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)

Gete Zeleke E.

Not for publication

Department of Soil Science and Geology

Wageningen Agricultural University - The Netherlands

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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.

Supervisors: Dr. P.M Driessen;
Ir. E.R. Jordens and
Ir. J.H. Kauffman

Department of Soil Science and Geology
Wageningen Agricultural University
The Netherlands

July, 1993.

16690

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

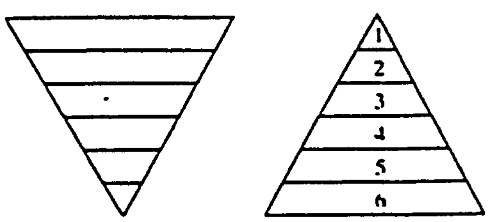
Realistic description of land use systems would have to be dynamic and consider biotechnical and socioeconomic processes in one integrated analysis. But in practice the complexity and massive data needs of evaluation models are prohibitive. It is possible to describe potential land suitability at a high 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 detail | Methods of land use 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:
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 re-distribute.
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)

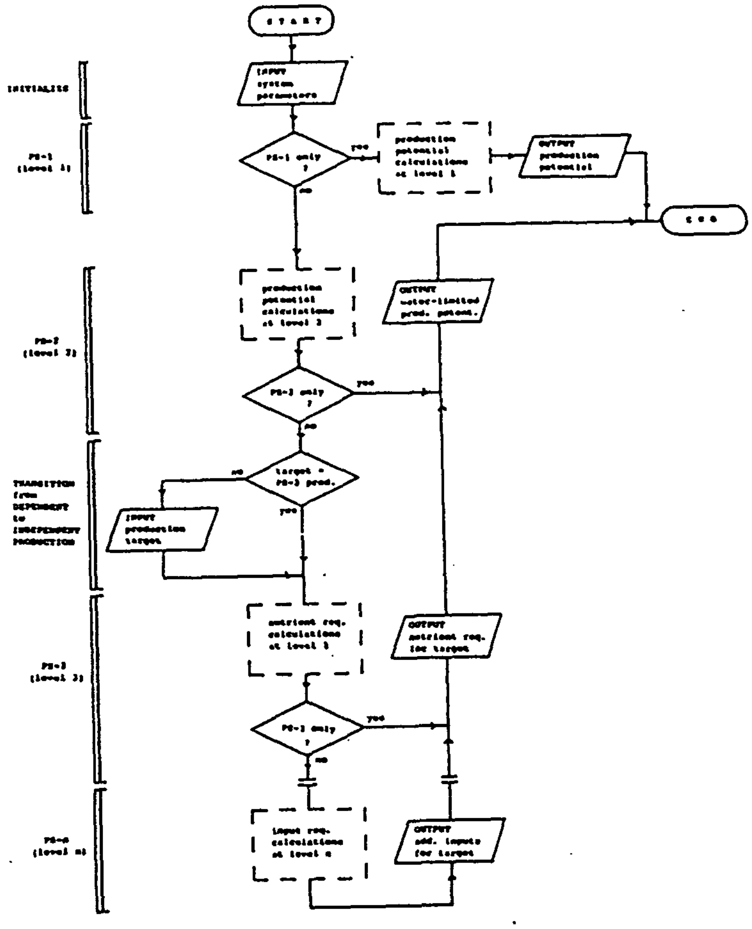


Figure 1.1 Relational diagram of production situations in PS123N.(adopted from lecture notes on land use systems analysis, Driessen, Konijn, 1992).

1.4.4 Qualitative Land Evaluation

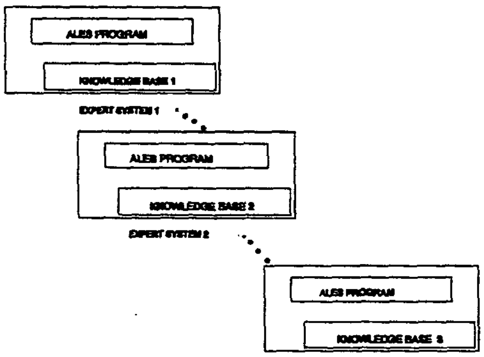
Qualitative Land Evaluation refers to systems which determine land suitability according to the framework of FAO (1976), i.e. by matching relevant land use requirements with the corresponding land qualities or land characteristics in a single land use system. Environmental factors are compared and ranked 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).



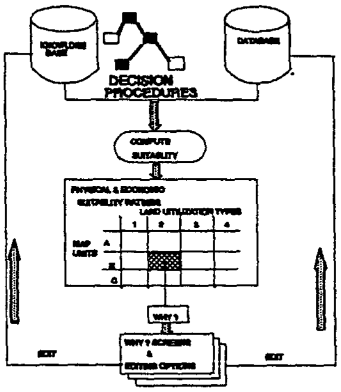


Figure 1.2 Relation between ALES program and models.

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 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 km^2), whereas the population density can be as low as 30 persons per 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.

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.)).

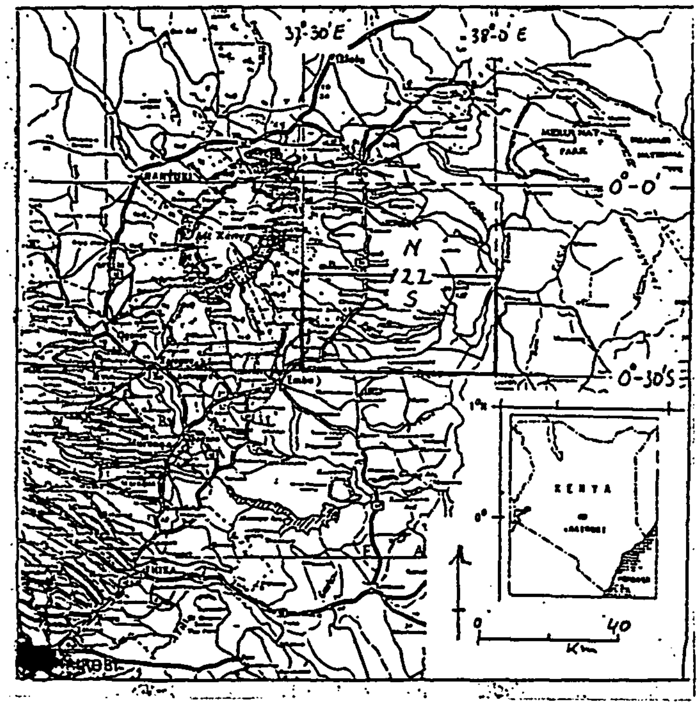


Figure 2.1. Location of the Chuka-South area

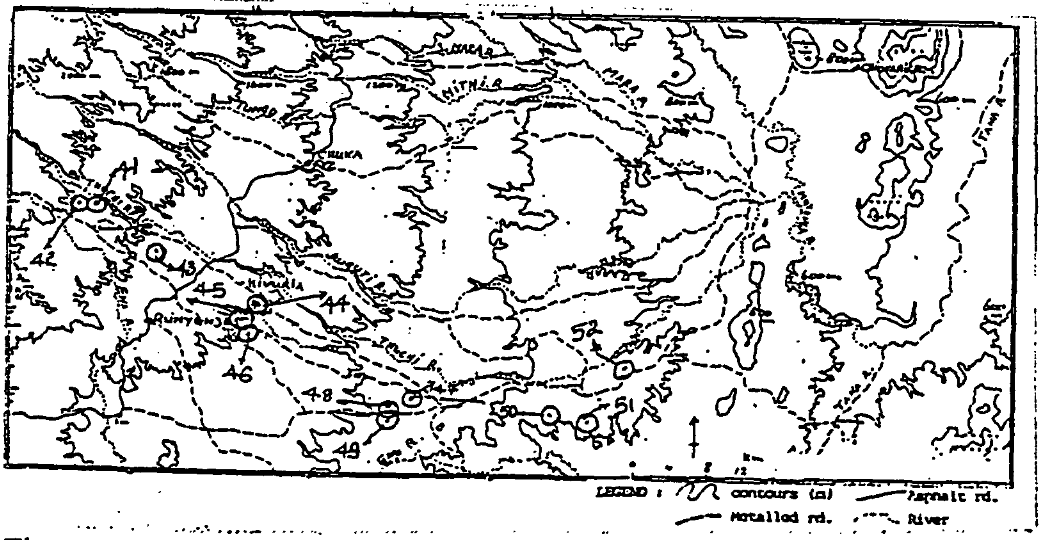


Figure 2.2. Approximate locations of soil monoliths.

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 ($^\circ$)
-elevation (m)
-empirical constants A & B
-MARKOV constant

Average monthly data
-minimum temperature ($^\circ$C)
-maximum temperature ($^\circ$C)
-radiation actually received ($MJ.m^{-2}.d^{-1}$)
-vapour pressure (mbar)---- (either vapour pressure or relative
-relative humidity (%) humidity data is needed)
-wind speed ($m.s^{-1}$)
-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,

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).

Table 3.1.Groups of soil monoliths

Monolith code	Location lat	long	Altitude (in m)	Group number	Representative profile
EAK41	0°,21'15 S	37°,32'30 E	1710	1	EAK41
EAK42	0°,21'20 S	37°,32'10 E	1715		
EAK43	0°,22'50 S	37°,34'35 E	1550	2	EAK43
EAK44	0°,24'40 S	37°,37'40 E	1410		
EAK45	0°,24'50 S	37°,37'30 E	1380	3	EAK44
EAK46	0°,25'00 S	37°,37'25 E	1330		
EAK47	0°,27'05 S	37°,42'00 E	1145		
EAK48	0°,27'05 S	37°,41'55 E	1142	4	EAK47
EAK49	0°,27'10 S	37°,41'51 E	1139		
EAK50	0°,27'10 S	37°,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 3.2 Climate stations from which data were taken for each group of profiles.

Group No		Data type		
	Rain fall	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

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

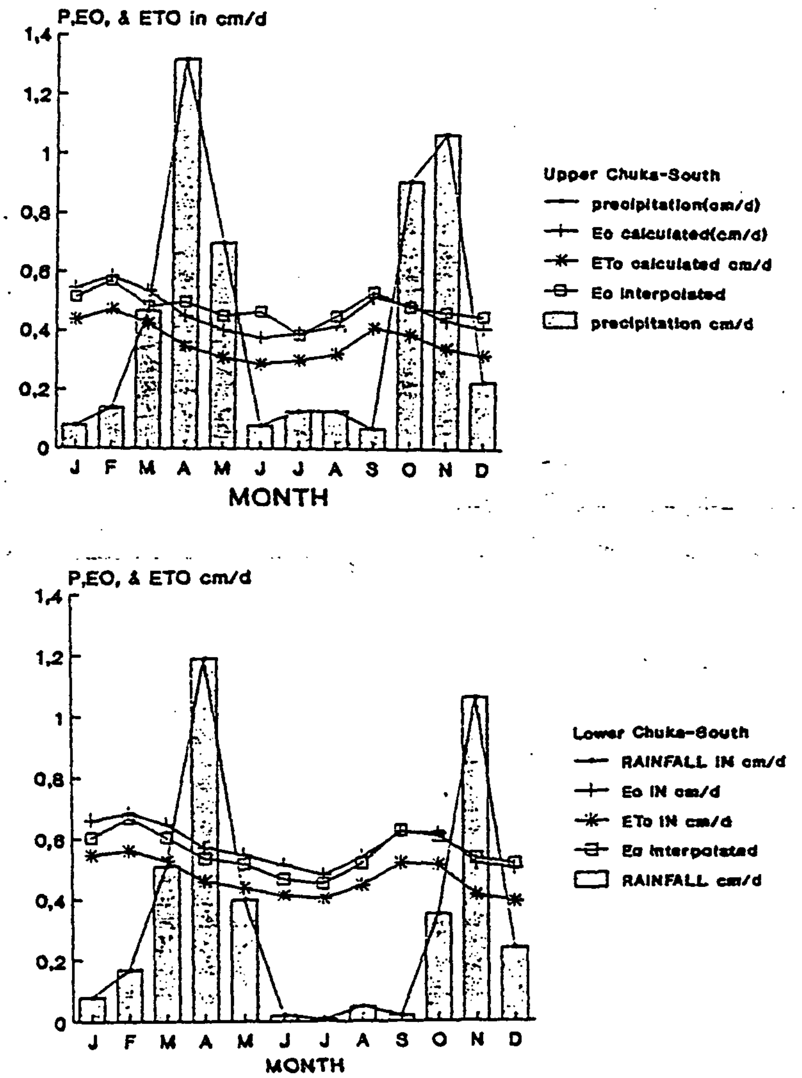


Figure 3.1. Calculated EO and ETO and interpolated EO for upper, middle and lower parts plotted together with rainfall data for Ruyenjes and Kanuyombra stations (upper and middle-lower parts respectively).

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^3 cm^{-3})
-GAM	- texture specific constant (cm^{-2})
-PSImax	- texture specific suction boundary (cm)
-KO	- saturated hydraulic conductivity (cm d^{-1})
-ALFA	- texture-specific geometry constant (cm^{-1})
-AK	- texture-specific empirical constant ($cm^{-2.4}$ d^{-1})
-SO	- reference sorptivity (cm $d^{-0.5}$)
-Ktr	- hydraulic permeability of transmission zone (cm d^{-1})

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.

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^3 cm^{-3})

$BD = W_t/V_t$

where
BD is bulk density (g cm^{-3})
Wt is dry soil sample weight (g)
Vt is sample volume (cm^3)

In 'normal' soil, bulk density values lie between 0.9 and 1.5 g cm^{-3}. 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^{-3}) of the soil material; it may be expressed as:

SD = Wt/Vt

Combination of the above two equations gives:

SMO = 1-BD/SD
SD = 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).

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^3 cm^{-3})
-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).

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

where
SMPSI is volume fraction of moisture in soil with suction PSI (cm^3 cm^{-3}).
SMO is total pore fraction (cm^3 cm^{-3})
GAM is texture-specific constant (cm^{-2})
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 =< PSI_{max} then KPSI = KO*exp(-ALPHA*PSI)
else KPSI = AK*PSI^{-n} (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.)

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, socio-economic 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 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.

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.

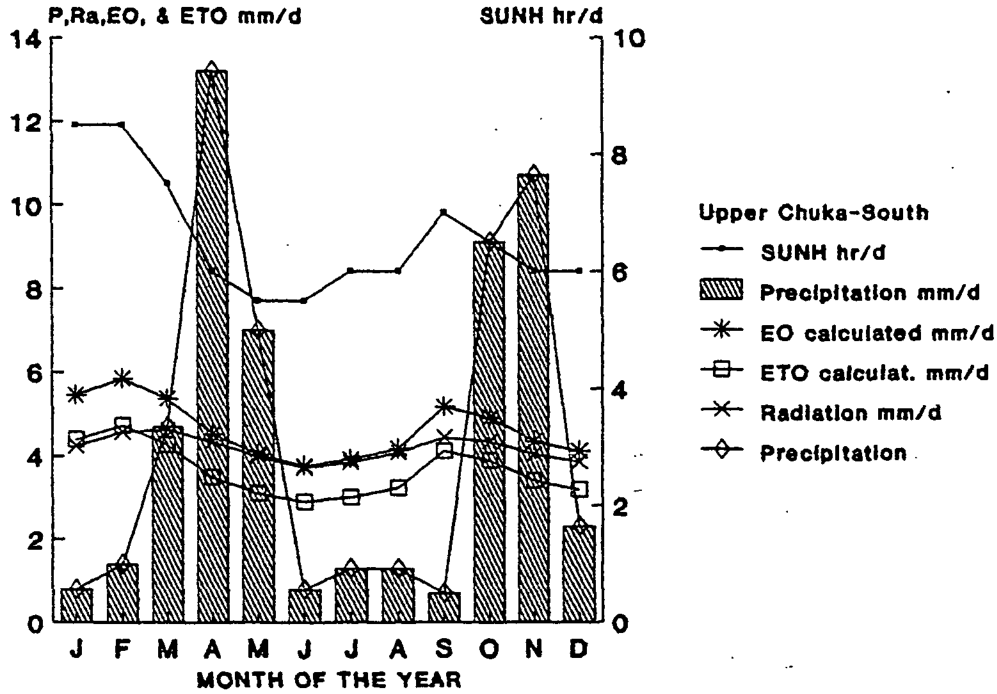


Figure 4.1 Effect of sunshine duration (SUNH), radiation (Ra), and Precipitation (P) on EO & ETO as predicted by the Penman method.

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-limited Production 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	1997	1816
sandy/light clay	1426	1654	1442
Clay loam	3430	3372	3500
Clay	2795	2975	2741

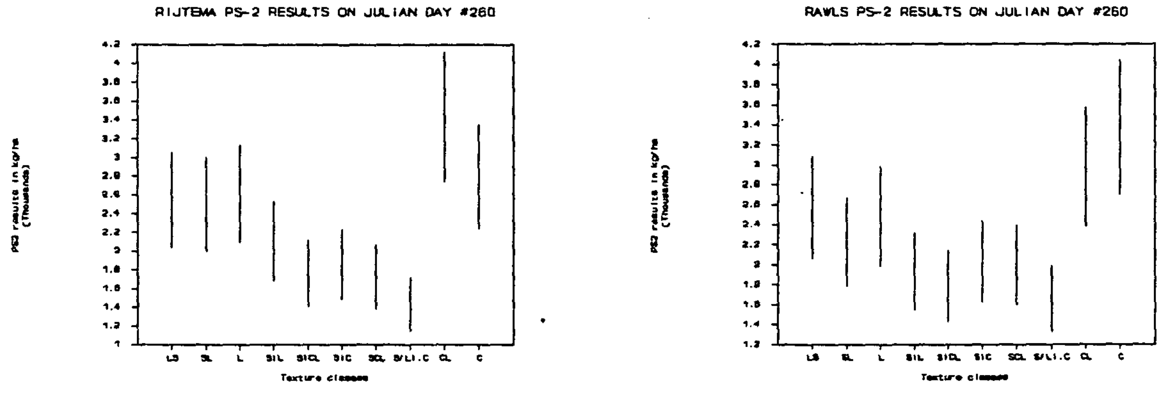


Figure 4.2. Calculated ranges in water-limited production potential of Arjuna maize for various texture classes using Rijtema & Rawls values.

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

Table 4.2 Soil textures aggregated to five groups

Group No	General terms	Average production (kg/ha) Rijtema	Rawls	Carsel	Group members
1	Sandy loam family	2422	2426	2415	loamy sand, sandy loam, loam
2	Silty loam	2106	1932	1851	silty loam only
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

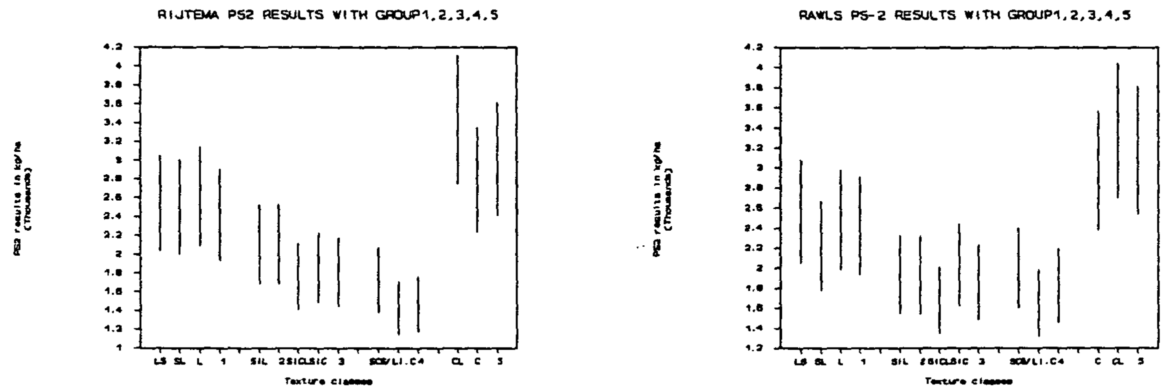


Figure 4.3. Texture classes and calculated water-limited production potentials (±20%) and their group value.

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 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).

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

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).

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

Soil monoliths	ALPHA1	ALPHA2	SMO
EAK41	0.017	0.017	0.520
EAK42	0.024	0.022	0.518
EAK43	0.018	0.015	0.514
EAK44	0.014	0.017	0.553
EAK45	0.017	0.012	0.469
EAK46	0.014	0.013	0.465
EAK47	0.016	0.018	0.422
EAK48	0.016	0.012	0.464
EAK49	0.025	0.027	0.516
EAK50	0.063	0.053	0.459
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.

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

Site	Production Potential & varieties									
	Gen. Maize		cv.ARIS		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	501	19010	640	23692	939	14064	2704	17859	739

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

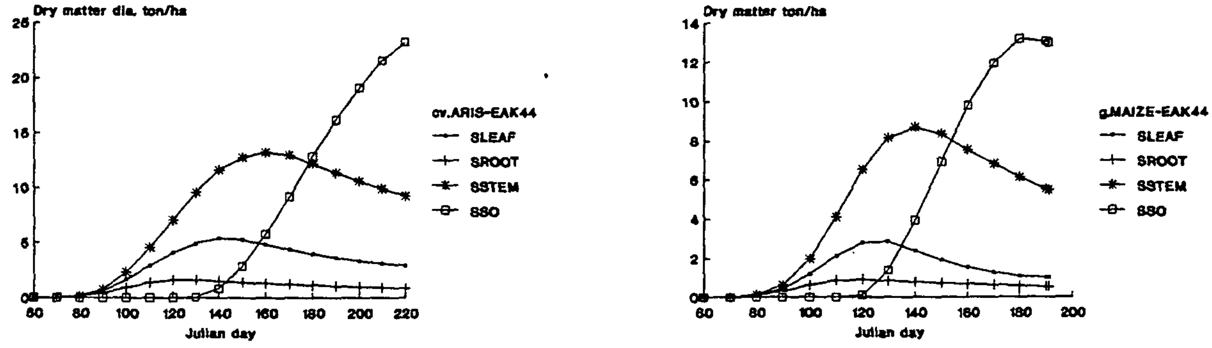


Figure 4.4. Dry matter distribution over organs of cv.ARIS and generic value (generic maize) under production situation 1 (PS-1). **Note that** specific crop characteristics give different model results.

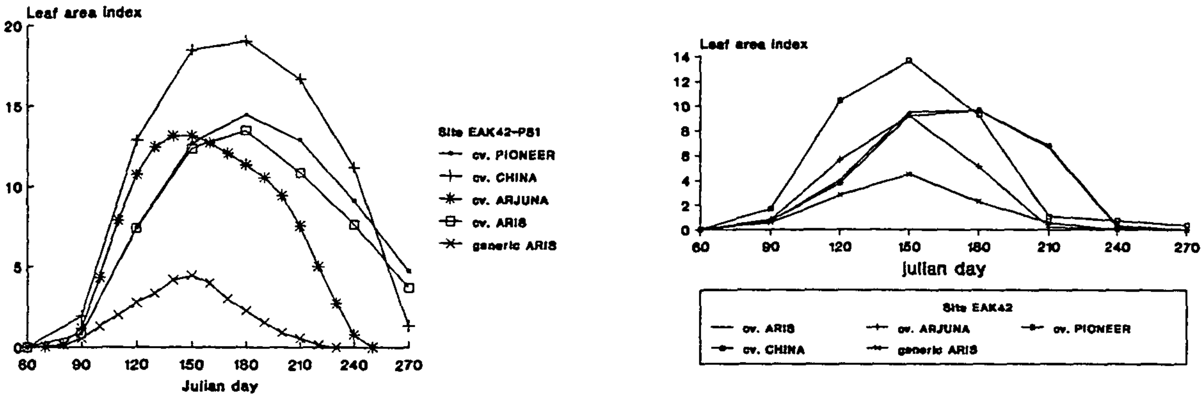


Figure 4.5.LAI for each variety during the growing period. Note the difference between generic value and others.

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.

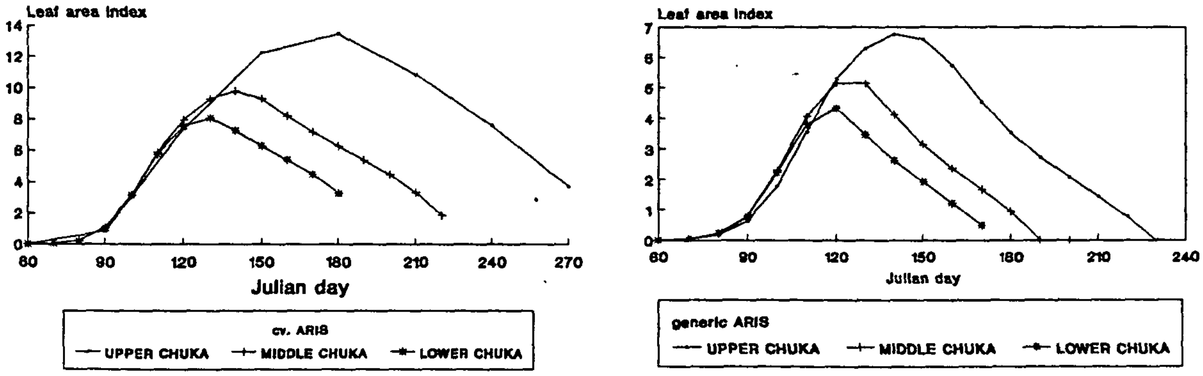


Figure 4.6. Reduction of total biomass and length of growth period going from west to east, indicated by leaf area index of cv.ARIS and generic value.

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°C, the crop matures early and total dry weight decreases from almost 18 ton (at TO = 10.5°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°C was gradual while at TO = 10.5°C it was not gradual.

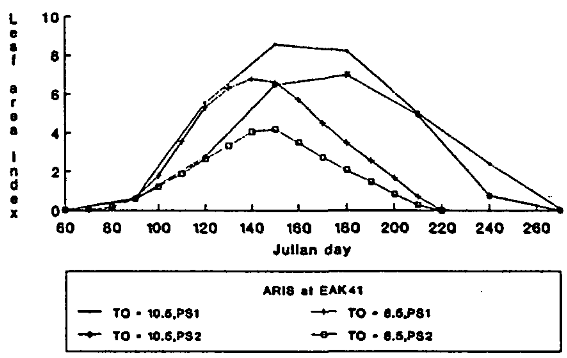


Figure 4.7.LAI of cv ARIS at PS-1 and PS-2 levels using various TO values.

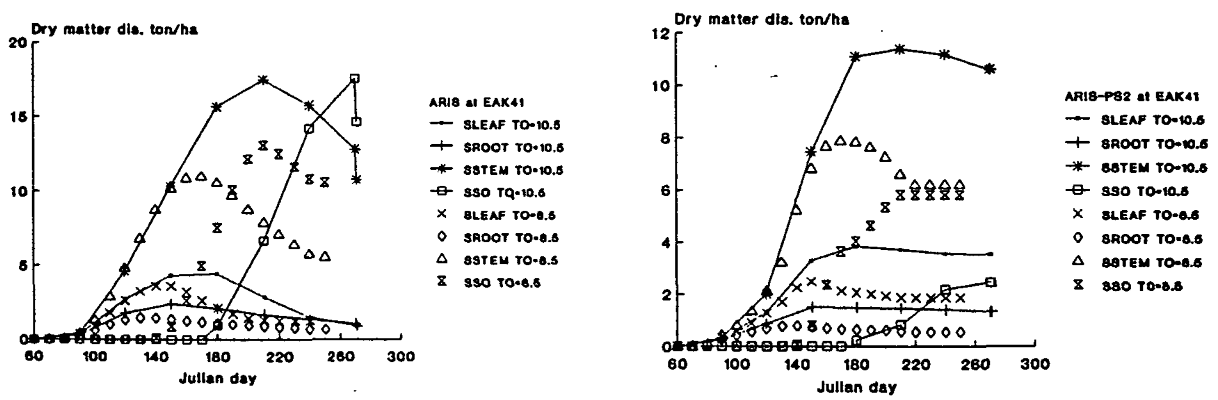


Figure 4.8.Dry matter distribution of cv. ARIS at PS-1 and PS-2 levels using various TO values. **Note that** SSO under PS-2 is considerably less at TO = 10.5 than at TO = 8.5

-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	Production 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.

-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.

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

Site	Production Potentials (kg/ha)		
	PS1	PS2	
		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

-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.

Order	Class	Description	Relative yield
S-suitable	S1	highly suitable	80-100%
	S2	moderately suitable	40-80%
	S3	marginally suitable	20-40%
N-not-suitable	N1/N2	not suitable	<20%

Table 4.8.Yield ranges for each suitability class

Class	Relative yield	Yield range (in kg/ha) Maize	Wheat
S1	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.

Soil units (Monoliths)	Land utilization type Maize (generic)	Wheat (china)
EAK41	S1	S1
EAK42	S1	S1
EAK43	S3	S3
EAK44	S1	S1
EAK45	S3	S2
EAK46	S3	S3
EAK47	N*	S1
EAK48	N	S2
EAK49	S1	S1
EAK50	N	S2
EAK51	N	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.

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.).

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

Site	Yield (in kg/ha) LUTs		Gross margin (in Ksh/ha/yr) LUTs		
	MTA	MTC (MTP)*	MTA	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

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

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

Soil units (Monoliths)	Physical LUTs		Economic LUTs		
	MTA	MTC (MTP)*	MTA	MTC	MTP**
EAK41	S1	S1	S2	S2	S3
EAK42	S2-2AFH	S2-2AFH	S2	S2	S3
EAK43	S2-2AFH	S2-2AFH	S3	N1	N1
EAK44	S1	S1	S1	S1	S1
EAK45	S2-2AFH	S2-2AFH	N1	N1	N1
EAK46	S2-2AFH	S2-2AFH	S3	N1	N1
EAK47	N-4MA/AO	N-4MA/AO	N2	N2	N2
EAK48	N-4MA	N-4MA	N2	N2	N2
EAK49	S1	S1	S1	S1	S1
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

*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).

-PS2

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.

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

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

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

ASAG = 60.5-2.1 = 58.4 kg ha^{-1} 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 kg ha^{-1} 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 kg ha^{-1} d^{-1}
WRT = 40 + 14.3*10 = 183 kg ha^{-1} (for ten days interval)
IWLV = 0.395*40.9 = 16.2 kg ha^{-1} d^{-1}
WLV = 100 + 16.2*10 = 262 kg ha^{-1}
IWST = 0.225*40.9 = 10.4 kg ha^{-1} d^{-1}
WST = 0 + 10.4*10 = 104 kg ha^{-1}

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

TDW = WRT + WLV + WST = 549 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^{-1} d^{-1}

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 kg ha^{-1} d^{-1}
GAA(lv) = 0.395*60.5 = 23.9 kg ha^{-1} d^{-1}
GAA(st) = 0.225*60.5 = 15.43 kg ha^{-1} 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 kg ha^{-1} d^{-1}

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

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

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

S(st) = 0 + 106.44 = 106.44 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 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^{-1}

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^{th} decade.

Period	Fgass	Frt	Flv	Fst	Fso	WRT	WLV	WST	WSO	MRES	TDW
(decade)						40	100				
1	60.5	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	671	2398	3176	879	88.5	7124
6.2	316.0	0.0	0.0	0.0	1.00	671	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 6th decade.

Period (decade)	Fgass	Frt	Flv	Fst	Fso	WRT	WLV	WST	WSO	MRES	TDW
						40	100				
1	60.5	0.350	0.395	0.255	0	183	262	104	0	3.4	545
2	127.2	0.165	0.445	0.390	0	327	604	437	0	11.0	1368
3	216.0	0.075	0.480	0.445	0	420	1220	1055	0	28.0	2695
4	260.4	0.070	0.400	0.530	0	521	1710	1898	0	56.6	4129
5	295.0	0.070	0.265	0.665	0	632	1903	3055	0	85.0	5590
6.1	316.0	0.025	0.060	0.225	0.69	640	1711	3178	1129	109.2	6658
6.2	316.0	0.0	0.0	0.0	1.00	626	1606	3079	1822	106.3	7133

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.

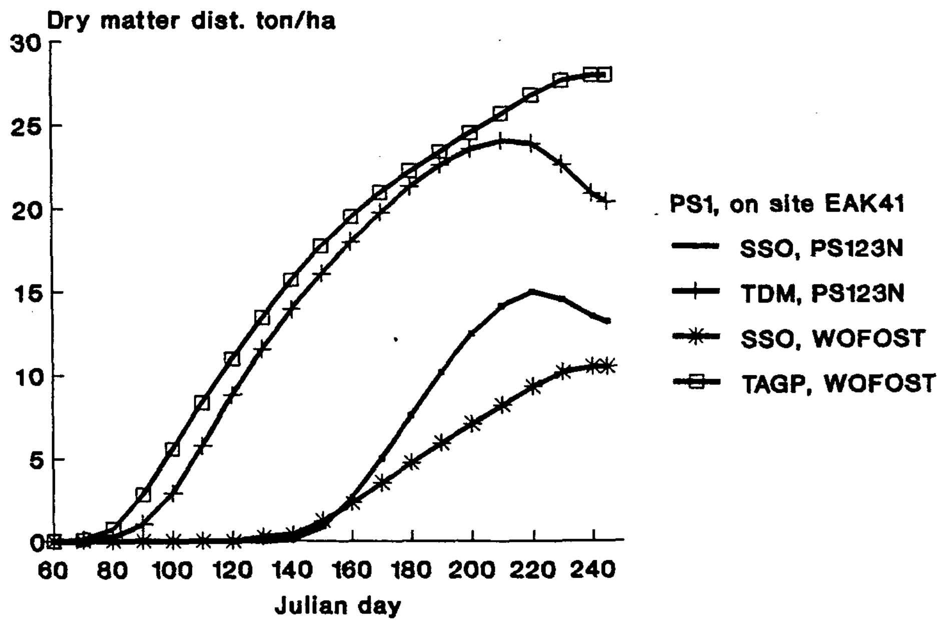


Figure 5.1. Dry matter allocation to storage organs relative to the total biomass as predicted by WOFOST and PS123N when maize is assumed to germinate on julian day #60. **Note that** TAGP represents the weight of above-ground dry matter, i.e., root weight is not considered.

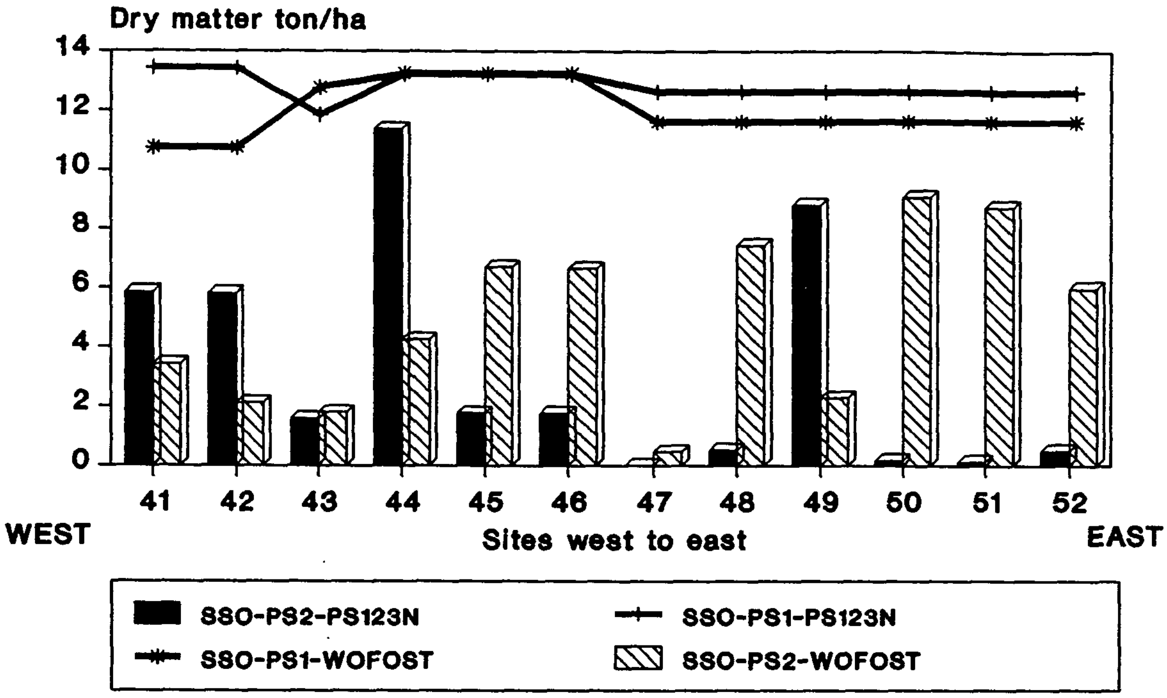


Figure 5.2. Calculated SSO under PS-1 & PS-2 conditions for all study sites as predicted by WOFOST and PS123N. In all cases maize is assumed to germinate on julian day #60.

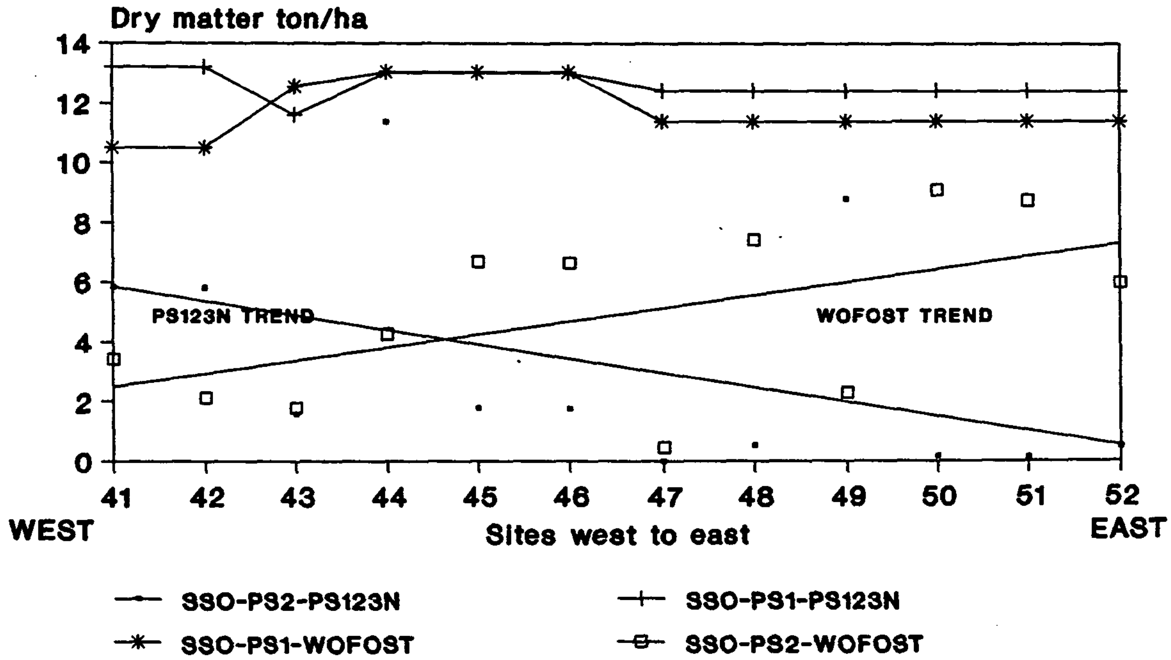


Figure 5.3. Trend of maize yield prediction under PS-2 condition by WOFOST and PS123N, form west to east.

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.

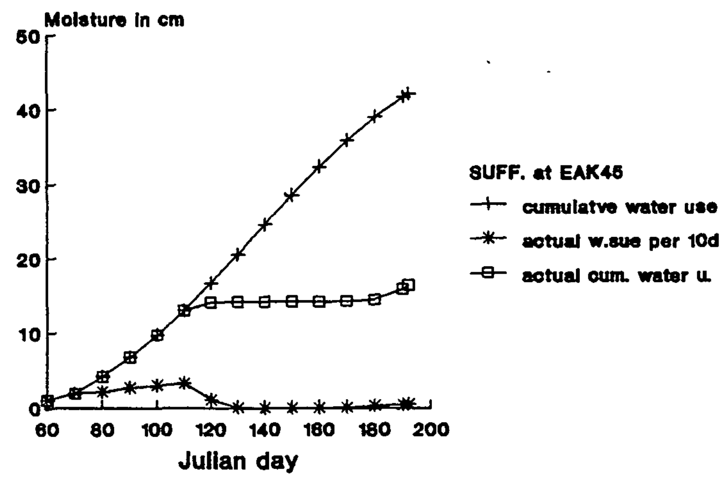


Figure 5.5 Comparison of required with actual water use

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.

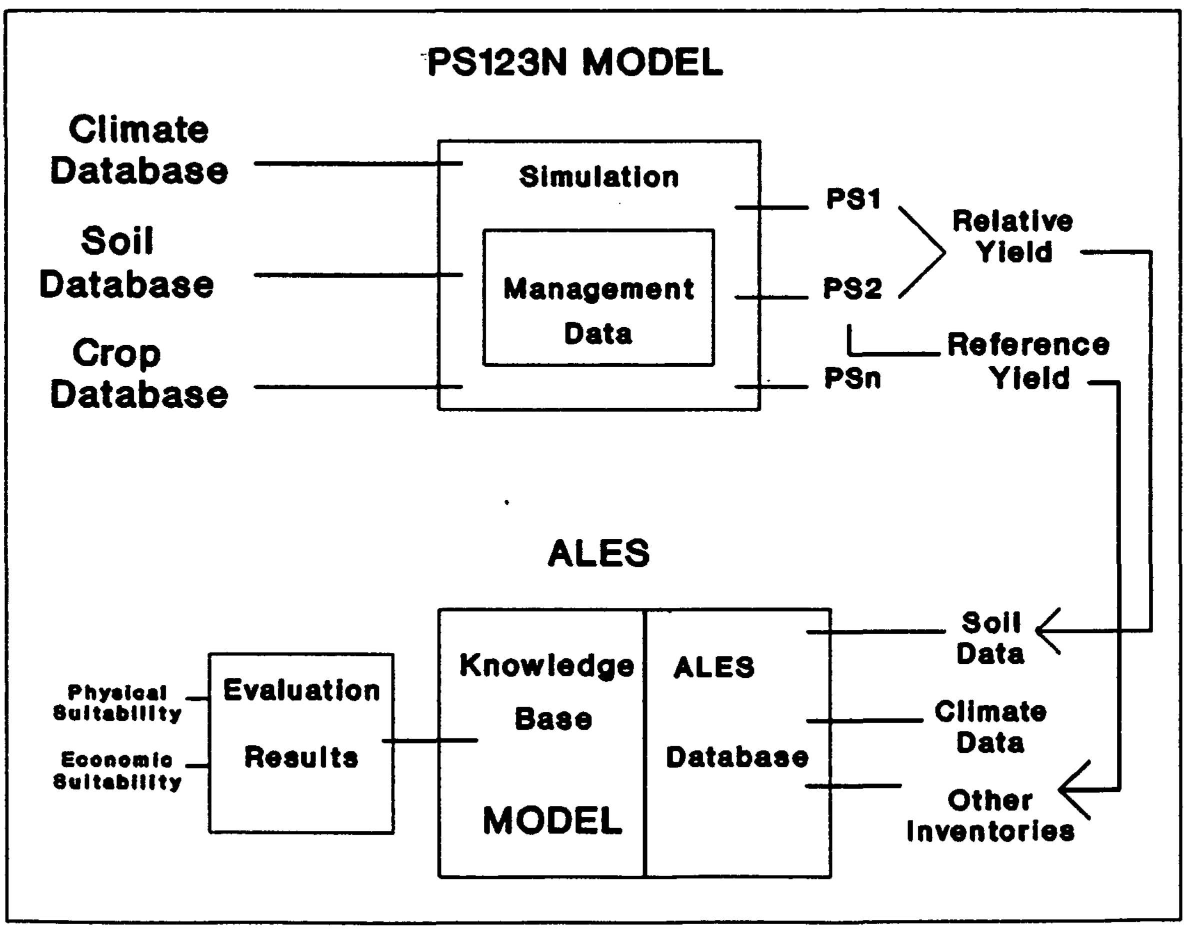


Figure 5.4. Information flow from PS123N to ALES.

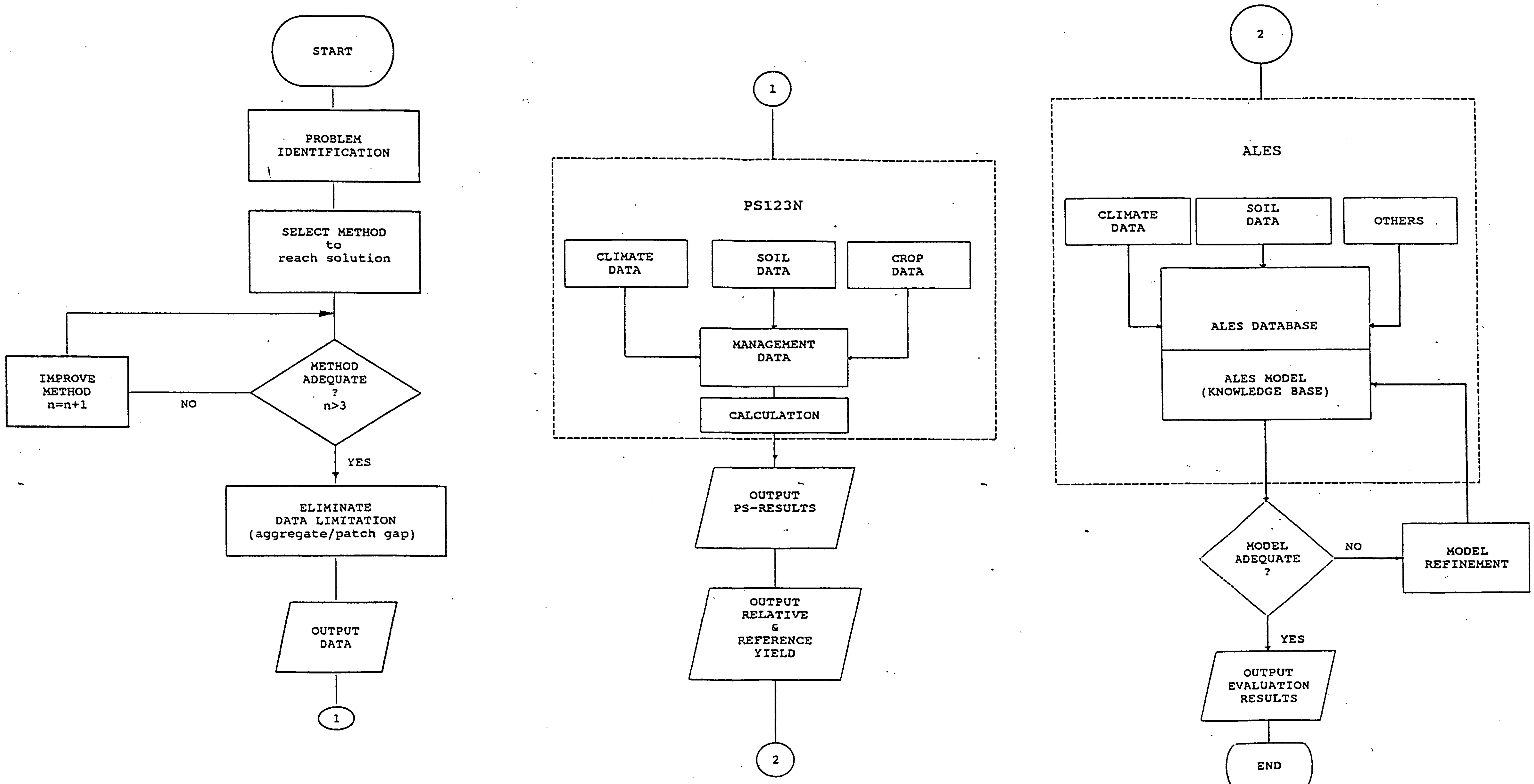


Figure 5.5 Designed three stages approach of land evaluation

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

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

```
DtId Type                            Where Used
---------------------------------------------------------------------------------
22   Severity Level                  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)
         .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
-------------------------------------------------------------------------------------
18   Proportional Yield                  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
         ?....................... : ?
      ?....................... : ?
   2 (moderate stress) > RE (Erosion hazard)
      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
         ?....................... : ?
      ?....................... : ?
   3 (moderate to seve) > RE (Erosion hazard)
      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
---------------------------------------------------------------------------
18   Proportional Yield             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
         ?...................... : ?
      ?...................... : ?
   4 (severe stress) > RE (Erosion hazard)
      1 (almost none) > NA (nutrient availability)
         1 (high)............... : .202
         2 (moderate)........... : .146
         3 (low)................ : .101
         4 (very 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
         ?...................... : ?
      ?...................... : ?
   ?...................... : ?
```

```
GZ-MV (Chuka Area, KENYA)
DtId Type                                   Where Used
---------------------------------------------------------------------------
17   Physical Subclass                      MTA
 > RE (Erosion hazard)
   1 (almost none) > MA (MOISTURE AVAILABILITY)
      1 (none to slight ) > NA (nutrient availability)
         1 (high)................ : 1
         2 (moderate)............ : =1
         3 (low)................. : =1
         4 (very low)............ : 4NA
         ?....................... : ?
      2 (moderate stress)..... : =1
      3 (moderate to seve).... : =1
      4 (severe stress) > NA (nutrient availability)
         1 (high)................ : 4MA
         2 (moderate)............ : =1
         3 (low)................. : =1
         4 (very low)............ : 4NA/MA
         ?....................... : ?
      ?....................... : ?
   2 (slight).............. : =1
   3 (moderate)............ : =1
   4 (severe) > MA (MOISTURE AVAILABILITY)
      1 (none to slight ) > NA (nutrient availability)
         1 (high)................ : 4RE
         2 (moderate)............ : =1
         3 (low)................. : =1
         4 (very low)............ : 4RE/NA
         ?....................... : ?
      2 (moderate stress)..... : =1
      3 (moderate to seve).... : =1
      4 (severe stress) > NA (nutrient availability)
         1 (high)................ : 4RE/MA
         2 (moderate)............ : =1
         3 (low)................. : =1
         4 (very low)............ : 4NA/MA/NA
         ?....................... : ?
      ?....................... : ?
   ?....................... : ?
```

Figure 3.3. Physical suitability subclass decision tree

```
GZ-MV (Chuka Area, KENYA)
DtId Type                                   Where Used
---------------------------------------------------------------------------
13   Proportional Yield                     MTC,MZT
 > 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
      ?....................... : ?
   ?....................... : ?
```

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

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

GZ-MV (Chuka Area, KENYA)

LC Id	Class	Class Code	LC Name / Class Name	Classes	Upper limit	Units	Infer from
C%			Organic carbon % for T-zone 4,	4		%	
	1	<.5	v.low		.5		
	2	.5-1	low		1		
	3	1.1-2	moderate		2		
	4	>2	high		5		
C-2 %			Organic carbon % for T-zone 1,	4		%	
	1	<1	v.low		1		
	2	1-1.5	low		1.5		
	3	1.6-2.5	moderate		2.5		
	4	>2.5	high		4		
Dr			soil drainage	5			
	1	we	well to excessively drain				
	2	mw	moderatly well drained				
	3	i	Imperfectly drained				
	4	p	poorly drained				
	5	vp	very poorly drained				
ECEC			Effective cation exchange capa	4		me/100g	
	1	0-2	v.low		2		
	2	2-4	low		4		
	3	4-10	moderate		10		
	4	10-20	high		20		
Ert			privous top soil erosion statu	4			
	1	n	nill				
	2	sl	slightly eroded				
	3	m	moderatly eroded				
	4	s	severly eroded				
Per			soil permeablity	7		cm/d	
	1	vs	very slow				
	2	s	slow				
	3	ms	moderately slow				
	4	m	moderate				
	5	mr	moderately rapid				
	6	r	rapid				
	7	vr	very rapid				
Pm			Average annual rain fall	5		centimeter	
	1	45-90	semi-arid rain fall		90		
	2	60-110	semi-humid to semi-arid		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			Relative moisture availability	4			
	1	s1	0.7-1				
	2	s2	0.4-0.7				
	3	s3	0.1-0.4				
	4	N	0-0.1				

GZ-MV (Chuka Area, KENYA)

LC Id		LC Name / Class Code	Class Name	Classes / Upper limit	Units	Infer from
SA		Soil acidity (pH-H20)		4	MS	
	1	<4	acidic	4		
	2	4-4.7	moderately acidic	4.7		
	3	4.8-5.5	slightly acidic	5.5		
	4	5.6-6.8	almost neutral	6.8		
SB		Soil basisity (pH-H2O)		4	MS	
	1	5.6-6.8	almost neutral	6.8		
	2	6.9-7.5	neutral to basic	7.5		
	3	7.6-8.7	moderately basic	8.7		
	4	>8.7	basic	10		
Sd		Soil depth		3	cm	
	1	s	shallow	50		
	2	m	moderate	80		
	3	d	deep	120		
Sla		slope angle		5	%	
	1	0-8	almost flat	8		
	2	8-16	gentle	16		
	3	16-30	moderately steep	30		
	4	30-70	steep	70		
	5	>70	very steep	90		
Texg		soil texture class groups base		5		
	1	g1slf	group1 sandy loam family			
	2	g2sil	group2 silty loam			
	3	g3sicl	group3 silty clay loam fa			
	4	g4scl	group4 sandy clay family			
	5	g5cl	group5 clay and caly loam			
Tma		mean annual temperature		6	°C	
	1	14-16	fairly cool	16		
	2	16-18	cool temperate	18		
	3	18-20	warm temperate	20		
	4	20-22	fairly warm	22		
	5	22-24	warm	24		
	6	24-30	fairly hot to hot	30		

```
GZ-MV (Chuka Area, KENYA)
LMU ID      LMU Name
    LC code      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           s3 (0.1-0.4)
    SA           4.8-5.5 (slightly acidic)  [4.7-5.5]
    Sd           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]
```

GZ-MV (Chuka Area, KENYA)

LMU ID / LC code	LMU Name / data
EAK44	**EAK44-Chuka, humic Nitosol, clay**
C-2 %	1.6-2.5 (moderate) [1.5-2.5]
Dr	mw (moderatly well drained)
ECEC	10-20 (high) [10-20]
Ert	n (nill)
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]
Texg	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 (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 (moderate) [1.5-2.5]
Dr	mw (moderatly well drained)
ECEC	4-10 (moderate) [4-10]
Ert	n (nill)
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	0-8 (almost flat) [0-8]
Texg	g3sicl (group3 silty clay loam family)
Tma	20-22 (fairly warm) [20-22]

```
GZ-MV (Chuka Area, KENYA)
LMU ID      LMU Name
    LC code      data
---------------------------------------------------------------------------------
EAK47       EAK47-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       EAK48-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 (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         g3sicl (group3 silty clay loam family)
    Tma          22-24 (warm)  [22-24]

EAK49       EAK49-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           sl (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]
    Texg         g5cl (group5 clay and caly loam family)
    Tma          22-24 (warm)  [22-24]
```

GZ-MV (Chuka Area, KENYA)

LMU ID / LC code	LMU Name / data
EAK50	EAK50-Chuka, chromic luvisol, sandy clay
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	EAK51-Chuka, chromic luvisol, sandy clay
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	EAK52-Chuka, calcic luvisol, silty cl.lo
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 SM0, GAM, PSI_{max}, K0, ALFA and AK for reference soil texture classes. Source: Rijtema (1969).

Texture	SM0 (cm^3 cm^{-3})	GAM (cm^{-1})	PSI_{max} (cm)	K0 (cm d^{-1})	ALFA (cm^{-1})	AK ($cm^{-2.4}$ d^{-1})
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	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_r	θ_s	α 1/cm	n	K_s cm/d
Sand	0.020	0.417	0.138	1.592	504.0
Loamy sand	0.035	0.401	0.115	1.474	146.6
Sandy loam	0.041	0.412	0.068	1.322	62.16
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	1.131	1.44

Average values for selected soil water retention and hydraulic conductivity parameters for 12 major soil textural groups according to *Carsel and Parrish* [1988]

Texture	θ_r	θ_s	α 1/cm	n	K_s cm/d
Sand	0.045	0.43	0.145	2.68	712.8
Loamy Sand	0.057	0.41	0.124	2.28	350.2
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	1.41	10.80
Sandy Clay Loam	0.100	0.39	0.059	1.48	31.44
Clay Loam	0.095	0.41	0.019	1.31	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	2.88
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
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12,22.9,11.3,.23,.81,.411,6,.319,18.82,4.68

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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
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1,26.4,13.6,.08,.65,.6,9,.491,23.64,7.04
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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
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7,21.4,13.1,.13,.76,.403,5.5,.32,18.26,4.53
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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
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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
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6,22.8,14.4,.08,.84,.448,7.5,.341,20.97,5.27
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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
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12,25.7,13.6,.23,.81,.472,7.5,.366,21.05,5.22

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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
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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,.621,7.5,.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
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"EAK48",-.27,37.41,1142
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9,28.3,14.6,.02,.65,.621,7.5,.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,.621,7.5,.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   TMAX IRRAT    VAPP  RHUM WIND  RAINT RAIND
EAK41 - Kenya
   -.21 1710.  0.25  0.45  1.0
   11.0   24.1 22.880     -1    70  3.2    25.     3.
   11.1   25.1 23.790     -1    71  3.2    40.     5.
   11.7   25.1 22.860     -1    73  2.0   146.    13.
```

```
    11.9    23.7 20.180      -1     84   1.4    396.      24.
    11.2    22.8 18.560      -1     87   1.4    218.      16.
    10.0    21.7 18.020      -1     84   1.1     25.       3.
     9.9    20.7 19.020      -1     82   1.2     41.       5.
    10.0    21.4 19.870      -1     80   1.1     42.       5.
    10.3    23.9 22.050      -1     73   2.2     21.       3.
    12.2    24.3 20.970      -1     75   2.0    284.      20.
    12.5    22.5 19.370      -1     81   1.8    321.      22.
    11.3    22.9 18.820      -1     81   1.5     73.       8.
EAK43 - Kenya
    -.22 1550.  0.25  0.45  1.0
    13.6    26.4 22.890      -1     65   3.2     25.       3.
    13.6    29.3 23.790      -1     63   3.2     40.       5.
    14.9    27.9 22.860      -1     66   2.0    146.      13.
    15.8    25.8 20.170      -1     77   1.4    396.      24.
    15.7    24.0 18.560      -1     85   1.4    218.      16.
    14.4    22.8 18.010      -1     84   1.1     25.       3.
    13.1    21.4 19.010      -1     76   1.2     41.       5.
    13.0    21.7 19.870      -1     82   1.1     42.       5.
    13.3    24.4 22.050      -1     69   2.2     21.       3.
    14.2    25.9 20.970      -1     70   2.0    284.      20.
    14.6    24.2 19.370      -1     81   1.8    321.      22.
    13.6    25.7 18.830      -1     81   1.5     73.       8.

EAK44 - Kenya
    -.25 1410.  0.25  0.45  1.0
    13.6    26.4 23.640      -1     65   3.2     25.       3.
    13.6    29.3 24.580      -1     63   3.2     40.       5.
    14.9    27.9 24.480      -1     66   2.0    146.      13.
    15.8    25.8 20.970      -1     77   1.4    396.      24.
    15.7    24.0 20.840      -1     85   1.4    218.      16.
    14.4    22.8 20.970      -1     84   1.1     25.       3.
    13.1    21.4 18.260      -1     76   1.2     41.       5.
    13.0    21.7 19.870      -1     82   1.1     42.       5.
    13.3    24.4 22.860      -1     69   2.2     21.       3.
    14.2    25.9 22.560      -1     70   2.0    284.      20.
    14.6    24.2 20.140      -1     81   1.8    321.      22.
    13.6    25.7 21.050      -1     81   1.5     73.       8.

EAK47 - Kenya
    -.27 1145.  0.25  0.45  1.0
    13.4    28.6 24.400      -1     67   3.2     27.       3.
    14.2    30.4 25.360      -1     67   2.4     49.       5.
    15.9    29.8 24.480      -1     70   2.3    161.      14.
    17.3    28.7 22.560      -1     73   1.8    359.      25.
    16.6    27.8 21.590      -1     77   2.5    127.      11.
    15.2    26.6 20.960      -1     73   2.4      6.       1.
    14.0    25.9 18.260      -1     68   2.7      4.       1.
    14.7    26.1 20.650      -1     68   2.8     16.       2.
    14.6    28.3 22.860      -1     65   2.7      7.       1.
    15.8    29.4 22.560      -1     65   2.4    109.      10.
    16.8    27.2 20.140      -1     79   2.5    318.      21.
    15.2    26.8 21.060      -1     83   2.4     75.       8.

EAK50 - Kenya
    -.19  950.  0.25  0.45  1.0
    13.4   28.6  24.390      -1     67   3.2     27.       3.
    14.2   30.4  25.350      -1     67   2.4     49.       5.
    15.9   29.8  24.470      -1     70   2.3    161.      14.
    17.3   28.7  22.560      -1     73   1.8    359.      25.
    16.6   27.8  21.610      -1     77   2.5    127.      11.
    15.2   26.6  20.980      -1     73   2.4      6.       1.
    14.0   25.9  18.270      -1     68   2.7      4.       1.
    14.7   26.1  20.660      -1     68   2.8     16.       2.
    14.6   28.3  22.860      -1     65   2.7      7.       1.
    15.8   29.4  22.560      -1     65   2.4    109.      10.
    16.8   27.2  20.130      -1     79   2.5    318.      21.
    15.2   26.8  21.040      -1     83   2.4     75.       8.
```

Galole - Kenya

-1.5	100.	0.25	0.45	1.0			
22.5	34.2	20.983	26.3	-1	1.4	35.	4.
23.1	35.3	22.879	26.3	-1	1.4	19.	2.
23.2	34.8	23.242	28.3	-1	1.5	34.	4.
22.2	34.0	20.878	28.2	-1	2.0	56.	6.
21.5	33.1	19.561	26.8	-1	2.7	30.	4.
21.0	31.2	17.445	25.7	-1	2.9	20.	3.
19.0	31.1	17.514	24.0	-1	3.2	21.	3.
19.0	31.3	17.731	23.3	-1	3.0	13.	2.
20.0	32.1	18.314	24.2	-1	3.1	49.	5.
21.0	32.3	20.050	26.7	-1	2.4	38.	4.
22.2	33.1	21.323	29.0	-1	1.5	94.	10.
22.0	33.2	21.738	27.8	-1	1.3	61.	7.

Garissa - Kenya

-0.5	147.	0.25	0.45	1.0			
22.1	35.5	20.241	23.5	-1	1.3	10.	2.
22.7	36.0	20.198	24.0	-1	1.3	6.	1.
24.3	36.0	20.151	25.2	-1	1.6	26.	3.
24.3	36.0	19.347	26.2	-1	1.9	55.	6.
23.2	35.0	17.575	24.5	-1	2.6	17.	2.
21.6	32.7	16.530	22.1	-1	2.5	5.	1.
21.0	32.1	16.555	20.8	-1	2.9	2.	1.
21.0	32.7	17.180	20.7	-1	3.2	5.	1.
21.6	33.8	18.804	21.2	-1	3.0	4.	1.
22.7	35.0	20.193	22.6	-1	2.5	22.	3.
23.8	35.0	19.905	25.1	-1	1.9	65.	7.
23.2	34.3	19.470	25.5	-1	1.0	65.	7.

Kericho - Kenya

-0.6	2070.	0.25	0.45	1.0			
11.1	26.3	22.364	12.3	-1	1.5	48.	5.
11.1	26.5	23.471	12.3	-1	1.4	83.	9.
11.5	26.1	22.594	13.0	-1	1.3	124.	12.
12.2	24.0	17.579	14.5	-1	1.1	239.	17.
11.3	23.1	18.463	14.7	-1	1.2	183.	15.
11.6	22.2	18.898	13.6	-1	1.3	154.	13.
10.7	21.8	16.808	13.5	-1	1.3	99.	10.
10.5	22.5	16.905	13.5	-1	1.4	126.	12.
10.1	23.0	18.419	13.3	-1	1.5	117.	11.
10.3	23.8	17.468	13.5	-1	1.4	78.	8.
10.5	24.1	17.381	13.5	-1	1.3	83.	9.
11.3	23.8	20.065	13.0	-1	1.6	116.	11.

Kisumu - Kenya

-0.1	1146.	0.25	0.45	1.0			
17.1	30.5	19.810	16.3	-1	1.5	57.	7.
17.5	31.0	22.067	16.5	-1	1.6	70.	8.
17.8	30.5	18.443	17.8	-1	1.4	160.	12.
18.0	28.7	20.658	19.5	-1	1.1	195.	18.
17.5	28.0	18.671	19.5	-1	0.9	177.	17.
16.5	27.8	20.857	18.1	-1	1.1	101.	12.
16.2	27.5	17.834	17.3	-1	1.1	68.	10.
16.2	28.0	18.990	17.2	-1	1.3	96.	12.
16.2	29.2	24.686	17.0	-1	1.3	79.	11.
17.0	30.5	21.394	16.7	-1	1.3	64.	11.
17.3	30.2	21.184	17.0	-1	1.2	106.	11.
17.2	30.0	21.821	17.0	-1	1.2	105.	10.

Kitale Airport - Kenya

1.0	1875.	0.25	0.45	1.0			
10.0	27.3	21.082	12.1	-1	2.0	30.	4.
10.3	27.7	21.763	12.0	-1	2.0	26.	3.
11.5	27.2	21.137	13.1	-1	2.0	74.	8.
12.6	26.0	19.755	15.3	-1	2.0	145.	13.
12.3	24.8	19.062	16.1	-1	2.0	156.	13.
11.3	24.0	17.927	15.3	-1	1.8	124.	12.
11.5	22.8	16.159	15.1	-1	1.8	161.	14.

11.1	23.5	16.872	15.1	-1	2.0	164.	14.
10.6	24.7	19.345	15.0	-1	2.0	115.	11.
11.0	25.5	19.382	14.6	-1	2.0	105.	11.
10.6	25.2	19.178	14.1	-1	2.0	82.	9.
10.5	25.6	19.503	13.3	-1	2.0	59.	6.

Machakos school - Kenya

-1.5 1680. 0.25 0.45 1.0

13.6	26.2	24.805	17.2	-1	2.0	49.	5.
13.7	27.6	25.351	17.1	-1	1.4	53.	6.
14.5	26.7	23.557	18.2	-1	1.7	124.	12.
14.7	25.3	20.475	18.8	-1	1.5	210.	16.
14.2	24.2	18.932	18.0	-1	1.7	76.	8.
12.7	23.2	18.115	15.6	-1	1.5	12.	2.
11.6	22.5	15.813	15.1	-1	1.7	5.	1.
12.2	22.7	14.998	15.0	-1	1.8	6.	1.
12.5	24.8	20.153	15.1	-1	1.8	9.	1.
13.3	26.1	22.159	16.2	-1	2.0	53.	6.
14.5	25.0	20.919	17.8	-1	1.8	189.	15.
14.3	24.2	21.514	17.6	-1	2.2	122.	12.

Mombasa Town - Kenya

-4.1 16. 0.25 0.45 1.0

24.1	31.5	20.840	28.2	-1	2.2	25.	3.
24.5	32.2	22.233	28.5	-1	2.0	17.	2.
25.1	32.5	22.341	30.0	-1	1.7	65.	7.
24.6	31.1	19.359	30.1	-1	1.5	200.	16.
23.3	29.0	16.468	28.3	-1	1.7	325.	22.
22.5	28.2	17.238	26.2	-1	2.0	118.	11.
21.7	27.6	16.358	25.0	-1	2.0	91.	10.
21.5	27.7	19.055	25.1	-1	2.0	64.	7.
22.0	28.3	20.849	25.5	-1	2.0	63.	7.
23.0	29.5	21.811	27.0	-1	2.0	86.	9.
23.7	30.8	22.227	29.0	-1	1.7	98.	10.
24.0	31.3	21.270	29.6	-1	1.8	59.	6.

Nairobi (Dag. Corner) - Kenya

-1.3 1798. 0.25 0.45 1.0

11.3	24.5	22.495	14.2	-1	2.3	88.	9.
10.5	25.6	24.127	13.6	-1	2.2	70.	7.
12.5	25.5	22.389	15.0	-1	2.2	96.	13.
13.6	24.1	18.689	16.0	-1	1.8	155.	17.
12.8	22.8	16.392	15.8	-1	1.3	189.	18.
10.5	22.1	15.622	13.7	-1	1.2	29.	5.
9.3	20.8	12.780	13.1	-1	1.1	17.	5.
9.7	21.8	13.616	13.0	-1	1.3	20.	5.
10.1	23.6	17.913	13.3	-1	1.5	34.	7.
12.3	24.7	19.282	13.7	-1	2.0	64.	8.
12.7	23.1	18.751	15.2	-1	2.2	189.	16.
12.5	23.2	20.240	15.2	-1	2.3	115.	11.

Simple system used for rain days calculation.
By observing other sites of Kenya I used the following method:

1.If monthly rain fall is less 10 mm, rain days = 1
2.For rain fall 10-100, then rain days = precip./10 + 1
3.For rain fall 100-120, then rain days = preci./10
4.For rain fall 120-150, then // // = preci./10 - 1
5.For // // 150-170, tehn // // = preci./10 - 2
6.For // // 170-190, then // // = preci./10 - 3
7.For // // 190-200, then, // // = preci./10 - 4
8.For // // 200-220, then, // // = preci./10 - 5
9.For // // 220-240, then, // // = preci./10 - 6
10.For // // 240-300, then, // // = preci./10 - 8
11.For // // 300-350, then, // // = preci./10 - 10
12.For // // >150 then, // // = preci./10 - 15

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
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Calculated EO & ETO, interpolated EO. Rain fall for upper and middle-lower areas also included.

	P	Eo	ETo	Eoav
EAK41 & EAK42				
	cm/d	cm/d	cm/d	cm/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

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, EAK45 & EAK46			
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, EAK48 & EAK49			
JAN	0.08	0.66	0.55	0.60
FEB	0.17	0.68	0.56	0.67
MAR	0.51	0.65	0.53	0.60
APR	1.19	0.57	0.46	0.53
MAY	0.40	0.55	0.44	0.52
JUN	0.02	0.51	0.41	0.47
JUL	0.01	0.48	0.40	0.45
AUG	0.05	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

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

Appendix F: WOFOST and PS123N final soil data for Chuka-South area nad some major tropical soils.

```
 soil data with CHUKA-SOUTH area
 comment lines start with an asterisk!
 each set of soil data occupies 4 lines

* line 1 = soil name (up to 30 characters)
* line 2 = sope (conductivity of top soil, cm/d), s0 (sorptivity,
* not  used), and ksub (conductivity of the sub soil, cm/d)
* line 3 = interpolation table with a maximum of 15 pairs of
* pF-values(log(cm)) and volumetric soil moisture content
* line 4 = table with up to 15 pairs of pF-values and the 10-logarithm of
* the conductivity(log(cm/d))


EAK41 (GROUP5-CHUKA)
    3.49     3.32     3.49
  -1.000  0.503   1.000  0.503   1.300  0.491   1.491  0.483   2.000  0.454
   2.400  0.428   3.700  0.406   3.400  0.351   4.204  0.285   6.000  0.153
   0.000  0.543   1.000  0.470   1.300  0.397   1.491  0.324   1.700  0.178
   2.000 -0.187   2.400 -2.841   2.700 -3.263   3.000 -3.684   3.400 -4.244
   3.700 -4.664   4.000 -5.084   4.204 -5.370
EAK42 (GROUP5-CHUKA)
    3.49     3.32     3.49
  -1.000  0.501   1.000  0.501   1.300  0.489   1.491  0.481   2.000  0.452
   2.400  0.426   2.700  0.405   3.400  0.350   4.204  0.284   6.000  0.153
   0.000  0.543   1.000  0.447   1.300  0.352   1.491  0.256   1.700  0.065
   2.000 -0.413   2.400 -2.841   2.700 -3.263   3.000 -3.684   3.400 -4.244
   3.700 -4.664   4.000 -5.084   4.204 -5.370
EAK43 (GROUP5-CHUKA)
    3.49     3.32     3.49
  -1.000  0.497   1.000  0.497   1.300  0.485   1.491  0.477   2.000  0.449
   2.400  0.423   2.700  0.401   3.400  0.347   4.204  0.282   6.000  0.152
   0.000  0.543   1.000  0.477   1.300  0.413   1.491  0.347   1.700  0.217
   2.000 -0.108   2.400 -2.843   2.700 -3.263   3.000 -3.684   3.400 -4.244
   3.700 -4.664   4.000 -5.083   4.204 -5.370
EAK44 (GROUP5-CHUKA)
    3.49     3.32     3.49
  -1.000  0.535   1.000  0.535   1.300  0.522   1.491  0.514   2.000  0.483
   2.400  0.455   2.700  0.432   3.400  0.374   4.204  0.304   6.000  0.163
   0.000  0.543   1.000  0.469   1.300  0.395   1.491  0.321   1.700  0.174
   2.000 -0.195   2.400 -2.843   2.700 -3.263   3.000 -3.684   3.400 -4.244
   3.700 -4.664   4.000 -5.083   4.204 -5.370
EAK45 (GROUP3-CHUKA)
    2.88     5.06     2.88
  -1.000  0.448   1.000  0.448   1.300  0.435   1.491  0.425   2.000  0.392
   2.400  0.362   2.700  0.338   3.400  0.279   4.204  0.211   6.000  0.093
   0.000  0.459   1.000  0.407   1.300  0.355   1.491  0.303   1.700  0.198
   2.000 -0.062   2.400 -1.851   2.700 -2.272   3.000 -2.693   3.400 -3.253
   3.700 -3.673   4.000 -4.093   4.204 -4.379
EAK46 (GROUP3-CHUKA)
    2.88     5.06     2.88
  -1.000  0.445   1.000  0.445   1.300  0.431   1.491  0.421   2.000  0.388
   2.400  0.359   2.700  0.335   3.400  0.276   4.204  0.210   6.000  0.092
   0.000  0.459   1.000  0.405   1.300  0.351   1.491  0.297   1.700  0.190
   2.000 -0.079   2.400 -1.851   2.700 -2.276   3.000 -2.693   3.400 -3.253
   3.700 -3.673   4.000 -4.093   4.204 -4.379
EAK47 (GROUP5-CHUKA)
    3.49     3.32     3.49
  -1.000  0.408   1.000  0.408   1.300  0.398   1.491  0.392   2.000  0.368
   2.400  0.347   2.700  0.330   3.400  0.285   4.204  0.232   6.000  0.124
   0.000  0.543   1.000  0.465   1.300  0.386   1.491  0.308   1.700  0.152
   2.000 -0.239   2.400 -2.841   2.700 -3.263   3.000 -3.684   3.400 -4.244
   3.700 -4.664   4.000 -5.084   4.204 -5.370
EAK48 (GROUP3-CHUKA)
    2.88     5.06     2.88
  -1.000  0.444   1.000  0.444   1.300  0.430   1.491  0.421   2.000  0.387
   2.400  0.358   2.700  0.334   3.400  0.276   4.204  0.209   6.000  0.092
```

```
   0.000  0.459   1.000  0.407   1.300  0.355   1.491  0.303   1.700  0.198
   2.000 -0.062   2.400 -1.850   2.700 -2.272   3.000 -2.693   3.400 -3.253
   3.700 -3.673   4.000 -4.093   4.204 -4.379
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
   2.400  0.425   2.700  0.403   3.400  0.349   4.204  0.283   6.000  0.152
   0.000  0.543   1.000  0.425   1.300  0.308   1.491  0.191   1.700 -0.043
   2.000 -0.629   2.400 -2.841   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
   2.400  0.348   2.700  0.323   3.400  0.263   4.204  0.196   6.000  0.081
   0.000  0.819   1.000  0.588   1.300  0.358   1.491  0.128   1.700 -0.332
   2.000 -1.483   2.400 -1.801   2.700 -2.130   3.000 -2.550   3.400 -3.110
   3.700 -3.530   4.000 -3.951   4.204 -4.236
EAK51 (GROUP4-CHUKA)
    6.59   14.90    6.59
  -1.000  0.429   1.000  0.429   1.300  0.415   1.491  0.405   2.000  0.371
   2.400  0.341   2.700  0.317   3.400  0.258   4.204  0.192   6.000  0.079
   0.000  0.819   1.000  0.597   1.300  0.376   1.491  0.154   1.700 -0.288
   2.000 -1.396   2.400 -1.708   2.700 -2.129   3.000 -2.551   3.400 -3.110
   3.700 -3.530   4.000 -3.951   4.204 -4.236

EAK52 (GROUP3-CHUKA)
    2.88     5.06    2.88
  -1.000  0.440   1.000  0.440   1.300  0.426   1.491  0.417   2.000  0.384
   2.400  0.355   2.700  0.331   3.400  0.273   4.204  0.207   6.000  0.091
   0.000  0.459   1.000  0.168   1.300 -0.123   1.491 -0.413   1.700 -0.995
   2.000 -1.293   2.400 -1.851   2.700 -2.272   3.000 -2.693   3.400 -3.253
   3.700 -3.673   4.000 -4.093   4.204 -4.379
EAK53 (GROUP4-CHUKA)
    6.59   14.90    6.59
  -1.000  0.455   1.000  0.455   1.300  0.441   1.491  0.430   2.000  0.394
   2.400  0.362   2.700  0.336   3.400  0.274   4.204  0.204   6.000  0.084
   0.000  0.819   1.000  0.558   1.300  0.298   1.491  0.037   1.700 -0.484
   2.400 -1.150   2.700 -1.708   2.700 -2.129   3.000 -2.551   3.400 -3.110
   3.700 -3.530   4.000 -3.951   4.204 -4.236

SiClLo (Yermosol Urumqi CHA)
    4.00     0.00    4.00
  -1.000  0.522   1.000  0.497   1.500  0.467   2.000  0.397   2.300  0.332
   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
  -1.000  0.410   2.500  0.351   4.200  0.146
   0.000  0.000   0.000  0.000
SiLo (Alfisol Peshawar PAK)
    2.00     0.00    2.00
  -1.000  0.480   2.500  0.264   4.200  0.052
   0.000  0.000   0.000  0.000
SiLo (Aridisol Lahore PAK)
    5.00     0.00    5.00
  -1.000  0.350   2.500  0.211   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   1.000  0.470   1.500  0.410   2.000  0.360   2.300  0.340
   2.700  0.300     3.400  0.210   4.200  0.200
   0.000  0.000   0.000  0.000
SiLo (Xerosol Kogoni MALI)
   15.00     0.00   15.00
  -1.000  0.370   1.000  0.360   1.500  0.340   2.000  0.150   2.300  0.100
   2.700  0.060     3.400  0.050   4.200  0.040
   0.000  0.000   0.000  0.000
```

```
Sand (Arenosol Gao MALI)
   20.00     0.00   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
   2.700  0.301     3.400  0.254   4.200  0.242
   0.000  0.000   0.000  0.000
Clay (Nitosol Unango MOC)
    6.00     0.00   10.00
  -1.000  0.537   1.000  0.516   1.500  0.407   2.000  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
  -1.000  0.406   1.000  0.403   1.500  0.377   2.000  0.333   2.300  0.313
   2.700  0.297     3.400  0.263   4.200  0.235
   0.000  0.000   0.000  0.000
Sand(Acrisol Rivers NIG)
   10.00     0.00   10.00
  -1.000  0.331   1.000  0.328   1.500  0.244   2.000  0.145   2.300  0.127
   2.700  0.120     3.400  0.063   4.200  0.060
   0.000  0.000   0.000  0.000

NG18 (Nigeria)
   10.00     0.00   10.00
  -1.000  0.354   1.000  0.336   1.500  0.302   2.000  0.285   2.300  0.269
   2.700  0.261     3.400  0.198   4.200  0.177
   0.000  0.000   0.000  0.000
Cuba soil
    3.00     0.00    3.00
  -1.000  0.498   1.000  0.498   1.500  0.485   2.000  0.463   2.300  0.455
   2.700  0.437     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
   3.400  0.350     4.200  0.320
   0.000  0.000   0.000  0.000
SiCl (Andosol Parcela CR)
   20.00     0.00   20.00
  -1.000  0.620   1.000  0.599   1.500  0.531   2.000  0.465   2.300  0.451
   2.700  0.425     3.400  0.384   4.200  0.371
   0.000  0.000   0.000  0.000
Clay (Inceptisol Tur4 CR)
   10.00     0.00   10.00
  -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
  -1.000  0.649   2.000  0.494   2.500  0.446   2.700  0.423   3.000  0.421
   3.700  0.397     4.000  0.388   4.200  0.385
   0.000  0.000   0.000  0.000
```

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
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
```

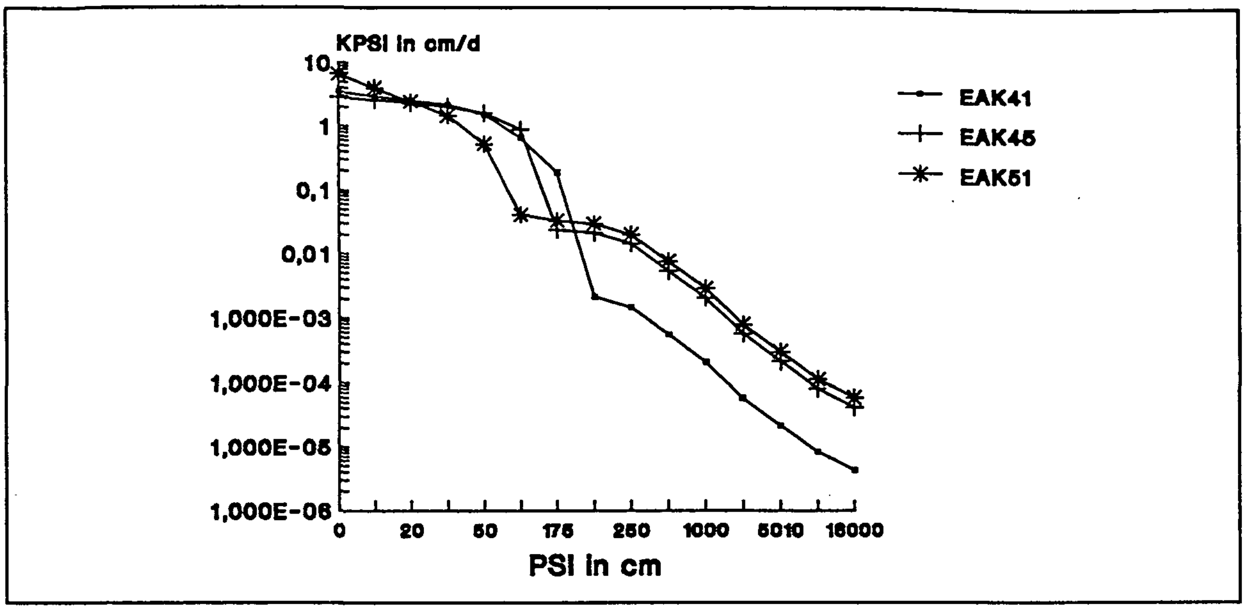

Figure 1. KPSI-PSI relations of clay family (EAK41), silty clay family (EAK45), and sandy clay family (EAk51), as used for the analysis.

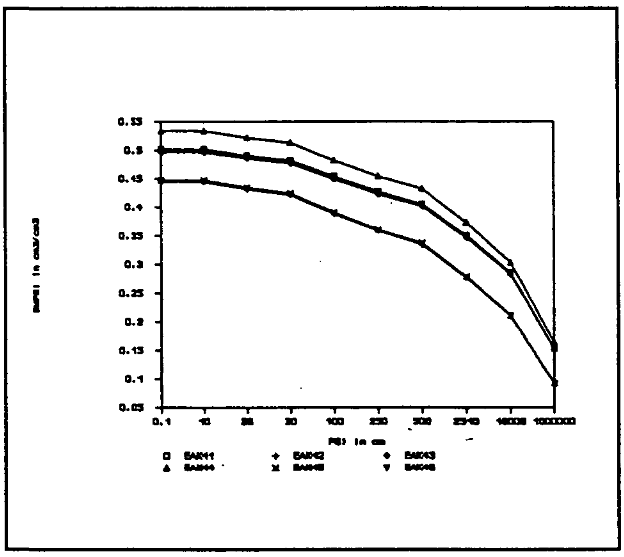

Figure 2 SMPSI-PSI relations as used for analysis.

Appendix G: Soil profile descriptions

ISRIC monolith number: EAK41 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: gleyic cambisol (Tent. class.)
USDA,1975: dystropept oxic, very fine, isothermic
Diagnostic horizons: umbric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : 2 km N. of Rukuriri school, Embu district.
: Latitude: 0 21 15 S Longitude: 37 32 30 E Altitude: 1710 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 9.85

GENERAL LANDFORM : hill Topography: mountainous
PHYSIOGRAPHIC UNIT : Minor valley, mount. footridge
SLOPE Gradient/Aspect/Form: 40 % concave
POSITION OF SITE : lower slope
MICRO RELIEF Kind: Pattern: none
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: nil stable slope

PARENT MATERIAL 1 : colluvium Derived from: volcanic breccia Texture:

— 2 : residual material Derived from: volcanic breccia Texture:
Depth boundary 1/2 (cm):

Remarks: Mt. Kenya Series

EFFECTIVE SOIL DEPTH cm : 110

WATER TABLE Depth cm : est.highest level: ? est. lowest level:107 Kind: apparent
DRAINAGE : well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: nil Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 100 cm moist 100 - + cm wet

LAND USE : (semi) natural vegetation, , ,
VEGETATION Structure: semi deciduous forest Status: cut over
Land use/vegetation remarks: intensive exploitation; charcoal prod.

CLIMATE Koeppen: Am Soil Moisture Regime: udic
Station: KEVOTE PRIM. SCHOOL ——0 27 S/37 32 E;1524 (m.a.s.l); 9 km S from site. Relevance: good
Station: RUYENJES ——0 25 S/37 36 E;1478 (m.a.s.l); 8 km SSE from site. Relevance: good
Station: EMBU PROV.AGRI.COLL. ——0 31 S/37 16 E;1494 (m.a.s.l); 20 km SSW from site. Relevance: moderate

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KEVOTE PRIM. SCHOOL															
Precipitation	mm	30	27	31	120	383	264	37	48	67	46	186	268	84	1559
RUYENJES															
Precipitation	mm	18	25	40	146	396	218	25	41	42	21	284	321	73	1547
EMBU PROV.AGRI.COLL.															
Precipitation	mm	33	22	25	91	301	224	28	45	43	42	147	203	59	1230
T max	C	11	26.4	29.3	27.9	25.8	24.0	22.8	21.4	21.7	24.4	25.9	24.2	25.7	25.0
T min	C	11	13.6	13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.2	14.6	13.6	14.1

PROFILE DESCRIPTION

A 0- 2cm 7.5YR 3.0/4.0 moist; clay,slightly gravelly; very coarse weak to moderate angular blocky; slightly sticky slightly plastic friable; common fine distinct sharp (7.5YR 2.0/0.0) mottles; continuous thin clay cutans ; many very fine pores; many very fine roots and few fine roots; non calcareous (by 10% HCL); abrupt smooth boundary to

Bu1 12- 63cm clay,slightly gravelly; very coarse weak angular blocky into medium angular blocky; slightly sticky slightly plastic very friable; continuous thin clay cutans ; many very fine pores; many very fine roots and few fine roots; non calcareous (by 10% HCL); gradual wavy boundary to

Bu2 63-107cm 5.0YR 3.0/4.0 moist; clay; very coarse weak angular blocky into medium angular blocky; slightly sticky slightly plastic very friable; few fine distinct sharp (7.5YR 2.0/0.0) mottles; broken thin clay cutans ; many very fine pores; common very fine roots and few fine roots; non calcareous (by 10% HCL); clear smooth boundary to

Bg 107-120cm 7.5YR 4.0/6.0 moist; clay; very coarse weak angular blocky; slightly sticky slightly plastic friable; few fine distinct sharp (7.5YR 4.0/6.0) mottles; broken thin clay cutans ; many very fine pores; few very fine roots and few fine roots; non calcareous (by 10% HCL);

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1	2				5		3	2		3	3		0.8	0.2	0.1	4.8	0.8	-1.0	-1.0
2	2				5			2		3	3		1.0	0.5	0.0	5.2	0.8	-1.0	-1.0
3	1				5			1.		3	3		0.9	0.6	0.1	4.9	0.9	-1.0	-1.0
4	2				5			1		3	3		1.1	0.5	0.1	5.4	0.7	-1.0	-1.0
5	1				5			2		2	3		1.3	0.5	0.1	5.5	0.8	-1.0	-1.0

ISRIC monolith number: EAK42 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: humic cambisol (Tent. class.)
USDA,1975: oxic, fine clayey, isothermic
Diagnostic horizons: umbric, cambic
(other) Diagn. criteria:
Local classification:

LOCATION : 2km N of Rurukiri school, Embu district, Central Province.
: Latitude: 0 21 20 S Longitude: 37 32 10 E Altitude: 1715 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 9.85

GENERAL LANDFORM : hill Topography: mountainous
PHYSIOGRAPHIC UNIT : major valley, mount. footridge
SLOPE Gradient/Aspect/Form: 3 % concave
POSITION OF SITE : open depression
MICRO RELIEF Kind: Pattern: none
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: nil stable slope

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PARENT MATERIAL 1 : colluvium Derived from: volcanic breccia Texture:

— 2 : alluvium Derived from: volcanic breccia. Texture:
Depth boundary 1/2 (cm):
Remarks: Mt Kenya Series

EFFECTIVE SOIL DEPTH cm : 60

WATER TABLE Depth cm : 55 est.highest level: 0 est. lowest level:60 Kind: groundwater table
DRAINAGE : moderately well
PERMEABILITY : moderate No slow permeable layer(s)

monolith number: EAK41 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	12	-1	1	1	2	3	2	8	8	34	50	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	12	40	-1	0	1	1	2	2	6	6	27	61	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	40	63	-1	0	1	2	3	2	8	5	16	71	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	63	107	-1	0	1	1	2	2	6	6	16	72	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
5	107	130	-1	0	1	1	2	2	6	7	14	73	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.3	5.5	-1.0	5.3	0.6	22.6	6.4	2.5	0.1	31.6	-1.0	-1.0	43.3	87	19	31.6	73.	-1	0.42
2	6.5	5.3	-1.0	1.3	0.2	6.5	3.1	1.8	0.0	11.4	-1.0	-1.0	20.1	33	4	11.4	57	-1	0.12
3	5.7	4.7	-1.0	1.1	0.2	3.1	2.6	1.5	0.1	7.3	-1.0	-1.0	16.6	23	4	7.3	44	-1	0.09
4	5.2	4.1	-1.0	1.1	0.2	0.8	0.6	1.4	0.5	3.3	-1.0	-1.0	15.9	22	4	3.3	21	-1	0.05
5	5.0	3.9	-1.0	1.0	0.2	0.4	0.4	1.2	0.2	2.2	-1.0	-1.0	16.6	23	4	2.2	13	-1	0.05

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

FLOODING frequency: , oxygenated water Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 40 cm dry 40 - 55 cm moist 55 - 80 cm wet

LAND USE : low level arable farming, banana, , ,
VEGETATION Structure: semi deciduous woodland Status: cut over
Land use/vegetation remarks: also taro/yam, grassland

CLIMATE Koeppen: Am Soil Moisture Regime: udic
Station: KEVOTE PRIM. SCHOOL ——0 27 S/37 32 E;1524 (m.a.s.l); 9 km S from site. Relevance: good
Station: RUYENJES ——0 25 S/37 36 E;1478 (m.a.s.l); 8 km S from site. Relevance: good
Station: EMBU PROV.AGRI.COLL. ——0 31 S/37 16 E;1494 (m.a.s.l); 20 km SSW from site. Relevance: moderate

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KEVOTE PRIM. SCHOOL															
Precipitation	mm	30	27	31	120	383	264	37	48	67	46	186	268	84	1559
RUYENJES															
Precipitation	mm	18	25	40	146	396	218	25	41	42	21	284	321	73	1547
EMBU PROV.AGRI.COLL.															
Precipitation	mm	33	22	25	91	301	224	28	45	43	42	147	203	59	1230
T max	C	11	26.4	29.3	27.9	25.8	24.0	22.8	21.4	21.7	24.4	25.9	24.2	25.7	25.0
T min	C	11	13.6	13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.2	14.6	13.6	14.1

PROFILE DESCRIPTION

A 0- 15cm 5.0YR 4.0/3.0 moist; clay; medium moderate subangular blocky; slightly sticky slightly plastic firm hard; continuous thin clay cutans ; many very fine pores; many very fine roots and few fine roots; (by 10% HCL); gradual smooth boundary to

Bu1 15- 50cm 5.0YR 4.0/4.0 moist; clay; coarse moderate subangular blocky; slightly sticky slightly plastic firm hard; continuous thin clay cutans ; many very fine pores; many very fine roots; (by 10% HCL); abrupt smooth boundary to

Bu2 50- 60cm 5.0YR 4.0/4.0 moist; clay,very gravelly; coarse weak subangular blocky into coarse moderate granular; slightly sticky slightly plastic firm; continuous thin clay cutans ; many very fine pores; common very fine roots; very frequent medium strongly weathered phonolite,vulc. fragments; (by 10% HCL); abrupt smooth boundary to

Bg 60- 80cm 10.0YR 4.0/4.0 moist; clay; coarse moderate subangular blocky; slightly sticky slightly plastic firm; continuous thin clay cutans ; many very fine pores; (by 10% HCL); clear wavy boundary to

Cr 80- 90cm clay,stony; ; frequent very coarse fresh phonolite,vulc. fragments and frequent extremely coarse fresh fragments;

monolith number: EAK42 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	15	-1	0	1	1	2	1	6	3	26	65	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	15	50	-1	0	1	2	3	2	7	5	12	76	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	50	60	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	60	80	-1	3	4	6	9	5	28	6	14	52	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.1	5.1	-1.0	5.2	0.6	15.0	4.7	1.7	0.2	21.6	-1.0	-1.0	38.0	58	18	21.6	57	-1	0.50
2	5.3	4.2	-1.0	1.7	0.3	2.7	1.2	1.6	0.2	5.7	-1.0	-1.0	18.6	25	6	5.7	31	-1	0.08
3	5.7	4.2	-1.0	0.6	0.1	1.7	1.3	0.8	0.5	4.3	-1.0	-1.0	16.6	44	2	4.3	26	-1	0.03
4	5.8	4.1	-1.0	0.8	0.1	1.9	1.6	0.9	0.7	5.1	-1.0	-1.0	16.3	31	3	5.1	31	-1	0.03

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1	2				5		3	2		3	3		1.0	0.6	0.1	4.8	0.8	-1.0	-1.0
2	1				5			1		4	3		1.3	0.6	0.1	5.0	0.8	-1.0	-1.0
3	1				5			1		4	3		0.9	1.0	0.4	3.9	0.5	-1.0	-1.0
4	1				5			1		4	3		0.7	0.6	0.1	2.5	0.5	-1.0	-1.0

ISRIC monolith number: EAK43 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: gleyic cambisol (Tent. class.)
USDA,1975: humitropept , very fine, isothermic
Diagnostic horizons: umbric, cambic
(other) Diagn. criteria:
Local classification:

LOCATION : 2km SE of Kiankungi school, near the road to Mufu, Embu district.
: Latitude: 0 22 50 S Longitude: 37 34 35 E Altitude: 1550 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 9.85

GENERAL LANDFORM : hill Topography: mountainous
PHYSIOGRAPHIC UNIT : major valley, mount. footridge
SLOPE Gradient/Aspect/Form: 6 % convex
POSITION OF SITE :
MICRO RELIEF Kind: Pattern:
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: nil stable slope

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PARENT MATERIAL 1 : colluvium Derived from: basic volcanic breccia Texture:
Weathering degree: Resistance: moderate
— 2 : residual material Derived from: basic volcanic breccia Texture:
Weathering degree: Resistance: moderate Depth boundary 1/2 (cm):
Remarks: Mt. Kenya Series

EFFECTIVE SOIL DEPTH cm : 80

WATER TABLE Depth cm : 80 est.highest level: 60 est. lowest level:80 Kind: groundwater table
DRAINAGE : moderately well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: nil Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 70 cm moist 70 - 140 cm wet

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LAND USE : low level arable farming, maize, seasonal irrigated, ,

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

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CLIMATE Koeppen: Am Soil Moisture Regime: ustic
Station: EMBU PROV.AGRI.COLL. ——0 31 S/37 16 E;1494 (m.a.s.l); 18 km SW from site. Relevance: good
Station: KEVOTE PRIM. SCHOOL ——0 27 S/37 32 E;1524 (m.a.s.l); 8 km SW from site. Relevance: good
Station: RUYENJES ——0 25 S/37 36 E;1478 (m.a.s.l); 4.5 km S from site. Relevance: very good

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
EMBU PROV.AGRI.COLL.															
Precipitation	mm	33	22	25	91	301	224	28	45	43	42	147	203	59	1230
T max	C	11	26.4	29.3	27.9	25.8	24.0	22.8	21.4	21.7	24.4	25.9	24.2	25.7	25.0
T min	C	11	13.6	13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.2	14.6	13.6	14.1
KEVOTE PRIM. SCHOOL															
Precipitation	mm	30	27	31	120	383	264	37	48	67	46	186	268	84	1559
RUYENJES															
Precipitation	mm	18	25	40	146	396	218	25	41	42	21	284	321	73	1547

PROFILE DESCRIPTION

Au1 0- 5cm 2.5YR 3.0/2.0 moist; clay; medium moderate subangular blocky into granular; slightly sticky slightly plastic friable; many coarse prominent 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 5.0Y 4.0/1.0 moist; clay; very coarse strong subangular blocky; slightly sticky slightly plastic firm; common fine prominent clear (5.0YR 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

Bbr1 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;

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	5	-1	1	3	4	4	2	15	7	18	60	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	5	30	-1	0	0	1	1	1	4	3	8	85	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	30	60	-1	0	0	1	1	1	3	4	10	83	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	60	75	-1	0	0	1	1	1	3	3	10	83	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
5	75	110	-1	0	1	1	2	2	6	5	14	76	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
6	110	120	-1	1	2	3	4	3	12	6	11	71	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
7	120	140	-1	1	2	2	3	2	9	8	8	76	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	5.3	4.3	-1.0	2.4	0.3	3.7	2.4	0.5	0.1	6.7	-1.0	-1.0	21.7	36	8	6.7	31	-1	0.12
2	4.7	3.8	-1.0	2.0	0.2	1.2	0.7	0.1	0.2	2.2	-1.0	-1.0	19.4	23	7	2.2	11	-1	0.08
3	4.5	3.8	-1.0	1.8	0.2	0.8	0.3	0.1	0.5	1.7	-1.0	-1.0	17.6	21	6	1.7	10	-1	0.05
4	4.5	3.7	-1.0	2.0	0.3	0.6	0.2	0.0	0.4	1.2	-1.0	-1.0	18.6	22	7	1.2	6	-1	0.07
5	4.6	3.6	-1.0	5.0	0.6	0.8	0.3	0.0	0.4	1.5	-1.0	-1.0	30.7	40	17	1.5	5	-1	0.06
6	4.8	3.4	-1.0	0.8	0.1	0.6	0.5	0.1	0.4	1.6	-1.0	-1.0	18.3	26	3	1.6	9	-1	0.04
7	4.7	3.5	-1.0	0.6	0.1	0.8	0.4	0.3	0.6	2.1	-1.0	-1.0	17.2	23	2	2.1	12	-1	0.05

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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
6	-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
7	-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

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

No	MICA/ ILL	VERM	CHLOR	SHEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1	2				6		3			2	3		0.6	0.8	0.2	5.8	0.6	-1.0	-1.0
2					6		3			2	3		0.7	0.5	0.1	6.0	0.8	-1.0	-1.0
3	3				6		2			2	3		1.2	0.5	0.1	6.1	0.7	-1.0	-1.0
4					6		3			2	3		1.3	0.5	0.1	4.7	0.6	-1.0	-1.0
5					6		3			2	3		0.8	0.6	0.1	1.4	0.3	-1.0	-1.0
6	2				6		3			2	3		0.6	0.3	0.1	2.1	0.2	-1.0	-1.0
7	2				6		3			2	3		0.5	0.3	0.1	2.5	0.3	-1.0	-1.0

ISRIC monolith number: EAK44 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: humic nitosol (Tent. class.)
USDA,1975: palehumult ustic, very fine, isothermic
Diagnostic horizons: umbric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : Near Kathungu coffee factory, Embu district.
: Latitude: 0 24 40 S Longitude: 37 37 40 E Altitude: 1410 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 9.85

GENERAL LANDFORM : plateau Topography: undulating
PHYSIOGRAPHIC UNIT : dissected mountain footridge
SLOPE Gradient/Aspect/Form: 3 % convex
POSITION OF SITE :
MICRO RELIEF Kind: Pattern:
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: nil stable slope

PARENT MATERIAL 1 : residual material Derived from: basic volcanic breccia Texture:
Weathering degree: Resistance: moderate
Remarks: Phonolite/lahar

EFFECTIVE SOIL DEPTH cm : 140

WATER TABLE Depth cm : est.highest level: 0 Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: nil Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 150 cm dry

LAND USE : medium level arable farming, coffee, , , terracing
VEGETATION Structure:
Land use/vegetation remarks: also: some maize, bananas, cassava

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CLIMATE Koeppen: Am Soil Moisture Regime: ustic
Station: EMBU PROV.AGRI.COLL. ——0 31 S/37 16 E;1494 (m.a.s.l); 20 km SW from site. Relevance: good
Station: RUYENJES ——0 25 S/37 36 E;1478 (m.a.s.l); 6 km W from site. Relevance: very good

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
EMBU PROV.AGRI.COLL.															
Precipitation	mm	33	22	25	91	301	224	28	45	43	42	147	203	59	1230
T max	C	11	26.4	29.3	27.9	25.8	24.0	22.8	21.4	21.7	24.4	25.9	24.2	25.7	25.0
T min	C	11	13.6	13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.2	14.6	13.6	14.1
RUYENJES															
Precipitation	mm	18	25	40	146	396	218	25	41	42	21	284	321	73	1547

PROFILE DESCRIPTION

A 0- 35cm 2.5YR 3.0/2.0 moist; 5.0YR 3.0/2.0 dry; clay; coarse- very coarse weak subangular blocky into fine moderate granular; sticky slightly plastic very friable soft; patchy thin clay cutans ; many micro/very fine pores; many very fine roots and common medium roots; gradual irregular boundary to

AB 35- 80cm 7.5YR 3.0/2.0 moist; 7.5YR 3.0/2.0 dry; clay; very coarse moderate subangular blocky; sticky slightly plastic friable slightly hard; broken thin clay cutans ; many micro/very fine pores; gradual wavy boundary to

B 80-150cm 2.5YR 3.0/2.0 moist; 5.0YR 3.0/4.0 dry; clay; very coarse strong subangular blocky; sticky slightly plastic firm hard; continuous moderately thick clay cutans ; many micro/very fine pores; common very fine roots; very few small spherical hard ferrigenous concretions;

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monolith number: EAK44 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	-1	-1	-1	1	1	1	1	1	6	19	41	34	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	-1	-1	-1	0	0	1	1	1	3	11	37	49	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	-1	-1	-1	0	0	0	1	1	2	7	33	58	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	-1	-1	-1	0	0	0	1	1	2	5	33	60	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
5	-1	-1	-1	0	0	0	1	1	2	2	15	82	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	MAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.6	5.6	-1.0	2.4	0.3	15.5	3.1	2.1	0.0	20.7	-1.0	-1.0	22.3	65	8	20.7	93	-1	0.20
2	6.9	5.7	-1.0	1.3	0.2	13.3	3.0	1.4	0.0	17.7	-1.0	-1.0	14.5	29	5	17.7	122	-1	0.16
3	7.0	5.8	-1.0	0.6	0.1	7.1	2.2	1.5	0.0	10.8	-1.0	-1.0	11.0	19	2	10.8	98	-1	0.21
4	7.0	5.9	-1.0	0.6	0.1	6.9	2.8	1.9	0.1	11.7	-1.0	-1.0	9.8	16	2	11.7	119	-1	0.19
5	6.9	5:9	-1.0	0.3	0.1	5.4	3.2	1.1	0.0	9.7	-1.0	-1.0	8.5	10	1	9.7	114	-1	0.14

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1					4		3			2	3		0.5	0.5	0.1	6.2	0.5	-1.0	-1.0
2					4		3			2	3		0.4	0.3	0.1	8.7	0.6	-1.0	-1.0
3					5		3			2	3		0.5	0.2	0.1	6.0	0.5	-1.0	-1.0
4					5		3			2	3		0.5	0.3	0.1	6.1	0.5	-1.0	-1.0
5					5		2			2	3		0.5	0.3	0.1	6.4	0.6	-1.0	-1.0

ISRIC monolith number: EAK45 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: humic acrisol (Tent. class.)
USDA,1975: paleustult , very fine, isothermic
Diagnostic horizons: umbric, argillic
(other) Diagn. criteria: plinthite
Local classification:

LOCATION : Near Kathungu coffee factory, Gitwa valley Embu district.
: Latitude: 0 24 50 S Longitude: 37 37 30 E Altitude: 1380 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 7.85

GENERAL LANDFORM : plateau Topography: hilly
PHYSIOGRAPHIC UNIT : minor valley, mount. footridge
SLOPE Gradient/Aspect/Form: 10 % straight
POSITION OF SITE : middle slope
MICRO RELIEF Kind: Pattern:
SURFACE CHAR. Rock outcrop: little rocky Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: slight loc. unstable and slight rill Aggradation: nil stable slope

PARENT MATERIAL 1 : colluvium Derived from: basic volcanic breccia Texture:
Weathering degree: Resistance: low
— 2 : residual material Derived from: basic volcanic breccia Texture:
Weathering degree: Resistance: moderate Depth boundary 1/2 (cm):
Remarks: phonolite, lahar

EFFECTIVE SOIL DEPTH cm : 80

WATER TABLE Depth cm : Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : moderate No slow permeable layer(s)

FLOODING frequency: nil Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 250 cm dry 250 - 370 cm moist

LAND USE : medium level arable farming, coffee, , , terracing
VEGETATION Structure:
Land use/vegetation remarks: pasture/grazing around the pit

CLIMATE Koeppen: Am Soil Moisture Regime: ustic
Station: EMBU PROV.AGRI.COLL. ——0 31 S/37 16 E;1494 (m.a.s.l); 20 km SW from site. Relevance: good
Station: RUYENJES ——0 25 S/37 36 E;1478 (m.a.s.l); 6 km W from site. Relevance: very good

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
EMBU PROV.AGRI.COLL.															
Precipitation	mm	33	22	25	91	301	224	28	45	43	42	147	203	59	1230
T max	C	11	26.4	29.3	27.9	25.8	24.0	22.8	21.4	21.7	24.4	25.9	24.2	25.7	25.0
T min	C	11	13.6	13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.2	14.6	13.6	14.1
RUYENJES															
Precipitation	mm	18	25	40	146	396	218	25	41	42	21	284	321	73	1547

PROFILE DESCRIPTION

A 0- 35cm 2.5YR 3.0/4.0 moist; 5.0YR 3.0/4.0 dry; silty clay; fine moderate crumb and fine moderate subangular blocky; slightly sticky slightly plastic very friable hard; continuous thin clay cutans ; many very fine pores; many very fine roots; gradual smooth boundary to

B 35-130cm 2.5YR 3.0/4.0 moist; 2.5YR 3.0/4.0 dry; silty clay; weak angular blocky into medium strong subangular blocky; slightly sticky slightly plastic very friable slightly hard; broken moderately thick clay cutans ; common very fine pores; common very fine roots; abrupt smooth boundary to

BC 130-250cm 2.5YR 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; silty clay,very gravelly; medium weak subangular blocky; slightly sticky slightly plastic very friable soft; patchy thin clay cutans ; common very fine pores; dominant medium spherical hard ferrigenous concretions; abrupt smooth boundary to

Cu1 250-300cm 10.0YR 4.0/6.0 moist; silty clay; ; many coarse faint diffuse (10.0YR 5.0/8.0) mottles; abrupt smooth boundary to

Cu2 300-350cm 10.0YR 5.0/4.0 moist; silty clay; ; abrupt smooth boundary to

Cu3 350-370cm 10.0YR 5.0/8.0 moist; silty clay; ; many coarse faint diffuse (10.0YR 4.0/6.0) mottles;

monolith number: EAK45 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	35	-1	0	0	1	1	1	3	1	9	87	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	35	80	-1	0	0	0	1	1	2	0	6	91	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	80	130	-1	0	0	0	1	1	3	0	9	88	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	130	160	-1	3	4	3	2	1	13	3	14	69	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	-1	-1	-1.0	1.6	0.2	6.4	3.1	1.2	0.0	10.7	-1.0	-1.0	13.0	15	6	10.7	82	-1	-1.00
2	-1	-1	-1.0	0.8	0.1	3.9	2.7	0.6	0.0	7.2	-1.0	-1.0	11.0	12	3	7.2	65	-1	-1.00
3	-1	-1	-1.0	0.5	0.1	3.9	3.3	0.1	0.0	7.3	-1.0	-1.0	8.9	10	2	7.3	82	-1	-1.00
4	-1	-1	-1.0	0.3	0.1	1.9	1.6	0.1	0.0	3.6	-1.0	-1.0	7.6	11	1	3.6	47	-1	-1.00

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1					6		2				3		0.3	0.3	0.1	5.0	0.5	-1.0	-1.0
2					6		2				3		0.3	0.3	0.1	5.1	0.4	-1.0	-1.0
3					6		2	1			3		0.2	0.2	0.1	5.1	0.5	-1.0	-1.0
4					6		2	2			3		0.2	0.2	0.1	7.8	0.9	-1.0	-1.0

ISRIC monolith number: EAK46 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: orthic acrisol (Tent. class.)
USDA,1975: humitropept ustic, very fine, isothermic
Diagnostic horizons: umbric, cambic
(other) Diagn. criteria:
Local classification:

LOCATION : Gitwa valley bottom, near Kathungu coffee factory, Embu district.
: Latitude: 0 25 0 S Longitude: 37 37 25 E Altitude: 1330 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 7.85

GENERAL LANDFORM : valley Topography: hilly
PHYSIOGRAPHIC UNIT : major valley, mount. footridge
SLOPE Gradient/Aspect/Form: 2 % concave
POSITION OF SITE : open depression
MICRO RELIEF Kind: Pattern: none
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: nil stable slope

PARENT MATERIAL 1 : colluvium Derived from: basic volcanic breccia Texture:
— 2 : alluvium Derived from: basic volcanic breccia Texture:
Depth boundary 1/2 (cm):
Remarks: Phonolite/lahar/ash

EFFECTIVE SOIL DEPTH cm : 80

WATER TABLE Depth cm : 105 est.highest level: 60 est. lowest level:140 Kind: apparent
DRAINAGE : moderately well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 60 cm dry 60 - 105 cm moist 105 - 200 cm wet

LAND USE : low level arable farming, banana, , , Land use/vegetation remarks: maize, sugarcane, papaya, napirgrass

CLIMATE Koeppen: Am Soil Moisture Regime: ustic
Station: RUYENJES ——0 25 S/37 36 E;1478 (m.a.s.l); 6 km W from site. Relevance: good
Station: EMBU PROV.AGRI.COLL. ——0 31 S/37 16 E;1494 (m.a.s.l); 20 km SW from site. Relevance: moderate

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
RUYENJES															
Precipitation	mm	18	25	40	146	396	218	25	41	42	21	284	321	73	1547
EMBU PROV.AGRI.COLL.															
Precipitation	mm	33	22	25	91	301	224	28	45	43	42	147	203	59	1230
T max	C	11	26.4	29.3	27.9	25.8	24.0	22.8	21.4	21.7	24.4	25.9	24.2	25.7	25.0
T min	C	11	13.6	13.6	14.9	15.8	15.7	14.4	13.1	13.0	13.3	14.2	14.6	13.6	14.1

PROFILE DESCRIPTION

A 0- 20cm 2.5YR 3.0/4.0 moist; 5.0YR 3.0/4.0 dry; silty clay; medium moderate subangular blocky into very fine moderate subangular blocky; slightly sticky slightly plastic very friable soft; common very fine pores; common very fine roots and few fine roots; gradual wavy boundary to

Bt 20- 60cm 5.0YR 3.0/3.0 moist; 5.0YR 3.0/3.0 dry; silty clay; medium weak subangular blocky into fine to very fine moderate subangular blocky; slightly sticky slightly plastic very friable slightly hard; patchy thin clay cutans ; many very fine pores; common very fine roots and few fine roots; few medium spherical hard manganiferous concretions; gradual smooth boundary to

Btg 60-105cm 2.5YR 3.0/4.0 moist; silty clay; fine to medium moderate subangular blocky; slightly sticky slightly plastic very friable slightly hard; many fine distinct clear (2.5YR 2.0/0.0) mottles; broken thin clay cutans ; common very fine pores; common very fine roots and few fine roots; gradual smooth boundary to

Bg 105-140cm 7.5YR 4.0/4.0 moist; silty clay; fine to very fine moderate angular blocky; sticky slightly plastic very friable; gradual smooth boundary to

Cr1 140-160cm 10.0YR 5.0/2.0 moist;; ; many fine prominent sharp (7.5YR 4.0/4.0) mottles; clear smooth boundary to

Cr2 160-185cm 5.0Y 5.0/1.0 moist;; ; abrupt smooth boundary to

Cr3 185-200cm 10.0YR 4.0/1.0 moist;; ; abrupt wavy boundary to

Cr4 200-210cm 5.0G 5.0/2.0 moist;; ;

monolith number: EAK46 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	20	-1	0	0	1	3	3	7	3	14	75	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	20	60	-1	0	0	1	2	2	5	3	16	76	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	60	105	-1	0	0	1	2	2	5	3	17	75	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	105	140	-1	0	1	2	4	2	9	6	17	68	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
5	140	160	-1	0	0	1	4	4	10	4	14	73	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	MAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	5.6	4.4	-1.0	2.0	0.2	5.4	2.4	0.6	0.0	8.4	-1.0	-1.0	13.2	18	7	8.4	64	-1	0.07
2	5.6	4.4	-1.0	1.7	0.2	5.2	2.4	0.3	0.0	7.9	-1.0	-1.0	12.1	16	6	7.9	65	-1	0.08
3	5.7	4.4	-1.0	1.3	0.1	3.7	2.9	0.1	0.3	7.0	-1.0	-1.0	10.5	14	4	7.0	67	-1	0.06
4	5.9	4.5	-1.0	0.8	0.1	4.2	3.1	0.1	0.2	7.6	-1.0	-1.0	10.7	16	3	7.6	71	-1	0.04
5	5.4	3.8	-1.0	1.0	0.1	3.3	2.0	0.3	0.3	5.9	-1.0	-1.0	11.9	16	3	5.9	50	-1	0.04

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1					5		2		2	2	3		0.8	0.3	0.1	4.9	0.5	-1.0	-1.0
2					5		2		1	2	3		1.1	0.4	0.1	5.0	0.4	-1.0	-1.0
3					5		2		1	2	3		1.3	0.3	0.1	5.2	0.4	-1.0	-1.0
4					5		2		2	2	3		1.5	0.3	0.1	5.4	0.4	-1.0	-1.0
5					6		2		2	2	3		0.9	0.3	0.1	2.4	0.2	-1.0	-1.0

ISRIC monolith number: EAK47   country: KENYA   SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION *FAO/UNESCO,1974:* orthic ferralsol (Tent. class.)
USDA,1975: haplohumox , very fine, isothermic
Diagnostic horizons: umbric, oxic
(other) Diagn. criteria:
Local classification: ferralo chromic Acr.

LOCATION : 0.5km S of Kavengero school, 10m from the road, Embu district
: Latitude: 0 27 05 S   Longitude: 37 42 0 E   Altitude: 1145 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 8.85

GENERAL LANDFORM : plateau   Topography: flat or almost flat
PHYSIOGRAPHIC UNIT : gently undulating plateau
SLOPE Gradient/Aspect/Form: 2 %   straight
POSITION OF SITE : crest
MICRO RELIEF Kind: Pattern: none
SURFACE CHAR. Rock outcrop: none   Stoniness: none
Cracking: nil   Sealing: nil   Salt: nil   Alkali: nil
SLOPE PROCESSES Soil erosion: nil   Aggradation: nil   stable slope

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PARENT MATERIAL 1 : residual material   Derived from: basic volcanic breccia   Texture:
Weathering degree: Resistance: moderate
Remarks: Phonolite/lahar

EFFECTIVE SOIL DEPTH cm : 90

WATER TABLE Depth cm :   Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : moderate   No slow permeable layer(s)
FLOODING frequency: nil   Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 150 cm dry

LAND USE : low level arable farming, maize, , ,
VEGETATION Structure:
Land use/vegetation remarks: mango, bataat, use of fertilizers

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CLIMATE Koeppen: Am   Soil Moisture Regime: ustic
Station: KABONDORI/KIRITIRI ——00 42 S/37 40 E;1143 (m.a.s.l); 23 km S from site. Relevance: moderate
Station: KANYUAMBORA ——0 28 S/37 43 E;1265 (m.a.s.l); 3 km ESE from site. Relevance: very good

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KABONDORI/KIRITIRI															
Precipitation	mm	35	20	21	121	227	68	4	2	5	7	75	209	91	849
T max	C	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	28.0
T min	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
KANYUAMBORA															
Precipitation	mm	11	27	49	161	359	127	6	4	16	7	109	318	75	1264

PROFILE DESCRIPTION

Ap 0- 18cm 5.0YR 3.0/3.0 moist; 5.0YR 3.0/4.0 dry; clay; very coarse moderate prismatic into very coarse strong subangular blocky; slightly sticky slightly plastic very friable hard; patchy thin clay cutans ; many very fine pores; many very fine roots; gradual smooth boundary to

AB 18- 35cm 5.0YR 3.0/3.0 moist; 5.0YR 3.0/4.0 dry; clay; very coarse moderate prismatic into very coarse strong subangular blocky; slightly sticky slightly plastic very friable hard; broken thin clay cutans ; many very fine pores; many very fine roots; gradual smooth boundary to

Bu1 35- 85cm 5.0YR 3.0/4.0 moist; 5.0YR 4.0/6.0 dry; clay; moderate prismatic into medium strong subangular blocky; slightly sticky slightly plastic very friable hard; broken thin clay cutans ; many very fine pores; many very fine roots; diffuse smooth boundary to

Bu2 85-150cm 2.5YR 3.0/6.0 moist; 5.0YR 4.0/6.0 dry; clay; very coarse strong prismatic into very coarse strong subangular blocky; slightly sticky slightly plastic very friable hard; patchy thin clay cutans ; many very fine pores; many very fine roots;

REMARKS:

Slides: 10,071 - 10,072.

monolith number: EAK47 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	15	-1	0	0	1	2	1	5	18	34	42	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	18	35	-1	0	0	1	2	1	4	11	22	63	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	35	85	-1	0	0	1	2	1	4	20	28	48	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	85	115	-1	0	0	1	2	2	5	22	23	50	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
5	115	150	-1	0	0	0	1	1	3	17	20	59	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
6	85	150	-1	0	0	1	2	1	4	20	24	53	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum meq /100g	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
1	6.1	4.9	-1.0	2.0	0.1	6.6	2.9	1.2	0.0	10.7	-1.0	-1.0	12.3	29	7	10.7	87	-1	0.11
2	5.9	4.8	-1.0	1.6	0.1	4.8	2.4	0.6	0.0	7.8	-1.0	-1.0	11.0	18	6	7.8	71	-1	0.06
3	5.7	5.0	-1.0	1.3	0.1	2.9	2.1	0.1	0.0	5.1	-1.0	-1.0	8.3	17	4	5.1	61	-1	0.07
4	5.9	5.4	-1.0	0.8	0.1	2.5	1.6	0.1	0.0	4.2	-1.0	-1.0	6.5	13	3	4.2	65	-1	0.03
5	6.0	5.5	-1.0	0.7	0.1	2.1	2.0	0.0	0.0	4.1	-1.0	-1.0	5.8	10	2	4.1	71	-1	0.03
6	5.7	5.4	-1.0	0.7	0.1	2.3	1.9	0.1	0.0	4.3	-1.0	-1.0	7.1	13	3	4.3	61	-1	0.04

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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
6	-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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1					4		2			4	3		0.5	0.4	0.1	5.5	0.4	-1.0	-1.0
2					4		2			4	3		0.5	0.5	0.1	5.2	0.5	-1.0	-1.0
3					4		2			4	3		0.5	0.5	0.1	5.8	0.5	-1.0	-1.0
4					5		2			4	3		0.6	0.5	0.1	5.9	0.5	-1.0	-1.0
5					5		2			4	3		0.6	0.4	0.1	5.9	0.5	-1.0	-1.0
6	2				5					4	3		0.6	0.4	0.1	5.8	0.5	-1.0	-1.0

ISRIC monolith number: EAK48 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: ferric acrisol (Tent. class.)
USDA,1975: plinthustult , isothermic
Diagnostic horizons: umbric, argillic
(other) Diagn. criteria: ferric properties
Local classification:

LOCATION : 0.5km S of Kavengero school, Embu district.
: Latitude: 0 27 05 S Longitude: 37 41 55 E Altitude: 1142 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 8.85

GENERAL LANDFORM : plateau Topography: undulating
PHYSIOGRAPHIC UNIT : minor valley in plateau
SLOPE Gradient/Aspect/Form: 7 % straight
POSITION OF SITE : middle slope
MICRO RELIEF Kind: terracettes Pattern: lineair
SURFACE CHAR. Rock outcrop: little rocky Stoniness: none
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: nil stable slope

PARENT MATERIAL I : residual material Derived from: basic volcanic breccia Texture:
Weathering degree: Resistance: moderate
Remarks: Phonolite

EFFECTIVE SOIL DEPTH cm : 100

WATER TABLE Depth cm : Kind: no watertable observed

DRAINAGE : well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: nil Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 130 cm dry

LAND USE : low level arable farming, maize, , , terracing
VEGETATION Structure:
Land use/vegetation remarks: fallow around the pit

CLIMATE Koeppen: Am Soil Moisture Regime: ustic
Station: KABONDORI/KIRITIRI ——00 42 S/37 40 E;1143 (m.a.s.l); 23 km S from site. Relevance: moderate
Station: KANYUAMBORA ——0 28 S/37 43 E;1265 (m.a.s.l); 3 km ESE from site. Relevance: very good

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KABONDORI/KIRITIRI															
Precipitation	mm	35	20	21	121	227	68	4	2	5	7	75	209	91	849
T max	C	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	28.0
T min	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
KANYUAMBORA															
Precipitation	mm	11	27	49	161	359	127	6	4	16	7	109	318	75	1264

PROFILE DESCRIPTION

Ap 0- 11cm 5.0YR 3.0/4.0 moist; 5.0YR 3.0/2.0 dry; silty clay; medium to coarse moderate subangular blocky into crumb; sticky slightly plastic very friable slightly hard; patchy thin clay cutans ; many very fine pores; many very fine roots and few medium roots; very few medium spherical hard concretions; abrupt smooth boundary to

Bu1 11- 90cm 5.0YR 4.0/6.0 moist; 5.0YR 4.0/6.0 dry; silty clay; very coarse moderate subangular blocky; sticky slightly plastic very friable slightly hard; broken thin clay cutans ; many very fine pores; common very fine roots and few fine roots; very few medium spherical hard concretions; clear wavy boundary to

Bu2 90-130cm 5.0YR 4.0/6.0 moist; 5.0YR 5.0/8.0 dry; silty clay,very gravelly; medium to coarse weak subangular blocky into single grain; sticky slightly plastic very friable slightly hard; patchy thin clay cutans ; many very fine pores; common very fine roots; frequent medium micro hard concretions; frequent medium strongly weathered nepheline phon. fragments and few coarse weathered fragments;

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monolith number: EAK48 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	11	-1	1	1	2	4	2	9	5	9	77	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	11	50	-1	1	1	1	2	1	6	5	7	82	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	50	90	-1	1	1	1	2	1	6	5	8	82	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	90	120	-1	7	2	1	2	1	13	4	9	74	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG- C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.4	5.3	-1.0	2.8	0.2	7.9	4.5	1.7	0.0	14.1	-1.0	-1.0	17.4	23	10	14.1	81	-1	0.10
2	5.4	4.5	-1.0	1.5	0.1	1.7	1.6	1.0	0.0	4.3	-1.0	-1.0	10.1	12	5	4.3	43	-1	0.06
3	5.2	4.4	-1.0	1.1	0.1	0.4	0.7	0.6	0.0	1.7	-1.0	-1.0	8.9	11	4	1.7	19	-1	0.03
4	5.4	4.4	-1.0	1.0	0.1	0.4	0.5	0.6	0.0	1.5	-1.0	-1.0	-1.0	4	3	1.5	48	-1	0.02

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1					5		2			3	3		0.5	0.6	0.1	4.7	0.5	-1.0	-1.0
2					4					3	3		0.5	0.6	0.1	4.8	0.7	-1.0	-1.0
3					5					2	3		0.5	0.6	0.1	5.0	0.6	-1.0	-1.0
4					5					2	3		0.5	0.5	0.1	5.3	0.8	-1.0	-1.0

ISRIC monolith number: EAK49   country: KENYA   SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: gleyic cambisol (Tent. class.)
USDA,1975: ustic, very fine, isothermic
Diagnostic horizons: umbric, cambic
(other) Diagn. criteria:
Local classification:

LOCATION : 0.5km S of Kavengero school, Embu district , Central province
: Latitude: 0 27 10 S Longitude: 37 41 55 E Altitude: 1139 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 8.85

GENERAL LANDFORM : plateau Topography: undulating
PHYSIOGRAPHIC UNIT : minor valley bottom in plateau
SLOPE Gradient/Aspect/Form: 1 % concave
POSITION OF SITE : open depression
MICRO RELIEF Kind: levees (artificial) Pattern: lineair Height (cm): 30
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: small cracks Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: nil Aggradation: present stable slope

PARENT MATERIAL 1 : colluvium Derived from: basic volcanic breccia Texture:

— 2 : alluvium Derived from: basic volcanic breccia Texture:
Depth boundary 1/2 (cm):

Remarks: Phonolite/Lahar/Ash

EFFECTIVE SOIL DEPTH cm : 100

WATER TABLE Depth cm : est.highest level: 0 est. lowest level:150 Kind: flooded
DRAINAGE : moderately well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: yearly , fresh water Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 50 cm dry 50 - 135 cm moist 135 - 160 cm wet

LAND USE : low level arable farming, banana, seasonal irrigated, draining

VEGETATION Structure:
Land use/vegetation remarks: cassava, sugarcane, vegetables

CLIMATE Koeppen: Am Soil Moisture Regime: ustic
Station: KABONDORI/KIRITIRI ——00 42 S/37 40 E;1143 (m.a.s.l); 23 km S from site. Relevance: moderate
Station: KANYUAMBORA ——0 28 S/37 43 E;1265 (m.a.s.l); 3 km ESE from site. Relevance: very good

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KABONDORI/KIRITIRI															
Precipitation	mm	35	20	21	121	227	68	4	2	5	7	75	209	91	849
T max	C	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	28.0
T min	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
KANYUAMBORA															
Precipitation	mm	11	27	49	161	359	127	6	4	16	7	109	318	75	1264

PROFILE DESCRIPTION

Ap 0- 25cm 7.5YR 3.0/2.0 moist; 5.0YR 4.0/4.0 dry; clay,gravelly; very coarse weak subangular blocky into fine to medium moderate crumb; slightly sticky slightly plastic friable hard; patchy thin clay cutans ; many very fine pores; many very fine roots and few fine roots; frequent small spherical hard manganiferous concretions and frequent medium spherical hard manganiferous concretions; clear wavy boundary to

Au1 25- 55cm 5.0YR 2.5/2.0 moist; 7.5YR 3.0/2.0 dry; clay,gravelly; very coarse moderate subangular blocky into fine to medium moderate crumb; slightly sticky slightly plastic friable hard; common medium distinct sharp (7.5YR 3.0/0.0) mottles; continuous cutans ; many very fine/fine pores; many very fine roots and few fine roots; clear smooth boundary to

Bg1 55- 90cm 5.0YR 2.5/2.0 moist; 5.0YR 3.0/2.0 dry; clay,gravelly; very coarse moderate subangular blocky into medium moderate subangular blocky; slightly sticky slightly plastic friable hard; many medium distinct sharp (5.0YR 2.5/1.0) mottles; broken thin clay and sesquioxides cutans ; many very fine/fine pores; many very fine roots and few fine roots; few small spherical hard manganiferous concretions and few medium spherical hard manganiferous concretions; gradual smooth boundary to

Bg2 90-140cm 5.0YR 2.5/2.0 moist; clay,slightly gravelly; very coarse moderate subangular blocky into medium moderate subangular blocky; slightly sticky slightly plastic friable hard; many medium distinct sharp (5.0YR 2.5/1.0) mottles; continuous thin clay and sesquioxides cutans ; many very fine/fine pores; common very fine roots; few small spherical hard manganiferous concretions and few medium spherical hard manganiferous concretions; gradual smooth boundary to

Bg3 140-160cm 10.0YR 4.0/2.0 moist; clay,slightly gravelly; very coarse moderate angular blocky; slightly sticky slightly plastic firm; many medium distinct sharp (10.0YR 2.0/1.0) mottles; continuous thin clay and sesquioxides cutans ; many very fine/fine pores; few small micro hard manganiferous concretions and few medium spherical hard manganiferous concretions; clear smooth boundary to

Bg4 160-165cm 7.5YR 4.0/2.0 moist; clay,slightly gravelly; ; slightly sticky slightly plastic; common fine distinct sharp (7.5YR 2.0/0.0) mottles; continuous thin clay cutans ; few small spherical hard manganiferous concretions and few medium spherical hard manganiferous ;

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monolith number: EAK49 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	25	-1	1	1	2	2	2	7	12	30	50	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	25	55	-1	2	2	3	4	2	13	4	22	61	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	55	90	-1	2	2	2	4	3	13	9	28	49	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	90	140	-1	4	3	4	6	4	21	8	19	52	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
5	140	160	-1	8	4	4	5	3	24	5	18	52	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	TOT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.2	4.9	-1.0	3.1	0.2	11.3	3.8	2.0	0.0	17.1	-1.0	-1.0	22.1	44	11	17.1	77	-1	0.10
2	6.4	4.8	-1.0	2.3	0.2	12.2	3.8	0.7	0.1	16.8	-1.0	-1.0	21.9	36	8	16.8	77	-1	0.06
3	6.4	4.8	-1.0	2.3	0.1	12.5	4.1	0.7	0.2	17.5	-1.0	-1.0	21.7	44	8	17.5	81	-1	0.06
4	6.3	4.8	-1.0	1.6	0.1	11.2	3.6	0.8	0.2	15.8	-1.0	-1.0	18.3	35	6	15.8	86	-1	0.09
5	6.4	4.9	-1.0	0.8	0.1	8.7	3.4	0.6	0.2	12.9	-1.0	-1.0	15.0	29	3	12.9	86	-1	0.08

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1	1				4				1	3	3		1.3	0.5	0.1	4.6	0.4	-1.0	-1.0
2	2				5				2	3	3		1.3	0.5	0.1	4.3	0.4	-1.0	-1.0
3	2				5				2	2	3		1.4	0.4	0.1	4.2	0.4	-1.0	-1.0
4	2				4				1	2	3		1.3	0.4	0.1	4.5	0.4	-1.0	-1.0
5	2				5				2	2	3		1.2	0.2	0.1	5.3	0.4	-1.0	-1.0

ISRIC monolith number: EAK50 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: chromic luvisol (Tent. class.)
USDA,1975: paleustalf rhodic, clayey, isohyperthermic
Diagnostic horizons: ochric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : Ishiara opposite of the watersupply near the Embu-Ishiara road
: Latitude: 0 27 10 S Longitude: 37 46 20 E Altitude: 855 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 8.85

GENERAL LANDFORM : plain Topography: undulating
PHYSIOGRAPHIC UNIT : dissected undulating upland
SLOPE Gradient/Aspect/Form: 4 % convex
POSITION OF SITE : upper slope
MICRO RELIEF Kind: termite mounds
SURFACE CHAR. Rock outcrop: none Stoniness: none
Cracking: nil Sealing: slaked Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: moderate rill and moderate gully Aggradation: nil stable slope

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PARENT MATERIAL 1 : residual material Derived from: gneiss Texture:
Weathering degree: partial/moderate Resistance: moderate
Remarks: basement system

EFFECTIVE SOIL DEPTH cm : 150

WATER TABLE Depth cm : Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : slow Slow permeable layer from (cm): 0 to: 1
FLOODING frequency: nil Run-off: rapid
MOISTURE CONDITIONS PROFILE : 0 - 150 cm dry

LAND USE : woodland, grazed
VEGETATION Structure: deciduous woodland Status: degraded
Land use/vegetation remarks: dense Acacia shrubbed wooodland

CLIMATE Koeppen: Aw Soil Moisture Regime: ustic
Station: KABONDORI/KIRITIRI -----00 42 S/37 40 E;1143 (m.a.s.l); 28 km SSW from site. Relevance: moderate
Station: KANYUAMBORA -----0 28 S/37 43 E;1265 (m.a.s.l); 6 km W from site. Relevance: moderate
Station: MARIMANTI -----00 09 S/037 59 E;587 (m.a.s.l); 40 km NNE from site. Relevance: moderate

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KABONDORI/KIRITIRI															
Precipitation	mm	35	20	21	121	227	68	4	2	5	7	75	209	91	849
T max	C	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	28.0
T min	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
KANYUAMBORA															
Precipitation	mm	11	27	49	161	359	127	6	4	16	7	109	318	75	1264
MARIMANTI															
EA class A pan	mm	10	159	177	225	181	166	168	180	208	242	254	173	154	2287
Precipitation	mm	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.MJ/m2		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 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	32.3
T min	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

monolith number: EAK50 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 roots; few small weathered quartz, mica fragments; gradual wavy boundary to

B 15-150cm 10.0R 3.0/4.0 moist; 2.5YR 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 quartz fragments;

REMARKS:

Parent material: Gabronotite, Gneiss, Talcum.
Woodland with Euphorbia nyikae 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.

monolith number: EAK50 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF-0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	15	-1	2	7	13	16	7	45	5	6	44	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	15	60	-1	2	6	13	16	8	45	6	8	41	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	60	105	-1	2	7	13	15	7	44	6	12	38	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	105	150	-1	2	7	13	15	7	45	7	14	34	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	TOT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.7	5.4	-1.0	0.6	0.1	4.1	7.6	0.7	0.0	12.4	-1.0	-1.0	10.9	25	2	12.4	114	-1	0.10
2	6.7	4.8	-1.0	0.2	0.0	3.9	7.5	0.2	0.0	11.6	-1.0	-1.0	10.8	27	1	11.6	107	-1	0.07
3	7.0	5.0	-1.0	0.2	0.0	5.8	6.4	0.2	0.1	12.5	-1.0	-1.0	10.6	28	1	12.5	118	-1	0.06
4	7.7	6.1	-1.0	0.2	0.0	8.6	6.5	0.3	0.1	15.5	-1.0	-1.0	11.6	34	1	15.5	134	-1	0.18

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1	4				4		2				2		0.4	0.2	0.0	3.2	0.2	-1.0	-1.0
2	4				4		3				2		0.3	0.1	0.0	3.0	0.2	-1.0	-1.0
3	4				4		3				2		0.3	0.1	0.0	3.0	0.1	-1.0	-1.0
4	4				4		3				2		0.2	0.1	0.0	2.6	0.2	-1.0	-1.0

ISRIC monolith number: EAK51 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: chromic luvisol, stony phase (Tent. class.)
USDA,1975: ~~rhodustalf , fine loamy, isohyperthermic~~
Diagnostic horizons: ochric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : Ishiara, 200m S of the junction near the hospital, Embu district.
: Latitude: 0 27 40 S Longitude: 37 47 25 E Altitude: 855 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 9.85

GENERAL LANDFORM : plain Topography: undulating
PHYSIOGRAPHIC UNIT : undulating upland
SLOPE Gradient/Aspect/Form: 3 % convex
POSITION OF SITE : upper slope
MICRO RELIEF Kind: Pattern: none
SURFACE CHAR. Rock outcrop: fairly rocky Stoniness: very stony Average Size (cm): 5
Cracking: nil Sealing: slaked Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: moderate sheet and moderate rill Aggradation: nil stable slope

PARENT MATERIAL 1 : residual material Derived from: gneiss Texture:
Weathering degree: partial/moderate Resistance: moderate
Remarks: Basement system

EFFECTIVE SOIL DEPTH cm : 70

WATER TABLE Depth cm : Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : slow Slow permeable layer from (cm): 0 to: 3
FLOODING frequency: nil Run-off: rapid
MOISTURE CONDITIONS PROFILE : 0 - 80 cm dry

LAND USE : shrubland, grazed, millet, ,
VEGETATION Structure: deciduous shrub Status: degraded
Land use/vegetation remarks: Acacia bushland

CLIMATE Koeppen: Aw Soil Moisture Regime: ustic

Station: KABONDORI/KIRITIRI -----00 42 S/37 40 E;1143 (m.a.s.l); 28 km SW from site. Relevance: moderate
Station: KANYUAMBORA -----0 28 S/37 43 E;1265 (m.a.s.l); 8 km W from site. Relevance: moderate
Station: MARIMANTI -----00 09 S/037 59 E;587 (m.a.s.l); 40 km NE from site. Relevance: moderate

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KABONDORI/KIRITIRI															
Precipitation	mm	35	20	21	121	227	68	4	2	5	7	75	209	91	849
T max	C	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	28.0
T min	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
KANYUAMBORA															
Precipitation	mm	11	27	49	161	359	127	6	4	16	7	109	318	75	1264
MARIMANTI															
EA class A pan	mm	10	159	177	225	181	166	168	180	208	242	254	173	154	2287
Precipitation	mm	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.MJ/m2		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 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	32.3
T min	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

monolith number: EAK51 02/10/93

PROFILE DESCRIPTION

Bu1 0- 10cm 2.5YR 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; sandy clay; 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; gradual wavy boundary to

Bu2 10- 25cm 2.5YR 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; sandy clay,very gravelly; coarse weak subangular blocky into granular; slightly sticky slightly plastic loose loose; continuous thin clay cutans ; many very fine pores; many very fine roots and few fine roots; gradual wavy boundary to

Bu3 25- 70cm 2.5YR 3.0/6.0 moist; 2.5YR 4.0/8.0 dry; sandy clay; coarse strong angular blocky; slightly sticky slightly plastic very friable hard; continuous thin clay cutans ; many very fine pores; common very fine roots and few fine roots; wavy boundary to

Bu4 70-120cm 2.5YR 3.0/6.0 moist; 2.5YR 3.0/6.0 dry; sandy clay; medium to coarse strong angular blocky; slightly sticky slightly plastic very friable hard; broken thin clay cutans ; many very fine pores; common very fine roots;

monolith number: EAK51 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	10	-1	3	5	9	13	6	36	10	5	50	-1	-1.00	-1	-1	-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	-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	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	6.9	5.5	-1.0	0.7	0.1	9.8	3.5	0.5	0.0	13.8	-1.0	-1.0	11.6	23	3	13.8	119	-1	0.08
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	-1	0.06
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	0.05
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	-1	0.04

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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

No	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX*	QUAR	FELD	GIBB	GOET	HEM	FEo	ALo	SIo	FEd	ALd	FEp	ALp
1	4				5		3				3		0.5	0.2	0.1	3.3	0.2	-1.0	-1.0
2	4				6		3				3		0.5	0.3	0.0	3.4	0.2	-1.0	-1.0
3	3				6		4				3		0.5	0.2	0.0	3.0	0.2	-1.0	-1.0
4	3				6		4				2		0.2	0.0	0.1	1.1	0.1	-1.0	-1.0

ISRIC monolith number: EAK52 country: KENYA SOIL DESCRIPTION print date (mm/dd/yy): 02/10/93

CLASSIFICATION FAO/UNESCO,1974: calcic luvisol (Tent. class.)
USDA,1975: haplustalf aridic, fine loamy o.clayey, isohyperthermic
Diagnostic horizons: ochric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : 4km E of Ishiara, Embu district
: Latitude: 0 26 40 S Longitude: 37 48 20 E Altitude: 845 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 9.85

GENERAL LANDFORM : plain Topography: undulating
PHYSIOGRAPHIC UNIT : gently und. upland near stream
SLOPE Gradient/Aspect/Form: 3 % convex
POSITION OF SITE : lower slope
MICRO RELIEF Kind: Pattern: none
SURFACE CHAR. Rock outcrop: none Stoniness: exceedingly stony Form: (sub)rounded Average Size (cm): .5
Cracking: nil Sealing: nil Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: severe sheet and moderate rill Aggradation: nil stable slope

PARENT MATERIAL 1 : residual material Derived from: gneiss Texture:
Weathering degree: partial/moderate Resistance: moderate
Remarks: Basement system

EFFECTIVE SOIL DEPTH cm : 150

WATER TABLE Depth cm : Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : moderate No slow permeable layer(s)
FLOODING frequency: nil Run-off: medium
MOISTURE CONDITIONS PROFILE : 0 - 150 cm dry

LAND USE : fallow, millet, , ,
VEGETATION Structure: deciduous shrub Status: degraded
Land use/vegetation remarks: Dense bushed woodland

CLIMATE Koeppen: Aw Soil Moisture Regime: ustic
Station: KABONDORI/KIRITIRI ——00 42 S/37 40 E;1143 (m.a.s.l); 30 km SW from site. Relevance: moderate
Station: KANYUAMBORA ——0 28 S/37 43 E;1265 (m.a.s.l); 10 km W from site. Relevance: moderate
Station: MARIMANTI ——00 09 S/037 59 E;587 (m.a.s.l); 40 km NE from site. Relevance: moderate

		Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KABONDORI/KIRITIRI															
Precipitation	mm	35	20	21	121	227	68	4	2	5	7	75	209	91	849
T max	C	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	28.0
T min	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
KANYUAMBORA															
Precipitation	mm	11	27	49	161	359	127	6	4	16	7	109	318	75	1264
MARIMANTI															
EA class A pan	mm	10	159	177	225	181	166	168	180	208	242	254	173	154	2287
Precipitation	mm	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.MJ/m2		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 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	32.3
T min	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

monolith number: EAK52 02/10/93

PROFILE DESCRIPTION

AB 0- 25cm 10.0YR 4.0/4.0 moist; 10.0YR 4.0/4.0 dry; silty clay loam; medium moderate subangular blocky; slightly sticky slightly plastic very friable slightly hard; continuous thin clay cutans on throughout ; many very fine pores; common very fine roots and few fine roots; frequent medium irregular hard calcareous concretions; clear smooth boundary to

B 25-150cm 10.0YR 6.0/4.0 moist; 10.0YR 5.0/6.0 dry; silty clay loam; very coarse moderate to strong angular blocky; slightly sticky slightly plastic very friable hard; many very fine pores; few very fine roots; few medium irregular hard calcareous concretions and large inclusions; abrupt irregular boundary to

BR 150- + cm; ; dominant strongly weathered gneiss fragments;

monolith number: EAK52 analytical data <missing value = -1> ISRIC print date: 02/10/93

NO	TOP	BOT	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT	50 20	20 2	<2 um	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
1	0	25	-1	2	8	10	9	5	33	7	17	43	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
2	25	70	-1	2	10	12	11	6	42	12	25	21	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
3	70	110	-1	2	10	12	11	8	43	13	25	18	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1
4	110	150	-1	4	11	13	11	5	44	10	26	20	-1	-1.00	-1	-1	-1	-1	-1	-1	-1	-1

No.	pH- H2O	KCl	CaCO3 %	ORG-C %	NAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						meq /100g													
1	8.2	6.7	-1.0	0.4	0.1	52.8	5.3	0.4	0.0	58.5	-1.0	-1.0	25.8	61	1	58.5	227	-1	0.23
2	8.3	6.8	-1.0	0.1	0.0	43.4	8.8	0.4	0.1	52.7	-1.0	-1.0	22.1	104	0	52.7	238	-1	0.24
3	8.3	6.9	-1.0	0.1	0.0	29.7	12.5	0.4	0.2	42.8	-1.0	-1.0	18.8	103	0	42.8	228	-1	0.28
4	8.4	7.0	-1.0	0.1	0.0	29.1	17.5	0.4	0.4	47.4	-1.0	-1.0	22.3	111	0	47.4	213	-1	0.27

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

No	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
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

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