given to make all required data identical. Hence the use of the above pedotransfer functions to generate entries in the WOFOST data base.

# -ALPHA and KO

ALPHA and KO was found using the following relations:

ALPHA =  $2.4*10^{4*}$ % silt +  $7.7*10^{4*}$ % sand +  $2*10^{5*}$ % silt\*% sand ( $R^2 = 0.922$ )

NB: This calculation does not apply to heavy clay, coarse sand and pure silt.

Another relation may be used as well (the correlation coefficient was a bit less).

ALPHA =  $0.0193 - 1.7*10^{4*}$ %CLAY +  $1.13*10^{3*}$ %SAND (R<sup>2</sup> = 0.84)

In the present study the first relation was used and ALPHA was calculated for each soil monolith (mapping unit).

KO = -229.89 + 7.307\*clay% + 7.7284\*sand% - 0.2969\*sand%\*clay% ( $R^2 = 0.7$ )

Apart from the low correlation coefficient, using KO from the above relation was discouraging, possibly because KO is affected by other soil physical properties than particle size distribution, (the result of the above relation was not used in the models).

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Table 4.3. Results of pedotransfer functions for each monolith (mapping unit).

EAK410.0170.0170.520EAK420.0240.0220.518EAK430.0180.0150.514EAK440.0140.0170.553EAK450.0170.0120.469EAK460.0140.0130.465EAK470.0160.0180.422EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	Soil monoliths	ALPHA1	ALPHA2	SMO
EAK430.0180.0150.514EAK440.0140.0170.553EAK450.0170.0120.469EAK460.0140.0130.465EAK470.0160.0180.422EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK41	0.017		0.520
EAK440.0140.0170.553EAK450.0170.0120.469EAK460.0140.0130.465EAK470.0160.0180.422EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK42	0.024	0.022	0.518
EAK450.0170.0120.469EAK460.0140.0130.465EAK470.0160.0180.422EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK43	0.018	0.015	0.514
EAK460.0140.0130.465EAK470.0160.0180.422EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK44	0.014	0.017	0.553
EAK470.0160.0180.422EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK45	0.017	0.012	0.469
EAK480.0160.0120.464EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK46	0.014	0.013	0.465
EAK490.0250.0270.516EAK500.0630.0530.459EAK510.0670.0510.450	EAK47	0.016	0.018	0.422
EAK500.0630.0530.459EAK510.0670.0510.450	EAK48	0.016	0.012	0.464
EAK51 0.067 0.051 0.450	EAK49	0.025	0.027	0.516
	EAK50	0.063	0.053	0.459
FAK52 0.061 0.067 0.460	EAK51	0.067	0.051	0.450
	EAK52	0.061	0.067	0.460

For SMPSI & KPSI results see appendix F.

#### 4.3. PS123N production situations

#### -Maize

Maize was assumed to germinate on day 60 (Julian), and the model was run two times for

each scenario, (i.e. for potential production (PS-1) and water-limited production potential (PS-2)). Table 4.4. lists results of PS-1 and PS-2 calculations for different varieties of maize for each site.

Note that each maize variety has a specific set of crop characteristics. The development, the growth rate of organs and the LAI are different for each variety (see figure 4.4 & 4.5.). LAI is high for all cultivars from day 150 to 180. This involves high maintenance costs and causes reduced net weight of storage organs for all cultivars.

Site	Produc	Production Potential & varieties									
	Gen. N	Gen. Maize cv.			cv.PIONEER cv.ARJUNA			cv.CHINA			
	PS1	PS2	PS1	PS2	PS1	PS2	PS1	PS2	PS1	PS2	
EAK41	13208	5851	26517	2127	28154	2621	15146	2793	22620	5358	
EAK42	13208	5813	26517	1928	28154	2552	15146	2616	22620	5043	
EAK43	11613	1585	22302	cd	23996	cd	12741	5728	16942	3292	
EAK44	13004	11375	23239	1837	24906	2350	13858	5138	17460	6590	
EAK45	13004	1766	23239	1332	24906	2009	13858	3735	17460	1068	
EAK46	13004	1757	23239	1300	24906	2035	13858	3225	17460	1055	
EAK47	12420	cd	19010	cd	23694	cd	14064	5476	17857	3922	
EAK48	12420	527	19010	1052	23694	1309	14064	2751	17857	856	
EAK49	12420	8803	19010	11897	23694	12819	14064	6114	17857	2490	
EAK50	12420	177	19010	662	23692	792	14064	1951	17859	411	
EAK51	12420	132	19010	562	23692	718	14064	1706	17859	452	
EAK52	12420	<b>50</b> 1	19010	640	23692	939	14064	2704	17859	739	

Table 4.4. PS1 & PS2 results for different varieties of maize, sown on julian day #60

cd = Crop dies due to excessive wetness during the beginning of the growth cycle.

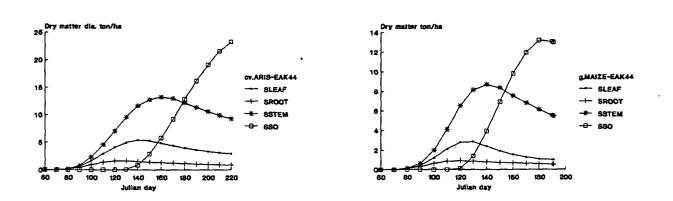


Figure 4.4. Dry matter distribution over organs of cv. ARIS and generic value (generic maize) under production situation 1 (PS-1). Note that specific crop characteristics give different model results.

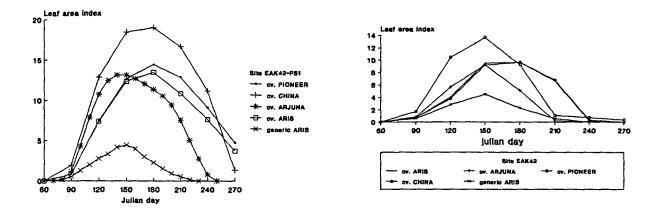


Figure 4.5.LAI for each variety during the growing period. Note the difference between generic value and others.

In all cases the biomass production decreases from west to east. These corresponds with the decrease length of the growth period. The main reason for this reduction lies in the temperature regime of the area. Here is time to appreciate the real prediction of the model. It might be even worth to use this model for LGP prediction rather than the FAO agro-ecological zonation system. The above shown in figure 4.6.

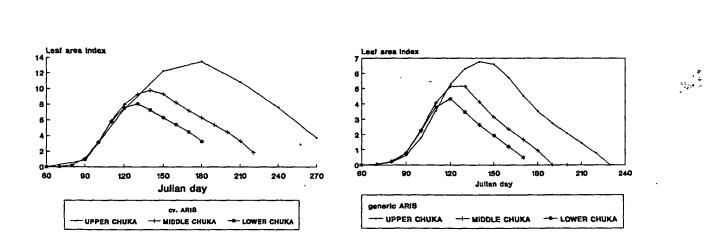


Figure 4.6. Reduction of total biomass and length of growth period going from west to east, indicated by leaf area index of cv.ARIS and generic value.

#### 4.3.1 The impact of TO (threshold temperature) on production

Of the various cultivars in the crop data base, Aris (Greek variety) was used for the analysis. It is found that TO has a profound effect on the plant performance. When it is decreases for show the performance of the crop at different value of TO.

If TO is set to  $TO = 8.5^{\circ}C$ , the crop matures early and total dry weight decreases from almost 18 ton (at  $TO = 10.5^{\circ}C$ ) to 14 ton. The LAI decreases from a maximum of 6.98 to 4.19 and dry matter distribution to the roots (SROOT) decreases considerably. On the other hand, the distribution of assimilates to storage organs increases at the expense of other plant organs. This is witnessed by the increment of SSO from about 2.5 ton to almost 6 ton. This result (i.e., SSO) is contradictory to the suggestions given by van Heemst (1986, see also van Keulen and Wolf, 1986, modelling of agricultural production page 27-35). The death of live leaves (LIVSLEAF) at  $TO = 8.5^{\circ}C$  was gradual while at  $TO = 10.5^{\circ}C$  it was not gradual.

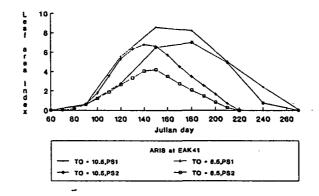


Figure 4.7.LAI of cv ARIS at PS-1 and PS-2 levels using various TO values.

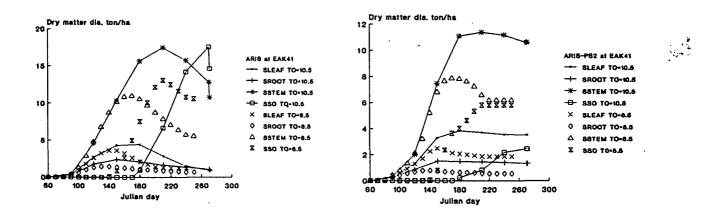


Figure 4.8.Dry matter distribution of cv. ARIS at PS-1 and PS-2 levels using various TO values. Note that SSO under PS-2 is considerably less at TO = 10.5 than at TO = 8.5

#### -Wheat

Only one variety of wheat, 'China', was included in the data base of the model. The crop was assumed to germinate on julian day 60, and the model was run for PS-1 & PS-2 production situations. It is found that this variety performs quite well in the area. (see table 4.5.). Due to lack of local production data, it was not possible to interpret the results.

Table 4.5. PS1 & PS2 production of Spring wheat assumed to germinate on julian day 60. A seeding density of 100kg/ha and 10% mortality were assumed.

Site	Productio	n Potentials
	PS1	PS2
EAK41	6702	6603
EAK42	6702	6730
EAK43	7064	1842
EAK44	7639	8009
EAK45	7639	2485
EAK46	7639	1762
EAK47	8599	8736
EAK48	8599	3023_
EAK49	8599	8736
EAK50	8598	2688
EAK51	8598	2246
EAK52	8600	3054

### 4.4. WOFOST production situations

#### -Maize

The model was tested only for "generic" maize (see van Heemst, 1988). The model gave no PS-2 results for sites with groundwater. When ground water was not considered the values obtained for PS-2 increase with decreasing moisture availability in the soil. The result are quite contradictory with actual maize yields (see Jaetzold & Schmidt, 1983) in the area, especially in the drier parts. Table 4.6, shows PS-1 and PS-2 results for each site.

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#### -Wheat

The model was run for spring wheat (the data were found in the data base of the model); both PS-1 & PS-2 results were not good and are not presented here.

Site	Production PS1	n Potentials (kg/ PS2	ha)	
		With ZT	With out ZT	_
EAK41	10507	4	3427	
EAK42	10507	0	2118	
EAK43	12547	0	1791	
EAK44	13034	no ZT	4266	
EAK45	13034	no ZT	6693	
EAK46	13034	0	6644	
EAK47	11397	0	467	
EAK48	11397	no ZT	7436	
EAK49	11397	0	2287	
EAK50	11408	no ZT	5987	
EAK51	11408	no ZT	8757	
EAK52	11408	no ZT	6716	

Table 4.6. WOFOST PS1 & PS2 simulation results for generic maize assumed to germinate on julian day 60 (with and without ground water).

-no ZT indicates that groundwater\_was not recorded in the profile description. Note that all profiles with ground water give no result under PS-2.

## 4.5 Physical land suitability assessment of the area based on PS123N analyses.

The physical suitability class was identified according to the FAO framework (1976,1983)(see table 4.7.). To establish relative LUS performance, a reference yield should be known. The physical suitability of each land unit can be expressed using its actual performance relative to the reference yield. The relative yield (FAO, 1985) was used as indicator of physical land suitability.

The main difference with classical land evaluation procedures lies in the definition of the reference yield. The reference yield was defined according to FAO's agro-ecological zoning rules as potential production multiplied by harvest index for high input farming. Arbitrarily 25% of the high-input reference yield was assumed low-input farming. Danalatos (1993), bases the reference yield on the biophysical production potential, and considers the water-limited production potential within the reach of the farmers (if irrigation is applied).

As mentioned in section 4.2, in most study sites the trend of water-limited production potential of maize (generic) predicted by PS123N tallies with the actual production at most study sites, with the exception of few areas which has high value.

The Chuka-south area has a bimodal rainfall distribution except for areas near Mt. Kenya that have a long growing season. In most parts two cropping seasons are possible. For maize about 50% of the PS-1 potential production (i.e. 5000kg/ha), was taken as a reference yield level. For wheat, because it is not a common crop in the area, defining the reference yield was difficult. Nevertheless, an arbitrary reference yield was defined, i.e. 60% of the

calculated PS-1 potential production (4800 kg/ha), was taken as the reference yield. Table 4.9. presents the physical suitability of the mapping units (monoliths) for maize and wheat under traditional rainfed agriculture.

Table 4.7.Land suitability classification structure (FAO, 1976, 1983), used in this study	Table 4.7.Land suitability	classification structure (FA)	<b>D.</b> 1976,1983).	, used in this study.
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Order	Class Description	Relative yield
S-suitable	<ul> <li>S1 highly suitable</li> <li>S2 moderately suitable</li> <li>S3 marginally suitable</li> </ul>	80-100% 40-80% 20-40%
N-not- suitable	N1/N2 not suitable	<20%

Table 4.8. Yield ranges for each suitability class

Class	Relative yiel	d Yield range	(in kg/ha)	
		Maize	Wheat	
<b>S</b> 1	80 - 100%	4000-5000	3840-4800	
S2*	40 - 80%	2000-4000	_ 1920-3840	
S3	20 - 40%	1000-2000	960-1920	
N	< 20%	< 1000	< 960	

\*Note that this range is wider than others; it is possible to make subclasses but for this study it is not necessary.

Table 4.9. Physical land suitability for maize (generic) and wheat under traditional rainfed agriculture.

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Soil units	Land utilization	type	
(Monoliths)	Maize (generic)	Wheat (china)	
EAK41	S1	si	
EAK42	<b>S</b> 1	S1	
EAK43	<b>S</b> 3	S3	
EAK44	<b>S</b> 1	S1	
EAK45	S3	S2	
EAK46	S3	S3	
EAK47	N*	S1	
EAK48	Ν	S2	
EAK49	<b>S</b> 1	S1	
EAK50	Ν	S2	
EAK51	Ν	S2	
EAK52	N	S2	

\*On this soil unit water logging is the main problem for maize.

# 4.6 Land suitability assessment using ALES

Land suitability was assessed on the basis of those land use requirements (LUR's) that are considered relevant to the identified LUT's, (see chapter 3). The most important LUR 'moisture availability' used in ALES the decision trees was quantified by PS123N results. This makes the assessment much more realistic and the outcome seems reasonable. A total of 12 'mapping units' and three land utilization types, MTA, MTC, and MTP (all are maize under different management), were treated. The results are presented in two main categories, namely, physical and economic, (see paragraph 3.2).

## 4.6.1 Evaluation of physical land suitability

The physical land suitability sub-classes defined during model construction show the kind(s) of limitation for each land use system, i.e. combination of each LUT and mapping unit.

For LUT MTA, most sites in the western and central part of the Chuka-South area (see table 4.11.), are classified as suitable to moderately suitable. Soil depth seems the commonest limiting factor. In the eastern part of the Chuka-South area moisture availability, (excess or shortage) and erosion hazard are most limiting. Therefore most land units are classified as not suitable.

For the other two LUT's, maize under traditional agriculture with soil conservation (MTC & MTP), erosion hazard was assumed to be not limiting due to soil conservation measures. The physical suitability sub-class remains the same, even though, erosion hazard is not considered for the eastern part.

Yield prediction is part of the physical evaluation of ALES. The physical suitability of land can best be expressed quantitatively in terms of yield. Yields of crops in each mapping unit are predicted on the basis of the proportional yield and reference yield levels. At this point the effect of soil conservation was visible in mapping unit EAK45. Table 4.10., shows yield predictions for each mapping unit and LUT. In most cases the yield predictions match those of the PS123N physical suitability assessment. The advantage of ALES is that one can readily see the limiting factor(s) for each suitability subclass.

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## 4.6.2 Evaluation of Economic land suitability

To determine the best use of a land unit and to compare its suitability for other uses, economic evaluation is essential. Though the term economic is used loosely (i.e it is limited to the financial aspects of farming and not to farm economics) ALES, economic evaluation is carried out on the above basis. Five economic aspects, namely, yields, gross margins (net benefits), costs, returns and economic suitability classes are evaluated. It is possible that land that is suitable in physical sense is not always economically suitable under different managements. (see table 4.11.).

Site		n kg/ha)	Gross margin (in Ksh/ha/yr)				
	LUTs MTA	MTC (MTP)*	MTA	LUTs MTC	MTA		
EAK41	2650	2950	4081	4615	4331		
EAK42	2650	2950	4081	4615	4331		
EAK43	1316	1500	1414	1726	1441		
EAK44	3650	4050	5991	6717	6432		
EAK45	951	1500	716	1726	1441		
EAK46	1316	1500	1414	1726	1441		
EAK47	0	0	0	0	0		
EAK48	0	0	0	0	0		
EAK49	3650	4050	5991	6716	6432		
EAK50	0	0	0	0	0		
EAK51	0	0	0	0	0		
EAK52	0	0	0	0	0		

Table 4.10. Yield predictions and Gross Margin results for each LUT-mapping unit combination, (i.e. for each land-use system).

\*The program predicts yields based on a "proportional yield" decision tree, but erosion hazard was not considered for the second and third LUT.

	Physical		Econo	mic		
Soil units (Monoliths)	LUTs MTA MTC	MTA	LUTs MTC	MTP**		
EAK41	S1	S1	S2	S2	S3	
EAK42	S2-2AFH	S2-2AFH	S2	S2	S3	
EAK43	S2-2AFH	S2-2AFH	<b>S</b> 3	N1	N1	
EAK44	<b>S</b> 1	S1 .	<b>S</b> 1	<b>S1</b>	<b>S</b> 1	
EAK45	S2-2AFH	S2-2AFH	N1	N1	N1	
EAK46	S2-2AFH	S2-2AFH	<b>S</b> 3	N1	N1	
EAK47	N-4MA/AO	N-4MA/AO	N2	N2	N2	
EAK48	N-4MA	N-4MA	N2	N2	N2	
EAK49	<b>S</b> 1	<b>S</b> 1	<b>S</b> 1	<b>S</b> 1	<b>S</b> 1	
EAK50	N-4RE/MA	N-4MA	N2	N2	N2	
EAK51	N-4RE/MA	N-4MA	N2	N2	N2	
EAK52	N-4MA	N-4MA	N2	N2	N2	

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Table 4.11. Physical and economic suitability sub-classes for land-use systems.

\*MTC and MTP are assumed to have similar physical suitability.

\*\*Different soil conservation measures may have similar effect but their initial and maintenance costs differ which effects the economic suitability class.

# Chapter 5

# **Discussion and Conclusions**

# 5.1 Discussion

# 5.1.1 Towards data aggregation and simplification

If one asks a farmer how many types of soil or texture classes he can identify in his land, he will most probably mention two or maximum three types interpreted in terms their effect on production. If the same question is asked to a soil scientist, the result might be entirely different from the farmers conceptions of reality.

There are numerous types of soil, that can be identified (from the point of view of soil classification), but for land evaluation purposes, these soil types can be aggregated.

For some soil physical parameters values needed by the models, one must substitute tabulated texture-specific default values. The presence of different values for the same texture class, as suggested by various authors is a limitation on the use of these values.

The soil texture class can be identified in the field without much difficulty. Field textures are much more important for land evaluation than texture classes identified in the laboratory. This was checked using the PS123N crop simulation model. The production potentials in table 4.1. show that, some texture classes give the same result with little difference.

Though not yet conclusive and in need of further research, it is possible that the value obtained can give an indication of the relevant number of texture class groups.

Based on these and other experiences (personal communication Driessen, 1993) the suggestion of five major texture groups (see table 4.2) seems logical.

# 5.1.2 Estimating hydraulic soil properties using pedotransfer functions.

Quantification of pressure head or moisture availability requires information on the moisture retention characteristics and unsaturated hydraulic conductivity of a soil. In this study this information was not readily available; the required hydraulic properties were derived using transfer functions.

It observed that the SMPSI-PSI curve as indicated on appendix F, fig.1.F., is smooth for some monoliths. The smoothness of the curve, especially at high suction values, seems not logical for well drained tropical soils. The saturated hydraulic conductivity (KO) used in the calculation was derived from standard tables; for some soils the actual value can be higher.

The relation used to derive ALPHA (i.e.,linear regression analysis mentioned in section 4.1.2) gives acceptable results. Besides the reasonable results obtained, the relation shows the possibility of deriving this parameter from texture classes without problem. The small number of samples used in the analysis should be mentioned in this context.

A similar relation was tried to determine KO, as stated in section 4.2.2, but the results obtained were not good. This can be explained by the small number of samples used for analysis and the possibility that hydraulic conductivity is affected more by other soil physical characteristics than by particle size distribution. Therefore the use of relations based on particle size distribution to determine KO might be misleading.

# 5.1.3 Production potentials

## -PS123N-PS1

The production potentials generated for the various varieties of maize (table 4.4.) were quite high. It is comparable to the production potentials at high latitude areas. Danalatos (1993), sets the potential production at more than 20t/ha for cv.Pioneer variety. This was possible because the amount of radiation received in Larissa (Greece) on june and july is very high. Radiation is more or less constant through out the year in the tropics. From this point of view, the result obtained seem unrealistic. On the other hand, the weight of the storage organs (SSO) is low comparing to the total dry matter production (TDM).

The reason is for all varieties some of the crop characteristics of all varieties in the data base were adjusted for local conditions. The maintenance respiration coefficient and the threshold temperature were altered. These values were tested on one variety (cv. Aris) until acceptable results were obtained (see table 4.4., values of generic maize). Based on this a biophysical production potentials of 10-12 t/ha was identified for the study area.

Without changing the crop characteristics obtained for wheat from China, the model predicts a biophysical production of 7-8.5 t/ha which seems realistic (see table 4.5).

## -*PS*2

Compared with the biophysical production potential the predicted PS-2 values are low for all varieties, except for cv.China in the western part. This can be explained by the high LAI, which requires high maintenance respiration so that less assimilates are allocated to storage organs. This assumption was tested by changing some of the crop characteristics mentioned above. The model prediction of PS-2 for generic maize (see table 4.4. & figure 5.2) gives a high value for the middle part of the area (with few exceptions) and slightly lower values in the western part of the area which is wet and high land. For the eastern dry part the prediction is low.

The prediction of the model was remarkably alike local conditions. With few exceptions, the simulated values are similar to local results, (see Jaetzold & Schmidt, 1983, and Legger & Meester, 1986). This indicates that moisture availability is indeed the determining factor in the area.

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The PS-2 value predicted for wheat seems high, especially on the western parts and on few middle parts. On other parts the results vary, especially in the eastern dry parts the simulated yield was higher than that of maize. The reason might be that the water requirement of maize (ETm) reaches, from 500 up to 800 mm of water for maximum production, whereas wheat requires only 450 to 650 mm, (see FAO, 1986).

On site EAk47 where maize was predicted to die because of excessive wetness, the wheat results were quite good. This can mean two things. Firstly the model seems to correlate crop characteristics and soil moisture relations correctly. Secondly wheat can stand a short time of wetness (see FAO yield response to water, vol.33, 1986). Nevertheless, for further use, revision of recurring crop characteristics might be important.

#### -WOFOST-PS1

The potential production of maize predicted by the model was comparable with that of PS123N, except for western areas where production is a bit lower (see figures 5.2 & 5.3). It was also observed that the total above ground biomass predicted is higher in relation to the assimilates allocated to storage organs. The other point noted was that, the crop matures with about 60% of the leaves still alive, (for the possible reasons suggested see section 5.1.4.below).

# -PS2

The biophysical production potential of maize simulated by WOFOST seemed reasonable but the predicted water-limited production potential is not realistic. As stated in section 4.4, the model predicts the highest values for the drier eastern parts. The predicted value is high for soil units with poor moisture status in the middle parts, namely, EAK45, EAK46 and EAK48. On the other hand, the simulated production is low for the western wetter parts and in the central part for land units with good moisture status. This seems in conflict with the actual situation in the area.

On soil units with shallow groundwater the crop perishes due to excessive wetness. But, when the model was run without considering the groundwater it gives a different value from the first run (see table 4.6). It might be said that errors in the water balance calculation subroutine of the program are accountable. This point will be discussed hereafter when results are compared with PS123N results.

### 5.1.4 Comparison of results generated with WOFOST and PS123N

As outlined in section 5.1.3, the biophysical production potentials calculated with the two models were similar, except for some minor differences. The fact that the total above ground biomass is higher in the case of WOFOST, might be attributed to a crucial difference in the calculation of maintenance respiration.

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In WOFOST maintenance respiration is deducted from total assimilate production after which the remaining assimilates are distributed to the various organs of the crop. But in PS123N, first the gross assimilate production is partitioned to each organ after which the maintenance respiration is calculated for each organ.

The path followed by PS123N seems logical. Besides, the crop reacts to its environment during the allocation of assimilates. For example in the dry environment much of the assimilate is invested in the roots to explore a greater soil volume in search of water. A crop under the shade invests heavily in the stem growth to compete for radiation, etc... Which means the maintenance costs vary according to the weight and the specific needs each organ. This assumption is illustrated with data on rice obtained from Paramaribo, Surinam (see van Keulen 1986), as follows:

The rice was transplanted with 40 kg/ha of root dry matter and 100 kg/ha of above ground parts (mainly leaf blades). Calculations using the above two procedures show the difference. Note that some minor differences between the models are not discussed.

-According to the WOFOST approach: (for detailed calculation procedures one is referred to van Keulen & Wolf, 1986, pages 43-57)

1.For the first decade:

-rate of gross assimilation, GASS =  $60.5 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

-Maintenance respiration was calculated from the initial live dry matter using a relative maintenance respiration rate,  $Rm = 0.015 \text{ kg kg}^{-1}$ 

MRES =  $140*0.015 = 2.1 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

-the net amount of assimilates available for increase in dry weight of the crop:

 $ASAG = 60.5 - 2.1 = 58.4 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

-the conversion of primary assimilation products in to structural plant material again entails loss of energy. This is the conversion efficiency:

CVF = 1/((FL/CVL+FS/CVS+FO/CVO)\*(1-FR)+FR/CVR)

= about 0.7

where

CVL is conversion factor of leaves

CVS is conversion factor of stems

CVO is conversion factor of storage organs

CVR is conversion factor of roots

-then total dry matter increase:

 $DMI = 0.7*58.4 = 40.9 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

-according to the development stage, fraction of assimilate allocated to each organ is: Fr = 0.35, Fl = 0.395, Fst = 0.225, Fo = 0

-the rate increase of dry matter for each organ:

 $IWRT = 0.35*40.9 = 14.3 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

WRT = 40 + 14.3\*10 = 183 kg ha<sup>-1</sup> (for ten days interval)

 $IWLV = 0.395*40.9 = 16.2 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

WLV = 100 + 16.2\*10 = 262 kg ha<sup>-1</sup>

 $IWST = 0.225*40.9 = 10.4 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

WST = 0 + 10.4\*10 = 104 kg ha<sup>-1</sup>

-Finally at the end of the first decade the total dry weight of the vegetation:

 $TDW = WRT + WLV + WST = 549 \text{ kg ha}^{-1}$ 

The second decade calculation is done with the same procedure. The procedure starts with the calculation of maintenance respiration losses as follows:

.....

MRES = 549\*0.015 = 8.2 kg ha<sup>-1</sup> d<sup>-1</sup>

The rest of calculation is the same up to the  $6^{th}$  decade and the results are presented on table 5.1.

According to PS123N approach: (see Driessen and Konijn, 1992), for detailed calculations).

The gross rate of assimilate production and fractions of assimilates allocated to each organ at each development stage are the same as those of WOFOST. Thus:

- the first assumption is that assimilates formed in photosynthetically active plant parts are allocated to the various plant organs and are used for maintenance respiration and growth respiration. So the fractions allocate to each organ are,

 $GAA(rt) = 0.35*60.5 = 21.2 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

 $GAA(lv) = 0.395*60.5 = 23.9 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

 $GAA(st) = 0.225*60.5 = 15.43 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

-then maintenance respiration is calculated for each living organ dry matter using organ

specific maintenance respiration coefficients as follows:

R(rt) = 0.01, R(lv) = 0.03, R(st) = 0.015, R(so) = 0.0035, (see van Heemst, 1986).

 $MRR(rt) = 40*0.01 = 0.4 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

 $MRR(lv) = 100*0.03 = 3 \text{ kg ha}^{-1} \text{ d}^{-1}$ 

Stem and storage organs were not formed so they require no maintenance respiration in this first interval.

-now the maintenance respiration (cost) of each organ is subtracted from their respective share of the total assimilates. Then it is possible to calculate the dry weight increase using conversion efficiency coefficient (Ec(org)) of each organ.

Ec(rt) = 0.72, Ec(lv) = 0.72, Ec(st) = 0.69, Ec(so) = 0.74, (generic value taken from van Heemst).

DWI(org) = (GAA(org) - MRR(org))\*Ec(org)\*DT, where DT is length of interval (d). Thus:

DWI(rt) = (21.2 - 0.40)\*0.72\*10 = 149.76 kg ha-1

 $DWI(lv) = (23.9 - 3.0)*0.72*10 = 150.46 \text{ kg ha}^{-1}$ 

 $DWI(st) = (15.43 - 0)*0.69*10 = 106.44 \text{ kg ha}^{-1}$ 

-the cumulative dry organ mass of each organ after each interval is found as follows:

(new)S(org) = (old)S(org) + DWI(org), then:

 $S(rt) = 40 + 149.76 = 189.76 \text{ kg ha}^{-1}$ 

 $S(lv) = 100 + 150.46 = 250.46 \text{ kg ha}^{-1}$ 

 $S(st) = 0 + 106.44 = 106.44 \text{ kg ha}^{-1}$ 

-the total dry matter weight at the end of each the decade is the sum total of weight of each organ.

 $DTM = 545 \text{ kg ha}^{-1}$ 

At this stage for this particular example the difference looks small. But as shown on table 5.2. for the consecutive intervals the gap keeps increasing. For comparison purpose in both cases the amount of dead leaves on the interval 6.2 were calculated as:

WDL = 0.02\*WLV\*DT, Where WDL = amount of dead leaves in kg ha<sup>-1</sup>

Note the difference in maintenance respiration losses assumed by the two models.

Table 5.1.Total biomass production of rice transplanted on november 1972 (van Slobbe, 1973), in Paramaribo, Surinam, using the procedures followed by WOFOST. The calculation is done only until the 6<sup>th</sup> decade.

.

Period Fgass (decade)	Frt	Flv	Fst	Fso	WRT 40	WLV 100	WST	WSO	MRES	TDW
· /	0.350	0.395	0.255	0	189	250	106	0	2.1	549
2 127.2	0.165	0.445	0.390	0	320	633	429	0	8.2	1382
3 216.0	0.075	0.480	0.445	0	423	1289	1037	0	20.7	2749
4 260.4	0.070	0.400	0.530	0	530	1903	1850	0	41.2	4283
5 295.0	0.070	0.265	0.665	0	643	2331	2925	0	64.2	5899
6.1 316.0	0.025	0.060	0.225	0.69	<b>67</b> 1	2398	3176	879	88.5	7124
6.2 316.0	0.0	0.0	0.0	1.00	<b>67</b> 1	2254	3176	1466	71.2	7711

Note that the  $6^{th}$  decade is treated in two parts. Because for the last three days leaves have died. Note also that the weight of roots and stems are considered to be constant after the  $6^{th}$  interval until the crop matures.

Table 5.2. Total biomass production of rice transplanted in november 1972 (van Slobbe, 19730, in Paramaribo, Surinam, using the procedures followed by PS123N. The calculation is done only until the  $6^{h}$  decade.

Fgass	Frt	Flv	Fst	Fso	WRT	WLV	WST	WSO	MRE	S T D W
e)					40	100				
60.5	0.350	0.395	0.255	0	183	262	104	0	3.4	545
127.2	0.165	0.445	0.390	0	327	604	437	0	11.0	1368
216.0	0.075	0.480	0.445	0	420	1220	1055	0	28.0	2695
260.4	0.070	0.400	0.530	0	521	1710	1898	0	56.6	4129
295.0	0.070	0.265	0.665	0	632	1903	3055	0	85.0	5590
316.0	0.025	0.060	0.225	0.69	640	1711	3178	1129	109.2	6658
316.0	0.0	0.0	0.0	1.00	626	1606	3079	1822	106.3	7133
	e) 60.5 127.2 216.0 260.4 295.0 316.0	60.50.350127.20.165216.00.075260.40.070295.00.070316.00.025	e) 60.5 0.350 0.395 127.2 0.165 0.445 216.0 0.075 0.480 260.4 0.070 0.400 295.0 0.070 0.265 316.0 0.025 0.060	e) 60.5 0.350 0.395 0.255 127.2 0.165 0.445 0.390 216.0 0.075 0.480 0.445 260.4 0.070 0.400 0.530 295.0 0.070 0.265 0.665 316.0 0.025 0.060 0.225	e) 60.5 0.350 0.395 0.255 0 127.2 0.165 0.445 0.390 0 216.0 0.075 0.480 0.445 0 260.4 0.070 0.400 0.530 0 295.0 0.070 0.265 0.665 0 316.0 0.025 0.060 0.225 0.69	e) $40$ 60.5 $0.350$ $0.395$ $0.255$ $0$ 183 127.2 $0.165$ $0.445$ $0.390$ $0$ 327 216.0 $0.075$ $0.480$ $0.445$ $0$ 420 260.4 $0.070$ $0.400$ $0.530$ $0$ 521 295.0 $0.070$ $0.265$ $0.665$ $0$ 632 316.0 $0.025$ $0.060$ $0.225$ $0.69$ 640	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	e) $40$ 100 60.5 0.350 0.395 0.255 0 183 262 104 127.2 0.165 0.445 0.390 0 327 604 437 216.0 0.075 0.480 0.445 0 420 1220 1055 260.4 0.070 0.400 0.530 0 521 1710 1898 295.0 0.070 0.265 0.665 0 632 1903 3055 316.0 0.025 0.060 0.225 0.69 640 1711 3178	e) $40$ 100 60.5 0.350 0.395 0.255 0 183 262 104 0 127.2 0.165 0.445 0.390 0 327 604 437 0 216.0 0.075 0.480 0.445 0 420 1220 1055 0 260.4 0.070 0.400 0.530 0 521 1710 1898 0 295.0 0.070 0.265 0.665 0 632 1903 3055 0 316.0 0.025 0.060 0.225 0.69 640 1711 3178 1129	e) $40  100$ 60.5  0.350  0.395  0.255  0  183  262  104  0  3.4 127.2  0.165  0.445  0.390  0  327  604  437  0  11.0 216.0  0.075  0.480  0.445  0  420  1220  1055  0  28.0 260.4  0.070  0.400  0.530  0  521  1710  1898  0  56.6 295.0  0.070  0.265  0.665  0  632  1903  3055  0  85.0 316.0  0.025  0.060  0.225  0.69  640  1711  3178  1129  109.2

From this simple example one can see the difference clearly. Another difference is that in PS123N redistribution of assimilates is assumed. This is clearly seen during the last 30 or 40 days in the growth cycle (see figure 4.8.). In WOFOST, this seems not the case.

The calculated water-limited production potentials were totally different. PS123N reacts well to local conditions, but WOFOST doesn't. Two possible reasons might be mentioned: overestimation of capillary rise and the choice of suction for field capacity.

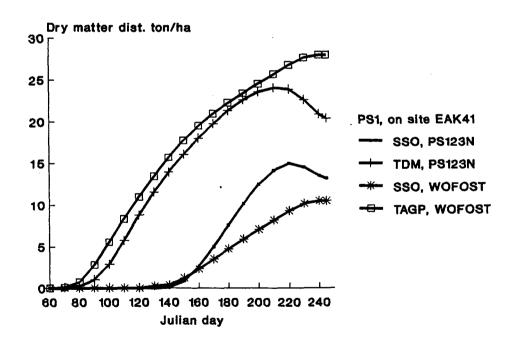


Figure 5.1. Dry matter allocation to storage organs relative to the total biomass as predicted by WOFOST and PS123N when maize is assumed to germinate on julian day #60. Note that TAGP represents the weight of above-ground dry matter, i.e., root weight is not considered.

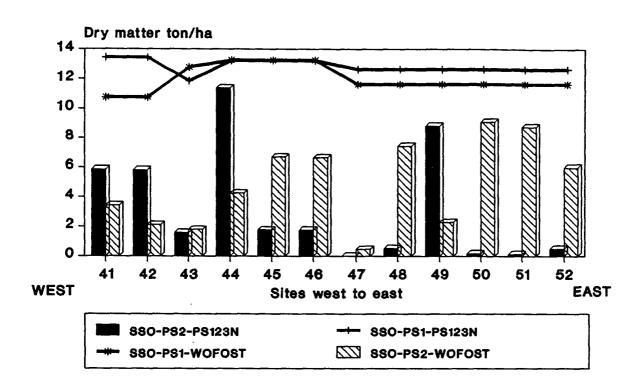


Figure 5.2. Calculated SSO under PS-1 & PS-2 conditions for all study sites as predicted by WOFOST and PS123N. In all cases maize is assumed to germinate on julian day #60.

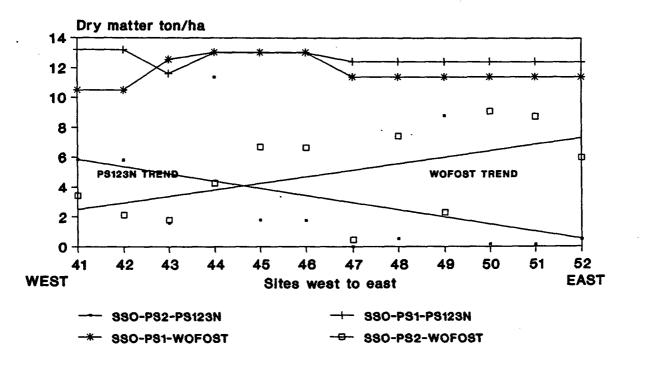


Figure 5.3. Trend of maize yield prediction under PS-2 condition by WOFOST and PS123N, form west to east.

# 5.1.5 Effects of temperature on simulation results

As indicated in section 4.2.1, a slight variation of the threshold temperature (TO) has a considerable effect on model results; mainly because of a short growth period, less biomass production and a high proportion of storage organ production. The former two can be explained as follows:

The growth period is equivalent to TSUM/(Tav - TO) days. When TO decreases, the duration of the growth cycle will decrease too. This can result in less biomass production. In some scenarios, the crop is assumed to stay alive for 10-20 days after all leaves have died. This condition is observed on soil units with poor moisture status and in high altitude areas. One possible reason might be that in the calculation of daily and night time temperature the effect of altitude is not considered. Air temperature varies with altitude during the day and also the night, i.e., during night air temperature increases with height and the reverse is true during the day (Rosenberg et al., 1983). This means that different method of calculation should be used for high altitude areas.

# 5.1.6 Limitations of water sufficiency as an indicator of water availability.

In most cases the response of crops to water supply is expressed as a yield response factor which relates relative yield decrease to relative evapotranspiration deficit (FAO, 1986). The sufficiency of water supply is traditionally expressed in a single rating for the entire growing period. Both "relative yield" and "sufficiency rating" were tried to quantify the land quality 'water availability'. A dynamic simulation model (WATSUF) was used to calculate water sufficiency. The actual water use per decade and the actual cumulative water use were compared (as shown in figure 5.5.), with the potential cumulative water use. From julian day #130 to day #170 the actual water use is nil, but, the crop still exists as predicted by the PS123N model. This method doesn't look promising for water availability determination.

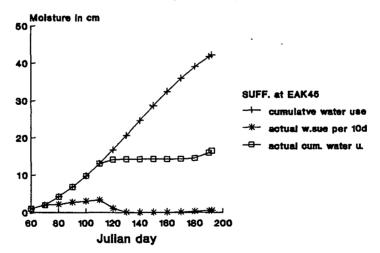


Figure 5.5 Comparison of required with actual water use

#### 5.1.7 Possible interactions between ALES and PS123N (WOFOST)

Perhaps it may seem unrealistic to envisage interactions between these two given the differences in the basic set up of each system. PS123N operates in a dynamic way and

describes state variables in detail. Whereas, ALES is a flexible system with a level of detail and accuracy that depend entirely on the expert system.

Despite these basic differences still it is possible to make relation between ALES and PS123N. ALES does not attempt to perform every function that might be needed for evaluation. On the other hand its structure allows to import information from other systems. Therefore it was tried to determine the most important land use requirement 'moisture availability' with the PS123N dynamic simulation model. Figure 5.4., shows the complete system.

The differences in production observed between PS1 and PS2 reflect differences in soil moisture conditions. The relative yield, i.e. the ratio between water-limited production potential and potential production, can be used as an indicator of the moisture status of the soil.

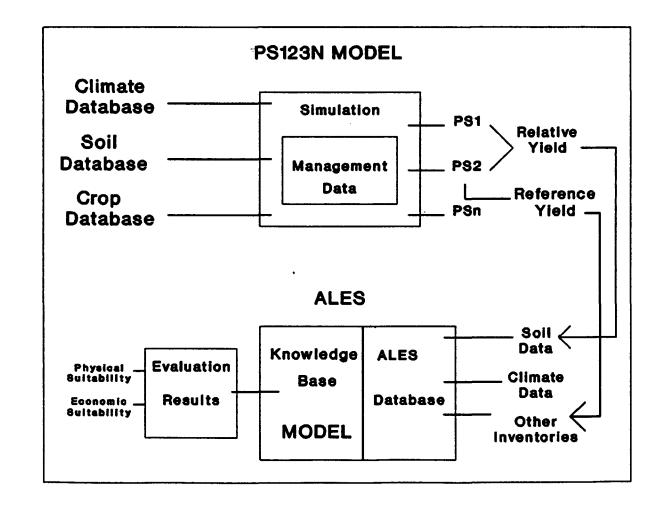


Figure 5.4. Information flow from PS123N to ALES.

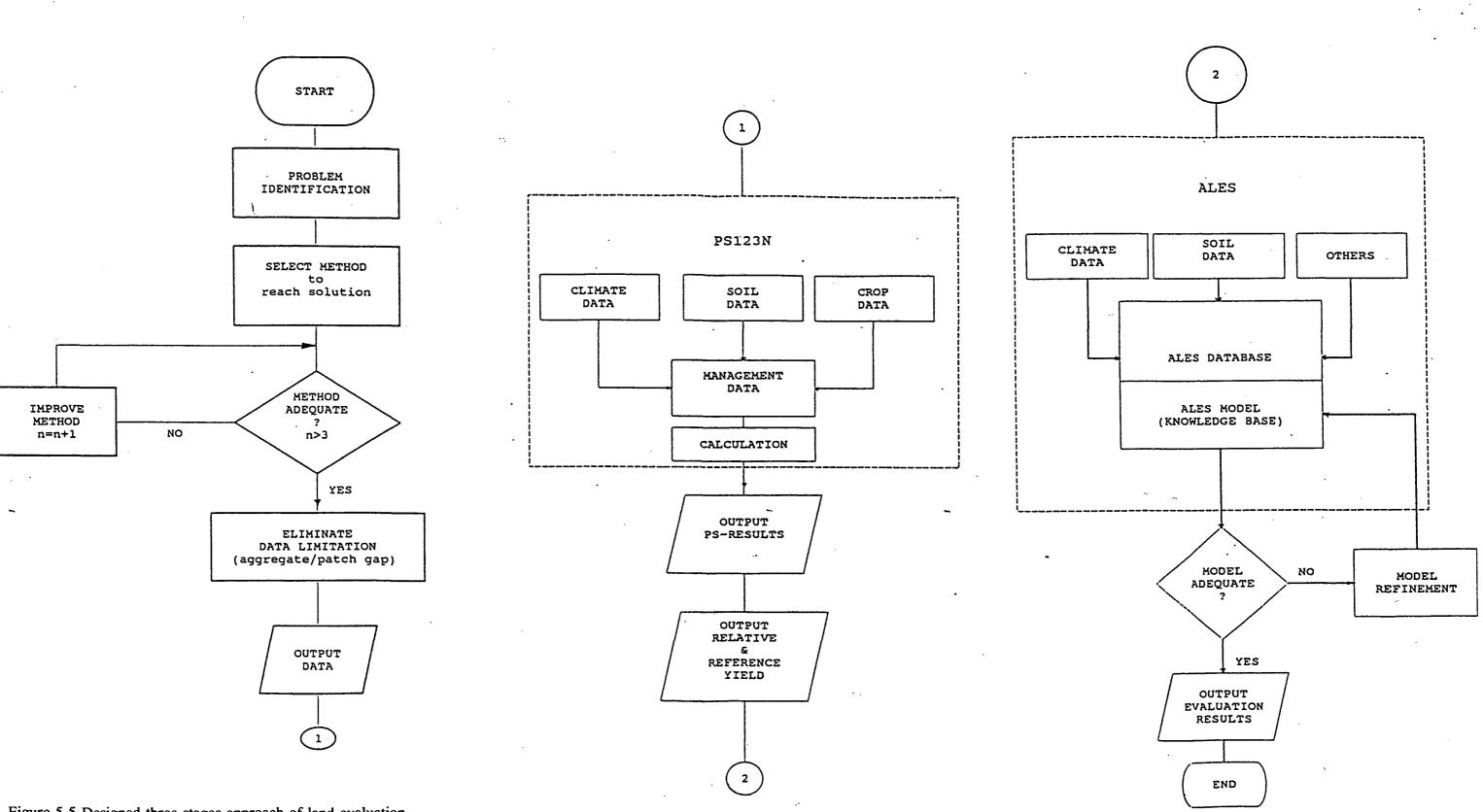


Figure 5.5 Designed three stages approach of land evaluation

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# 5.2 Conclusions

# 5.2.1 Model validation and system applicability

Land evaluation models describe the performance of a land area when used in a specified way. A comprehensive model validation would require that all land units in the area of interest, or at least a representative set of them, be subject to relevant land uses, with replications both in space and time. Validation on this scale is plainly impossible for the present study. But, it is possible to validate the two crop simulation models (PS123N & WOFOST) by comparing their result against experimental results. On the other hand ALES can be validated (Rossiter, 1990), if it accurately reflects the land evaluator's best judgment.

## -PS123N-

A crop interacts with its environment in a dynamic way. Using PS123N respects the dynamic nature of the system. Based on the experience gained so far, PS123N describes the system very well. The model generates production potentials that show clearly the moisture regime in the area has a west to east orientation. It can be said that PS123N can be used for land-use systems analysis albeit with some limitations:

-The model needs an ample amount of good quality data and requires knowledge of various disciplines.

-For accurate result it needs calibration of some system characteristics.

-The model does only indicate potential production, not actual production. In addition to this, expert judgment is required to asses physical suitability.

## -WOFOST-

WOFOST is a comprehensive, dynamic crop-growth simulation model that is basically similar to PS123N. The data used in this study were similar to those needed by PS123N, but the outcome of the model was not promising. Therefore it can be concluded that, unless the water balance subroutine of the model is revised, WOFOST is not yet fit to support land evaluation studies.

#### -ALES-

Given the similarity between the general picture of the area and the predictions of ALES, it is possible to say the model constructed is a valid one. However, the system (ALES) can only be applied for land use systems analysis under traditional agriculture, if accurate and efficient methods to predict land use requirements and characteristics are implemented. The system has some basic limitations that are clearly visible from the present study:

-ALES is an "empty shell"; input specification, data base construction and decision making are left entirely to the model builder.

-Even though, it operates on the knowledge-base system, in some cases (especially under economic evaluation) it forces the model builder to specify standard inputs. Some calculations and assumptions made in the program itself are also not conform the wish of the expert and

can have considerable impact on the evaluation result.

-When few LURs and LCs are considered, building decision trees is not much of a problem. However, when many factors are considered, the many possibilities can create such confusion that one fails to comprehend what is happening.

-The system is subjective. Dynamic analysis of land use systems is not considered.

-The precision of the yield predictions depends also on the availability of site specific agronomic data and correct selection of the optimum yield level. To establish yield reduction factors, research data are required. Besides this, the program allows to define only one optimum yield for the whole study area, in reality different parts of the area can have different optimum yield levels.

-The term "economic evaluation" is loosely used. The use of gross margins to specify economic class limits and to compare economic suitability between LUTs seems a bit pessimistic since gross margins do not reflect the actual net farm income. The setting of limits for economic classes has to be based on criteria that easily relate to farm income if the word "economic" is to be used in its more strict sense.

## 5.2.2 ALES discussed with a view to quantified land evaluation

Yield prediction in ALES is a step towards quantified land evaluation. However, the precision achieved depends on the knowledge of factors that affect yields and how they do so. LURs and LCs used for evaluation of a specific land unit for specific use need to be quantified outside ALES.

In this study some of the basic requirements of ALES, namely optimum yield, land use requirements like moisture availability and availability of oxygen for root growth were inferred from PS123N results. It can be concluded that ALES can benefit from quantified land evaluation models like PS123N and WOFOST, for better and more reliable land use systems analysis.

### 5.2.3 Soil data base for land evaluation

Quantified land evaluation models try to represent and predict, for different locations, the response of a particular crop to the specific radiation, temperature, moisture and nutrient regimes, by simulating the occurrence of events and processes on a real time scale. They are dynamic as they describe growth and development of a given crop over time. The capability of the models to predict the performance of a specific land-use systems depends on the soil, crop, weather and management data provided. Unfortunately, getting the required data is not always easy.

Since a few years, various direct and indirect methods have been developed to get required resource data. Indirect methods are cost effective; but many lean on soil laboratory results. Texture-specific hydraulic soil characteristics are an example. However, as outlined in the previous sections, the use of soil texture classes obtained from the laboratory might be misleading. Though it needs further research, this study shows the possibility to aggregate the texture classes to a smaller number of broader classes that can be easily identified in the field.

# 5.2.4 Concluding remarks

This treatise tried to show the possibilities and limitations of QLE models for land use systems analysis. It shows various ways to prepare the resource data base required by the models.

In addition to this the applicability of ALES and its interaction with QLE models was investigated and the results found are promising. But, the paper should not be concluded without some words of caution. Thus:

-The basic principles, data base aggregation and simplicity, and the additional facilities for evaluation of irrigation requirement and salinity control found in the PS123N model are strong points that have to be appreciated.

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# **APPENDICES**

Appendix A: severity level decision trees of ALES

- Appendix B: Land characteristics ratings and land mapping unit data
- Appendix C: Different soil hydraulic conductivity parameter values from various authors for the same texture class
- Appendix D: Raw climate data calculated using Penman method and WOFOST climate data for Chuka area, Kenya.
- Appendix E: PS123N climate data format example
- Appendix F: WOFOST & PS123N final soil data for Chuka-South area and some major tropical soils
- Appendix G: Soil profile descriptions

Appendix A: Severity level decision trees of ALES

Figure 3.2 Severity level decision tree for land use requirement 'nutrient availability' on land utilization type MTA.

```
Where Used
DtId Type
             _____
     Severity Level
22
                                     MTA, NA
> ECEC (Effective cation exchange capacity)
   0-2 (v.low) [0-2 me/100g : 4 (very low)
   2-4 (low) [2-4 me/100g] > Tma (mean annual temperature)
14-16 (fairly cool) [10-16 °C] > C% (Organic carbon % for T-zone 4,5,6)
         <.5 (v.low) [0-.5 %].... : 4 (very low)
         .5-1 (low) [.5-1 %] > SA (Soil acidity (pH-H20))
            <4 (acidic) [0-4 MS].... : 4 (very low)
            4-4.7 (moderately acidic : 3 (low)
            4.8-5.5 (slightly acidic : 2 (moderate)
            5.6-6.8 (almost neutral) : =3
            ?....:?
         1.1-2 (moderate) [1-2 %] : =2
         >2 (high) [2-5 %]..... : =2
         ?.... ?
      16-18 (cool temperate) [ : =1
      18-20 (warm temperate) [ : =1
      20-22 (fairly warm) [20-22 °C] > C-2 % (Organic carbon % for T-zone 1,2,
<1 (v.low) [0-1 %]..... : 4 (very low)
         1-1.5 (low) [1-1.5 %] > SA (Soil acidity (pH-H20))
            <4 (acidic) [0-4 MS].... : 4 (very low)
            4-4.7 (moderately acidic : 3 (low)
            4.8-5.5 (slightly acidic : 2 (moderate)
            5.6-6.8 (almost neutral) : =3
            ?....:?
         1.6-2.5 (moderate) [1.5- : =2
>2.5 (high) [2.5-4 %]... : =2
         ?....
                             ....: ?
      22-24 (warm) [22-24 °C]. : =4
      24-30 (fairly hot to hot : =4
      ?....:?
   4-10 (moderate) [4-10 me/100g] > Tma (mean annual temperature)
14-16 (fairly cool) [10-16 °C] > C% (Organic carbon % for T-zone 4,5,6)
<.5 (v.low) [0-.5 %]... : 3 (low)</pre>
         .5-1 (low) [.5-1 %] > SA (Soil acidity (pH-H20))
            <4 (acidic) [0-4 MS].... : 4 (very low)
            4-4.7 (moderately acidic : 3 (low)
            4.8-5.5 (slightly acidic : 2 (moderate)
            5.6-6.8 (almost neutral) : =3
            ?....:?
         1.1-2 (moderate) [1-2 %] := 2
         >2 (high) [2-5 %]..... : =2
         ?....:?
      16-18 (cool temperate) [ : =1
      18-20 (warm temperate) [ : =1
      20-22 (fairly warm) [20-22 °C] > C-2 % (Organic carbon % for T-zone 1,2,
         <1 (v.low) [0-1 %]..... : 3 (low)
         1-1.5 (low) [1-1.5 %] > SA (Soil acidity (pH-H20))
            <4 (acidic) [0-4 MS].... : 4 (very low)
4-4.7 (moderately acidic : 3 (low)
4.8-5.5 (slightly acidic : 2 (moderate)
            5.6-6.8 (almost neutral) : =3
             ?....:?
         1.6-2.5 (moderate) [1.5-:=2]
         >2.5 (high) [2.5-4 %]... : =2
```

GZ-MV (Chuka Area, KENYA) DtId Type Where Used ------22 Severity Level MTA,NA (continued) 22-24 (warm) [22-24 °C]. : =4 24-30 (fairly hot to hot : =4 ?....:? 10-20 (high) [10-20 me/100g] > SB (Soil basisity (pH-H2O)) 5.6-6.8 (almost neutral) : 1 (high) 6.9-7.5 (neutral to basi : =1 7.6-8.7 (moderately basi : 3 (low) >8.7 (basic) [8.7-10 MS] : 4 (very low) ?..... ?....:?

GZ-MV (Chuka Area, KENYA) DtId Type Where Used \_\_\_\_\_ ------------Proportional Yield 18 MTA,MZT > MA (MOISTURE AVAILABILITY) 1 (none to slight ) > RE (Erosion hazard) 1 (almost none) > NA (nutrient availability) 1 (high)..... : .73 2 (moderate)..... : .53 3 (low)..... : .36 4 (very low)..... : .2 ?....:? 2 (slight) > NA (nutrient availability) 1 (high)..... : .53 2 (moderate)..... : .38 3 (low)..... : .26 4 (very low)..... : .15 ?..... : ? 3 (moderate) > NA (nutrient availability) 1 (high)..... : .37 2 (moderate)..... : .26 3 (low)..... : .18 4 (very low)..... : .101 ?..... : ? 4 (severe) > NA (nutrient availability) 1 (high)..... 203 2 (moderate)..... : .15 3 (low)..... : .101 4 (very low)..... : .06 ?....:? ?....:? (moderate stress) > RE (Erosion hazard) 2 1 (almost none) > NA (nutrient availability) 1 (high)..... : .53 2 (moderate)..... : .38 3 (low)..... : .26 4 (very low)..... : .15 2 (slight) > NA (nutrient availability) 1 (high)..... : .38 2 (moderate)..... : .275 3 (low)..... : .19 4 (very low)..... : .11 ?..... : ? 3 (moderate) > NA (nutrient availability) 1 (high)..... : .26 2 (moderate)..... : .19 3 (low)..... : .132 4 (very low)..... : .073 ?....:? 4 (severe) > NA (nutrient availability) 1 (high)..... : .15 2 (moderate)..... : .11 3 (low)..... : .073 4 (very low)..... : .04 ?....:? ?....:? (moderate to seve) > RE (Erosion hazard) 3 1 (almost none) > NA (nutrient availability)

Figure 3.5. Proportional yield decision tree for land uitilization type MTA.

GZ-MV (Chuka Area, KENYA) DtId Type Where Used Proportional Yield 18 MTA, MZT (continued) 1 (high)..... : .36 2 (moderate)..... : .26 3 (low)..... : .18 4 (very low)..... : .101 2 (slight) > NA (nutrient availability) 1 (high)..... : .26 2 (moderate)..... : .19 3 (low)..... : .132 4 (very low)..... : .073 ?..... : ? 3 (moderate) > NA (nutrient availability) 1 (high)..... : .18 2 (moderate)..... : .132 3 (low)..... : .09 4 (very low)..... : .05 ?..... : ? 4 (severe) > NA (nutrient availability) 1 (high)..... : .101 2 (moderate)..... : .073 3 (low)..... : .051 4 (very low)..... : .028 ?....:? ?..... ? (severe stress) > RE (Erosion hazard) 1 (almost none) > NA (nutrient availability) 1 (high)..... : .202 2 (moderate)..... : .146 3 (low)..... : .101 4 (verý low)..... : .056 ?..... : ? 2 (slight) > NA (nutrient availability) 1 (high)..... : .15 2 (moderate)..... : .106 3 (low)..... : .073 4 (very low)..... : .041 ?..... : ? 3 (moderate) > NA (nutrient availability) 1 (high)..... : .101 2 (moderate)..... : .073 3 (low)..... : .051 4 (very low)..... : .028 ?..... ? 4 (severe) > NA (nutrient availability) 1 (high)..... : .056 2 (moderate)..... : .041 3 (low)..... : .028 4 (very low)..... : .016 ?....:? ?....:? 

G2-MV (Chuka Afea, Afwik) Dtld Type	Where Used	
17 Physical Subclass	мта	
> RE (Erosion hazard)		
1 (almost none) > MA (MOIS	URE AVAILABILITY)	
	(nutrient availability)	
1 (high)		
2 (moderate)		
3 (low)		
4 (very low)		
?		
2 (moderate stress)		
3 (moderate to seve)		
4 (severe stress) > NA	· · · · · · · · · · · · · · · · · · ·	
1 (high)		
2 (moderate)		:
3 (low)		
4 (very low)		:
· ?		
· ?		
2 (slight):		
3 (moderate):		
4 (severe) > MA (MOISTURE )		
	A (nutrient availability)	
1 (high)		
2 (moderate)		
3 (low)		i
4 (very low)		:
?		
2 (moderate stress)		
3 (moderate to seve)		1
4 (severe stress) > NA		
1 (high)		
2 (moderate)		
3 (low)		
4 (very low)		
?		
?		
?	· · · · · · · · · · · · · · · · · · ·	



GZ-MV (Chuka Area, KENYA) Where Used DtId Type MTC,MZT Proportional Yield 13 > MA (MOISTURE AVAILABILITY) 1 (none to slight ) > NA (nutrient availability) 1 (high)..... : .81 2 (moderate)..... : .59 3 (low)..... : .41 4 (very low)..... : .23 ?....:? 2 (moderate stress) > NA (nutrient availability) 1 (high)..... : .59 2 (moderate)..... : .42 3 (low)..... : .3 4 (very low)..... : .16 ?..... ? 3 (moderate to seve) > NA (nutrient availability) 1 (high)..... : .41 2 (moderate)..... : .3 3 (low)..... : .2 4 (very low)..... : .112 ?....:? 4 (severe stress) > NA (nutrient availability) 1 (high)..... : .23 2 (moderate)..... : .16 3 (low)..... : .113 4 (very low)..... : .06 ? ?..... 

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Figure 3.4. Proportional yield decision tree for land uitilization type MTC.

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Appendix B:Land characteristics ratings and land mapping unit data.

GZ-MV LC Id		Chuka Ar Class C	ea, KENYA LC Name ode	A) Class Name	Cla		Units 1 limit	Infer	from
C%			Organic	carbon % for T-zone 4,	4		8		
1		<.5		v.low		.5			
2		.5-1		low		1			
3		1.1-2		moderate		2			
4	ŧ	>2		high		5			
:-2 %	5		Organic	carbon % for T-zone 1,	4		8		
1		<1		v.low	-	1	•		
2		1-1.5		low		1.5			
3	3	1.6-2.5		moderate		2.5			
4	ŀ	>2.5		high		4			
r			soil dra	vinago	5				
,r 1		we	SULL ULC	well to excessively dra	-				
2		mw		moderatly well drained					
3		i		Imperfectly drained					
4		p		poorly drained					
5	5	vp		very poorly drained					
		_							
ECEC			Effectiv	ve cation exchange capa	4	-	me/100g		
1		0-2		v.low		2			
2		2-4		low		4			
3		4-10 10-20		moderate		10 20			
4	ŧ	10-20		high		20			
Ert			privous	top soil erosion statu	4				
1		n		nill					
2		sl		slightly eroded					
3		m		moderatly eroded					
4	ł	S		severly eroded					
Per			soil per	rmeablity	-7		cm/d		
1	L	VS	_	very slow					
2		S		slow					
3		ms		moderately slow					
4		m		moderate					
5		mr		moderately rapid					
6		r		rapid					
,	/	vr		very rapid					
Pm			Average	annual rain fall	5		centimeter		
נן	L	45-90	-	semi-arid rain fall		90			
	2	60-110		semi-humid to semi-ari	d	110			
	3	80-140		semi-humid rain fall		140			
	4	100-160		sub-humid rain fall		160			
	5	110-270		humid rain fall		270			
Ry			Relativ	e moisture availability	4				
1	L	sl		0.7-1					
2	2	s2		0.4-0.7					
	3	<b>s</b> 3		0.1-0.4					
	4	N		0-0.1					

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GZ- LC		(Chuka Area, L( Class Code	C Name	Cl		Units r limit	Infer	from
SA	1 2 3 4	Sc <4 4-4.7 4.8-5.5 5.6-6.8	oil acidity (pH-H20) acidic moderately acidic slightly acidic almost neutral	4	4 4.7 5.5 6.8	MS		
SB	1 2 3 4	Sc 5.6-6.8 6.9-7.5 7.6-8.7 >8.7	bil basisity (pH-H2O) almost neutral neutral to basic moderately basic basic	4	6.8 7.5 8.7 10	MS		
Бđ	1 2 3	So s d	bil depth shallow moderate deep	3	50 80 120	Cm		
Sla	1 2 3 4 5	s] 0-8 8-16 16-30 30-70 >70	lope angle almost flat gentle moderately steep steep very steep	5	8 16 30 70 90	8		
Tex	kg 1 2 3 4 5	so glslf g2sil g3sicl g4scl g5cl	bil texture class groups ba group1 sandy loam fa group2 silty loam group3 silty clay lo group4 sandy clay fa group5 clay and caly	amily cam fa amily				
<b>F</b> ma	1 2 3 4 5 6	me 14-16 16-18 18-20 20-22 22-24 24-30	ean annual temperature fairly cool cool temperate warm temperate fairly warm warm fairly hot to hot	`6	16 18 20 22 24 30	°C .		

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LC COO	le data
EAK41	EAK41-Chuka, Gleyic Cambisol, clay
C%	>2 (high) [2-5]
Dr	mw (moderatly well drained)
ECEC	10-20 (high) [10-20]
Ert	n (nill)
Per	m (moderate)
Pm	110-270 (humid rain fall) [160-270]
Ry	s2 (0.4-0.7)
SA	5.6-6.8 (almost neutral) [5.5-6.8]
SB	5.6-6.8 (almost neutral) [0-6.8]
Sd	d (deep) [80-120]
Sla	30-70 (steep) [30-70]
Texg	g5cl (group5 clay and caly loam family)
Tma	18-20 (warm temperate) [18-20]
EAK42	EAK42-Chuka, humic cambisol, clay
C%	>2 (high) [2-5]
Dr	mw (moderatly well drained)
ECEC	10-20 (high) [10-20]
Ert	n (nill)
Per	m (moderate)
Pm	110-270 (humid rain fall) [160-270]
Ry	s2 (0.4-0.7)
SA	5.6-6.8 (almost neutral) [5.5-6.8]
SB	5.6-6.8 (almost neutral) [0-6.8]
Sd	m (moderate) [50-80]
Sla	0-8 (almost flat) [0-8]
Texg	g5cl (group5 clay and caly loam family)
Tma	18-20 (warm temperate) [18-20]
EAK43	EAK43-Chuka, gleyic cambisol, clay
C−2 %	1.6-2.5 (moderate) [1.5-2.5]
Dr	mw (moderatly well drained)
ECEC	2-4 (low) [2-4]
Ert	n (nill)
Per	m (moderate)
Pm	110-270 (humid rain fall) [160-270]
Ry	<b>s</b> 3 (0.1-0.4)
SA	4.8-5.5 (slightly acidic) [4.7-5.5]
Sđ	m (moderate) [50-80]
Sla	0-8 (almost flat) [0-8]
Texg	g5cl (group5 clay and caly loam family)
Tma	20-22 (fairly warm) [20-22]

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GZ-MV (Chul LMU ID LC code	ka Area, KENYA) LMU Name e data
	EAK44-Chuka, humic Nitosol, clay
C-2 %	
Dr	mw (moderatly well drained)
ECEC Ert	10-20 (high) [10-20] n (nill)
Ert Per	m (moderate)
Pm	100-160 (sub-humid rain fall) [140-160]
Ry	s1 (0.7-1)
SA	5.6-6.8 (almost neutral) [5.5-6.8]
SB	5.6-6.8 (almost neutral) [0-6.8]
Sd	d (deep) [80-120]
Sla	0-8 (almost flat) [0-8]
Texq	g5cl (group5 clay and caly loam family)
Tma	20-22 (fairly warm) [20-22]
EAK45	EAK45-Chuka, humic acrisol, silty clay
C-2 %	$1.6-2.5 \pmod{\text{moderate}} [1.5-2.5]$
Dr	we (well to excessively drained)
ECEC	4-10 (moderate) $[4-10]$
Ert	sl (slightly eroded)
Per	m (moderate)
Pm	100-160 (sub-humid rain fall) [140-160]
Ry	s3 (0.1-0.4)
SA	5.6-6.8 (almost neutral) [5.5-6.8]
SB	5.6-6.8 (almost neutral) [0-6.8]
Sd	m (moderate) [50-80]
Sla	8-16 (gentle) [8-16]
Texg	g3sicl (group3 silty clay loam family)
Tma	20-22 (fairly warm) [20-22]
EAK46	EAK46-Chuka, orthic acrisol, silty clay
C−2 %	$1.6-2.5 \pmod{\text{moderate}} [1.5-2.5]$
Dr	mw (moderatly well drained)
ECEC	4-10 (moderate) [4-10]
Ert	n (nill)
Per	m (moderate)
Pm By	100-160 (sub-humid rain fall) [140-160]
Ry	$s_{3}(0.1-0.4)$
SA SB	5.6-6.8 (almost neutral) [5.5-6.8] 5.6-6.8 (almost neutral) [0-6.8]
Sd	$m \pmod{2} \begin{bmatrix} 50-8.8 \\ 50-80 \end{bmatrix}$
Sla	0-8  (almost flat)  [0-8]
Texq	g3sicl (group3 silty clay loam family)
Tma	20-22 (fairly warm) [20-22]
	(restal mean) [no ne]

	U Name	
LC code	data 	
EAK47 EAH	K47-Chuka, orthic ferralsols, clay	
C−2 %	1.6-2.5 (moderate) [1.5-2.5]	
Dr	vp (very poorly drained)	
ECEC	4-10 (moderate) [4-10]	
Ert	n (nill)	
Per	m (moderate)	
Pm	80-140 (semi-humid rain fall) [110-140]	
Ry	N (0-0.1)	
SA	5.6-6.8 (almost neutral) [5.5-6.8]	
SB	5.6-6.8 (almost neutral) [0-6.8]	
Sd	d (deep) [80-120]	
Sla	0-8 (almost flat) $[0-8]$	
Texg	g5cl (group5 clay and caly loam family)	
Tma	22-24 (warm) [22-24]	
EAK48 EAH	K48-Chuka, ferric acrisol, silty clay	
C-2 %	1.6-2.5 (moderate) [1.5-2.5]	
Dr	we (well to excessively drained)	
ECEC	$4-10 \pmod{4-10}$	
Ert	n (nill)	
Per	m (moderate)	
Pm	80-140 (semi-humid rain fall) [110-140]	
Ry	N (0-0.1)	
SĀ	5.6-6.8 (almost neutral) [5.5-6.8]	
SB	5.6-6.8 (almost neutral) [0-6.8]	
Sd	d (deep) [80-120]	
Sla	0-8 (almost flat) [0-8]	
Texg	g3sicl (group3 silty clay loam family)	
Tma	22-24 (warm) [22-24]	
EAK49 EAH	K49-Chuka, gleyic cambisol, clay	
C-2 %	>2.5 (high) [2.5-4]	
Dr	mw (moderatly well drained)	
ECEC	10-20 (high) [10-20]	
Ert	n (nill)	
Per	m (moderate)	
Pm	80-140 (semi-humid rain fall) [110-140]	
Ry	s1 (0.7-1)	
SĂ	5.6-6.8 (almost neutral) [5.5-6.8]	
SB	5.6-6.8 (almost neutral) [0-6.8]	
Sđ	d (deep) [80-120]	
Sla	0-8 (almost flat) $[0-8]$	
Texg	g5cl (group5 clay and caly loam family)	
Tma	22-24 (warm) [22-24]	

GZ-MV (Chul	ka Area, KENYA)
LMU ID	LMU Name
LC code	e data
EAK50	<pre>EAK50-Chuka, chromic luvisol, sandy clay</pre>
C-2 %	<1 (v.low) [0-1]
Dr	we (well to excessively drained)
ECEC	10-20 (high) [10-20]
Ert	m (moderatly eroded)
Per	s (slow)
Pm	60-110 (semi-humid to semi-arid ) [90-110]
Ry	N (0-0.1)
SA	5.6-6.8 (almost neutral) [5.5-6.8]
SB	5.6-6.8 (almost neutral) [0-6.8]
Sd	d (deep) [80-120]
Sla	0-8 (almost flat) [0-8]
Texg	g4scl (group4 sandy clay family)
Tma	24-30 (fairly hot to hot) [24-30]
EAK51	<pre>EAK51-Chuka, chromic luvisol, sandy clay</pre>
C-2 %	<1 (v.low) [0-1]
Dr	mw (moderatly well drained)
ECEC	10-20 (high) [10-20]
Ert	m (moderatly eroded)
Per	s (slow)
Pm	60-110 (semi-humid to semi-arid ) [90-110]
Ry	N (0-0.1)
SA	5.6-6.8 (almost neutral) [5.5-6.8]
SB	5.6-6.8 (almost neutral) [0-6.8]
Sd	m (moderate) [50-80]
Sla	0-8 (almost flat) [0-8]
Texg	g4scl (group4 sandy clay family)
Tma	24-30 (fairly hot to hot) [24-30]
EAK52	<pre>EAK52-Chuka, calcic luvisol, silty cl.lo</pre>
C-2 %	<1 (v.low) [0-1]
Dr	we (well to excessively drained)
ECEC	10-20 (high) [10-20]
Ert	m (moderatly eroded)
Per	m (moderate)
Pm	60-110 (semi-humid to semi-arid ) [90-110]
Ry	N (0-0.1)
SB	7.6-8.7 (moderately basic) [7.5-8.7]
Sd	d (deep) [80-120]
Sla	0-8 (almost flat) [0-8]
Texg	g3sicl (group3 silty clay loam family)
Tma	24-30 (fairly hot to hot) [24-30]

Appendix C:Different soil hydraulic conductivity parameter values from different authors for the same texture class.

Indicative values for soil constants SMO, GAM, PSI\_, KO, ALFA and AK for reference soil texture classes. Source: Rijtema (1969).

Texture	SM0 (ст <sup>3</sup> ст <sup>.,</sup> )	GAM (cm <sup>-2</sup> )	PSI (cm)	КО (ст d <sup>-1</sup> )	ALFA (cm <sup>-i</sup> )	AK (cm²⁴d⁴
coarse sand	0.395	0.1000	80	1120	0.244	0.08
loamy sand	0.439	0.0330	200	26.5	0.0398	16.4
fine sand	0.364	0.0288	175	50	0.0500	10.9
fine sandy loam	0.504	0.0207	300	12.0	0.0248	26.5
silt loam	0.509	0.0185	300	6.5	0.0200	47.3
loam	0.503	0.0180	300	5.0 <sup>.</sup>	0.0231	14.4
loess loam	0.455	0.0169	130	14.5	0.0490	22.6
sandy clayloam	0.432	0.0096	200	23.5	0.0353	33.6
silty clayloam	0.475	0.0105	300	1.5	0.0237	36.0
clayloam	0.445	0.0058	300	0.98	0.0248	1.69
light clay	0.453	0.0085	300	3.5	0.0274	2.77
silty clay	0.507	0.0065	50	1.3	0.0480	28.2
heavy clay	0.540	0.0042	80	0.22	0.0380	4.86
peat	0.863	0.0112	50	5.3	0.1045	6.82

Average values for selected soil water retention and hydraulic conductivity parameters for 11 major soil textural groups according to *Rawls et al.* [1982]

Texture	θ,	θ,	a 1/cm	п	<i>لا</i> ب مس/ط
Sand	0.020	0.417	0.138	1.592	
Loamy sand	0.035	0.401	0.115	1.474	146.6
Sandy loam	0.041	0.412	0.068	1.322	67.16
Loam	0.027	0.434	0.090	1.220	· 16.32
Silt loam	0.015	0.486	0.048	1.211	31.68
Sandy clay loam	0.068	0.330	0.036	1.250	10.32
Clay loam	0.075	0.390	0.039	1.194	5.52
Silty clay loam	0.040	0.432	0.031	1.151	3.60
Sandy clay	0.109	0.321	0.034	1.168	2.88
Silty clay	0.056	0.423	0.029	1_127	2.16
Clay	0.090	0.385	0.027	L131	L44

. Average values for selected soil water retention and hydraulic conductivity parameters for 12 major soil
textural groups according to Carsel and Parish (1988)

Texture	θ,	<i>θ</i> ,	a 1/cm	n	К, /d
Sand	0.045	0.43	0.145	2.68	712.3
Loamy Sand	0.057	0.41	0.124	2.28	350.Z
Sandy Loam	0.065	0.41	0.075	1.89	106.1
Loam	0.078	0.43	0.036	1_56	24.96
Silt	0.034	0.46	0.016	1.37	6.00
Silt Loam	0.067	0.45	0.020	L41	10.80
Sandy Clay Loam	0.100	0.39	0.059	1,48	31.44
Clay Loam	0.095	0.41	0.019	131	6.24
Silty Clay Loam	0.089	0.43	0.010	1.23	1.68
Sandy Clay	0.100	0.38	0.027	1.23	2.38
Silty Clay	0.070	0.36	0.005	1.09	0.48
Clay	0.068	0.38	0.008	1.09	4.80

Appendix D: Raw climate data calculated using Penman method and WOFOST climate data of Chuka-South area Tmax, Tmin, P, RHA, Eo, SUNH, ETo, Rs, Rnl

(°C, °C, cm/d, %, cm/d, Hr/d, cm/d, MJ/m2/d, MJ/m2/d.)

#### "EAK41",-.21,37.32,1710

1, 24.1, 11, .08, .7, .546, 8.5, .439, 22.88, 6.78 2, 25.1, 11.1, .14, .71, .585, 8.5, .472, 23.79, 6.65 3, 25.1, 11.7, .47, .73, .537, 7.5, .426, 22.86, 5.83 4, 23.7, 11.9, 1.32, .84, .452, 6, .349, 20.18, 4.48 5, 22.8, 11.2, .7, .87, .404, 5.5, .31, 18.56, 4.18 6, 21.7, 10, .08, .84, .377, 5.5, .289, 18.02, 4.41 7, 20.7, 9.9, .13, .82, .392, 6, .301, 19.02, 4.87 8, 21.4, 10, .13, .8, .418, 6, .323, 19.87, 4.89 9, 23.9, 10.3, .07, .73, .516, 7, .412, 22.05, 5.67 10, 24.3, 12.2, .91, .75, .49, 6.5, .389, 20.97, 5.1 11, 22.5, 12.5, 1.07, .81, .435, 6, .34, 19.37, 4.63 12, 22.9, 11.3, .23, .81, .411, 6, .319, 18.82, 4.68

#### "EAK42",-.21,37.32,1715

1, 24.1, 11, .08, .7, .546, 8.5, .439, 22.88, 6.78 2, 25.1, 11.1, .14, .71, .585, 8.5, .472, 23.79, 6.65 3, 25.1, 11.7, .47, .73, .537, 7.5, .426, 22.86, 5.83 4, 23.7, 11.9, 1.32, .84, .452, 6, .349, 20.18, 4.48 5, 22.8, 11.2, .7, .87, .404, 5.5, .31, 18.56, 4.18 6, 21.7, 10, .08, .84, .377, 5.5, .289, 18.02, 4.41 7, 20.7, 9.9, .13, .82, .392, 6, .301, 19.02, 4.87 8, 21.4, 10, .13, .8, .418, 6, .323, 19.87, 4.89 9, 23.9, 10.3, .07, .73, .516, 7, .412, 22.05, 5.67 10, 24.3, 12.2, .91, .75, .49, 6.5, .389, 20.97, 5.1 11, 22.5, 12.5, 1.07, .81, .435, 6, .34, 19.37, 4.6312, 22.9, 11.3, .23, .81, .411, 6, .319, 18.82, 4.68

#### "EAK43",-.23,37.34,1550

1, 26.4, 13.6, .08, .65, .589, 8.5, .484, 22.89, 6.69 2, 29.3, 13.6, .14, .63, .69, 8.5, .579, 23.79, 6.58 3, 27.9, 14.9, .47, .66, .583, 7.5, .475, 22.86, 5.74 4, 25.8, 15.8, 1.32, .77, .492, 6, .391, 20.17, 4.34 5, 24, 15.7, .7, .85, .436, 5.5, .339, 18.56, 3.86 6, 22.8, 14.4, .08, .84, .403, 5.5, .312, 18.01, 4.08 7, 21.4, 13.1, .13, .76, .415, 6, .327, 19.01, 4.86 8, 21.7, 13, .13, .82, .433, 6, .335, 19.87, 4.62 9, 24.4, 13.3, .07, .69, .53, 7, .428, 22.05, 5.63 10, 25.9, 14.2, .91, .7, .516, 6.5, .418, 20.97, 5.08 11, 24.2, 14.6, 1.07, .81, .455, 6, .358, 19.37, 4.37 12, 25.7, 13.6, .23, .81, .438, 6, .344, 18.83, 4.33

#### "EAK44",-.24,37.37,1410

 $1,26.4,13.6,.08,.65,.6,9,.491,23.64,7.04\\2,29.3,13.6,.14,.63,.702,9,.588,24.58,6.92\\3,27.9,14.9,.47,.66,.608,8.5,.492,24.48,6.39\\4,25.8,15.8,1.32,.77,.504,6.5,.399,20.97,4.63\\5,24,15.7,.7,.85,.473,7,.364,20.84,4.71\\6,22.8,14.4,.08,.84,.448,7.5,.341,20.97,5.27\\7,21.4,13.1,.13,.76,.403,5.5,.32,18.26,4.53\\8,21.7,13,.13,.82,.431,6,.334,19.87,4.62\\9,24.4,13.3,.07,.69,.541,7.5,.435,22.86,5.97\\10,25.9,14.2,.91,.7,.541,7.5,.434,22.56,5.73\\11,24.2,14.6,1.07,.81,.466,6.5,.366,20.14,4.67\\12,25.7,13.6,.23,.81,.472,7.5,.366,21.05,5.22$ 

#### "EAK45",-.25,37.37,1380

1,26.4,13.6,.08,.65,.6,9,.491,23.64,7.03 2,29.3,13.6,.14,.63,.702,9,.588,24.58,6.92 3,27.9,14.9,.47,.66,.608,8.5,.492,24.48,6.39 4,25.8,15.8,1.32,.77,.503,6.5,.399,20.97,4.63 5,24,15.7,.7,.85,.472,7,.363,20.84,4.71 6,22.8,14.4,.08,.84,.448,7.5,.341,20.97,5.27 7,21.4,13.1,.13,.76,.403,5.5,.32,18.26,4.53 8,21.7,13,.13,.82,.43,6,.333,19.87,4.62 9,24.4,13.3,.07,.69,.541,7.5,.435,22.86,5.97 10,25.9,14.2,.91,.7,.54,7.5,.434,22.56,5.73 11,24.2,14.6,1.07,.81,.466,6.5,.365,20.14,4.67 12,25.7,13.6,.23,.81,.472,7.5,.366,21.05,5.22

## "EAK46", ~.25,37.37,1330

 $1,26.4,13.6,.08,.65,.6,9,.491,23.64,7.03\\2,29.3,13.6,.14,.63,.702,9,.589,24.58,6.92\\3,27.9,14.9,.47,.66,.608,8.5,.492,24.48,6.39\\4,25.8,15.8,1.32,.77,.503,6.5,.399,20.97,4.63\\5,24,15.7,.7,.85,.472,7,.363,20.84,4.71\\6,22.8,14.4,.08,.84,.447,7.5,.34,20.97,5.27\\7,21.4,13.1,.13,.76,.402,5.5,.32,18.26,4.53\\8,21.7,13,.13,.82,.43,6,.333,19.87,4.62\\9,24.4,13.3,.07,.69,.54,7.5,.435,22.86,5.97\\10,25.9,14.2,.91,.7,.54,7.5,.434,22.56,5.73\\11,24.2,14.6,1.07,.81,.466,6.5,.365,20.14,4.67\\12,25.7,13.6,.23,.81,.472,7.5,.365,21.05,5.22$ 

# "EAK47",-.27,37.42,1145

1, 28.6, 13.4, .08, .67, .66, 9.5, .546, 24.4, 7.04 2, 30.4, 14.2, .17, .67, .682, 9.5, .56, 25.36, 6.78 3, 29.8, 15.9, .51, .7, .646, 8.5, .526, 24.48, 5.83 4, 28.7, 17.3, 1.19, .73, .57, 7.5, .459, 22.56, 5.03 5, 27.8, 16.6, .4, .77, .545, 7.5, .437, 21.59, 4.96 6, 26.6, 15.2, .02, .73, .513, 7.5, .413, 20.96, 5.43 7, 25.9, 14, .01, .68, .482, 5.5, .404, 18.26, 4.53 8, 26.1, 14.7, .05, .68, .536, 6.5, .444, 20.65, 5.14 9, 28.3, 14.6, .02, .65, .615, 7.5, .511, 22.86, 5.8 10, 29.4, 15.8, .35, .65, .615, 7.5, .511, 22.56, 5.6 11, 27.2, 16.8, 1.06, .79, .515, 6.5, .414, 20.14, 4.32 12, 26.8, 15.2, .24, .83, .501, 7.5, .392, 21.06, 4.86

# "EAK48",-.27,37.41,1142

1, 28.6, 13.4, .08, .67, .66, 9.5, .546, 24.4, 7.04 2, 30.4, 14.2, .17, .67, .682, 9.5, .56, 25.36, 6.78 3, 29.8, 15.9, .51, .7, .646, 8.5, .526, 24.48, 5.83 4, 28.7, 17.3, 1.19, .73, .57, 7.5, .459, 22.56, 5.03 5, 27.8, 16.6, .4, .77, .545, 7.5, .437, 21.59, 4.96 6, 26.6, 15.2, .02, .73, .513, 7.5, .413, 20.96, 5.43 7, 25.9, 14, .01, .68, .482, 5.5, .404, 18.26, 4.53 8, 26.1, 14.7, .05, .68, .536, 6.5, .444, 20.65, 5.14 9, 28.3, 14.6, .02, .65, .615, 7.5, .517, 22.86, 5.8 10, 29.4, 15.8, .35, .65, .615, 7.5, .511, 22.56, 5.6 11, 27.2, 16.8, 1.06, .79, .515, 6.5, .414, 20.14, 4.32 12, 26.8, 15.2, .24, .83, .501, 7.5, .392, 21.06, 4.86

## "EAK49",-.27,37.41,1139

 $1,28.6,13.4,.08,.67,.66,9.5,.546,24.4,7.04\\2,30.4,14.2,.17,.67,.682,9.5,.56,25.36,6.78\\3,29.8,15.9,.51,.7,.646,8.5,.526,24.48,5.83\\4,28.7,17.3,1.19,.73,.57,7.5,.459,22.56,5.03\\5,27.8,16.6,.4,.77,.545,7.5,.437,21.59,4.96\\6,26.6,15.2,.02,.73,.513,7.5,.413,20.96,5.43\\7,25.9,14,.01,.68,.482,5.5,.404,18.26,4.53\\8,26.1,14.7,.05,.68,.536,6.5,.444,20.65,5.14\\9,28.3,14.6,.02,.65,.615,7.5,.517,22.86,5.8\\10,29.4,15.8,.35,.65,.615,7.5,.511,22.56,5.6\\11,27.2,16.8,1.06,.79,.515,6.5,.414,20.14,4.32\\12,26.8,15.2,.24,.83,.501,7.5,.392,21.06,4.86$ 

### "EAK50",-.27,37.46,855

1,28.6,13.4,.08,.67,.66,9.5,.548,24.4,7.04 2,30.4,14.2,.17,.67,.682,9.5,.562,25.36,6.78 3,29.8,15.9,.51,.7,.644,8.5,.526,24.48,5.83 4,28.7,17.3,1.19,.73,.568,7.5,.458,22.56,5.03 5,27.8,16.6,.4,.77,.543,7.5,.436,21.59,4.96 6,26.6,15.2,.02,.73,.511,7.5,.413,20.96,5.43 7,25.9,14,.01,.68,.481,5.5,.405,18.26,4.53 8,26.1,14.7,.05,.68,.535,6.5,.444,20.65,5.14 9,28.3,14.6,.02,.65,.62,7.5,.518,22.86,5.8 10,29.4,15.8,.35,.65,.614,7.5,.513,22.56,5.6 11,27.2,16.8,1.06,.79,.513,6.5,.413,20.14,4.32 12,26.8,15.2,.24,.83,.498,7.5,.391,21.06,4.86

#### "EAK52",-.26,37.48,845

 $1,28.6,13.4,.08,.67,.66,9.5,.548,24.4,7.05\\2,30.4,14.2,.17,.67,.682,9.5,.562,25.36,6.78\\3,29.8,15.9,.51,.7,.644,8.5,.526,24.48,5.83\\4,28.7,17.3,1.19,.73,.568,7.5,.458,22.56,5.03\\5,27.8,16.6,.4,.77,.543,7.5,.437,21.6,4.96\\6,26.6,15.2,.02,.73,.511,7.5,.413,20.96,5.43\\7,25.9,14,.01,.68,.481,5.5,.405,18.26,4.53\\8,26.1,14.7,.05,.68,.535,6.5,.444,20.65,5.14\\9,28.3,14.6,.02,.65,.62,7.5,.518,22.86,5.8\\10,29.4,15.8,.35,.65,.614,7.5,.513,22.56,5.6\\11,27.2,16.8,1.06,.79,.513,6.5,.413,20.14,4.32\\12,26.8,15.2,.24,.83,.498,7.5,.391,21.06,4.86$ 

"EAK70", -.19,37.47,950 1,28.6,13.4,.08,.67,.66,9.5,.547,24.39,7.05 2,30.4,14.2,.17,.67,.682,9.5,.561,25.35,6.78 3,29.8,15.9,.51,.7,.645,8.5,.526,24.47,5.83 4,28.7,17.3,1.19,.73,.569,7.5,.459,22.56,5.03 5,27.8,16.6,.4,.77,.544,7.5,.437,21.61,4.95 6,26.6,15.2,.02,.73,.512,7.5,.414,20.98,5.43 7,25.9,14,.01,.68,.482,5.5,.405,18.27,4.53 8,26.1,14.7,.05,.68,.536,6.5,.444,20.66,5.13 9,28.3,14.6,.02,.65,.62,7.5,.518,22.86,5.8 10,29.4,15.8,.35,.65,.614,7.5,.512,22.56,5.6 11,27.2,16.8,1.06,.79,.513,6.5,.413,20.13,4.32 12,26.8,15.2,.24,.83,.499,7.5,.391,21.04,4.86

WOFOST climate data prepared for Chuka-South area and some other stations for comparison purposes.

\* climate data; average monthly values \* comment lines, starting with \*, are permitted between the data sets. each set of data for a climate takes 14 lines line 1: climate name (up to 30 characters; additional char's are ignored) line 2: latitude (°), elevation (m), empirical constants A and B for Angstrom formula, and a MARKOV constant (between 0.0 and 1.0; controls clustering of generated rainfall; if 1.0 no clustering of rainy days occurs. lines 3-14: 8 columns with average monthly data \* The respective columns represent: \* column 1: average minimum temperature (°C) column 2: average maximum temperature (°C) column 3: average radiation actually received (MJ.m-2.d-1) column 4: average vapour pressure (mbar) \* column 5: average relative humidity (%) column 6: average wind speed (m/s) \* column 7: average monthly rainfall (mm) column 8: average number of rainy days per month \*Note that of the columns vapour pressure and relative humidity, only one need \* to be given. The other one must than be -1 (missing value). TMIN RHUM WIND TMAX IRRAT VAPP RAINT RAIND EAK41 - Kenya -.21 1710. 0.25 0.45 1.0 70 -1. 11.0 24.1 22.880 3.2 25. з. 11.1 25.1 23.790 -1 71 3.2 40. 5. 11.7 25.1 22.860 -1 73 2.0 146. 13.

$\begin{array}{cccccccccccccccccccccccccccccccccccc$	20.180-118.560-118.020-119.020-119.870-122.050-120.970-119.370-118.820-1	84 1.4 87 1.4 84 1.1 82 1.2 80 1.1 73 2.2 75 2.0 81 1.8 81 1.5	218. 2 25. 41. 42. 21. 284. 2	24. 3. 5. 5. 3. 20. 22. 8.
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{ccccccc} 0.25 & 0.45 & 1 \\ 22.890 & -1 \\ 23.790 & -1 \\ 22.860 & -1 \\ 20.170 & -1 \\ 18.560 & -1 \\ 18.010 & -1 \\ 19.010 & -1 \\ 19.870 & -1 \\ 22.050 & -1 \\ 20.970 & -1 \\ 19.370 & -1 \\ 18.830 & -1 \end{array}$	65       3.2         63       3.2         66       2.0         77       1.4         85       1.4         84       1.1         76       1.2         82       1.1         69       2.2         70       2.0         81       1.8	146. 396. 218. 25. 41. 42. 21. 284.	3. 5. 13. 24. 16. 3. 5. 5. 3. 20. 22. 8.
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{ccccccc} 0.25 & 0.45 & 1 \\ 23.640 & -1 \\ 24.580 & -1 \\ 24.480 & -1 \\ 20.970 & -1 \\ 20.840 & -1 \\ 20.970 & -1 \\ 18.260 & -1 \\ 19.870 & -1 \\ 22.860 & -1 \\ 22.560 & -1 \\ 20.140 & -1 \\ 21.050 & -1 \end{array}$	0 65 3.2 63 3.2 66 2.0 77 1.4 85 1.4 84 1.1 76 1.2 82 1.1 69 2.2 70 2.0 81 1.8 81 1.5	40. 146. 396. 218. 25. 41. 42. 21. 284.	3. 5. 13. 24. 16. 3. 5. 5. 3. 20. 22. 8.
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	49. 161. 359. 127. 6. 4. 16. 7. 109.	3. 5. 14. 25. 11. 1. 2. 1. 10. 21. 8.
EAK50 - Kenya 19 950. 13.4 28.6 14.2 30.4 15.9 29.8 17.3 28.7 16.6 27.8 15.2 26.6 14.0 25.9 14.7 26.1 14.6 28.3 15.8 29.4 16.8 27.2 15.2 26.8	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	359. 127. 6. 4. 16. 7. 109.	3. 5. 14. 25. 11. 1. 2. 1. 10. 21. 8.

Galole - Kenya -1.5 100. 0.25 0.45 1.0 22.5 34.2 20.983 26.3 23.1 35.3 22.879 26.3 23.2 34.8 23.242 28.3 22.2 34.0 20.878 28.2 21.5 33.1 19.561 26.8 21.0 31.2 17.445 25.7 19.0 31.1 17.514 24.0 19.0 31.3 17.731 23.3 20.0 32.1 18.314 24.2 21.0 32.3 20.050 26.7 22.2 33.1 21.323 29.0 22.0 33.2 21.738 27.8	$\begin{array}{cccccc} -1 & 1.4 \\ -1 & 1.5 \\ -1 & 2.0 \\ -1 & 2.7 \\ -1 & 2.9 \\ -1 & 3.2 \\ -1 & 3.0 \\ -1 & 3.1 \\ -1 & 2.4 \\ -1 & 1.5 \\ -1 & 1.3 \end{array}$	35. 19. 34. 56. 30. 20. 21. 13. 49. 38. 94. 61.	4. 2. 4. 3. 3. 2. 5. 4. 10. 7.
Garissa - Kenya -0.5 147. 0.25 0.45 1.0 22.1 35.5 20.241 23.5 22.7 36.0 20.198 24.0 24.3 36.0 20.151 25.2 24.3 36.0 19.347 26.2 23.2 35.0 17.575 24.5 21.6 32.7 16.530 22.1 21.0 32.1 16.555 20.8 21.0 32.7 17.180 20.7 21.6 33.8 18.804 21.2 22.7 35.0 20.193 22.6 23.8 35.0 19.905 25.1 23.2 34.3 19.470 25.5	$\begin{array}{cccc} -1 & 1.3 \\ -1 & 1.6 \\ -1 & 1.9 \\ -1 & 2.6 \\ -1 & 2.5 \\ -1 & 2.9 \\ -1 & 3.2 \\ -1 & 3.0 \\ -1 & 2.5 \\ -1 & 1.9 \\ -1 & 1.0 \end{array}$	10. 6. 26. 55. 17. 5. 2. 5. 4. 22. 65. 65.	2. 1. 3. 6. 2. 1. 1. 1. 3. 7. 7.
Kericho - Kenya -0.6 2070. 0.25 0.45 1.0 11.1 26.3 22.364 12.3 11.1 26.5 23.471 12.3 11.5 26.1 22.594 13.0 12.2 24.0 17.579 14.5 11.3 23.1 18.463 14.7 11.6 22.2 18.898 13.6 10.7 21.8 16.808 13.5 10.5 22.5 16.905 13.5 10.1 23.0 18.419 13.3 10.3 23.8 17.468 13.5 10.5 24.1 17.381 13.5 11.3 23.8 20.065 13.0	$\begin{array}{cccc} -1 & 1.5 \\ -1 & 1.4 \\ -1 & 1.3 \\ -1 & 1.1 \\ -1 & 1.2 \\ -1 & 1.3 \\ -1 & 1.3 \\ -1 & 1.4 \\ -1 & 1.5 \\ -1 & 1.4 \\ -1 & 1.3 \\ -1 & 1.6 \end{array}$	48. 83. 124. 239. 183. 154. 99. 126. 117. 78. 83. 116.	5. 9. 12. 17. 15. 13. 10. 12. 11. 8. 9. 11.
Kisumu - Kenya -0.1 1146. 0.25 0.45 1.0 17.1 30.5 19.810 16.3 17.5 31.0 22.067 16.5 17.8 30.5 18.443 17.8 18.0 28.7 20.658 19.5 17.5 28.0 18.671 19.5 16.5 27.8 20.857 18.1 16.2 27.5 17.834 17.3 16.2 28.0 18.990 17.2 16.2 29.2 24.686 17.0 17.0 30.5 21.394 16.7 17.3 30.2 21.184 17.0 17.2 30.0 21.821 17.0	$\begin{array}{cccc} -1 & 1.5 \\ -1 & 1.6 \\ -1 & 1.4 \\ -1 & 1.1 \\ -1 & 0.9 \\ -1 & 1.1 \\ -1 & 1.1 \\ -1 & 1.3 \\ -1 & 1.3 \\ -1 & 1.3 \\ -1 & 1.2 \\ -1 & 1.2 \\ -1 & 1.2 \end{array}$	57. 70. 160. 195. 177. 101. 68. 96. 79. 64. 106. 105.	7. 8. 12. 18. 17. 12. 10. 12. 11. 11. 11. 10.
Kitale Airport - Kenya 1.0 1875. 0.25 0.45 1.0 10.0 27.3 21.082 12.1 10.3 27.7 21.763 12.0 11.5 27.2 21.137 13.1 12.6 26.0 19.755 15.3 12.3 24.8 19.062 16.1 11.3 24.0 17.927 15.3 11.5 22.8 16.159 15.1	-1 2.0 -1 2.0 -1 2.0 -1 2.0 -1 2.0 -1 2.0 -1 1.8 -1 1.8	30. 26. 74. 145. 156. 124. 161,	4. 3. 8. 13. 13. 12. 14.

10.6 24.7 19.345 1	15.0 -1	2.0 164. 2.0 115. 2.0 105. 2.0 82. 2.0 59.	14. 11. 11. 9. 6.
13.7 27.6 25.351 1 14.5 26.7 23.557 1	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	1.7       76.         1.5       12.         1.7       5.         1.8       6.         1.8       9.         2.0       53.	5. 6. 12. 16. 8. 2. 1. 1. 1. 1. 1. 5. 15. 12.
Mombasa Town - Kenya -4.1 16. 0.25 0.45 24.1 31.5 20.840 24.5 32.2 22.233 25.1 32.5 22.341 24.6 31.1 19.359 23.3 29.0 16.468 22.5 28.2 17.238 21.7 27.6 16.358 21.5 27.7 19.055 22.0 28.3 20.849 23.0 29.5 21.811 23.7 30.8 22.227 24.0 31.3 21.270	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	3. 2. 7. 16. 22. 11. 10. 7. 7. 9. 10. 6.
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	5 1.0 14.2 -1 13.6 -1 15.0 -1 16.0 -1	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	9. 7. 13. 17. 18. 5. 5. 5. 7. 8. 16. 11.
Simple system used for ra By observing other sites 1.If monthly rain fall is 2.For rain fall 10-100, t	of Kenya 1 s less 10 m then rain d	I used the fol: nm, rain days : days = precip.,	= 1 /10 + 1
3.For rain fall 100-120, 4.For rain fall 120-150, 5.For // // 150-170,	then //	// = preci	./10 ./10 - 1 ./10 - 2

then // // = preci./10 - 1
tehn // // = preci./10 - 2
then // // = preci./10 - 3
then, // // = preci./10 - 4
then, // // = preci./10 - 5
then, // // = preci./10 - 6
then, // // = preci./10 - 10
then, // // = preci./10 - 15 4.For fain fail 120-150, 5.For // // 150-170, 6.For // // 170-190, 7.For // // 190-200, 8.For // // 200-220, 9.For // // 220-240, 10.For // // 240-300, 11.For // // 300-350, 12.For // // >150

ц.<sup>1</sup> м.т. – м

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i.

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#### Appendix E: PS123N climate data format example Monthly:

"EAK41", -.21,37.32,1710
1,24.1,11,.08,.7,.546,8.5,.439
2,25.1,11.1,.14,.71,.585,8.5,.472
3,25.1,11.7,.47,.73,.537,7.5,.426
4,23.7,11.9,1.32,.84,.452,6,.349
5,22.8,11.2,.7,.87,.404,5.5,.31
6,21.7,10,.08,.84,.377,5.5,.289
7,20.7,9.9,.13,.82,.392,6,.301
8,21.4,10,.13,.8,.418,6,.323
9,23.9,10.3,.07,.73,.516,7,.412
10,24.3,12.2,.91,.75,.49,6.5,.389
11,22.5,12.5,1.07,.81,.435,6,.34
12,22.9,11.3,.23,.81,.411,6,.319

Converted to daily value:

"EAK41",-.21,37.32,1710 1,23.55,11.13,.14,.74,.48,7.3,.38 2,23.59,11.12,.14,.74,.48,7.4,.38 3,23.63,11.11,.13,.74,.49,7.5,.39 4,23.67,11.1,.13,.73,.49,7.6,.39 5,23.71,11.09,.12,.73,.5,7.6,.4 6,23.75,11.08,.12,.73,.5,7.7,.4 7,23.79,11.07,.11,.72,.51,7.8,.4 8,23.82,11.06,.11,.72,.51,7.9,.41 9,23.86,11.05,.1,.72,.51,8,.41 10,23.9,11.04,.1,.71,.52,8,.41 11,23.94,11.03,.09,.71,.52,8.1,.42 12,23.98,11.02,.09,.71,.53,8.2,.42 13,24.02,11.01,.08,.7,.53,8.3,.43 14,24.06,11,.08,.7,.54,8.4,.43 15,24.1,11,.07,.69,.54,8.5,.43 16,24.13,11,.08,.7,.54,8.5,.44 17,24.16,11,.08,.7,.54,8.5,.44 18,24.19,11,.08,.7,.54,8.5,.44 19,24.22,11.01,.08,.7,.55,8.5,.44 20,24.26,11.01,.08,.7,.55,8.5,.44 21,24.29,11.01,.09,.7,.55,8.5,.44 22,24.32,11.02,.09,.7,.55,8.5,.44 23,24.35,11.02,.09,.7,.55,8.5,.44 24,24.39,11.02,.09,.7,.55,8.5,.44 25,24.42,11.03,.09,.7,.55,8.5,.44 26,24.45,11.03,.1,.7,.55,8.5,.45 27,24.48,11.03,.1,.7,.56,8.5,.45 28,24.51,11.04,.1,.7,.56,8.5,.45 29,24.55,11.04,.1,.7,.56,8.5,.45 30,24.58,11.04,.1,.7,.56,8.5,.45 31,24.61,11.05,.11,.7,.56,8.5,.45 32,24.64,11.05,.11,.7,.56,8.5,.45 33,24.68,11.05,.11,.7,.56,8.5,.45 34,24.71,11.06,.11,.7,.56,8.5,.45 35,24.74,11.06,.11,.7,.57,8.5,.46 36,24.77,11.06,.12,.7,.57,8.5,.46 37,24.8,11.07,.12,.7,.57,8.5,.46 38,24.84,11.07,.12,.7,.57,8.5,.46 39,24.87,11.07,.12,.7,.57,8.5,.46 40,24.9,11.08,.12,.7,.57,8.5,.46 41,24.93,11.08,.13,.7,.57,8.5,.46 42,24.97,11.08,.13,.7,.57,8.5,.46 43,25,11.09,.13,.7,.58,8.5,.46 44,25.03,11.09,.13,.7,.58,8.5,.46 45,25.06,11.09,.13,.7,.58,8.5,.47 46,25.1,11.1,.14,.7,.58,8.5,.47 47,25.1,11.12,.15,.71,.58,8.4,.47 48,25.1,11.14,.16,.71,.58,8.4,.46 49,25.1,11.16,.17,.71,.57,8.3,.46

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62,25 63,25 64,25 65,25	.1,11 .1,11 .1,11 .1,11	44,	32,.7 34,.7 35,.7 6,.72	72,.55 72,.55 72,.55 2,.55	5,7.9, 5,7.8, 5,7.8, 7.8,	.44 .44 .44 44
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344,22.83,11.5,.37,.81,.41,6,.32	
340,22.80,11.42,.31,.81,.41,0,.32 347 22 87 11 38 28 81 41 6 32	
348,22.88,11.34,.25,.81,.41,6,.31	
349,22.89,11.3,.23,.81,.41,6,.31	
351, 22.97, 11.28, .22, .8, .41, 6.1, .32	
352,23.01,11.27,.21,.79,.42,6.2,.33 353,23.05,11.26,.21,.79,.42,6.3,.33	
354,23.09,11.25,.2,.79,.43,6.4,.33	
355,23.13,11.24,.2,.78,.43,6.4,.34	
356,23.17,11.23,.19,.78,.44,6.5,.34	
357,23.2,11.22,.19,.78,.44,6.6,.34 358,23,24,11,21,.18,.77,.45,6,7,.35	
358,23.24,11.21,.18,.77,.45,6.7,.35 359,23.28,11.2,.18,.77,.45,6.8,.35	
360,23.32,11.19,.17,.77,.45,6.8,.36	
361,23.36,11.18,.17,.76,.46,6.9,.36	
362,23.4,11.17,.16,.76,.46,7,.36 363,23.44,11.16,.16,.76,.47,7.1,.37	
364,23.48,11.15,.15,.75,.47,7.2,.37	
365,23.51,11.14,.15,.75,.48,7.2,.38	

# Calculated EO & ETO, interpolated EO. Rain fall for upper and middlelower areas also included.

		EA	K41 &	EAK42
	Ρ	Eo	ETo	Eoav
	cm/d	cm/d c	m/d c	m/d
JAN	0.08	0.55	0.44	0.52
FEB	0.14	0.59	0.47	0.57
MAR	0.47	0.54	0.43	0.48
APR	1.32	0.45	0.35	0.50
MAY	0.70	0.40	0.31	0.45
JUN	0.08	0.38	0.29	0.47
JUL	0.13	0.39	0.30	0.39
AUG	0.13	0.42	0.32	0.45
SEP	0.07	0.52	0.41	0.53
OCT	0.91	0.49	0.39	0.48
NOV	1.07	0.44	0.34	0.47
DEC	0.23	0.41	0.32	0.45
		EAK43		
JAN	0.08	0.59	0.48	0.52
FEB	0.14	0.69	0.58	0.57
MAR	0.47	0.58	0.48	0.48
APR	1.32	0.49	0.39	0.50
MAY	0.70	0.44	0.34	0.42
JUN	0.08	0.40	0.31	0.47
JUL	0.13	0.42	0.33	0.39
AUG	0.13	0.43	0.34	0.45

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			ş		
SEP	0.07	0.53	0.43	0.53	
OCT	0.91	0.52	0.42	0.48	
NOV	1.07	0.46	0.36	0.47	
DEC	0.23	0.44	0.34	0.45	
	EAK44	, EAK4	5 & EA		
JAN	0.08	0.60	0.49	0.56	
FEB	0.14	0.70	0.59	0.67	
MAR	0.47	0.61	0.49	0.56	
APR	1.32	0.50	0.40	0.53	
MAY	0.70	0.47	0.36	0.52	
JUN	0.08	0.45	0.34	0.47	
JUL	0.13	0.40	0.32	0.40	
AUG	0.13	0.43	0.33	0.52	
SEP	0.07	0.54	0.44	0.62	
OCT	0.91	0.54	0.43	0.56	
NOV	1.07	0.47	0.37	0.47	
DEC	0.23	0.47	0.37	0.52	
	EAK47			K49	
JAN	0.08	0.66	0.55	0.60	
FEB	0.17	0.68	0.56	0.67	
MAR	0.51 1.19	0.65 0.57	0.53 0.46	0.60 0.53	
APR MAY	0.40	0.57	$0.40 \\ 0.44$	0.53	
JUN	0.40	0.55	$0.44 \\ 0.41$	0.52	
JUL	0.02	$0.31 \\ 0.48$	$0.41 \\ 0.40$	0.45	
AUG	0.01	0.54	0.44	0.52	
SEP	0.02	0.62	0.52	0.62	
OCT	0.35	0.62	0.51	0.60	
NOV	1.06	0.52	0.41	0.53	
DEC	0.24	0.50	0.39	0.52	
220					
EAK50	, 51 &	EAK52			
JAN	0.08	0.66	0.55	0.60	
FEB	0.17	0.68	0.56	0.67	
MAR	0.51	0.64	0.53	0.60	
APR	1.19	0.57	0.46	0.53	
MAY	0.40	0.54	0.44	0.52	
JUN	0.02	0.51	0.41	0.47	
JUL	0.01	0.48	0.41	0.45	
AUG	0.05	0.54	0.44	0.52	
SEP	0.02	0.62	0.52	0.62	
OCT	0.35	0.61	0.51	0.60	
NOV	1.06	0.51	0.41	0.53	
DEC	0.24	0.50	0.39	0.52	

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soil dat comment each set		art wit	h an as	terisk!	3			
* line 1	- soil r	ame (ur	- . to 30 /	characte	arel			
* line 2	= sope (	conduct	ivity o	f top so	oil, cm/d	1), s0	(sorptiv:	ity,
* not us * line 3								
* pF-valu	les(log(c	m)) and	l volume	tric soi	ll moistu	ire cont	ent	
* line 4 * the con				pairs of	pF-valu	les and	the 10-1	logarithm c
EAK41 (GR 3.49		JKA) ` 3.49	)					
-1.000	0.503	1.000	0.503		0.491		0.483	2.000 0.
	0.428				0.351			6.000 0. 1.700 0.
2.000	0.543 -0.187	2.400	-2.841	2.700	0.397 -3.263		-3.684	
3.700	-4.664	4.000	-5.084	4.204	-5.370			
EAK42 (GF								
3.49 -1.000	3.32 0.501	3.49	0.501	1.300	0.489	1.491	0.481	2.000 0.
2.400	0.426	2.700	0.405	3.400	0.350	4.204	0.284	6.000 0.
0.000	0.543 -0.413	1.000	0.447	1.300	0.352	1.491		1.700 0.
	-0.413 -4.664		-2.841 -5.084		-3.263	3.000	-3.684	3.400 -4.
EAK43 (GF	ROUP5-CHU	JKA)				•		
3.49		3.49		1 200	0 495	1 401	0 477	2.000 0.
	0.497 0.423		0.497 0.401		0.485 0.347	$1.491 \\ 4.204$		
0.000	0.543	1.000	0.477	1.300	0.413	1.491	0.347	1.700 0.
	-0.108		-2.843		-3.263	3.000	-3.684	3.400 -4.
3.700 EAK44 (GF	-4.664		-5.083	4.204	-5.370			
3.49	3.32	3.49						
	0.535 0.455	1.000	0.535	1.300	0.522 0.374	1.491		2.000 0. 6.000 0.
	0.455		0.452			4.204		1.700 0
2.000	-0.195	2.400	-2.843	2.700	-3.263	3.000	-3.684	3.400 -4
3.700 EAK45 (GF			-5.083	4.204	-5.370			
2.88	5.06	2.88	3					
	0.448	1.000	0.448		0.435	1.491		2.000 0
	0.362 0.459		0.338 0.407	3.400	0.279 0.355	$4.204 \\ 1.491$		6.000 0. 1.700 0.
		2.400			-2.272		-2.693	3.400 -3
3.700	-3.673		-4.093		-4.379			
EAK46 (GF 2.88	OUP3-CHU 5.06	JKA) 2.88	, ,					
-1.000	0.445		0.445	1.300	0.431	1.491	0.421	2.000 0.
2.400	0.359	2.700	0.335	3.400	0.276	4.204	0.210	6.000 0
	0.459	1.000			0.351 -2.276	1.491	0.297 -2.693	1.700 0. 3.400 -3.
	-0.079 -3.673	4.000	-1.851 -4.093		-4.379	3.000	-2.095	5.400 -5.
EAK47 (GF	ROUP5-CHU	JKA)						
3.49 -1.000	3.32 0.408	3.49	) 0.408	1 200	0.398	1 401	0.392	2.000 0.
			0.330		0.285			6.000 0.
0.000	0.543	1.000	0.465	1.300	0.386	1.491	0.308	1.700 0.
	-0.239 -4.664		-2.841		-3.263 -5.370	3.000	-3.684	3.400 -4
EAK48 (GF			-5.084	4.204	-5.570			
2.88	$5.06 \\ 0.444$	2.88	0.444		0.430	1.491	0.421	2.000 0.

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0.000 0.459 2.000 -0.062 1.000 0.407 2.400 -1.850 1.491 0.303 3.000 -2.693 1.300 0.355 1.700 0.198 2.700 -2.272 3.400 -3.253 3.700 -3.673 4.204 -4.379 4.000 -4.093 EAK49 (GROUP5-CHUKA) 3.49 3.32 3.49 -1.000 0.499 1.000 0.499 1.300 0.487 1.491 0.479 2.000 0.451 0.425 2.700 0.403 3.400 0.349 4.204 0.283 6.000 0.152 2.400 1.000 0.425 1.300 0.308 1.491 0.191 0.000 0.543 1.700 -0.043 2.400 -2.841 2.000 -0.629 2.700 -3.263 3.000 -3.684 3.400 -4.243 3.700 -4.664 4.000 -4.770 4.204 -5.319 EAK50 (GROUP4-CHUKA) 6.59 14.90 6.59 -1.000 0.437 1.000 0.437 1.300 0.423 1.491 0.413 2.000 0.378 4.2040.1961.4910.128 2.400 0.348 2.700 0.323 1.000 0.588 3.4000.2631.3000.358 6.000 0.081 0.000 0.819 1.700 -0.332 2.400 -1.801 2.700 -2.130 3.000 -2.550 2.000 -1.483 3.400 - 3.1103.700 -3.530 4.000 -3.951 4.204 -4.236 EAK51 (GROUP4-CHUKA) 6.59 14.90 6.59  $\begin{array}{rrr} 1.300 & 0.415 \\ 3.400 & 0.258 \end{array}$ 0.371 0.429 1.000 0.429 1.491 0.405 2.000 -1.0002.700 0.317 4.204 0.192 6.000 0.079 2.400 0.341 1.000 0.597 1.300 0.376 0.000 0.819 1.491 0.154 1.700 -0.288 2.000 -1.396 2.700 -2.129 2.400 -1.708 3.000 -2.551 3.400 -3.110 3.700 -3.530 4.000 -3.951 4.204 -4.236 EAK52 (GROUP3-CHUKA) 5.06 2.88 2.88 1.000 0.440 2.700 0.331 1.300 0.426 3.400 0.273 1.491 0.417 4.204 0.207 2.000 0.384 6.000 0.091 -1.000 0.440 2.400 0.355 1.000 0.168 1.491 -0.413 1.700 -0.995 0.000 0.459 1.300 -0.123 3.000 -2.693 2.000 -1.293 2.400 -1.851 2.700 -2.272 3.400 -3.253 3.700 -3.673 4.000 -4.093 4.204 -4.379 EAK53 (GROUP4-CHUKA) 6.59 6.59 14.90 1.000 0.455 -1.0000.455 1.300 0.441 1.491 0.430 2.000 0.394 2.400 3.400 0.274 1.300 0.298 4.2040.2041.4910.037 0.362 2.700 0.336 6.000 0.084 1.000 0.558 0.000 0.819 1.700 - 0.4842.400 -1.150 3.700 -3.530 2.700 -1.708 4.000 -3.951 2.700 -2.129 3.000 -2.551 3.400 -3.110 4.204 -4.236 SiClLo (Yermosol Urumqi CHA) 4.00 0.00 4.00 1.000 0.497 1.500 0.467 2.000 0.397 2.300 0.332 -1.0000.522 2.700 0.239 3.400 0.143 4.200 0.119 0.000 0.000 0.000 0.000 Clay (Vertisol Trivan INDIA) 3.00 0.00 3.00 2.500 0.351 -1.0000.410 4.200 0.146 0.000 0.000 0.000 0.000 SiLo (Alfisol Peshawar PAK) 2.00 0.00 2.00 2.500 0.264 0.000 0.000 -1.0000.480 4.200 0.052 0.000 0.000 SiLo (Aridisol Lahore PAK) 5.00 0.00 5.00 0.350 2.500 0.211 -1.000 4.200 0.073 0.000 0.000 0.000 0.000 \* SiCl (Acrisol Bamako MALI) 2.00 0.00 2.00 -1.000 0.480 2.000 0.360 2.300 0.340 2.700 0.300 0.000 0.000 0.000 0.000 SiLo (Xerosol Kogoni MALI) 15.00 0.00 15.00 1.000 0.360 1.500 0.340 2.000 0.150 -1.0000.370 2.300 0.100 3.400 0.050 4.200 0.040 2.700 0.060 0.000 0.000 0.000 0.000

Sand (Arenosol Gao MALI) 0.00 20.00 20.00 -1.000 0.310 1.000 0.310 1.500 0.250 2.000 0.070 2.300 0.050 2.700 0.050 3.400 0.020 4.200 0.020 0.000 0.000 0.000 0.000 Clay (Ferralsol Lichinga MOC) 15.00 0.00 25.00 -1.000 0.508 1.000 0.502 1.500 0.437 2.000 0.353 2.300 0.322 0.301 2.700 3.400 0.254 4.200 0.242 0.000 0.000 0.000 0.000 Clay (Nitosol Unango MOC) 0.00 10.00 6.00 0.537 1.000 0.516 1.500 0.407 -1.0002.000 0.325 2.300 0.299 2.700 0.283 3.400 0.266 4.200 0.254 0.000 0.000 0.000 0.000 Sand (Planosol Limpopo MOC) 5.00 0.00 5.00 0.406 1.000 0.403 1.500 0.377 2.000 0.333 -1.000 2.300 0.313 3.400 0.263 4.200 0.235 2.700 0.297 0.000 0.000 0.000 0.000 Sand(Acrisol Rivers NIG) 10.00 0.00 10.00 1.500 0.244 2.000 0.145 -1.000 0.331 1.000 0.328 2.300 0.127 3.400 0.063 4.200 0.060 2.700 0.120 0.000 0.000 0.000 0.000 NG18 (Nigeria) 0.00 10.00 10.00 1.000 0.336 1.500 0.302 2.000 0.285 0.354 2.300 0.269 -1.000 3.400 0.198 4.200 0.177 2.700 0.261 0.000 0.000 0.000 0.000 Cuba soil 3.00 0.00 3.00 0.498 1.000 0.498 1.500 0.485 2.000 0.463 -1.0002.300 0.455 0.437 2.700 3.400 0.419 4.200 0.408 0.000 0.000 0.000 0.000 Clay (Nitosol Napo ECU) 6.00 0.00 6.00 -1.000 0.580 1.000 0.560 1.500 0.510 2.000 0.470 2.700 0.420 4.200 0.320 3.400 0.350 0.000 0.000 0.000 0.000 SiCl (Andosol Parcela CR) 20.00 20.00 0.00 -1.0000.620 1.000 0.599 1.500 0.531 2.000 0.465 2.300 0.451 0.425 3.400 0.384 4.200 0.371 2.700 0.000 0.000 0.000 0.000 Clay (Inceptisol Tur4 CR) 10.00 10.00 0.00 -1.000 0.576 2.000 0.465 2.500 0.439 2.700 0.417 3.000 0.408 3.700 0.375 4.000 0.375 4.200 0.287 0.000 0.000 0.000 0.000 Clay (Inceptisol Tur25 CR) 10.00 0.00 10.00 2.000 0.494 2.500 0.446 2.700 0.423 3.000 0.421 -1.000 0.649 0.397 4.000 0.388 4.200 0.385 3.700 0.000 0.000 0.000 0.000

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PS123N SOIL DATA
Each line represents;
1. SMO & GAMA
2. KPSI, KO, ALPHA & AK
3. SO & KTr
4. Dummy value
"eak41 group 5"
.519,.0064
190,3.49,.0186,3.28
3.315,2.33
0
"eak42 group 5" .518,.0064
190,3.49,.0211,3.28
3.315,2.33
0
"eak43 group 5"
.516,.0064
190,3.49,.0103,3.28
3.315,2.33
0
"eak44 group 5"
.553,.0064
190,3.49,.0273,3.28
                            ŗ.,
3.315,2.33
0
"eak45 group 3"
.469,.0085
175,2.88,.0107,32.1
5.065,1.69
0
"eak46 group 3"
.465,.0085
175,2.88,.0117,32.1
5.065,1.69
0
"eak47 group 5"
.422,.0064
190,3.49,.0264,3.28
3.315,2.33
0
"eak48 group 3"
.464,.0085
175,2.88,.0101,32.1
5.065,1.69
0
"eak49 group 5"
.516,.0064
190,3.49,.0258,3.28
3.315,2.33
0
"eak50 group 4"
.459,.0091
250,6.59,.0597,44.6
14.9,4.415
0
"eak51 group 4"
.558,.0091
250,6.59,.0674,44.6
14.9,4.415
0
"eak52 group 3"
.46,.0085
175,2.88,.0472,32.1
5.065,1.69
0
```

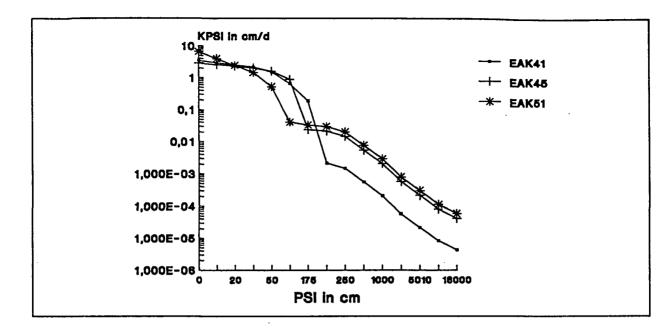
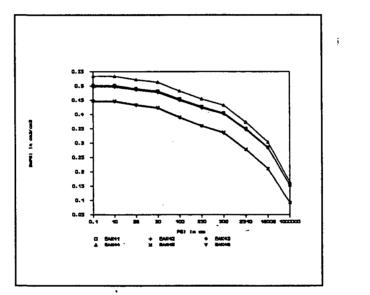


Figure 1. KPSI-PSI relations of clay family (EAK41), silty clay family (EAK45), and sandy clay family (EAk51), as used for the analysis.



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Figure 2 SMPSI-PSI relations as used for analysis.

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Appendix G: Soil profile descriptions

ISRIC monolith number	er: EAK41	country:	KENYA		so	IL DESC	RIPTION	print	date (	(m)/dd/)	Y): 02/	10/93
(other) Dia	/UNESCO,1974: USDA,1975: tic horizons: gn. criteria: assification:	: dystropept : umbric, ar :	oxic, very f	class.) ine, isot	thermic							
LOCATION LUTHOR(S) - DATE (IN			Rukuriri sch 0 21 15 S	Longitu		32 30	E	Altitu	ie: 171	0 (m.a.s	5.1.)	
POSITION OF SITE	/Aspect/Form	: 40 % : lower slop :	ey, mount. fo concave e	Patte	em: Dob	ue i	IY: DOLE	tainou	5 ·			
SURFACE CRAR.	Rock outcrop Cracking				iness: n ing: nil				: nil		lkali:	
SLOPE PROCESSES	Soil erosion	: nil			<u>ж</u>	gradat.	lon: al	L 		\$	table s	lope
PAPENT MATERIAL 1		: colluvium		Deriv	ved from	I: Volci	anic bro	eccia		T	exture:	
2		: residual m : Ht. Kenya		Deriv	ved from	I: Volca	anic bru		pth bou	-	exture: /2 (cm	):
ETTECTIVE SOIL DEPT	1 02	: 110										
VATER TABLE DRAINAGE PERICABILITY FLOODING NOISTURE CONDITIONS	frequency	: well : moderate : mil	cm moist li		Re		level:1	le laye				
LAND USE VEGETATION Land use/vegeta	Structure	: seni decio	tural vegetat iucus forest exploitation			tatus:	cut ove	r				. <u></u>
CLDOATE Station: KEVOTE PRI Station: RUYINUES Station: ENGU PROV.	IH. SCHOOL -	0 25 S	/37 36 E;147	4 (m.a.s. 8 (m.a.s.	1); 8	ton S ton SS	from 8 from	site. site.	Releva	nce: go nce: go nce: go	od	-
KEVOTE PRIM. SCH	Period	Jan Feb	Nar Apr	: Nay	Jun	Jul	λug	Sep	Oct	Nov	Dec	Innual
	ma 30	27 31	120 383	264	37	48	67	46	186	268	84	1559
	18 01.L	25 40	146 396	218	25	41	42	21	284	321	13	1547
	an 33	22 25	91 301		28	45	43	42	147	203	59	1230
T min		26.4 29.3 13.6 13.6	27.9 25.8 14.9 15.8		22.8 14.4	21.4 13.1	21.7 13.0	24.4 13.3	25.9 14.2	24.2 14.6	25.7 13.6	25.0 14.1
: (	7.5YR 3.0/4. slightly stic	ty slightly tin clay cut	ay,slightly g plastic frla ans ; many ve CL); abrupt s	ble; comm ry fine p	con fine ores; m	distin any ver	ct shar	n ( 7.5	VR 2 N/	(0 0) <del></del>	ttlee.	
5	slightly stic	xy slightly	very coarse w plastic very few fine roo	friable:	contin	uous th	in clay	cutans	• BARN	VOTY 6	ine por dary to	ies;
s L	lightly stic proken thin c	xy slightly lay cutans ;	ay; very coar plastic very ; many very f	friable; ine pores	few fin ; common	ne dist a verv	inct sh	arn ( 7	ŚVD 2	0/0 nî	ant tion	;
	OU CATCALEOU	15 (by 10% BC	L); clear sm	ooth bours	dary to	_					~,	

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11o		ICA/ 11	VERN	CHLOR	51EC	KNOL	HALL NI	X* QUAR FE	LD GIBB	GOET	HEEM.	FEO	λlo	SIO	FEd	лıd	ស្ដ	p Al	lφ	
1 2 3 4	2 2 1 2					5 5 5 5	3	2 2 1. 1	3 3 3 3	3 3 3 3		1.0 0.9 1.1	0.5 0.6 0.5	0.1 0.0 0.1 0.1	5.2 4.9 5.4	0.8 0.9 0.7	-1.0 -1.0 -1.0	0 -1 0 -1 0 -1	.0 .0 .0	
5	1			uaber		5	~	2 277: KENTA	2	3				0.1					.0 1d/11): 02/1	1/93
-		FICK	Dia Dia ther)	E110/U	NESCO USDA c hor . cri	,1974: ,1975: izons: teria:	humic oxic, umbric	cambisol ( , fine clay ;, cambic	Tent. c											
	CATI JTHOR		- DAT	E (100).	 77)	:		of Rurukin xde:021			gitude:						171	5 (1	.a.s.1.)	
PE SI PC SI	ntsio Lope Isiti Icro Irfa	CRAP CON O RELI Z CE	F SIT EF	NIT ient// E Ro	ck ou Cra	/Form Kind tcrop cking	:3`t :open.o	valley, zo co iepression	unt. fo	P	ge attern: tonine: ealing:	: none ss: non : nil	ie i	ion: n	Si	nous	i1		Alkali: ni stable slo	
P	NREN	KAT	ERIAL	1			: collu	viun		, D	erived	fron:	volc	anic b	reccia				Texture:	
				2	Re		: alluv : Nt Ke	ium nya Series		D	erived	fron:	volc	anic b	recci		bou	ndar	Texture: 7 1/2 (cm):	
E	m	TIVE	SOIL	DEPTH		 CB	: 60													
D	ATER RAIN ERME	NGE			Depti			ately will		el: O	e.	st. lon Ho :		permea					ater table	
D P	RAIN	AGE ABILI	ntr nber: >2		1000	ana 	: moder : moder alytical	ately well ate 1 data TOT 50 2	Quissir 		ue = -) Butk	Ho:	slow	ISRIC	ptint	ayer(: date	s) : 		02/10/93	
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VEGETATION Structure:

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Land use/vegetation remarks: also taro/yam, bananas and sugarcane

CLINATE		Koep	pea: Aa				Soi	l Moist	ure Regi	ne: us	tic				
Station: DOBU F	PROV. NG	RI.COLL.	0	31 S	37 16	E;1494	(m.a.s.	.1); 1	8 baiŠi	i from	site.	Releva	ance: q	boc	
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Precipitation RUVENJES		30	27	31	120	383	264	37	48	67	46	185	258	84	1559
Precipitation	m	18	25	40	146	396	218	25	41	42	21	284	321	73	1547

PROFILE DESCRIPTION

Aul 0- 5cm 2.5YR 3.0/2.0 moist; clay; medium moderate subangular blocky into granular; slightly sticky slightly plastic friable; many coarse promiment diffuse (2.5YR 2.0/0.0) mottles; patchy thin clay cutans; many very fine pores; many very fine roots between peds and few fine roots between peds; clear smooth boundary to

- Au2 5- 60cm 2.5YR 3.0/2.0 moist; clay; coarse strong subangular blocky into granular; slightly sticky slightly plastic friable; patchy thin clay cutans; many very fine pores; many very fine roots between peds and few fine roots between peds; gradual irregular boundary to
- Bg 60- 80cm 2.5YR 4.0/2.0 moist; clay; very coarse strong subangular blocky; slightly sticky slightly plastic firm; many fine distinct diffuse ( 2.5YR 5.0/8.0) mottles; broken thin clay cutans; many very fine pores; many very fine roots and few fine roots between peds; clear smooth boundary to
- Abr 80-110cm 5.07 4.0/1.0 moist; clay; very coarse strong subangular blocky; slightly sticky slightly plastic firm; common fine prominent clear ( 5.07R 6.0/8.0) mottles; many very fine pores; many very fine roots between peds and few fine roots between peds; clear smooth boundary to
- Bbrl 110-120cm 10.0YR 4.0/3.0 moist; ; very coarse strong subangular blocky; slightly sticky slightly plastic firm; few fine prominent clear ( 5.0YR 6.0/8.0) mottles; many very fine pores; many very fine roots between peds; clear smooth boundary to

Bbr2 120-140cm	10.0YR 3.0/3.0 moist; clay; very coarse strong subangular blocky; slightly sticky slightly plastic	
	firm; many very fine pores;	

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1 0 35 -1 0 0 2 35 80 -1 0 0 3 80 130 -1 0 0 4 130 160 -1 3 4	1 1 1 3 1 9 87 -1 - 0 1 1 2 0 6 91 -1 - 0 1 1 3 0 9 88 -1 - 3 2 1 13 3 14 69 -1 -	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
H20 KC1 CaCO ORG- N %	EXCE CAT EXCE AC.  C Ca Ng X Na sua H+A1 A1 so meq /100g	2C   ECEC BASE AL EC 2.5 Ll clay OrgC SAT & SAT & mS/cm 	i I
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6.4 3.1 1.2 0.0 10.7 -1.0 -1.0 13 3.9 2.7 0.6 0.0 7.2 -1.0 -1.0 11 3.9 3.3 0.1 0.0 7.3 -1.0 -1.0 8 1.9 1.6 0.1 0.0 3.6 -1.0 -1.0 7	.0       15       6       10.7       82       -1       -1.00         .0       12       3       7.2       65       -1       -1.00         .9       10       2       7.3       82       -1       -1.00         .6       11       1       3.6       47       -1       -1.00	
ELEMENTAL CONFOSITION OF TO	TAL SOIL (in weight %) AND HOLAR RATIO	<u>.</u>	
No Si02 A1203 Fe203 CaO	NgO K2O Na2O TIO2 KmO2 P2O5 IG LO	A. S102/ S102/ S102/ N1203/ SS N1203 Fe203 R203 Fe203	
2 -1.0 -1.0 -1.0 -1.00 - 3 -1.0 -1.0 -1.0 -1.00 -	-1.00 -1.00 -1.00 -1.00 -1.00 -1.00 -1 -1.00 -1.00 -1.00 -1.00 -1.00 -1 -1.00 -1.00 -1.00 -1.00 -1.00 -1 -1.00 -1.00 -1.00 -1.00 -1.00 -1.00 -1	.0 -1.0 -1.0 -1.0 -1.0 .0 -1.0 -1.0 -1.0 -1.0	
CLAY NINERALOGY < 1 very w	eak, 2 weak, 3 medium, 4 strong, 5 ver	r strong > EXTRACT. Fe Al Si	
No NICA/ VERN CELOR SHEC : ILL	KNOL HALL NIX* QUAR FELD GIBB GOET HEM	FEO NLO SIO FEÀ NLÀ FEP NLA	3
1 2	6 2 3 5 7 1		
3	5 2 1 3 5 2 2 3	0.3 0.3 0.1 5.0 0.5 -1.0 -1.0 0.3 0.3 0.1 5.1 0.4 -1.0 -1.0 0.2 0.2 0.1 5.1 0.5 -1.0 -1.0 0.2 0.2 0.1 7.8 0.9 -1.0 -1.0	
		SOIL DESCRIPTION print date (mm/do	
CLASSIFICATION FNO/UNESCO,	1974: orthic acrisol (Tent. class.)		
		otheratic	
		e: 37 37 25 E Altitude: 1330 (m.a.	.s.1.)
AUTHOR(S) - DATE (mm.yy) 	: Kuyper : valley	- 7.85 Topography: hilly	
PHYSICCRAPHIC UNIT SLOPE Gradient/Aspect/	: major valley, mount. footridge	Topography: milly	
POSITION OF SITE	: open depression	F11: DOGE	
SURFACE CHAR. Rock out	crop: none Stoni	ness: none ng: nil Salt: nil	Alkali: nil
	sion: ail	Aggradation: nil	stable slope
PARENT HATEBIAL 1		ed from: basic volcanic breccia ed from: basic volcanic breccia	Texture:
	arks: Phonolite/lahar/ash	Depth-boundary	
EFFECTIVE SOIL DEPTH	cm : 80		
DRAINAGE	cm : 105 est.highest level: 60 : moderately well	est. lowest level:140 Kind: apparent	
PERMEABILITY FLOODING frequencies NOISTURE CONDITIONS PROFILE	: moderate ency: ; :0 - 60 cm dry 60 - 105 cm	No slow permeable layer(s) Run-off: mediu moist 105 - 200 cm wet	a
	: low level arable farming, banana		

E

Characterization of the state

Shifting A. and J. Tend and a second second

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	UTZ				Ko	eppen							ure Regis							
			tenjes Nu pro		1.006								ica V ica Svi					ce:g ce:m	ood oderate	
					Perio	i j	an	Feb	Mar	λpr	Кау	Jun	Jui	λug	Sep	œ	t	llov	Dec	Annual
Te		tatio	n AGRI.	m m	18		25	40	146	396	218	25	41	42	21	28	4	321	73	1547
	ipi (	tatio		na C	33 11		22 .4	25 29.3	91 27.9	301 25.8	224 24.0	28 22.8	45 21.4	43 21.7	42 24.4	14 25.1		203 24.2	59 25.7	1230 25.0
		-		c	n			13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.3		14.6	13.6	14.1
RO	ΠĽ	DESC	RIPTI	OK									-							
•		0- 2	20cm	into soft	very ; com	fine son v	mode ery f	rate s	subangu	lar blo	cty; sl	ightly s	pedium sticky sl and few	lightly	plast!				2	
st	:	20- 6	50cm	into slig and	fine htly   few f	to v hard; ine r	ery f pato oots;	ine m hy thi	oderate in clay medium	subang cutang	ular bl ; many	ocky; sl very fi	nedium lightly s ine pores liferous	sticky s; com	slight. non ver	ly pl	asti	c ver	y friab	le
Btg	l	60-10	)5 <b>ca</b>	slig dist	htly : inct	stick clear	y sll ( 2.	ghtly SYR 2.	plasti .0/0.0)	c very	friable s; brok	slight) en thin	irate suit ly hard; clay cui mooth bo	many i tans ;	line common		fin	e por	<b>es</b> ;	
3g	16	05-14	1008										oderate boundarj		ar bloc	ŋ;				
ri	14	40-10	5 <b>0ca</b>					st;; ury to	;	fine j	orcainen	t sharp	( 7.5YR	4.0/4	.0) mot	Lles;				
~	•																			
Cr2	10	60-11	8503	5.0	¥ 5.0	/1.0	moist		; abru	ot smool	th bound	ary to								
(172 (173		60-11 85-21									th bound y bounda	•								
	1		10 <b>cm</b>	10.0	YR 4.	0/1.0	nois		; abri			•					- <u>.</u>			
273 274	11	85-21 00-2:	10 <b>cm</b>	10.0 5.0	YR 4. G 5.0	0/1.0 /2.0	nois noist	st;;	; abru ;	ipt wavy		ოკი		ISRI	C print	a date	•		02/10/5	93
2r3 2r4	11	85-21 00-2:	nber: >2	10.0 5.0 EAK40 2000	YR 4. G 5.0	0/1.0 /2.0 a:	moist maist	ical d	; abri ; lata	ipt wavy	ing valu	ოკი						4.2	02/10/5	23
2r3 2r4 	11 22 colit TOP 0	85-21 00-23 th pu BOT	00cm 10cm mber: >2 .ma -1	10.0 5.0 EAK40 2000 1000 0	YR 4. G 5.0 5 1000 500 0	0/1.0 /2.0 a: 500 250	noisi noisi nalyt 250 1 100	st;; ical d 00 K 50	; abru ; lata 0T 50 20 7 3	<pre>cmiss 20 &lt;2 2 um 14 75</pre>	ing valu DISP	ry to ue = -1> BULK DENS -1.00	pF 0.0 1. -1 -	.0 1.5 ·1 -1	2.0 2.3	2.7	 3.4 -1	-1	02/10/S	23
2r3 2r4 100 1 2 3	11 20 0011tt TOP 0 20 60	85-21 00-2: th nu BOT 20 60 105	00cm 10cm mber: 22 m -1 -1 -1 -1	10.0 5.0 EAK40 2000 1000 0 0 0	YR 4. G 5.0 5 1000 500 0 0 0	0/1.0 /2.0 	noist noist 250 1 100 3 2 2	ical d 00 TC 50 3 2 2	; abru ; lata 0T 50 20 7 3 5 3 5 3	cniss 20 <2 2 un 14 75 16 76 17 75	DISP	ry to ue = -1> BULK DENS -1.00 -1.00 -1.00	pF 0.0 1. -1 - -1 - -1 -	 0 1.5 -1 -1 -1 -1 -1 -1	-1 -1 -1 -1 -1 -1 -1 -1	-1 -1 -1 -1		-1 -1 -1	02/10/9	33
2r3 2r4 100 100 12 3 4	1: 2: molit TOP 0 20	85-21 00-2: th nu BOT 20 60 105 140	00cm 10cm mber: 22 m -1 -1 -1 -1 -1 -1	10.0 5.0 EAK40 2000 1000 0 0 0	YR 4. G 5.0 5 1000 500 0 0 0 1	0/1.0 /2.0 aa 500 250	noist noist 250 1 100 3 2 2	ical d 00 T 3 2 2 2	; abru ; lata 7 50 20 7 3 5 3 9 6	cniss 20 <2 2 un 14 75 16 76 17 75	bounda	BULK DENS -1.00 -1.00 -1.00 -1.00	pf 0.0 1. -1 - -1 -	 0 1.5 -1 -1 -1 -1 -1 -1 -1 -1	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1	 2.7 -1 -1 -1 -1		-1 -1 -1 -1	02/10/9	33
2r3 2r4 100 100 12 3 4	11 22 colitt TOP 0 20 60 105	85-21 00-2: th nu BOT 20 60 105 140	00cm 10cm mber: 22 m -1 -1 -1 -1 -1 -1	10.0 5.0 EAK40 2000 1000 0 0 0 0 0	YR 4. G 5.0 5 1000 500 0 0 0 1	0/1.0 /2.0 250 1 1 1 250	nois noist naiyt 250 1 100 3 2 2 4	ical d 00 T 3 2 2 2	; abru ; lata 77 50 20 7 3 5 3 9 6	20 <2 2 uni 14 75 16 76 17 75 17 68	DISP	BULK DENS -1.00 -1.00 -1.00 -1.00	pF 0.0 1. -1 -1 -1 -1	 0 1.5 -1 -1 -1 -1 -1 -1 -1 -1	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1	 2.7 -1 -1 -1 -1		-1 -1 -1 -1	02/10/5	33
1 2 3 4 5	11 20 50011tt TOP 0 20 500 105 140	85-21 00-2: th nu BOT 20 60 105 140 160	00cm 10cm >2 nm -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	10.0 5.0 2000 1000 0 0 0 0 0 0 0 0 0 0 0 0 0 0	YR 4. G 5.0 5 1000 500 0 0 0 1 0 HAT.	0/1.0 /2.0 500 250 1 1 2 1 2 2 50 250	250 1 100 3 2 4 4 4 CAT. Kg	st;; ical d 00 TC 50 3 2 2 2 4 1	; abru ; lata 77 50 20 7 3 5 3 5 3 9 6 10 4 	caiss 20 2 2 14 75 16 76 17 75 17 68 14 73   50 Sua B <sup>4</sup>	DISP	ry to = -1> BULK DENS -1.00 -1.0	pF 0.0 1. -1 -1 -1 -1	 0 1.5 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1			-1 -1 -1 -1 -1		93
2r3 2r4  100 1 2 3 4 5  100 1 2 3 4 5  100 1 2 3 4 5  100 1 2 3 4 5  100 1 2 3 4 5  100 100 100 100 100 100 10	11 22 0011tt TOP 0 20 60 105 140 . pH- H2C 5.6	85-21 00-2: 	00cm 10cm mber: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	10.0 5.0 2000 1000 0 0 0 0 0 0 0 0 0 0 0 0 0 0	YR 4. G 5.0 5 1000 500 0 0 0 1 0 HAT. R 3 0.2	0/1.0 /2.0 250 1 1 2 250 250 250 250 250 250 250 250 250 2	250 1 250 1 250 1 100 3 2 4 4 CAT. Hg  2.4	ical d 00 TC 3 2 2 2 4 1 	; abru; ; lata 77 50 20 7 3 5 3 9 6 0 4  Na 0.0	coiss 20 <2 coiss 20 <2 coiss 14 75 17 68 14 73 14 73 14 73 17 68 18 73 18 73 18 75 17 68 18 75 18 75 19 76 19 76 19 77 19 76 19 77 19 76 19 77 19 77 10 77 10 77 10 77 10 77 10 76 10 77 10 77 10 10 77 100	DISP -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	ry to = -1:00	pF 0.0 1. -1 -1 -1 -1 -1 -1  1  1 1 1 1 1 1 1 1 1 1 1 1 1 1         -	-1 -	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1		-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	-1 -1 -1 -1 20 2.9 as/cs	5	33
1 2 3 4 5 1 2 3	11 22 collit TOP 0 20 605 140 . pH- H2C 5.6 5.7	85-21 00-2: th pu BOT 20 60 105 140 160 	Docm 10cm mber: >22 ma -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	10.0 5.0 2000 1000 0 0 0 0 0 0 0 0 0 0 0 0 0 0	YR 4. G 5.0 5 1000 500 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0	0/1.0 /2.0 /2.0 250 1 1 1 2 250 1 1 1 2 1 1 2 1 1 2 5.4 5.4 5.2 3.7	250 1 250 1 100 3 2 4 4 CAT. Ng 2.4 2.4 2.4 2.4 2.4 2.4 2.4 2.4	ical d ical d 00 TC 50 3 2 2 2 4 1 	; abru; ; // 50 20 7 3 5 3 5 3 5 3 9 6 0.0 4 	(miss) 20 C2 um 14 75 16 76 17 75 14 73   20 5un 84   20 8.4 -1 7.9 -1 7.0 -1	DISP -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	ry to <u>100</u> = -1) BULK DENS -1.00	pf 0.0 1. -1 - -1 - -1 - -1 - -1 - -1 - -1 - -	 0 1.5 -1	-1 -		-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -	-1 -1 -1 -1 EC 2.9 ES/C	5	93

ELEMENTAL COMPOSITION OF TOTAL SOIL (in weight 1) AND MOLAR RATIOS

No	\$i02	A1203	Fe203	CaO	HgO	<b>X2</b> 0	Ha20	tio2	HinO2	P205		Si02/ A1203			
1	-1.0	-1.0	-1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.0	-1.0	-1.0	-1.0	-1.0
2	-1.0	-1.0	-1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.0	-1.0	-1.0	-1.0	-1.0
3	-1.0	-1.0	-1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.0	-1.0	-1.0	-1.0	-1.0
4	-1.0	-1.0	-1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.0	-1.0	-1.0	-1.0	-1.0
5	-1.0	-1.0	-1.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.0	-1.0	-1.0	-1.0	-1.0

ILL													
	5	2	2	· 2	3		0.8 0.	.3 0.1	4.9	0.5	-1.0 -1.	0	
2	5	-	1	2	3			.4 0.1			-1.0 -1.		
3	5	-	2	2	3		1.3 0.	.3 0.1			-1.0 -1. -1.0 -1.		
5	6	2	2		3			.3 0.1			-1.0 -1.		
ISRIC monolith	number: EAK47	countr	y: KENTA				SOIL DE	SCRIPTI	ON pr	int da	te (m/d	d/77):	02/10/93
LASSIFICATION				•		•							
Dia	gnostic horiz	975: haplohu ons: umbric.		1 1106	, 15001	eraic							
(other)	Diagn. crite	ría:											
Local	l classificat	los: ferralo	chronic	Acr.									
LOCATION		: 0.5km S : Latitud					n the ro 37 42 (				145 (m.a	e 1 )	
AUTHOR(S) - DAT	E (##1.77)	: Kuyper	e: u <i>21</i>	055	loog	- :			ALUU	UUE: 1	143 (m.a	.5.1. j	
GENERAL LANDFORM	4	: plateau					Topogra	iphy: fl	at or a	almost	flat		
PETSIOGRAPHIC U		: gently					-						
SLOPE Gradi POSITION OF SIT	ieat/Aspect/Fo E	crest	1	straigh	L								
ALCRO RELIEF	ĸ	íod:			• -	ttern: i							
SURFACE CHAR.	Rock outc	rop: none ing: nil				oniness aliness			e-1	1+!!	1	Alkali	
slope processes					26	aling: 1		tion: n		it: ni)	•	stable	
PARENT NATERIAL	1	: residua	l materia	1	De	rived f	rom: bas	sic volc	anic b	reccia		Textur	 P:
Veati		ree: rks: Phonoli	te/lahar		Res	sistano	e: moder	rate		•			
EFFECTIVE SOIL	DEPTH	cma: 90											
VATER TABLE	Depth									tind• r	n vater	table of	hearvar
DRAINAGE	Depth	: well								Kind: r	10 water	table of	bserved
DEAINAGE PERCEABILITY	·	: well : moderat					No slow	e permea	ble la	ver(s)			bserved
DRAINAGE PERCABILITY FLOODING	freque	: well : moderat ncy: nil					No slow	e permea	ble la	ver(s)	no water f: mediu		bserved
DRAINAGE PERCABILITY FLOODING	freque	: well : moderat ncy: nil		 1			Ho slow	e permea	ble la	ver(s)			bserved
VATER TABLE DEALINGE PERICABILITY FLOODING NOISTURE CONDIT.	freque	: well : moderat ncy: nil		,			Ho slow	e permea	ble la	ver(s)			bserved
DRAINAGE PERCEABILITY FLOODING	freque	: well : moderat ncy: nil		,			Ho slow	<i>i permea</i>	ble la	ver(s)			bserved
DRAINAGE PERICABILITY FLOODING HOISTURE CONDIT.	freque IONS PROFILE	: well : moderat ncy: nil : 0 - 1 : low leve	50 cæ dri		, maize	e, , ,	No slov	e permez	ble la	ver(s)			bserved
DRAINAGE PERICABILITY FLOODING HOISTURE CONDIT.	freque IONS PROFILE Structu	: well : moderat ncy: nii : 0 - 1 : 0 - 1 : low leve re:	50 cm dri I arable	farming			No slov	n permea	ble la	ver(s)			bserved
DEALHAGE PEREABILITY FLOODING NOISTURE CONDIT. AND USE ECETATION Land USE/Vege	freque IONS PROFILE Structur Structur	: well : moderat ncy: nii : 0 - 1 : 0 - 1 : low leve re:	50 cm dri I arable	farming	ertilize	ers	No slov	- -	ble la	ver(s)			bserved
DEALINAGE PERSCABILITY FLOODING NOISTURE CONDIT. NOI USE COETATION Land USE/Vege LIDATE Lation: KABORDO	freque IONS PROFILE Structur Itation remark Koep RI/KIRITIRI	: well : moderat mcy: nii : 0 - 1 : low leve re: cs: mango, b pen: Am 00 42	50 cm dr arable ataat, us	farming e of fe E;1143	ertiliza Soil (m.a.s.	ers 1 Hoist .1); Z	ure Regi 3 km S	ine: ust from	ble lay	yer(s) Run-ofi Relev	f: mediu	a oderate	
DEALINAGE PERGEABILITY FLOODING NOISTURE CONDIT: NOI USE COETATION Land USE/Vege LINATE Lation: KABONDON	freque IONS PROFILE Structuu station remark Koep RI/KIRITIRI SORA	: well : moderat ncy: nil : 0 - 1 : low leve re: cs: mango, b pen: Am 0 42 0 28	50 cm dr 1 arable ataat, us 5/37 40 5/37 43	farming e of fe E;1143 E;1265	Soil (m.a.s. (m.a.s.	ers 1 Hoistu .1); 2 .1); 3	ure Regi 3 km S km 25	une:ust from Σfrom	ble la l l ic site. site.	ver(s) Rum-Off Relev Relev	f: mediu vance: m vance: v	oderate ery goo	4
DEALNAGE PERCABILITY FLOODING NOISTURE CONDIT. AND USE ECETATION Land USE/vege LIDATE tation: KANYUAG ELECHTORI / KIRLY	freque IONS PROFILE Structur etation remark RI/KIRITIRI SORA Period	: well : moderat ncy: nii : 0 - 1 : low leve re: cs: mango, b pen: Am 0 42 0 28 Jan Feb	50 cm dr i arable ataat, us 5/37 40 5/37 43 Kar	farming e of fe E;1143 E;1265 Apr	Soil (m.a.s. (m.a.s. May	ers 1 Hoistu .1); 2 .1); 3 Jun	ure Regi 3 ka S ka 25 Jul	une:ust froa 52 froa Aug	ble la ic site. site. Sep	yer(s) Rum-off Relev Relev Oct	f: mediu vance: m vance: v Hov	oderate ery goo Dec i	d Annual
DEALNAGE PERGABILITY FLOODING NOISTURE CONDIT: NOISTURE CONDIT: NOISTURE CONDIT: NOISTURE CONDIT: NOISTURE CONDIT: LINATE LAIN USE LINATE LAIN USE/VEGE LINATE LAIN SANGUE LINATE LAIN SANGUE LAIN	freque IONS PROFILE Structur station remark Koepp RI/KIRITIRI SORA Period FIRI 35	: well : moderat ncy: nii : 0 - 1 : low leve re: cs: mango, b pen: Am 0 42 0 42\\_0	50 cm dr 1 arable ataat, us 5/37 40 5/37 43 Kar 121	farming e of fe E;1143 E;1265 Apr 227	Soil (m.a.s. (m.a.s. Nay 68	ers 1 Hoistu .1); 2: .1); 3 Jun 4	ure Regi 3 km 25 km 25 Jul 2	une: ust from SE from Aug 5	ble la ic site. site. Sep 7	yer(s) Rum-off Relev Relev Relev Oct 75	f: mediu Vance: m vance: v Kov 209	oderate ery goo Dec i 91	d Annual 849
DEALWAGE PERGABILITY FLOODING HOISTURE CONDIT UND USE CETATION Land USE/Vege LINATE Lation: KARONDON tation: KARONDON FABORDONI/KIRM recipitation max	freque IONS PROFILE Structuu station remark Koepy RI/KIRITIRI SORA Period TIRI SEM 35 C 11	: well : moderat ncy: nil : 0 - 1 : low leve re: cs: mango, b 0 42 0 42 0 28 Jan Feb 20 21 28.6 30.4	50 cm dr i arable staat, us 5/37 40 5/37 43 Kar 121 29.8	farming e of fe E;1143 E;1265 Apr 227 28.7	Soil (m.a.s. (m.a.s. (m.a.s. Kay 68 27.8	ers 1 Holstu .1); 2: .1); 3 Jun 4 26.6	ure Regi 3 ka S ka Z Jul 2 25.9	une: ust froa SE from Aug 5 26.1	ic site. site. Sep 7 28.3	Relev Relev Relev Oct 75 29.4	f: mediu vance: m vance: v Hov	oderate ery goo Dec i 91 25.8	d Annual
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12334 ño. 12334 ELD No	0 11 50 90 11 50 90 11 50 90 12 50 90 12 50 90 12 50 90 12 50 120 120 120 120 120 120 120 120 120 12	5.3 - kcl c 5.3 - kcl c kcl c 1.1 kcl c 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -	2000 1000 1 1 1 7 0RG- C % 2.8 1.5 1.1 1.0 ITIOE e203 -1.0	1000 500 1 1 2 7AT. N % 0.2 0.1 0.1 0.1 0.1 CaO	500 250 2 1 1 1 2 1 1 2 1 1 2 1 1 1 2 0 2 50 2 5	250 100 4 2 2 2 2 2 1 CAT 1 1 0. 5 0 1 0 0 5 0 1 0 0 0 0 0 0 0 0 0 0 0 0	100 50 2 1 1 1 1 1 5 5 1 6 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 1 1 1 1	10T 9 6 6 13 13  X  7  0  5  9  7  9  7  9  7  9  7  9  7  9  7 	50 20 5 5 5 4 Ra 8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0	20 2 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 7 8 9 9 9 7 8 9 9 9 7 8 9 9 9 7 8 9 9 9 9	<pre><?? ua 77 82 82 74 EXCF H+AJ /100% -1.0 -1.0 HD HO1 HnO2 -1.00 -1.00</pre></pre>	DISP -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	BUL DEX -1.0 -1.0 -1.0 -1.0 -1.0 -1.0 -1.0 -1.0	K pi S 0, 0	.0 1. -1 - -1 -	 0 1.5 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 2.02/ S 203 1.0	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -	2.3 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1		-1 -1 -1 -1 -1 -1 -1 -1 -1 -1	 4.2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	5 m (0 )6		3
1 2 3 4	0 11 50 90 12 90 13 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 50 12 12 12 12 12 12 12 12 12 12	5.3 - 11 50 90 20 	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -	2000 1000 1 1 1 1 7 7 0RC- C % 2.8 1.5 1.1 1.0 1T108 e203 -1.0 -1.0	1000 500 1 1 2 HAT. N % 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	500 250 2 1 1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1 1 2 0 2 0	250 100 4 2 2 2 2 2 1 CAT 1 1 1 0. 5 01L 00 -1 00 -1	100 50 2 1 1 1 1 5 1 5 5 1 6 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5	99 65 13 13 	50 20 55 5 5 4 8 8 8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0	20 2 9 7 8 9 7 5 5 0 14.1 4.3 1.7 1.5 1.5 1.00	<pre><?? ua 77 82 82 74 EXCC H+AJ /1000 -1.0 -1.0 HD HO HD HD HD -1.00 -1.00 -1.00 -1.00</pre></pre>		BUTL DEN -1.0 -1.0 -1.0 -1.0 -1.0 -1.0 -1.0 -1.0	K pi S 0, 0	.0 1. -1 - -1 -		 2.0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	 2.3 -1 -1 -1 -1 -1 -1 BASE AT 1 81 43 19 48 48 43 19 48 		-1 -1 -1 -1 -1 -1 -1 -1 -1 -1	 4.2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	5 m (0 )6		3

n on der Sternensternen ib der odere sterbingen utbesternen in einer Bergeneten er einen einen einen einen eine

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CLAY MINERALOCY < 1 very weak, 2 weak, 3 medium, 4 strong, 5 very strong > EXTRACT. Fe Al Si

1 2 3 4	5 4 5 5	2		3 3 3 3 2 3 2 3		0.5 0 0.5 0	.6 0.1 .6 0.1 .5 0.1	4.8 5.0	0.6 -1.	0 -1.0 0 -1.0					
ISRIC monolith n	unber: EAX49	country: 1	KENYA			SOILD	ESCRIPTI	ON pri	nt date	(ma/dd/	<b>77): 0</b> 2	2/10/93			
Diag (other)	FNO/UNESCO,1974: USDA,1975: mostic horizons: Diagn. criteria: classification:	ustic, ve	ry fine,										-		
LOCATION AUTHOR(S) - DATE	:	0.5km S of Latitude: Kuyper			Longitude:				nce ude: 113	9 (m.a.	s.l.)		_		
CENERAL LANDPORM		plateau				Topogra	aphy: un	dulatim	•				-		
PHYSIOGRAPHIC UN	IT :	minor valle			ateau		- <b>F</b> -1		2						
SLOPE Gradl POSITION OF SITE	ent/Aspect/Form:	open depre		cave					•						
NICRO RELIEF		levees (ar	tificial	.)	Pattern:					H	eight (	cm): 30			
SURFACE CRAR.		small crac	ts		Stonines Sealing:			Sal	t: nil	X	lkali:	nil			
SLOPE PROCESSES	Soil erosion:						ation: p	resent		5	table s	lope	_		
PARENT NATERIAL	1 . :	œliwiua			Derived	rom: ba:	sic volc	anic bro	eccia	T	exture		-		
	2 :	alluvium			Derived	from: ha	sic volc	anic hr	eccia		exture:				
									epth bou						
	Remarks:	Phonolite/	iahar/ks	:a 					-				-		
EFFECTIVE SOIL D	EPTH CHI:	100						•							
VATER TABLE	Depth ca:	est	highest	level:	0 es	t. lowes	t level:	150 K	ind: flo	oded			-		
DRAINAGE PERMEABILITY		moderately moderate	well			No ela	w permea	bla 1						•	
FLOODING	frequency:		resh wat	er		NO 310	a berada		un-off:	nedium					
HOISTURE CONDITI	ions profile :	0 - 50	ca des	EA	176										
Egetation	Structure:	low level	arable	(arming,	banana, s		irrigate		ning						
ECETATION Land use/vegu TLINATE Station: KABONDO	Structure: etation remarks: Koeppen: RI/KIRITIRI	low level cassava, su ha 00 42 5/3	arable f ogarcane 37 40 E	(arming, , veget: ;1143 (1	banana, s ables Soil Nois a.a.s.l);	ture Reg 23 km S	irrigate jime: usi 5 from	d, drain iic site.	ning Relevan Relevan				-		
Land use/vego TLINATE Station: KABONDO	Structure: etation remarks: Koeppen: RI/KIBITIRI	low level cassava, su hm 00 42 5/3 0 28 5/3	arable f ngarcane 37 40 E 37 43 E	arming, , vegeta ;1143 (a ;1265 (n	banana, s bbles Soil Nois a.a.s.l); a.a.s.l);	ture Reg 23 ka S 3 ka E	irrigate yine: ust 5 from SE from	d, drain tic site. site.	Relevan	ce: vei	ry good		-		
ECETATION Land use/veg LinktE Station: KABONDOR Station: KABONDORI/KIRIY	Structure: etation remarks: Koeppen: BJ/KIBITIRI BORA Period Ja FIRI	low level cassava, st Am	arable f ngarcane 37 40 E 37 43 E Nar	arming, , vegeta ;1143 (n ;1265 (n Apr	banana, s hbles Soil Hois .a.s.l); a.a.s.l); Hay Jun	ture Reg 23 ka S 3 ka E	irrigate yine: ust 5 from SE from	d, drain tic site. site. Sep	Relevan Relevan Oct	Nov	ry good Dec A	noval	-		
ECETATION Land use/veg CLINATE Station: KABONDON KABONDORI/KIRI Precipitation	Structure: etation remarks: Koeppen: H/KIBITIRI EORA	low level cassava, su Ma 00 42 5/1 0 28 5/1 n Feb 0 21	arable 1 ogarcane 37 40 E 37 43 E Nar 121	(arming, , vegeta ;1143 (n ;1265 (n Apr 227	banana, s bibles Soil Hois a.a.s.l); a.a.s.l); May Jum 68	ture Reg 23 km S 3 km E Jul 2	jine: ust 5 from SE from Aug 5	d, drain tic site. site. Sep 7	Relevan Relevan Oct 75	ice: ve: Nov 209	Dec A 91	849	-		
EGETATION Land use/vegr LikhTE Station: KABONDON Station: KABONDORI/KIRIT Precipitation f max t min	Structure: etation remarks: Koeppen: BJ/KIBITIRI BORA Period Ja FIRI	low level cassava, st Am 00 42 5/3 0 28 5/3 n Feb 0 21 6 30.4	arable 1 ogarcane 37 40 E 37 43 E Mar 121 29.8	(arming, , vegatz ;1143 (a ;1265 (a Apr 227 28.7 ;	banana, s hbles Soil Hois .a.s.l); a.a.s.l); Hay Jun	ture Reg 23 km S 3 km E Jul 25.9	jine: ust 5 from SE from Aug 5 26.1	d, drain tic site. site. Sep	Relevan Relevan Oct 75 29.4	Nov	ry good Dec A	noval	-		
TEGETATION Land use/vegy Likate Station: KABONDOR Station: KABONDOR Station: KABONDOR KABONDORI/KIRI Precipitation Nax Nax Nax Nax Nax Nax	Structure: etation remarks: Koeppen: BORA Period Ja TIRI	low level cassava, st 	arable 1 ogarcane 37 40 E 37 43 E Nar 121 29.8 15.9	(arming, , vegatz ;1143 (n ;1265 (n Apr 227 28.7 ; 17.3 1	banana, s bbles Soil Hois a.a.s.l); a.a.s.l); Hay Jun 68 4 (7.8 26.6 (6.6 15.2	ture Reg 23 km S 3 km S Jul 25.9 14.0	jine: ust 5 from SSE from Aug 5 26.1 14.7	d, drain tic site. site. Sep 7 28.3 14.6	Relevan Relevan Oct 75 29.4 15.8	ICE: VE Nov 209 27.2 16.8	91 26.8 15.2	849 28.0 15.3	-		
ECETATION Land use/vegr CLIMATE Station: KABONDOR Station: KABONDORI/KIRIT Trecipitation Nax Sain KANYUANBORA Precipitation	Structure: etation remarks: RI/KIRITIRI Period Ja TIRI C 11 28 C 11 28 C 11 13 ma 11 2	low level cassava, st Am 00 42 5/3 0 28 5/3 n Feb 0 21 6 30.4	arable 1 ogarcane 37 40 E 37 43 E Mar 121 29.8	(arming, , vegatz ;1143 (a ;1265 (a Apr 227 28.7 ;	banana, s bbles Soil Hois a.a.s.l); t.a.s.l); Hay Jun 68 4 27.8 25.6	ture Reg 23 km S 3 km S Jul 25.9 14.0	jine: ust 5 from SE from Aug 5 26.1	d, drain tic site. site. Sep 7 28.3	Relevan Relevan Oct 75 29.4	ICE: VE NOV 209 27.2	91 26.8 15.2	849 28.0	-		
TECETATION Land use/vegy LinktE Station: KABONDORI Station: KABONDORI/KIRIT Precipitation f max min KAMYUANBORA Precipitation PROFILE DESCRIPT	Structure: station remarks: Koeppen: RI/KIBITIRI	low level cassava, st 	arable 1 ogarcane 37 40 E 37 43 E 137 43 E 14 121 15.9 15.9 161	(arming, , vegetz ;1143 (n ;1265 (n Åpr 227 28.7 ; 17.3 1 359 4.0 dry; b; slig pores; s concre	banana, s banana, s soil Hois a.a.s.l); a.a.s.l); a.a.s.l); Hay Jum 68 4 (7.8 26.6 (6.6 15.2 127 6 ; clay,graw hily sticky many very sticky and y	ture Reg 23 km S 3 km Z Jul 25.9 14.0 4 elly; ve slight] fine roc	jine: ust from SE from SE from Aug 5 26.1 14.7 16 ery coarri y plasti sts and f	d, drain tic site. site. site. 28.3 14.6 7 7	Relevan Relevan Oct 75 29.4 15.8 109 subangul ble hard; roots;	209 27.2 16.8 318 ar bloo patch	ry good Dec A 91 26.8 15.2 75 cky	849 28.0 15.3	-		
VECETATION Land use/vegr CLIMATE Station: KABONDORI Station: KABONDORI/KIRIT Precipitation f max T min KANYUANBORA Precipitation PROFILE DESCRIPT: Ap 0- 25cm	Structure: tation remarks: Koeppen: RI/KIBITIRI	low level cassava, st 	arable f ogarcane 37 40 E 37 43 E Nar 121 29.8 15.9 161 0YE 4.0/ ate crus iniferou ; clear 5YE 3.0/ ate crus	(arming, , vegetz ;1143 (a ;1265 (n kpr 227 28.7 ; 17.3 1 359 4.0 dry; b; sligi pores; socret wavy box 2.0 dry; b; sligi 578 3.0,	banana, s bles Soil Hois a.a.s.l; a.a.s.l; may Jum 68 4 (27.8 26.6 16.6 15.2 127 6 ; clay,grav tly stick; many very ; tlons and modar to ; clay,grav tly stick; 0.0, moti V.	ture Reg 23 km S 3 km E Jul 25.9 14.0 4 elly; ve slight1 fine roc frequent elly; ve	irrigate pine: ust 5 from SZE from Aug 5 26.1 14.7 16 ery coars t medium ery coars ty plasti t medium	d, drain tic site. site. site. 28.3 14.6 7 7 28.3 14.6 7 7 28.5 90 weak ic friab spheric spheric friab	Relevan Relevan Oct 75 29.4 15.8 109 subangul he hard; roots; al hard rate suba	Nov 209 27.2 16.8 318 ar bloo patch freque	ry good Dec Au 91 26.8 15.2 75 cky 7 ent blocky	849 28.0 15.3 1264	-		
VECETATION Land use/vegy CLIMATE Station: KABONDOR Station: KABONDOR KABONDORI/KIRIT Precipitation T max T min KANYUANBORA Precipitation PROFILE DESCRIPT Ap 0- 25cm Aul 25- 55cm	Structure: etation remarks: Koeppen: KIRITIRI Period Ja Period Ja Period Ja C 11 28. C 11 28. C 11 28. C 11 28. C 11 28. IOS 7.5TR 3.0/2.0 into fine to mo thin clay cutan manganiferous of 5.0TR 2.5/2.0. into fine to mo common medium of	Low level Low level	arable i ogarcane 37 40 E 37 43 E Nar 121 29.8 15.9 161 0YR 4.0/ ate crum ery fibe aniferous; clear 5TR 3.0/ ate crum arp (7. few fine 0YR 3.0/ ngular b p (5.07; many w tions an	(arming, , vegetz ;1143 (1 ;1265 (1 kpr 227 28.7 ; ;17.3 i ;359 4.0 dry; ;359 4.0 dry; ;359 4.0 dry; ;359 5;119 5;	banana, s banana, s banana, s Soil Hois a.a.s.l; t.a.s.l; t.a.s.l; Hay Jum 68 4 (7.8 26.6 65.6 15.1 (6.6 15.1 (6.6 15.1 (1.7) 127 6 (1.7) many very stions and mdary to ; clay,graw tily sticky (0.0) motti clear soc ; clay,graw tily sticky (0.0) motti clear soc ; clay,graw	elly; ve slight] elly; ve slight] fine roc frequent elly; ve slight] es; cont oth bour elly; ve	irrigate gine: ust is from SZ from Aug 5 26.1 14.7 16 ery coarrights is and in t medium ery coarrights innous c odary to ery coarrights innous c odary to ery coarrights innous c indiry coarrights innous c indiry to ery coarrights in thin c (c) in	d, drain d, drain d, drain d, drain d, drain site. Sep 7 7 28.3 14.6 7 7 7 28.3 14.6 7 7 50 weak friablew file spheric friablew file friablew file f	Relevan Relevan Oct 75 29.4 15.8 109 subangul ile hard; roots; ai hard ate suba ile hard; ate suba riable h sesquion mail spb	Nov 209 27.2 16.8 318 ar bloo patch freque ngular ard; fides C	pec N 91 26.8 15.2 75 cky 7 mat blocky blocky blocky that s	naual 849 28.0 15.3 1264	-		
VECETATION Land use/vegy CLIMATE Station: KABONDOS Station: KABONDOS KABONDORI/KIRIT Precipitation T max T min KANYUANBORA Precipitation PROFILE DESCRIPT Ap 0- 25cm Aul 25- 55cm	Structure: station remarks: Koeppen: KOEPPEN: KOEPPEN: KOEPPEN: KOEPPEN: KOEPPEN: KOEPPEN: KOEPPEN: KOEPPEN: ROB Period Ja Period Ja TIN TIN TIN TIN TIN TIN TIN TIN	Low level Low level	arable i ogarcane 37 40 E 37 43 E Nar 121 29.8 15.9 161 15.9 161 0YE 4.0/ ate cruminery fibe aniferous; clear 5YE 3.0/ ate cruminerous; clear 5YE 3.0/ 5YE 3.0/ 5Y	(arming, , vegetz ;1143 [1 ;1265 [1 ;1265 [1 ;1265 [1 ;1265 [1 ;127 ;17.3 1 ;17.3 1 ;17.5 1 ;1	banana, s banana, s banana, s Soil Nois a.a.s.l; .a.s.s.l; .a.s.s.l; .a.s.s.l; .a.s.s.s.s.s.s.s.s.s.s.s.s.s.s.s.s.s.s.	elly; ve slight fine roc frequent elly; ve slight fine roc frequent ficky sli ; broken few fin icky sli ; contir few fin icky sli	irrigate gine: usi from SZ from SZ from SZ from SZ from Aug 5 26.1 14.7 16 ery coars (y plasti tinuous of odary to ery coars ightly pla athin climetry pla athin climet	d, drain d, dra	Relevan Relevan Oct 75 29.4 15.8 109 subangul ele hard; roots; al hard ele hard; many ve rate suba riable h sesquion mail sph ilar bloc	Nov 209 27.2 16.8 318 ar bloo patch; freque ard; ry fine ard; ides cf erical xy ard; uioxid	ry good Dec N 91 26.8 15.2 75 cky 7 ent blocky blocky utans ;	naval 849 28.0 15.3 1264	-		

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e.	Bg4 160-165ca	7.5YR 4.0/2.0 moist; clay,slightly grave common fine distinct sharp ( 7.5YR 2.0/0. small spherical hard manganiferous concre manganiferous ;	<pre>ily; ; slightly sticky slightly plastic; 0) mottles; continuous thin clay cutans ; few tions and few medium spherical hard</pre>	-
	monolith number	EAX49 analytical data culssing	value = -1> ISRIC print date: 02/10/93	
		2000 1000 500 250 100 TOT 50 20 <2 1009 500 250 100 50 20 2 um	DISP BULK pF	
	1 0 25 - 2 25 55 - 3 55 90 - 4 90 140 - 5 140 160 -	1       1       2       2       7       12       30       50         2       2       3       4       2       13       4       22       61         2       2       2       4       3       13       9       28       49         4       3       4       6       4       21       8       19       52         8       4       4       5       3       24       5       18       52	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-
		Юлт. ЕХСН САТ. —— —— ——   ЕХСН ОНБ- К % Са Ng I Na sua 1941 С % —— —— —— меq /100g —		
	2 6.4 4.8 -1. 3 6.4 4.8 -1. 4 6.3 4.8 -1.	3.1       0.2       11.3       3.8       2.0       0.0       17.1       -1.0         2.3       0.2       12.2       3.8       0.7       0.1       16.8       -1.0         2.3       0.1       12.5       4.1       0.7       0.2       17.5       -1.0         1.6       0.1       11.2       3.6       0.8       0.2       15.8       -1.0         0.8       0.1       8.7       3.4       0.6       0.2       12.9       -1.0	-1.0 21.9 36 8 16.8 77 -1 0.06 -1.0 21.7 44 8 17.5 81 -1 0.06 -1.0 18.3 35 6 15.8 86 -1 0.09	
	ELEMENTAL CONFO	TICH OF TOTAL SOIL (in weight %) AND HOLA	IR RATIOS	
	No Si02 A1203	203 CaO NgO X20 Na20 T102 Na02	P205 IGH. Si02/ Si02/ Si02/ Al203/ LOSS Al203 Fe203 R203 Fe203	
	2 -1.0 -1.0 3 -1.0 -1.0 4 -1.0 -1.0	1.0 -1.00 -1.00 -1.00 -1.00 -1.00 -1.00 - 1.0 -1.00 -1.00 -1.00 -1.00 -1.00 -	1.00 -1.0 -1.0 -1.0 -1.0 -1.0 -1.00 -1.0 -1.0 -1.0 -1.0 -1.0 -1:00 -1.0 -1.0 -1.0 -1.0	
	CLAY MINERALOGY	1 very weak, 2 weak, 3 medium, 4 strong,	5 very strong > EXTRACT. Fe Al Si	
	No NICA/ VERN ILL	lor shec knol hall hix* quar feld gibb go	ET HEX FEO ALO SIO FEA ALA FEP ALP	
	1 1 2 2 3 2 4 2 5 2	4       1       3       3         5       2       3       3         5       2       2       3         4       1       2       3         5       2       2       3         5       2       2       3	1.3 0.5 0.1 4.3 0.4 -1.0 -1.0 1.4 0.4 0.1 4.2 0.4 -1.0 -1.0	
	Diag	O/UNESCO,1974: chromic luvisol (Tent. cla USDA,1975: paleustalf rhodic, clayey, stic horizons: ochric, argillic		-
	LOCATION	: Latitude: 0 27 10 S L	tersupply near the Embu-Ishiara road ongitude: 37 46 20 E Altitude: 855 (m.a.s.l.)	-
	AUTHOR(S) - DATE GENERAL LANDFORM PHYSIOGRAPHIC UN SLOPE GRAD HICKO RELIEF SUBFACE CHAR. SLOPE PROCESSES	: plain	Stoniness: none Sealing: slaked Salt: nil Alkali: nii	
	PARENT NATERIAL Weath	: residual material ring degree: partial/moderate Remarks: basement system	Derived from: gneiss Texture: Resistance: moderate	
	EFFECTIVE SOIL I	7TE ca: 150 Depth ca:	Kind: no valertable observed	

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CLIMATE		Koep	pen: Aw				Soil	l Nolstu	re Regi	ime: us	tic				
Station: KABONDOR	(/XI	RITIRI	·0	0 42 S	/37 40	E;1143	{m.a.s.	.1); 28	i lon S	SW from	site.	Releva	ance: m	derati	e
Station: KANYUAHBO	RA		0	28 S	/37 43	E;1265	(B.a.s.	.1); 6	ka ¥	from	site.	Releva	ance: m	derati	e
Station: NARIMANTI	l		0	0 09 S	037 59	E;587	( <b>1.8.5</b> .	.1); 40	kan Ki	C⊈ froma	site.	Releva	ance: m	derati	6
		Period	Jan	Feb	Kar	Apr	Kay	Jun	Jul	λug	Sep	Oct	Bov	Dec	Annua.
EABORDORI/KIRITI	RI									·····					
Precipitation		35	20	21	121	227	68	- 4	2	5	7	75	209	91	84
T max	С	11	28.6	30.4	29.8	28.7	27.8	26.6	25.9	26.1	28.3	29.4	27.2	26.8	
T HIR KANYUANBORA	c		13.4	14.2	15.9	17.3	16.6	15.2	14.0	14.7	14.6	15.8	16.8	15.2	15.3
Precipitation BARIKANTI	R	11	27	49	161	359	127	6		16	1	109	318	75	126
21 class & pan	m	10	159	177	225	181	166	168	180	208	242	254	173	154	228
Precipitation		12	19	33	79	268	97	10	2	1	3	88	225	- 54	879
No of Raindays		10	4	3	- 4	12	6	2	2	1	1	- 4	12	6	5
Tot.global rad.KJ	2	10	19.3	20.1	20.4	20.8	20.1	17.1	15.3	16.5	18.8	20.0	19.6	19.0	452.
T max	c	10	31.9	33.8	34.6	33.1	32.2	31.7	31.0	31.3	33.2	34.2	30.0	30.9	32.
T sia	с	10	18.4	19.8	20.9	21.4	20.8	19.2	19.4	19.5	20.0	21.1	20.3	18.9	20.

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monolith number: EAX50	02/10/93

## PROFILE DESCRIPTION

AB 0-15cm 10.0R 3.0/4.0 moist; 2.5YR 3.0/4.0 dry; sandy clay; medium to coarse strong subangular blocky and very fine granular; slightly sticky slightly plastic very friable hard; continuous thin clay cutans; many very fine pores; many very fine roots and few fine moots; few small weathered quartz, mice fragments; gradual wavy boundary to

B 15-150cm 10.0R 3.0/4.0 moist; 2.57R 3.0/4.0 dry; sandy clay; coarse-very coarse strong subangular blocky; slightly sticky slightly plastic very friable hard; continuous thin clay cutans ; many very fine pores; many very fine roots and few fine roots; few small fresh quartx fragments;

#### REMARKS:

Parent material: Gabromotite, Gneiss, Talcum. Woodland with Euphorbia ayikae and Acacia senegal. A high bioactivity by termites, large (15mm) and small ants. The soil of this pit is used for the production of local bricks. Slides: 10,105 - 10,113 and 10,134.

<b>30</b> ]																									
T	OP B	or				1000 500					50 2 20	20 <2 2 ua	DISP	BULK	pF- 0.0	1.0 1.	.5 2.	0 2.3	2.1	 3.4	4.2				
1	0 15 60 1 05 1	15 60 105 150		-1 -1 -1 -1	2 2 2 2	7 6 7 7	13 13 13 13	16 16 15 15	7 8 7 7	45 45 44 45	5 6 6 1 7 1	6 44 8 41 12 38 14 34	-] -] -] -]	-1.00 -1.00 -1.00 -1.00	-1 -1 -1 -1	-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -	-1 - -1 - -1 -	1 -1 1 -1 1 -1 1 -1	-1 -1 -1 -1	-1 -1 -1 -1	-1 -1 -1 -1				
•	p#- 820	 KC	i ca	$\mathbf{n}$	ORG-	1 5	C 2		n	T	Ka st	m Re	al 11	soild	lay Org	c		BASE SAT N	SAT	<u>)</u> 1 1 1	ec 2 ≡S/	2.5 Ca			
	6.7 6.7 7.0 7.7	5. 4. 5. 6.	4 -1 8 -1 0 -1 1 -1	1.0 1.0 1.0	0.6 0.2 0.2 0.2	0.1 0.0 0.0 0.0	4.1 3.9 5.4 8.6	7 7 7 8 6 6 6	.6 0 .5 0 .4 0 .5 0	.7 0 .2 0 .2 0 .3 0	.0 12 .0 11 .1 12 .1 15	.4 -1 .6 -) .5 -1 .5 -1	1.0 -1.0 1.0 -1.0 1.0 -1.0 1.0 -1.0	) 10.9 ) 10.8 ) 10.6 ) 11.6	25 27 28 34	2 1 1 1 1 1 1 1	2.4 1.6 2.5 5.5	114 107 118 134	: • •	-1 -1 -1 -1	0. 0. 0. 0.	10 .07 .06 .18			
D	ENT	NL I	0019	705.	TIO	OF T	OTAL	<b>S</b> 01	l (in	weig	ht 3)	YND )	IOLAR RI	TIOS											
,	sia	2 1	120	3 Fe	203	CaO	H	<b>;</b> 0	120	Ka20	) TIO	12 H.M			SI02/ A1203										
	-1. -1. -1. -1.	0 0 0	-1.( -1.( -1.)	0 -	-1.0 -1.0 -1.0 -1.0	-1.00 -1.00 -1.00 -1.00	-1. -1. -1.	00 - 00 - 00 - 00 -	1.00 1.00 1.00 1.00	-1.00 -1.00 -1.00 -1.00	) -1.0 ) -1.0 ) -1.0 ) -1.0	10 -1.1 10 -1.1 10 -1.1 10 -1.1	00 -1.0 00 -1.0 00 -1.0 00 -1.0	0 -1.0 0 -1.0 0 -1.0 0 -1.0	-1.0 -1.0 -1.0 -1.0	-1.0 -1.0 -1.0 -1.0	-1 -1 -1 -1	.0 .0 .0	-1.0 -1.0 -1.0 -1.0						
	,	••	N/ V	•										aetå 2	trong > FEo			. Fe			FEp	 λLį	p		
<b>R</b> 0	,		N/ W	•		Or Sm	ec Kj	IOL I	all i	HIX* (	QUAR I	feld (	IBB GOP	very s T een	trong >	λLο 0.2	SI0 0.0	. Fe . FEd	NL0	3 1	1.0	-1.0	D		
1 2 3 4		HICI ILL 4 4 4		TERM	I CHL	Or Sh	EC KJ 4 4 4	ol I	DALL I	HIX*   2 3 3 3	QUAR 1	Feld (	2 2 2 2 2 2 2	aetà 2	FE0 0.4 0.3 0.2	ALO 0.2 0.1 0.1 0.1	SIO 0.0 0.0 0.0 0.0	Fe	AL	3 - 2 - 1 - 2 -	1.0 1.0 1.0 1.0	-1.( -1.( -1.( -1.(	0 0 0	); 07	2/10/9
1 2 3 4 1S	) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	HICI ILL 4 4 4 HOI	N/ V noli Cati	ith OK Dia pia	numb FRO	er: E	4 4 4 4 00,19 DJ,10 DJ,10 DJ,10 DJ,10	OL 1 774: 775: Mas: ria:	Cou chro thad	HIX*	QUAR 1 KENY	FELD C A 1, sto ine in	2 2 2 2 2 2	very s T HEX	FE0 0.4 0.3 0.3 0.2 SOII	ALO 0.2 0.1 0.1 0.1 0.1	SIO 0.0 0.0 0.0 0.0	Fe	AL	3 - 2 - 1 - 2 -	1.0 1.0 1.0 1.0	-1.( -1.( -1.( -1.(	0 0 0	): 02	:/10/9
1 2 3 4 15 	RIC ASS	HICI ILL 4 4 4 1FI ION	N/ V noli LATI (oth	th Dia Dia icr)	numb FRO Dia il ci	er: E /UNESS tic h gn. c	4 4 4 4 00,19 DJ,10 DJ,10 DJ,10 DJ,10	OL 1 074: 075: 00: : :	COU chro stad ochr	MIX* 2 3 3 3 miry: mic 1 ustal ic, a ara, tude:	KENYA vviso. 200m :	A A 1. str ina k ic	IBB GOE 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 3	very s 7 HEX e (Tent sobypert	FE0 0.4 0.3 0.3 0.2 SOII	ALO 0.2 0.1 0.1 0.1 0.1 DESC )	SIO 0.0 0.0 0.0 0.0 RIPTI	FE0 3.2 3.0 2.6 ON p	AL 0.: 0.: 0.: rint dist	i 1 2 - 2 - dati	1.0 1.0 1.0 9 (m	-1.( -1.( -1.( m/de	0 0 0 1/77		:/10/9
TO 1234 IS CL	RIC ASS CAT: THOM YSIC OPE SITI	HICL 4 4 HOO 1 HICL 4 4 4 HOO 1 HICL 4 4 4 4 4 HICL 4 4 4 4 4 HICL 4 4 4 4 4 4 4 4 4 4 4 4 4	N/ V Noli CATI (oth I UARI CATI	ER ith Dia Dia er) CON ECT	numb FAO Dia il cl TE (m MIT MIT	er: E /UNESS tic h ga. c assif	4 4 4 4 4 4 4 4 5 00,19 010000000000	OL 1 774: 775: ans: : : : : : : : : : : : : :	cou chro thad ochr Ishi Lati Kuyp plai undu 3 %	MIX* 1 2 3 3 3 mic 1 ustal ic, a ara, tude: er n latin	KENY vviso f, f rgill 200m 200m 200m 200m 200m 200m 200m	A I, str inc k S of 1 7 40 S	2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	very s 7 HEX e (Tent sobypert	0.4 0.3 0.3 0.2 0.2 0.1 0.2 0.1 0.2 0.2 0.1 0.2 0.2 0.1 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2	ALO 0.2 0.1 0.1 0.1 0.1 DESC )	SIO 0.0 0.0 0.0 81PT1	. Fe	ALC 0.1 0.1 rint districted	i 1 2 - 2 - dati	1.0 1.0 1.0 9 (m	-1.( -1.( -1.( m/de	0 0 0 1/77		:/10/9
IN 1234 IS-CL - LO AU-GEPESIONISU	RIC RIC ASS CAT: THOM YSIC OPE SITI CRO RFM	HICI ILL 4 4 HOI IFI ION R(S) AL ION RE CE (	N/ V Noli Cati (oth I NPHI G	Dia Dia Dia Dia DAT DAT	numb FAO genos Dia il ci TE (m MIT Ilient TE	er: E /UNESS US tic h ga. c assif /Aspe Rock ( C	4 4 4 4 4 4 4 5 00,19 07,100000000000000000000000000000000000	OL 1 774:: 775:: 7	cou chro rhad ochr Ishi Lati Kuyp plai undu 3 % uppe fair nil	MIX* 2 3 3 miry: mic 1 wstal ic, a ara, tude: er ara, latin r slo ly ro	KENY vviso f, f gupl gupl pe cky	A 1, stu ina 1: ic S of 1 7 40 S and conve	EIBB GOE	very s T EDM F (Tent ibhypert rtion ne ongitude Pattern Sealing	trong > FEo 0.4 0.3 0.3 0.2 SOII 	ALO 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	SIO 0.0 0.0 0.0 81PT1 tal, 5 7: W	FEd 3.2 3.2 3.2 3.2 2.6 CM p Embu Alt dulat	ALC 0.: 0.: 0.: 0.: 0.: 1: distu itude	i : 2 - 2 - datu rict : 8	1.0 1.0 1.0 e (m	-1.( -1.( -1.( m/dc	0 0 0 d/yy a.s.	 1.) 	
	RIC ASS CAT: THOM NERI NERI COPE	HICI ILL A A A IDOI IFIC ION RES CE C PRC	A/ V nolli CATI (oth Lier OF Lier CEAU CEAU	Dia Dia Dia Dia Dia Dia Dia Dia Dia Dia	numb FAO Dia il ci Il ci ci ci ci ci ci ci ci ci ci ci ci ci c	er: E /UNESS /UNESS US tich ggn. cf a.yy) /Aspe Rock ( Soil (	ec Ki 4 4 4 4 4 4 4 5 0,19 0,19 0,19 0,19 0,19 0,19 0,19 0,19	OL I 774: 775: 775: 775: 775: 775: 775: 775:	cou chro rhod ochr Ishi Lati Kuyp plai undu 3 t uppe fair node resi part	HIX* 2 3 3 mic 1 wstal ic, a mic 1 wstal ic, a ara, tude: er n i tude: er latin r slo ly ro rate dual (mainten)	KENY vviso f, f gupl gupl pe cky	A A 1, str ine 1: ic S of 1 7 40 S  and c inter 1: and c inter 1: inter 1: and c inter 1: inter	EIBB GOS 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	very s T EEX T EEX	trong > FEo 0.4 0.3 0.3 0.2 SOII 	ALO 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	SIO 0.0 0.0 0.0 0.0 81PT1 tal, 7: ur 7: ur 5	FEd 3.2 3.2 3.2 3.2 2.6 CM p Embu Alt dulat	ALC 0.: 0.: 0.: 0.: 0.: 1: distu itude ing e Sin	i : 2 - 2 - datu rict : 8	1.0 1.0 1.0 e (m	-1.( -1.( -1.( m/dc	Alic stal	 1.) 	nil
NO 1 2 3 4 IS CL LO AU GE PH SL PAN	RIC RIC ASS THOM YSIO OPE REM	HICLILL 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	(oth Lief CATI ) - LARI CATI CATI	Dia Dia Dia Dia Dia Dia Dia Dia Dia Dia	numb FAO Dia Dia RII Ci MIT Itent TC	er: E //UNESS tic h gn. c assif //Aspe Rock ( C Soil (	ec Ki 4 4 4 4 4 4 4 4 4 4 4 4 4 5 1 5 1 5 1 5	OL I 774: 775: 775: 775: 775: 775: 775: 775:	cou chro those ochro flshi Lati Kuypp plai undu 3 t uppe fair nil mode Fast	HIX* 2 3 3 mic 1 wstal ic, a mic 1 wstal ic, a ara, tude: er n i tude: er latin r slo ly ro rate dual (mainten)	CUAR 1 KENY, vriso f, f rgill 200m : 0 2 g upl pe cty sheet mater odera	A A 1, str ine 1: ic S of 1 7 40 S  and c inter 1: and c inter 1: inter 1: and c inter 1: inter	EIBB GOS 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	very s T EEX T EEX	FE0 0.4 0.3 0.3 0.2 SOII class soin class	ALO 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	SIO 0.0 0.0 0.0 0.0 81PT1 tal, 7: ur 7: ur 5	FEd 3.2 3.2 3.2 3.2 2.6 CM p Embu Alt dulat	ALC 0.: 0.: 0.: 0.: 0.: 1: distu itude ing e Sin	i : 2 - 2 - datu rict : 8	1.0 1.0 1.0 e (m	-1.( -1.( -1.( m/dc	Alic stal	ali:	nil
	RICC ASS: CAT: THOS SITI CRO REPA OPE SITI CRO REPA COPE	HICI A A A A A A A A A A A A A	A/ V 1011 CATII CATI CATII CATI CATI CATII CATI CATI CAT	th Dia ber) Dia ber) Dia ber) Dia ber) Dia ber) Co Co Co Co Co Co Co Co Co Co Co Co Co	numb FAO genos Dia il ci RIT RIT E (m RIT E ient E DEPT	er: E //UNESS tic h gn. c assif /Aspe Roct C Soil ng R Dep	ec K/ 4 4 4 4 4 4 4 5 7 7 7 7 7 7 7 7 7 7 7 7	OL I 774: 775: mas: ria:	COU chro	MIX* 2 3 3 mic 1 wital ic, a mic 1 wital mic 1	CUAR 1 KENY, vriso f, f rgill 200m : 0 2 g upl pe cty sheet mater odera	A I, string in a line in	EIBB GOS 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	very s T EEX T EEX	trong > FEo 0.4 0.3 0.3 0.2 SOII class beraic  9.85 Topc Topc :: none sss: ver sss: ver hggr from: nce: m	ALO 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	SIO 0.0 0.0 0.0 RIPTI tal, 7 tal, 7 tal, 5	FEd 3.2 3.0 3.0 2.6 OM p Darbu Alt dulat	ALC 0.: 0.: 0.: rint districted ing e Sin alt: Kinc r fro	i : n	1.0 1.0 1.0 e (m 555 cm): cm): cm): cm):	-1.( -1.( -1.( -1.( (n.a) 5	Alk stal	ali: bles ture: e obs	nil

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CLINATE		Koep	pen: h				Soi	l Noistu	re Regis	ne: us	tic				
Station: XABONDO		RITIRI	(	0 42 S				.1); 28	ba∎ŚW	from	site.	Relev	ance: m	oderate	
Station: KANYUN	BORA		(	28 S	/37 43	E;1265	(p.a.s	.1); 8	ion V	from	site.	Relev	ance: m	oderate	ł
Station: KARIKAN	ΠI		(	00 09 S	/037 59	£;587	(m.a.s	.1); 40	ica KE	from	site.	Reiev	ance: m	oderate	
		Period	Jan	Feb	Mar	λpr	Kay	Jun	Jul	λug	Sep	Oct	Nov	Dec	Annua I
XABONDORI/XIRI	TIRI												*****		
Precipitation	20	35	20	21	121	227	68	- 4	2	5	1	75	209	91	849
TRAX	c	11	28.6	30.4	29.8	28.7	27.8	26.6	25.9	26.1	28.3	29.4	21.2	26.8	28.0
T RÍÐ KANYUANBORA	c	11	13.4	14.2	15.9	17.3	16.6	15.2	14.0	14.7	14.6	15.8	16.8	15.2	15.3
Precipitation		11	27	49	161	359	127	6	4	15	1	109	328	75	1264
EA class A pan		10	159	177	225	181	166	168	180	208	242	254	173	154	2287
Precipitation	<b>51</b> 2	12	19	33	79	268	97	10	2	1	3	88	225	54	879
No of Raindays		10	4	3	4	12	6	2	2	1	1	4	12	6	57
Tot.global rad.h	U/≥2	10	19.3	20.1	20.4	20.8	20.1	17.1	15.3	16.5	18.8	20.0	19.6	19.0	452.0
T SAL	Ċ	10	31.9	33.8	34.6	33.1	32.2	31.7	31.0	31.3	33.2	34.2	30.0	30.9	32.3
TRÍS	c	10	18.4	19.8	20.9	21.4	20.8	19.2	19.4	19.5	20.0	21.1	20.3	18.9	20.0

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P. Nation Sciences

omolith number: EAK51	02/10/93
ROFILE DESCRIPTION	
ul 0-10cm 2.5YB 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; sandy clay; coarse strong subangular b slightly sticky slightly plastic very friable hard; continuous thin clay cutans very fine pores; many very fine roots and few fine roots; gradual wavy boundary	; cany
u2 10-25cm 2.5YR 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; sandy clay,very gravelly; coarse weak into granular; slightly slicky slightly plastic loose loose; continuous thin clay cutans ; many very fine pores; many very fine roots and few fine roots gradual wavy boundary to	
u3 25-70cm 2.5YR 3.0/6.0 moist; 2.5YR 4.0/8.0 dry; sandy clay; coarse strong angular bloc slightly sticky slightly plastic very friable hard; continuous thin clay cutans very fine pores; common very fine roots and few fine roots; wavy boundary to	
U4 70-120cm 2.5YR 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; sandy clay; medium to coarse strong an slightly sticky slightly plastic very friable bard; broken thin clay cutans; ma common very fine roots;	
· ·	
monolith number: EAK51 analytical data <missing value="-1"> ISRIC print date</missing>	: 02/10/93
NO TOP BOT >2 2000 1000 500 250 100 TOT 50 20 <2 DISP BULL pF	
1 0 10 -1 3 5 9 13 6 36 10 5 50 -1 -1.00 -1 -1 -1 -1 -1 -1 2 10 25 -1 5 6 9 12 6 37 0 6 58 -1 -1.00 -1 -1 -1 -1 -1 -1 3 25 70 -1 2 6 13 16 7 44 8 8 40 -1 -1.00 -1 -1 -1 -1 -1 -1	-1 -1
4 70 120 -1 5 17 27 21 7 76 5 5 15 -1 -1.00 -1 -1 -1 -1 -1 -1 	
No. pH  NAT. EXCH CAT EXCH MC.   CBC   EXCH MC.   CBC   EXCH BASE   H20 KCl CaCO ORG- H & Ca Mg K Ha stan H+Al Al soil clay OrgC SAT & SAT 3 C & Beq /100g	Al EC 2.5 3 mS/cm
2 6.7 5.0 -1.0 0.6 0.1 9.5 3.8 0.2 0.0 13.5 -1.0 -1.0 11.0 19 2 13.5 123 3 6.8 4.9 -1.0 0.3 0.0 8.3 4.3 0.1 0.0 12.7 -1.0 -1.0 9.6 24 1 12.7 132	-1 0.08 -1 0.06 -1 0.05
4 7.2 5.3 -1.0 0.1 0.0 5.8 2.4 0.1 0.0 8.3 -1.0 -1.0 5.6 38 0 8.3 148 ELEMENTAL COMPOSITION OF TOTAL SOIL (in weight 4) AND NOLAR RATIOS	-1 0.04
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