Q.E.L.

A Quantified Evaluation of Land
for the Chuka-South area,
Kenya

by: J.H.M. Pulles
March 1988

Agricultural University of Wageningen
Department of Soil Science and Geology

TABLE OF CONTENTS

OBJECTIVES OF THE STUDY 2

DESCRIPTION OF THE STUDY AREA 2
Location 2
Climate 2
Soils and geology 4

PROCEDURES AND DATA 5
The Geographic Information System 5
The Simulation Model 5

DATA 8
Climatic data 8
Land and Soil data 8
Crop data 9
Maize (Zea mays); Bulrush millet (Pennisetum typhoides); Mungbean (Vigna radiata)

THE ANALYTICAL SET-UP 12

RESULTS 14
Maize 14
Millet 21
Mungbean 23
Conclusions 24

POSTSCRIPT 25

LITERATURE 26

FIGURES 28

ANNEX A. CLIMATE 53

ANNEX B. MAPPING UNITS AND SOILS 64

ANNEX C. CROPS 72

ANNEX D. PROGRAM CODE OF SIMULATION PART 74

OBJECTIVES OF THE STUDY

The objectives of this study were twofold. The first objective was to carry out a quantified land evaluation for the Chuka area in Kenya. The second was to link this land evaluation to a Geographic Information System (GIS). The information system used is the Comprehensive Resource Inventory and Evaluation System (CRIES), which was to be tried out for possible future use in the Department of Soil Science at the University of Wageningen.

The evaluation was to be at a broad regional level; it is restricted to assessment of the potential suitability for three annual crops (two cereals, maize and millet, and one pulse crop, mungbean) under rainfed agriculture, and the determination of the optimum sowing time. The evaluation is a physical one based on quantitative estimates of the potential water limited yields.

For this purpose a data base and a crop simulation model were constructed, both commensurate with the availability of data in the study area. The model was experimented with to understand its reactions to different inputs, and it was used to evaluate selected scenarios. In these scenarios it is assumed that the management (e.g. weeding, plant density, fertilizer application and water conservation measures) and nutrient availability are optimal, and that pests and diseases are fully controlled. All calculated yield potentials are expressed in kg dry matter per unit area.

DESCRIPTION OF THE STUDY AREA

Location

The study area is located in Kenya at approximately 160 km from the capital city, Nairobi. It is located between latitudes 0°15' and 0°30'S , and longitudes 37°30' and 38°00'E, and covered by the Chuka and Ishiara mapsheets (122/3 and 122/4 respectively, at scale 1:50,000) by the Survey of Kenya. A large part of the area consists of the southeastern windward slopes of Mount Kenya; hence the altitude varies from more than 2100 m in the nortwestern part to less than 500 m near the Tana river (see Figures 1 and 2).

Climate

The location of the study area near the equator accounts for the little variation in mean monthly temperatures during the year ($<$ 4°C), and for the occurrence of two rainy seasons which coincide with the passing of the Intertropical Convergence Zone twice a year. There is a clear relation between altitude and climate. With increasing altitude, the amount of annual rainfall increases and both temperature and rate of evaporation decrease.

Four different seasons can be distinguished over the year:

Jan-Feb : short dry season, relatively high temperatures, clear skies

Mar-May : long rainy season, starting at the end of March in the eastern parts (duration 40-50 days) and in mid-March in the western parts (75-80 days)

Jun-Sep : long dry season, relatively low temperatures and a persistent cloud cover, especially during July and at higher altitude

Oct-Dec : short rainy season, starting at the end of October in the eastern parts (40-50 days) to mid-October in the western parts (60-70 days).

The high northwestern part of the area has a trimodal rainfall pattern with a small third rainy period during July and August. Annual rainfall varies from 2200 mm at higher altitudes to approximately 700 mm near the Tana river. Both the amount of rainfall and the reliability of the rainfall decrease towards the East, as demonstrated by the coefficient of variation for annual rainfall which doubles from 0.25 in the West to 0.50 in the East.

The average annual rainfall pattern of the study area is presented in Figure 3. The area can be divided in different soil moisture availability zones (Sombroek et al., 1982) expressed in different r / Eo * 100% ratios (the annual precipitation, r, over the potential evaporation, Eo). If evaporation is approximated with :

$$Eo(mm) = 2422 - 0.358 \cdot altitude(m) \qquad (1)$$

(Woodhead, 1968), this ratio varies from 130% (humid) in the northwestern part to 25-40% (semi-arid) in the eastern parts (Figure 4).

The annual temperature of the study area is related to altitude by the relationship (Braun, 1986) :

$$T(°C) = 29.3 - 0.0066 * altitude(m) \qquad (2)$$

The mean annual temperature ranges from about 15°C at high altitudes to 26°C in the East (see Table 1 and the altitude map, Figure 2, which presents implicit temperature zones). The coldest month of the year is July with a mean temperature of less than 4°C below that of the warmest month, March (see ANNEX A, Table 1).

Table 1. Temperature zones; relation between temperature and altitude and the areas occupied by each zone.

Zone	annual	minimum	maximum	altitude(m)	area(%)
VI	14 - 16	20 - 22	8 - 10	2300 - 2000	1
V	16 - 18	22 - 24	10 - 12	2000 - 1700	7
IV	18 - 20	24 - 26	12 - 14	1700 - 1400	15
III	20 - 22	26 - 28	14 - 16	1400 - 1100	22
II	22 - 24	28 - 30	16 - 18	1100 - 800	20
I	24 - 26	30 - 32	18 - 20	800 - 500	33
I+	26 - 27	32 - 33	20 - 21	500 - 350	2

Soils and geology

In general the area can be divided in two distinct units : the slopes of Mt. Kenya in the West and the areas belonging to the Basement System in the East. The slopes of Mt. Kenya are strongly dissected by perennial streams and rivers, descending from the mountain, with steep valley sides (slope > 16%). The soils have developed on so_called lahars (consolidated mudflows) which embed all kinds of volcanic rock in a matrix of pyroclastics, and are in general deep, clayey NITISOLS (de Meester, 1987).

The Basement System consists of dissected, undulating to rolling uplands (slopes < 16%) together with some hills and mountains. Most hills and mountains are intrusive rocks, granitoid or (ultra)mafic. The remaining area consists of gneisses rich in ferromagnesian minerals (hornblende and biotite), or granitoid gneisses. The soils developed on ferromagnesian gneisses have a deep red colour due to iron compounds formed upon weathering. Soils developed on granitoid gneisses have a more orange colour, because of the lower amounts of ferromagnesian minerals and higher amounts of quartz, and a higher gravel content. They are in general moderately deep to deep, slightly gravelly to gravelly, sandy clayloam to sandy clayey LUVISOLS.
In contrast with the slopes of Mt. Kenya, the soils of the Basement system area show a large variation in properties such as depth, gravel content or texture.

PROCEDURES AND DATA

The Geographic Information System

Geographic Information Systems provide means to facilitate the storage and manipulation of spatially distributed data. The data are stored in a grid based reference system which permits analyses on a locational basis. Each grid cell possesses row and column numbers as its location identifiers.
For the present exercise, these numbers correspond with the map grid coordinates. Columns 333 to 388 correspond with map grid coordinates 3.33 to 3.88 E., and rows 1 to 27 with coordinates 99.71 to 99.45 S. These rows correspond with latitudes from 0°15'S to 0°30'S.
Each grid cell is chosen to represent an area of one square kilometer because of the small map scale and the low resolution of climatic and soil data.
Several single attribute rasters are necessary to describe a cell. More specifically, these are one raster with overall altitude readings, one with mapping unit codes and one with the codes of the representative climatic station. The GIS used (CRIES) can only support single value rasters; the values in the individual raster cells refer to data files containing data of a more complex nature about climatic zones, mapping units and soils.

Potential yield estimations from the simulation model described in the next paragraph, are presented in a format suitable for the GIS (Schultink et al., 1986). This offers the possibility of making overlays, grouping of yields into (suitability) classes, and cross- tabulation of several rasters.

The Simulation Model

In line with the scarcity of climatic and soil physical data, the simulation observes time intervals of one decade (ten days) for the calculation of assimilation rates. Yet, the distribution and conversion of formed assimilates into structural dry matter, which is dependent only of the crop, is on a daily basis.
For more detailed information on crop performance simulation the reader is referred to Driessen (1986) and van Keulen and Wolf (1986). For the actual program code see ANNEX D.

A hierarchical simulation model is used which considers different land qualities/limitations at different levels. At the highest level, the potential production is calculated, as solely determined by solar radiation, temperature, and crop properties. Assessing water limited production possibilities means calculation of a factor by which the potential is multiplied to account for possible negative effects of water stress on crop performance.

Crop development from emergence to maturity is measured in terms of thermal units (°C.day). To reach maturity a crop needs a specific total sum of thermal units (temperature sum) established by accumulation of effective daily temperature sums, i.e. the mean daily temperatures minus the threshold temperature of the crop.

The latitude and the assimilation type of the crop (C3 or C4) determine the gross CO_2 assimilation rate for a closed canopy on clear and overcast days (Goudriaan, 1978; see ANNEX C). Thus data on cloudiness suffice to calculate the potential canopy assimilation rate (Fgc). The gross assimilation rate (Fga) is assessed by reducing Fgc for temperature effects (too cold or too hot) and/or an incomplete crop cover.
In tropical regions, the process temperature is considered equal to the average of minimum and maximum temperature. For C3 crops temperature is assumed optimal between 15 and 25 °C and for C4 crops between 20 and 30 °C. Part of the assimilates are necessary for maintenance respiration, the rest (net assimilation) is partitioned to the different plant parts as a function of the crop phenological stage.
The increase in structural dry matter of each plant part is dependent of the conversion efficiency of the assimilates into dry matter. As from halfway between flowering and maturity, roots and stems are assumed to die at specific rates. Leaves die when reaching a crop or variety specific life span.

Potential production is achieved as long as the crop can transpire freely. A too high or too low water content of the soil will reduce the water uptake rate of the crop, and henceforth its transpiration and assimilation rates. The assimilation rate is reduced by the ratio of actual and potential crop transpiration.

Due to lack of accurate data on climate (e.g. daily rainfall and intensities) and soil physical properties, and the general nature of the evaluation, there is no sense in a complicated physical description of soil moisture movements. Therefore water budget calculations consider only two compartments of which the upper layer is rooted and the lower layer not (see Figure 5). The lower layer need not always be present. The maximum rooted depth is arbitrarily set at 0.7 times the maximum rooting depth of the crop (Driessen, 1986) or at the effective rootable soil depth, whichever is less. With root growth the depth of the rooted layer increases while the layer below becomes smaller.

For the interval calculations, the upper layer is assumed to have a homogenous moisture content, that is affected by rainfall, evaporation and transpiration. If the soil moisture content exceeds field capacity, water is lost to the lower layer. This flow rate may be limited by the hydraulic conductivity of the soil. The lower layer may loose water in the same way to the subsoil. It is assumed that ground water is very deep and capillary rise is negligible.

The potential evaporation rate from the soil surface is reduced because of shading by the leaves of a crop (equation 3.). The actual evaporation from the soil's surface may be less than maximum (Em) due to a low moisture content (equation 4.).
The maximum rate of crop transpiration (Tmax) depends on the evaporation and evapotranspiration rates multiplied by a "leaf reduction factor" (LRF) to account for an incomplete cover.
The critical soil moisture content (SMcr) is the soil moisture content below which the transpiration is hampered by water stress. It is co-determined by a "depletion factor" (p) which is dependent of the crop and the maximum transpiration rate (equations 5 and 6.).

$$Em = E0 \cdot \exp(-0.4 \cdot LAI) \qquad (3)$$

$$Ea = Em \cdot (SM - SMa)/(SM0 - SMa) \qquad (4)$$

$$Tmax = LRF \cdot (ET0 - 0.1 \cdot E0) \qquad (5)$$

$$SMcr = (1 - p) \cdot (SM0 - 0.04 - SMpwp) + SMpwp \qquad (6)$$

The water reduction factor is 1.0 at moisture contents from SM0 to SMcr, and 0.0 at more than SM0-0.04 or less than SMpwp. Values in- between are found by linear interpolation.

The book keeping of water budgets starts one interval before emergence to approximate the initial soil moisture content at emergence. At the end of each interval the soil moisture contents are adjusted, just as the actual rooted depth.
Thus the water reduction factor for a certain interval is determined by the soil moisture content of the preceding interval ('state variable approach').
The simulation is halted when maturity is reached (development stage 1.0 or 100%), or when no living leaves remain, or when prohibitive water logging or drought occur. If drought occurs in the decade before emergence (= decade of planting), emergence is assumed to fail.

DATA

However precise a model can be in describing 'reality', its results can never be more accurate than the data it is fed with. When conclusions are drawn, they refer strictly to the scenario, the data and the model used; some caution is necessary when extrapolating them to the 'real' world.

Climatic data

Potential production calculations only need data on temperature and radiation (or cloudiness); the calculations of water limited production need additional data on rainfall and evaporation. A difficulty is that a wide range of altitudes is found in the study area with a large range of climatic properties. Confronted with the absence of actual temperature data and a considerable variation within the study area, it was decided to relate monthly temperature to altitude. The resulting monthly temperatures are differentiated over decades.

Except for rainfall figures, site specific climatic data were lacking and had to be extrapolated from outside locations (see ANNEX A). Fourteen (14) sites (see Figure 6 for their location) with rainfall data were selected to represent different zones of rainfall. For each zone, estimations of the cloudiness regime were made based on data from Kindaruma, Tebere and Thika (see ANNEX A and Figure 1). In the area, five cloudiness regimes are distinguished attributing to higher altitude areas a higher cloudiness figure and a bigger amplitude over the year (see Figure 8). Annual evaporation is, just as temperature, related to the altitude, and the whole area is assumed to have a uniform distribution of the annual evaporation sums over the months.

In contrast to rainfall and cloudiness, the climatic variables temperature and evaporation are not treated zonally, but are calculated for each grid cell in accordance with the grid cell's altitude (see ANNEX A).

Land and Soil data

The option of converting the boundaries on the soil map into digital form by means of a digitizing tablet has not been used. Each grid cell is characterized by a data set which refers to the mapping unit that occupies the largest area within its boundaries (predominance method). On this criterion 33 mapping units were distinguished in the study area out of the 37 in the legend of the reconnaissance map.
The characteristics that are selected from the soil map (de Meester, 1987) are soil depth, gravel content and soil texture.

The distribution of texture-based soil types is shown in Figure 9. The equivalent net rootable soil depth (= depth · (1 - gravel fraction)) is presented in Figure 10 according to the five depth classes used by the Kenyan Soil Survey.

Data on the physical properties of these soils were only scarcely available; the data set had to be completed with data from Kindaruma (van de Weg, 1975).

The properties that were used are :

- soil porosity,
- soil moisture content at field capacity (pF 2),
- soil moisture content at permanent wilting point (pF 4.2),
- soil moisture content when airdry (pF 6),
- initial soil moisture content,
- saturated hydraulic conductivity of the rootable soil,
- saturated hydraulic conductivity of the subsoil.

The initial soil moisture contents postulated, correspond with pF values 4.1 to 4.2 for NITISOLS and FERRALSOLS (volcanic area) and pF 5 for the other soils (in general Basement area). This is the moisture content that is supposed to occur at the end of the dry season, based on pF measurements at different catenas (see ANNEX B).

The values for saturated hydraulic conductivity are copied from Driessen (1986) and are derived for Dutch soils; they are probably too low for Chuka soils. Knowing that the time interval is 10 days, this is considered acceptable, for an even higher value can never follow the dynamics of rainfall and infiltration.

After characterizing each grid cell by its dominant mapping unit, it appeared that mapping units with a soil type of loamy sand were too small to be represented on the map. This limits the number of relevant soil types to only five.

Crop data

In this paragraph each crop used is briefly outlined. The phenological data of the various crops can be found in ANNEX C. The Figures 11 to 13 show the distribution of assimilates to the different plant parts as determined by the development stage. Figures 14 and 15 show how the length of the growing period is related to altitude (temperature).

It must be noted that the model pays no attention to the decade in which drought or water logging occurs. A drought or excessive rainfall during flowering will often significantly reduce yields, but this is not taken into account. Little research has been done on the phenological data for crops. Millet data were derived from the input data for the WOFOST model (Rappoldt, 1983). Thus they may be less suitable for the variety used in this study which may differ from that in the WOFOST data base.

Phenological data on both maize and mungbean are copied from Driessen (1986). Some characteristics on the three crops are presented in Table 2.

Table 2. Temperature sum, assimilation type, minimum rootable depth requirement, maximum rooting depth, development stage at flowering, life span of leaves and the maximum altitude at which the selected crops are grown.

Crop	Temp.sum (°C.day)	Assim. type	RDmin (cm)	RDm (cm)	flowering at dvs	Span (day)	Max.alt. (m)
Maize	1350	C4	50	135	0.60	60	-
Millet	1020	C4	30	120	0.67	60	1200
Mungbean	1650	C3	30	70	0.39	35	1500

Maize (Zea mays)

Maize is the most important cereal in the area, having a high output/input ratio and a wide tolerance with regard to environmental conditions. A young maize plant is moderately drought resistant, but is susceptible to unfavourable soil air/moisture ratios during the first 3 decades; it requires a well aerated soil. From five weeks onward the maize plant is less drought resistant; the most critical period is at the time of silking when even moderate drought stress can cause incomplete pollination, whereas severe drought can cause crop loss.
This makes the planting time a very important parameter. In "short rainfall" areas, maize that is sown late may suffer both in the early stages when the soil is too wet, and later when the soil is too dry (Acland, 1971).
Maize reacts to even the slightest degree of water logging, and needs a good supply of nutrients. The growing period is strongly dependent on the altitude (temperature) and amounts to 6-8 months at 1900 m and 5 months at 1500 m. These lengths are satisfactorily reproduced by the model (see Figures 14 and 15).

In 1977 Jaetzold (1983) made a Small Farm Survey which demonstrates a clear relation between early planting of maize and grain yield. It also showed that above 1700 to 1800 m maize and beans yielded higher when planted in the short rains than in the long rains.
Jaetzold considers a maize yield of 5000 kg/ha a high production level above 1400 m, and 3000 kg/ha at lower altitude. Ooms (1987) measured 1100 to 2500 kg/ha for Katumani maize at 1000 m, and 900 to 3200 kg/ha for cvs. 511/512 at 1100 to 1500 m.

Bulrush millet (*Pennisetum typhoides*)

Bulrush millet is commonly grown as a rainfed crop in the semi-arid regions of Kenya, above the 250 mm isohyet. An even distribution of the rainfall is more important than the total precipitation sum. A warm climate is necessary and millet is seldom grown above 1200 m (Acland, 1971).
The crop is both drought resistant and drought evading because of its short maturation period. It will not tolerate water logging. The rapid initial growth (see rate of root growth in ANNEX C) makes it tolerant of weed competition.
Its merit is that it gives economic yields, albeit low, in soils too infertile for other cereals. The crop is best suited for the short rains, which allows slower maturing crops to be sown in the longer rains.
Bulrush millet is often dry sown to profit from the first rains, but has to be resown when rains are delayed or when a drought occurs after germination. The crop is often intercropped, e.g. with grams.

Yields vary greatly, records for the second rains of 1985 (less than average) vary from 200 to 1400 kg/ha (Ooms, 1987). Jaetzold (1983) indicates that a production of 1700 kg/ha is feasible under a good management level. Yields of over 3000 kg/ha have been recorded with improved hybrids in India.

Mungbean (*Vigna radiata*)

Mungbean is not widely grown in the Chuka area but is selected in this evaluation for practical purposes: phenological crop data were available for mungbean and the crop may be attractive for inclusion in a crop rotation.
The crop can be grown from sea level up to 1500 m altitude and gives reasonable yields in areas which receive an average annual rainfall of 650 mm only (Acland, 1971). It is usually intersown, matures quickly (app. 3 months) and is well suited to the short rains. It can be used as a subsistence pulse crop or a cash crop. Mungbean is drought resistant and susceptible to water logging. Flowering occurs 6 to 8 weeks after sowing; if there is too much rain during this period, there is poor seed setting.

THE ANALYTICAL SET-UP

First, the area was screened for cells that are clearly unsuitable for agricultural use and need no calculation. These concern montane areas, areas/cells with less soil depth than required by the crop, or with a too high altitude (too low temperatures) for millet or mungbean.

The optimum decades of emergence were determined at 14 locations in different climatic zones by calculating the potential and water limited yield with emergence in all decades of the year, and with measured rainfall.
The characteristics of the locations used for this part of the study are listed in Table 3.

Table 3. Altitude, soil depth, soil type and climatic zone at selected locations/grid cells.

Coord.	Climate	Altitude	Eff.depth	Soil	Description
13/377	1	647	122	3	Karua
12/377	2	663	122	3	Katze
13/373	3	708	122	3	Tharaka
3/378	4	762	75	6	Chiokariga
22/365	5	838	94	6	Ishiara
15/361	6	884	122	3	Murinduko
23/357	7	1110	150	2	Kanyuambora
22/347	8	1290	150	1	Embu
19/341	9	1480	150	1	Runyenjes
21/336	10	1510	150	1	Kevote
9/347	11	1470	150	1	Chuka
15/337	12	1690	150	1	Kairuri
10/333	13	1900	150	1	Irangi
7/334	14	1910	150	1	Chogoria

To quantify the influence of soil depth and soil type on the potential yields, calculated for the locations Ishiara, Kanyuambora and Runyenjes, the water limited maize yield potential was calculated for the 5 types of soil and 4 different depths, viz. 50, 80, 120 and 150 cm.

The relation between length of the growing period and the altitude is studied for runs starting with decades 10 and 31 (1st and 2nd rains) for all three crops.

Those decades that showed the highest water limited production potential, were used in an evaluation of the performance of the whole area. This was repeated for all zones because the optimum decade of emergence varies throughout the area.

From different rasters in one growing season an overlay was made with the maximum yield of all decades dominating. The maximum calculated average yield of the total area was used for the division of the area into relative yield classes.

Table 4. Relative yield classes as percentages of the highest yield.

Yield class	% of highest yield	Description	Symbol
1	0 - 20	very low	-
2	20 - 40	low	=
3	40 - 60	moderate	+
4	60 - 80	high	*
5	80 - 100	very high	#

Conversion to relative yields, makes the results independent of the absolute values that are calculated.

For maize, alternative runs with evaporation values 10 percent higher or lower than the normative average value and a run with cloudiness values of Xindaruma (see ANNEX A) used for all cells in the area were evaluated to test the model's sensivity to - variations in basic input values.

RESULTS

Figures 14 and 15 present the lengths of the growing period for maize, millet and mungbean at different altitudes when emergence takes place at decades 10 or 31. The average annual temperature at different altitudes according to equation (2) is also drawn. If emergence is in the 10th decade, the length of the growing period is longer than in situations with emergence in the 31st decade due to the lower temperatures during growth. The failure of mungbean at high altitude is due to the fact that the development rate and net assimilation rate of the crop are low and the leaves die when their age equals their tabulated life span. For such cool conditions tabulated life span values are to be adjusted. However, in reality mungbean is not grown above approximately 1500 m altitude.

Maize

In Table 5 output is shown from simulations for potential and water limited production of maize with emergence in the 10th decade of 1982. The heading describes the characteristics of the location, in this case Ishiara. The several columns represent (from left to right) respectively the decade, the average temperature, the development stage, the cloudiness fraction, the gross CO_2 assimilation rate of a closed canopy, the leaf area index, the leaf reduction factor, the temperature reduction factor, the gross assimilation rate of the crop, the maintenance respiration rate, net assimilation rate, total dry weight and the living dry weights of roots, stems, leaves and storage organs. In the water limited production chart, the amount of infiltrated water, evapotranspiration, drainage from the rooted zone, moisture content of the rooted zone and the water reduction factor are included instead of the leaf correction factor and the dry organ weights.

The simulation gives realistic values for the leaf area and the length of the growing period.
In the water limited scenario, the production is limited by water stress during the last decades of the season due to lack of rainfall.

Table 5. Simulated potential and water limited production of maize at Ishiara (22/365); emergence in the 10th decade.

Row : 22	Col.: 365	Crop : Maize		Clim. : 5	Depth : 100
Unit : 72	Alt.: 838	Prodtype : 1		Soil : 6	Grav% : 6
Latitude :	0.45	Decade : 10		Inf.% : -1	SMfc : 0.25

DC	TEMP	DVS	CLF	Fgc	LAI	LRF	TRF	Fga	MR	Fn	TDW	WRT	WST	WLL	WSO
10	25.1	11	0.32	800	0.02	0.02	1.00	8	0	8	76	29	0	47	0
11	24.8	22	0.33	788	0.08	0.06	1.00	31	2	29	286	95	1	190	0
12	24.5	33	0.34	773	0.34	0.21	1.00	112	7	106	1043	284	69	691	0
13	24.2	43	0.34	761	1.24	0.58	1.00	301	25	277	3012	650	640	1722	0
14	23.9	54	0.34	748	3.10	0.89	1.00	452	68	384	5715	996	2037	2682	0
15	23.4	64	0.37	722	4.83	0.97	1.00	476	121	355	8198	1169	3714	3137	167
16	22.9	73	0.40	694	5.65	0.98	1.00	464	163	301	10372	963	3317	3175	1894
17	22.5	82	0.43	669	5.72	0.98	1.00	448	174	274	12376	770	2654	3032	3897
18	22.2	91	0.48	640	5.46	0.98	1.00	427	177	250	14198	616	2123	2532	5720
19	22.0	100	0.56	597	4.56	0.96	1.00	390	171	219	15799	493	1698	1501	7320

The growing period was 100 days.

Row : 22	Col.: 365	Crop : Maize		Clim. : 5	Depth : 100
Unit : 72	Alt.: 838	Prodtype : 3		Soil : 6	Grav% : 6
Latitude :	0.45	Decade : 10		Inf.% : -1	SMfc : 0.25

DC	TEMP	DVS	Fgc	LAI	LRF	TRF	P+I	E+T	D	SM	WRF	Fga	MR	Fn	TDW	WLL	WSO
10	25.1	11	800	0.0	0.02	1.00	135	33	13	0.25	1.00	8	0	8	76	47	0
11	24.8	22	788	0.1	0.06	1.00	157	33	125	0.25	1.00	31	2	29	286	190	0
12	24.5	33	773	0.3	0.21	1.00	42	35	7	0.25	1.00	112	7	106	1043	691	0
13	24.2	43	761	1.2	0.58	1.00	59	42	17	0.25	1.00	301	25	277	3012	1722	0
14	23.9	54	748	3.1	0.89	1.00	39	44	0	0.24	1.00	452	68	384	5715	2682	0
15	23.4	64	722	4.8	0.97	1.00	0	41	0	0.19	1.00	476	121	355	8198	3137	167
16	22.9	73	694	5.6	0.98	1.00	0	37	0	0.16	1.00	464	163	301	10372	3175	1894
17	22.5	82	669	5.7	0.98	1.00	0	20	0	0.13	0.55	248	161	87	11010	2750	2531
18	22.2	91	640	5.0	0.97	1.00	1	9	0	0.13	0.23	98	136	-38	11010	2117	2531
19	22.0	100	597	3.8	0.93	1.00	0	5	0	0.12	0.10	36	110	-73	11010	1501	2531

Crop died after 100 days !

The potential yield curve (see Figure 16) is reasonably smooth although small steps occur where the climatic zone changes from 3 to 5 or 5 to 6 which coincides with a change of cloudiness regime. The water limited yield curve shows more abrupt fluctuations resulting from differences in soil factors and differences in rainfall regime from one climate zone to another.

The maize yields calculated for the 14 locations selected show clearly the influence of the decade of emergence and the altitude.
Recall that the potential yield is influenced by the temperature and the cloudiness fraction. Yields are negatively affected by low radiation or a high leaf weight which has high maintenance requirements.

For selected locations, the results are presented in Figures 17 to 21. In these Figures, the decades of the year are shown on the horizontal axis; any of these could be chosen as the decade of emergence. Plotted against the decade of emergence are the potential yield, the average water limited yield with measured rainfall, and the maximum water limited yield.
At Ishiara (Figure 18) this maximum never reaches the potential indicating that this region is permanently short of rainfall. Moving to climatic zones with more rainfall the number of decades at which the maximum exceeds the potential is increasing.
It is shown clearly that water limited yields may exceed the potential. Note that dry conditions always lower the quantity of total dry matter produced. However if leaf mass (assimilatory capacity) is not seriously affected, the decrease of maintenance respiration losses results in a higher yield.

Irangi (Figure 21) in particular, has many decades of emergence for which the potential yield level may be exceeded. Rainfall is evenly distributed over the year which is acknowledged by the fact that this area is well known for its tea production.
Here occurs an inconsistency in the data base. The climatic zone Irangi has less rainfall than Chogoria. Indeed, the estimated average rainfall sum for Irangi amounts to some 125 mm less than for Chogoria, but the gauged annual average rainfall sum is about 25 mm higher (see ANNEX A).

The difference between the average and maximum yields says something about the variability of rainfall. A large difference suggests that a high maize yield may be possible only during an exceptional year. A small difference means that in most years the actual yield is right close to the maximum.

The ratio of the average water limited and potential yields shows whether rainfall is, on the whole, sufficient or not. This ratio increases in general from zones 1 to 14, with in the low rainfall area the highest ratio during the 2nd rains (until Ishiara), and for the other area during the 1st rains.

Each location has a distinct minimum yield potential. Karua (Figure 17) has its minimum potential if the maize emerged in mid-May because of low radiation at time of cob filling. Irangi (Figure 21) has its minimum if emergence is early March; the crop dies during the period with high cloudiness because no living leaves remain. Karua reaches its maximum production if emergence

takes place in the 23rd decade, which is associated with high radiation during cob filling.
The phenomenon of lack of living leaves at high altitude is caused by the assumption that the life span of leaves is a specific number of days. It may be more realistic in an area with a large variation in lengths of the growing period to express the life span of leaves in thermal units!

The second rains are normally associated with higher potential yields than the first rains, but the average of the water limited yield potentials may turn out lower than those calculated for the first season because at higher altitude both the amount and the reliability of the 2nd rains is less than of the 1st rains.
In general, the ratio of water limited yield potential and the potential yield is highest in the low-rainfall zones in the 2nd rains, and in the high-rainfall zones during the 1st rains. Exceptions to this trend are Tharaka, Murinduko and Chogoria.

The following number of the optimum decade of emergence varies from 9 at Karua to 14 at Chogoria during the 1st rains with decades 9 and 10 most frequently occurring. The 2nd rains have their optimum between decades 29 and 31. The optimum decade for the intermediate rains at high altitude is decade 21.

Table 6 shows average and maximum water limited maize yield - potentials for different soil - depth combinations at those three locations that represent climatic zones 5, 7 and 9. The results for Ishiara and Runyenjes are presented in Figure 22. It must be noted that the maize has an assumed maximum <u>effective</u> rooting depth of only 0.7 times 135 = 95 cm.

The table shows that, at Ishiara, the highest yield level for decade 10 is reached on soil 1 with a depth of 95 or 120 cm. If the same soil is given a depth of 150 cm, the water limited yield potential is less.
Reason for this is that drainage to the lower layer is stored over a larger soil volume when 150 cm deep. Thus when roots grow deeper, the rooted layer extends into a subsoil that is relatively low in moisture. After averaging, the overall moisture content of the root zone becomes lower than in the case of shallower soils.
Soils 4 and 6 have a lower waterholding capacity and need less rain to drain and less drainage to attain field capacity. Therefore, these soils have the same maximum yield figures over the entire depth range of 95 to 150 cm; soils 1, 2 and 3 show the above described yield decrease at depths over 120 cm.

Table 6. Average and maximum water limited maize yields for emergence at decade 10 and for the different types of soil at effective depths of 50, 80, 95, 120 and 150 cm.

Ishiara (Coord.: 22/365; Potential : 7320 kg/ha)

	50		80		95		120		150 cm	
1	1095	3584	2692	6416	3440	7320	3445	7320	2765	6492
2	719	2313	1934	5072	2620	6241	2621	6241	2569	6177
3	657	1894	1649	4759	2266	5794	2292	5833	2090	5426
4	50	167	409	1129	584	1496	583	1496	583	1496
6	419	1162	872	2327	1308	3269	1303	3269	1311	3269

Kanyuambora (Coord.: 23/357; Potential : 6846 kg/ha)

	50		80		95		120		150 cm	
1	579	3647	1787	6067	2611	7128	2518	7128	2381	7128
2	375	2448	1186	4434	1852	5537	1827	5537	1771	5537
3	283	2039	1011	4005	1560	4961	1509	4961	1453	4961
4	35	228	192	1091	328	1341	323	1341	323	1341
6	144	1375	414	2238	750	2828	750	2828	748	2828

Runyenjes (Coord.: 19/341; Potential : 5256 kg/ha)

	50		80		95		120		150 cm	
1	849	5256	2411	5256	3179	5344	3179	5344	3024	5256
2	952	5256	2087	5256	2762	5256	2762	5256	2752	5256
3	521	5256	1591	5256	2181	5256	2180	5256	2125	5256
4	374	4992	880	5590	1224	5590	1224	5590	1223	5590
6	505	5421	1353	5256	1572	5256	1572	5256	1572	5256

At Kanyuambora, the potential yield at decade 10 is exceeded by the maximum water limited yield for soil 1 at a depth of 95 cm or more. No soil shows a difference in maximum yields between runs with depths 95 cm or more. The difference between the soil types is still clear, but this difference has disappeared for Runyenjes where most combinations equal or exceed the potential yield.

Remarkable is that at Runyenjes, soil type 4 (with an available soil moisture fraction of only 9 volume percent) shows the highest maximum yields. This confirms that the type of soil and its depth becomes less important for high yields if rainfall is less limiting, as at Runyenjes.
Both in the long and the short rains a soil depth of 50 cm is strongly limiting unless the soil has an excellent waterholding capacity. Physical soil conditions on the whole become more constraining if climate conditions are poor. If the yields of table 6 are plotted against their corresponding moisture capacity (see ANNEX B), a close to linear relationship appears.

When assessing yield classes for 'maize in the first rains', not all optimum decades were used. Decades 9 and 10 were considered the most important although 13 and 14 are optimum under climates 12 to 14. For these latter decades the water limited yields at Kairuri and Irangi closely approach the potential of more than 6 tons/ha.
This resulted in a strong shift of the highest yield class (class size 1410 against 1085 for decades 8 to 10) from approximately between 1100 and 1400 to more than 1600 m altitude (except under climate 14). The yield classes for maize in the first and second rains are presented in Figures 23 and 24.

An abrupt change in yield level occurs where climate 7 borders climate 8 (Figure 23). It is associated with a change in cloudiness regime from 4 to 5, and, which is of more importance, a change in rainfall regime. This manifests itself in an increase in yield level from class 3 to 5. In most zones, e.g. 9, 10 and 14, locations at relatively lower altitude get a relatively higher yield class.

In the semi-arid eastern part of the area, soils that are deeper feature the highest yield classes. The highest yields (still moderate) are achieved on very deep soils of type 3. For equal depths soil 6 performs better than 4 due to its higher moisture holding capacity.
Climate zone 2 is very low yielding at all locations.
Zones 11 and 12 get relatively low yields compared to 13 and 10 although the cloudiness is identical and the altitudes comparable.

For the 2nd rains the picture is much different. The vegetative growth is now in the warmer part of the year so growth is faster. Cob filling is now just before the cold, cloudy period. Chiokariga performs relatively well this time. In zone 3, very deep soils of type 3 yield very low although they were best-yielding in the 1st rains. Because there is little rainfall now, the larger depth is a disadvantage due to distribution of water of a larger soil volume.

Alternative runs have been done concerning the effects of cloudiness and evaporation on maize yields. Figure 25 shows the

yield classes for the first rains with an average cloudiness regime (from climate zones 6 and 7) throughout the area. Compared to Figure 23 with different cloudiness regimes, the class size is 6% larger and the area with a very high yield has decreased by 6%. The belt with a very high yield remains at the same place, between about 1100 and 1400 m altitude.
For the second rains the difference is minimal.

The effect of a change in evaporation is shown in Figures 26 and 27 where evaporation during the first rains has been lowered or increased by 10% . With a decrease or increase of evaporation the calculated yield will change in the other direction. The largest effect of the change in evaporation on the average yield is due to the assumption that the crop will die if the moisture content of the rooted zone reaches wilting point (see the simulation model). If the rooted depth is limited and the evaporation from the rooted zone relatively high, the crop will die.

Millet

Table 7. Simulated potential and water limited production of bulrush millet at Ishiara (22/365); emergence in the 10th decade.

Row : 22	Col.: 365	Crop	: Bulrush millet		Clim. :	5	Depth :	100
Unit : 72	Alt.: 838	Prodtype	:	1	Soil :	6	Grav% :	6
Latitude :	0.45	Decade	:	10	Inf.% :	-1	SMfc :	0.25

DC	TEMP	DVS	CLF	Fgc	LAI	LRF	TRF	Fga	MR	Fn	TDW	WRT	WST	WLL	WSO
10	25.1	15	0.32	800	0.01	0.00	1.00	2	0	2	17	8	0	9	0
11	24.8	29	0.33	788	0.02	0.01	1.00	5	0	5	52	16	0	35	0
12	24.5	44	0.34	773	0.07	0.04	1.00	19	1	18	181	33	29	118	0
13	24.2	57	0.34	761	0.25	0.12	1.00	60	4	56	575	62	257	256	0
14	23.9	71	0.34	748	0.54	0.24	1.00	120	12	108	1326	73	918	311	23
15	23.4	84	0.37	722	0.65	0.28	1.00	137	24	113	2130	58	1102	308	461
16	22.9	97	0.40	694	0.65	0.28	1.00	131	31	100	2858	47	892	302	1178
17	22.5	101	0.43	669	0.63	0.27	1.00	124	35	89	3054	44	839	295	1373

The growing period was 73 days.

Row : 22	Col.: 365	Crop	: Bulrush millet		Clim. :	5	Depth :	100
Unit : 72	Alt.: 838	Prodtype	:	3	Soil :	6	Grav% :	6
Latitude :	0.45	Decade	:	10	Inf.% :	-1	SMfc :	0.25

DC	TEMP	DVS	Fgc	LAI	LRF	TRF	P+I	E+T	D	SM	WRF	Fga	MR	Fn	TDW	WLL	WSO
10	25.1	15	800	0.0	0.00	1.00	135	33	14	0.25	1.00	2	0	2	17	9	0
11	24.8	29	788	0.0	0.01	1.00	157	31	126	0.25	1.00	5	0	5	52	35	0
12	24.5	44	773	0.1	0.04	1.00	42	31	11	0.25	1.00	19	1	18	181	118	0
13	24.2	57	761	0.2	0.12	1.00	59	32	27	0.25	1.00	60	4	56	575	256	0
14	23.9	71	748	0.5	0.24	1.00	39	34	6	0.25	1.00	120	12	108	1326	311	23
15	23.4	84	722	0.7	0.28	1.00	0	33	0	0.21	1.00	137	24	113	2130	308	461
16	22.9	97	694	0.6	0.28	1.00	0	27	0	0.18	1.00	131	31	100	2858	302	1178
17	22.5	101	669	0.6	0.27	1.00	0	7	0	0.17	1.00	124	35	89	3054	295	1373

The growing period was 73 days.

Table 7 shows runs for potential and water limited production for millet emerged in the 10th decade of 1982. It can be observed that millet reaches its potential yield without irrigation whereas the growth of a maize crop remained strongly reduced by water stress (see Table 6). Next to the rapid root growth of millet (40 cm/decade against 12 cm/decade for maize), a reason for this is that the leaf weight, and hence the leaf area, is too small. Probably the data set borrowed from the WOFOST model can not be used for Kenyan varieties without adjustments.

The values for the length of the growing period and the leaf area

in the table above are also very unusual. Therefore it will be clear that the results concerning millet must be considered with care.
Figures 28 to 31 show the potential, and the average and maximum water limited millet yields for different decades of emergence. Compared with the performance of maize at the same locations, millet yields <u>relatively</u> better in the drier climatic zones and the yield potential is reached at more decades and in more years. So the risk of a crop failure seems less when millet is cultivated instead of maize.

It seems that the millet potential reacts to an increase in altitude (from Karua to Kanyuambora) with an increase of the yield. This suggests that conclusions based on maps of 'yield classes' have to be made with care because of the 'altitude effect'. With increasing altitude the length of the vegetative period increases which results in a higher leaf area.
In general, the average millet yield is closer to the potential during the 2nd rains than in the 1st rains.

Yield classes for bulrush millet during the first and second rains are presented in Figures 32 and 33. Relative yield classes, i.e. the ratio of average waterlimited potential and potential yield (Figures 34 and 35), were mapped as well. Compared to Figures 32 and 33 with 'common' yield classes the suitability of most grid cells is upgraded by one class. The strong effect of altitude, due to the quality of the crop data, is now less disturbing.

During the 1st rains the highest millet yields are associated with emergence at decade 10 or decade 11 at Murinduko and Kanyuambora. The 2nd rains have their optimum at decades 31 and 32.

Mungbean

Runs for potential and water limited production of mungbean with emergence at the 10th decade of 1982 are given in Table 8. The leaf area index has an acceptable value. However, during the last decades of the growing period, growth has stopped. Given the fact that mungbean is supposed to be a quickly maturing crop (see crop data) the chosen temperature sum may be too large.

Table 8. Simulated potential and water limited production of mungbean at Ishiara (22/365); emergence in the 10th decade.

Row : 22	Col.: 365	Crop : Mungbean	Clim. : 5	Depth : 100	
Unit : 72	Alt.: 838	Prodtype : 1	Soil : 6	Grav% : 6	
Latitude : 0.45		Decade : 10	Inf.% : -1	SMfc : 0.25	

DC	TEMP	DVS	CLF	Fgc	LAI	LRF	TRF	Fga	MR	Fn	TDW	WRT	WST	WLL	WSO
10	25.1	9	0.32	624	0.01	0.01	0.99	3	0	3	31	10	7	14	0
11	24.8	18	0.33	615	0.04	0.02	1.00	10	1	10	99	28	24	46	0
12	24.5	27	0.34	605	0.14	0.08	1.00	33	2	31	320	75	84	162	0
13	24.2	35	0.34	597	0.49	0.25	1.00	103	7	96	1002	179	284	530	0
14	23.9	44	0.34	588	1.59	0.61	1.00	246	22	224	2584	345	887	1247	74
15	23.4	52	0.37	570	3.74	0.89	1.00	348	55	293	4608	460	1360	1754	685
16	22.9	60	0.40	551	5.26	0.96	1.00	360	84	275	6471	518	1533	1691	1769
17	22.5	67	0.43	534	5.07	0.95	1.00	347	97	250	8136	503	1384	1099	3189
18	22.2	75	0.48	515	3.30	0.86	1.00	303	91	212	9538	443	1107	424	4550
19	22.0	82	0.56	486	1.27	0.53	1.00	177	79	98	10184	368	885	47	5182
20	21.7	89	0.62	462	0.14	0.08	1.00	26	70	-44	10184	294	708	0	5182
21	21.8	96	0.62	469	0.00	0.00	1.00	0	65	-65	10184	235	567	0	5182
22	21.9	101	0.61	483	0.00	0.00	1.00	0	63	-63	10184	207	499	0	5182

The growing period was 126 days.

Row : 22	Col.: 365	Crop : Mungbean	Clim. : 5	Depth : 100	
Unit : 72	Alt.: 838	Prodtype : 3	Soil : 6	Grav% : 6	
Latitude : 0.45		Decade : 10	Inf.% : -1	SMfc : 0.25	

DC	TEMP	DVS	Fgc	LAI	LRF	TRF	P+I	E+T	D	SM	WRF	Fga	MR	Fn	TDW	WLL	WSO
10	25.1	9	624	0.0	0.01	0.99	135	33	14	0.25	1.00	3	0	3	31	14	0
11	24.8	18	615	0.0	0.02	1.00	157	32	126	0.25	1.00	10	1	10	99	46	0
12	24.5	27	605	0.1	0.08	1.00	42	32	10	0.25	1.00	33	2	31	320	162	0
13	24.2	35	597	0.5	0.25	1.00	59	35	24	0.25	1.00	103	7	96	1002	530	0
14	23.9	44	588	1.6	0.61	1.00	39	40	0	0.25	1.00	246	22	224	2584	1247	74
15	23.4	52	570	3.7	0.89	1.00	0	41	0	0.17	1.00	348	55	293	4608	1754	685
16	22.9	60	551	5.3	0.96	1.00	0	19	0	0.13	0.48	173	76	97	5264	1546	1067
17	22.5	67	534	4.6	0.94	1.00	0	5	0	0.12	0.10	34	67	-34	5264	980	1067

Crop died after 80 days!

Rainfed mungbean (Table 8) died due to drought stress in 1982. In Figures 36 to 39 the potential yield, the average and maximum water limited yield of mungbean is shown for different decades of emergence. In high temperature climate zones the amplitudo of potential yields is remarkably large with its maximum during the cloudy, low-temperature season due to a prolonged growing period.

The yield classes for the two rainy seasons are presented in Figures 40 and 41. Yield classes for relative yields (see millet) show no substantial differences. High to very high yields are reached between approximately 1100 and 1400 m in climate zones 8 and 9.

During the short rains, rainfall in the eastern part is not sufficient to realize the potential yield. Therefore, irrigation practices is thought to be profitable.

Conclusions

The present study does not have the pretention of being a complete land evaluation; it is merely an analysis of some physical aspects of land. Perennial crops such as coffee and tea are not considered, although they are of great importance in a major part of the area.

The optimum <u>sowing</u> time for rainfed maize is at the end of March in the major part of the area, and at the end of April for areas above 1700 m. The optimum sowing time for the short rains is at the end of October.
In the eastern part of the area, the benefits that can be expected of irrigation are largest for the short rains because both the potential and the difference between the potential and the maximum waterlimited yields is relatively high then.

The calculated yield figures were reached under the assumption of 100% infiltration of rainfall. Part of the difference between actual and calculated yields can be subscribed to the occurrence of runoff.

In the eastern part of the area, the net soil depth, and consequently the water storage capacity, are strongly limiting the rainfed yield potential.

Division of the area in climatic zones with different cloudiness regimes has a distinct effect on the result of the simulation. In many cases the borders of yield classes coincide with a change of climatic zone.

For hard conlusions on the suitability of bulrush millet and mungbean, more precise data on these crops will be necessary.

POSTSCRIPT

One of the objectives of the present study was to evaluate the CRIES Geographic Information System. An important quality of such a system must be the ease of manipulation of raster data. Technically, the GIS works very well in facilitating the manipulation of rasters, and in efficiently storing raster data, but on the computer- user interface many improvements are possible.

The interaction with the user is by means of questions that have to be answered; it would be of more ease if a menu were presented with suggested defaults. When output is sent to the printer much paper is wasted by excessive headers.

A plus of the program is the use of function keys with which it is very easy to select different actions ("phases") to apply on rasters. CRIES however misses the facility that it 'remembers' the last file processed or the settings that were selected in the last run of a phase. Each run the same questions have to be answered.

Another disadvantage is the lack of possibilities for storing real data values (division of grid cell values is also impossible), negative values or complex data such as climatic data or mapping unit characteristics. The coordinate system is rigidly defined; the origin must be in the left upper corner with the coordinate value increasing downwards or to the right, with negative values not allowed.
Error handling is not sufficiently implemented; when errors occurred during execution of the CHLOROLINE phases (Schultink et al., 1986), the messages had disappeared before they possibly could be read.

A linking possibility with a data base program such as DBASE would have been very attractive, just as a query language to manipulate rasters or to select grids with certain characteristics.
Compared with other (business) software like LOTUS 1-2-3 or DBASE IIIplus, the CRIES GIS seems less friendly, simple and costly. Notwithstanding these facts, the GIS offers a possibility to store and manipulate spatially distributed single value data.

LITERATURE

Acland, J.D., 1971. East African Crops. FAO/Longman.

Braun, H.M.H., 1986. Some characteristics and altitude relationships of temperatures in Kenya. Miscellaneous Paper M18, Kenya Soil Survey, Nairobi.

Driessen, P.M., 1986. The Q.L.E. Primer. A First Introduction to Quantified Land Evaluation Procedures. Lecture notes for J050-140, "Land Evaluation II". Agricultural University, Wageningen.

EAMD, 1975. Climatological statistics for East Africa, Part 1 - Kenya. East African Meteorological Department, Nairobi.

FAO, 1983. Guidelines: land evaluation for rainfed agriculture. Soils Bulletin 52. Rome.

Frere, M. and G.F. Popov, 1979. Agrometeorological crop monitoring and forecasting. FAO plant production and protection series 17. Rome.

Goudriaan, J. and H.H. van Laar, 1978. Calculation of daily totals of the gross CO_2 assimilation of leaf canopies. Netherlands Journal of Agricultural Science 26:373-382.

Jaetzold, R. and H. Schmidt, 1983. Farm management handbook of Kenya. Vol. II/C. East Kenya (Eastern and Coast Provinces). Ministry of Agriculture of Kenya, German Agricultural Team, Nairobi.

Keulen, H.van and J. Wolf (eds.), 1986. Modelling of agricultural production: weather, soils and crops. Simulation Monographs. Pudoc, Wageningen.

KMD, 1985. Climatological statistics for Kenya. Kenya Meteorological Department, Nairobi.

Koorevaar, P., G. Menelik and C. Dirksen, 1983. Elements of soil physics. Elseviers Scientific Publishing Co., Amsterdam.

Meester, T. de, 1988. Soil Survey Report of the Chuka-area, scale 1:100,000. In preparation.

Ooms, B., 1987. An ecological suitability classification for the cereals of the Chuka area, Kenya. Internal report, T.P.I.P., Agricultural University of Wageningen.

Purseglove, J.W., 1985. Tropical Crops. Monocotyledons and Dycotyledons. Longman, New York.

Rappoldt, C., 1986. Crop growth simulation model WOFOST, documentation version 3.0. Staff working paper SOW-86-05, Centre for World Food Studies, Amsterdam-Wageningen.

Sombroek,W.G., B.J.A. van der Pouw and H.M.H. Braun, 1982. Exploratory soil map and agro-climatic zone map of Kenya, 1980. Exploratory Soil Survey Report E1, Kenya Soil Survey, Nairobi.

User's Guide to the CRIES Geographic Information System (preliminary version), G. Schultink, A. Zusmanis, B. Buckley, D. Brown, S. Nair, S. Chen. Version 6.0, Comprehensive Resource Inventory and Evaluation System (CRIES) Project, Michigan State University, East Lansing, USA, 1986.

Weg, R.F. van de and J.P. Mbuvi (eds.), 1975. Soils of the Kindaruma area. Reconnaissance Soil Survey Report R1. Kenya Soil Survey, Nairobi.

Woodhead, 1968. An estimation of potential evaporation in Kenya. Nairobi.

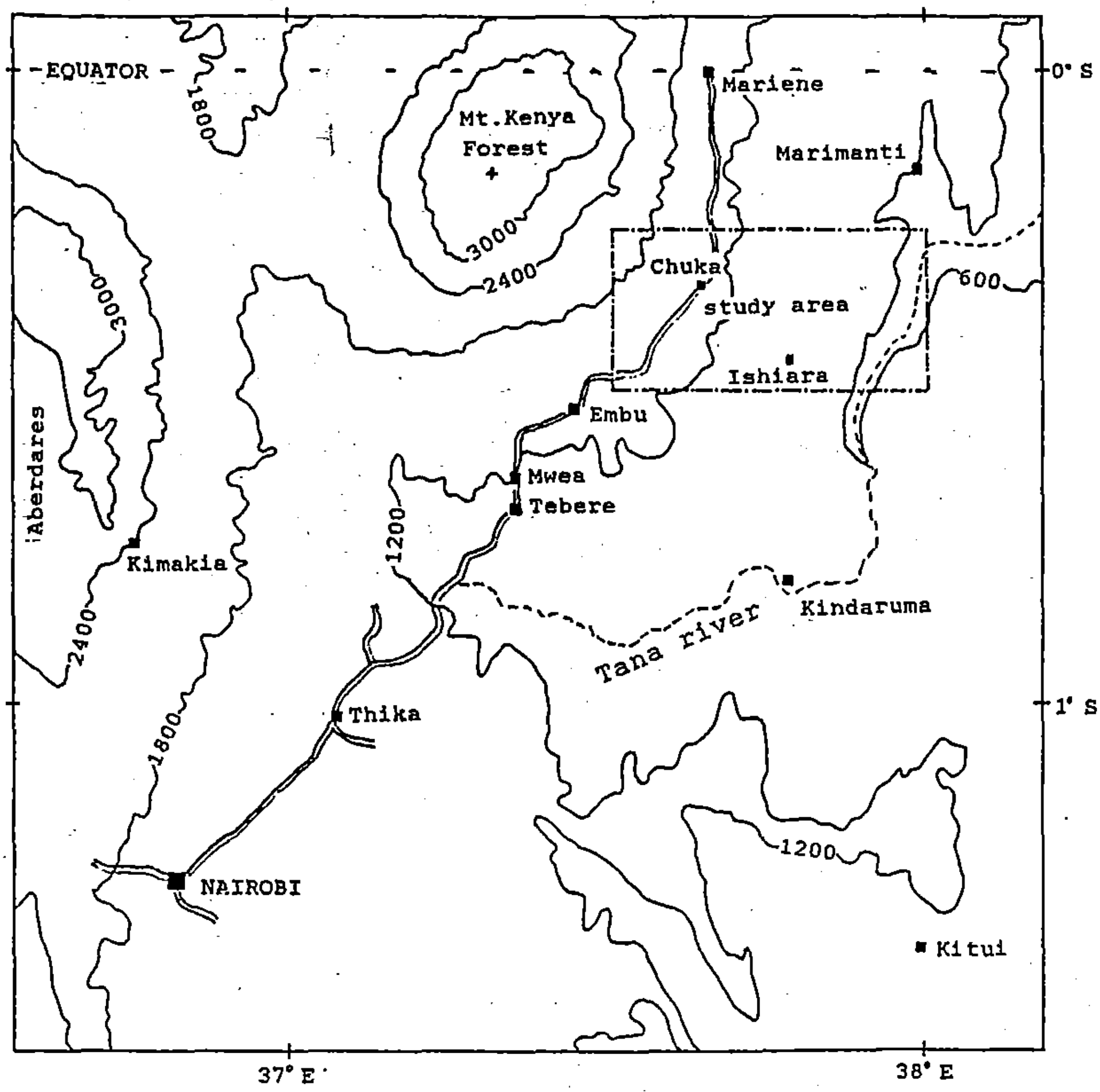


Figure 1. Location of the study area in Kenya.

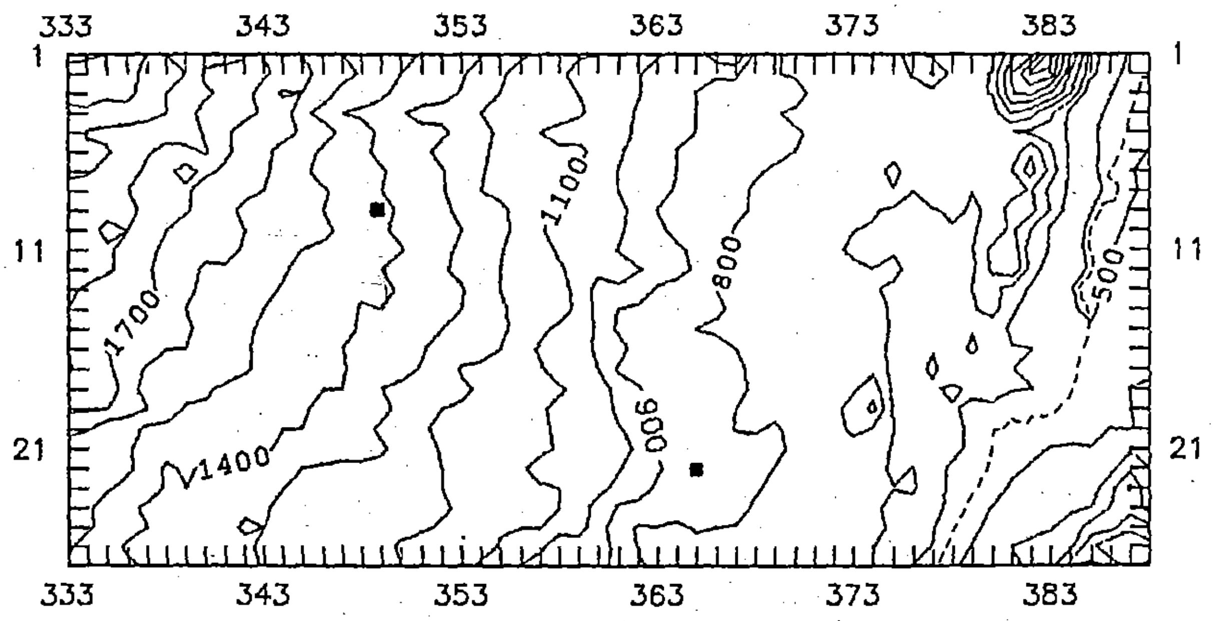


Figure 2. Contour map of the study area with contours for each 100 m altitude.

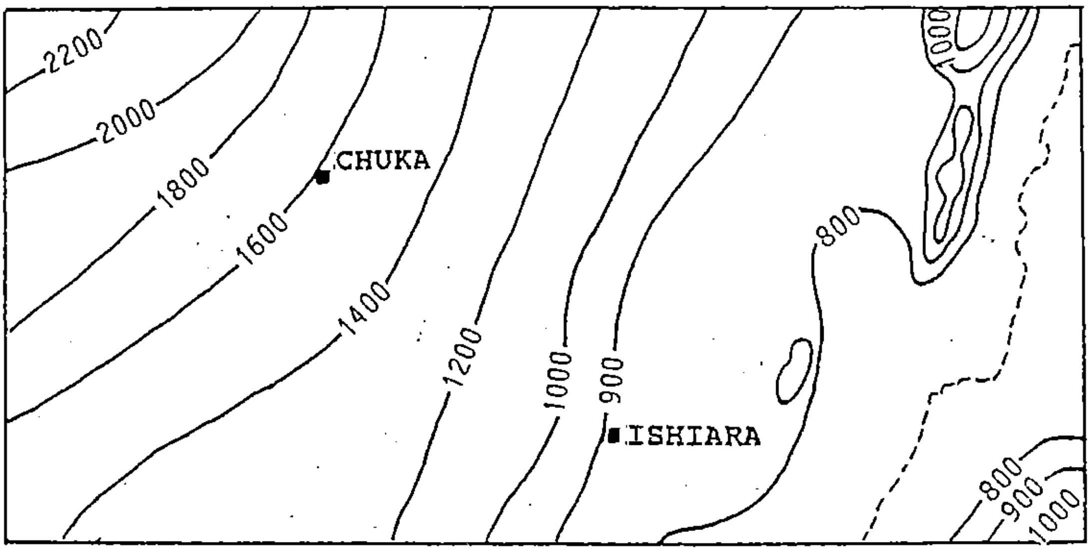


Figure 3. Rainfall map with estimated annual rainfall (mm/year) for the study area.

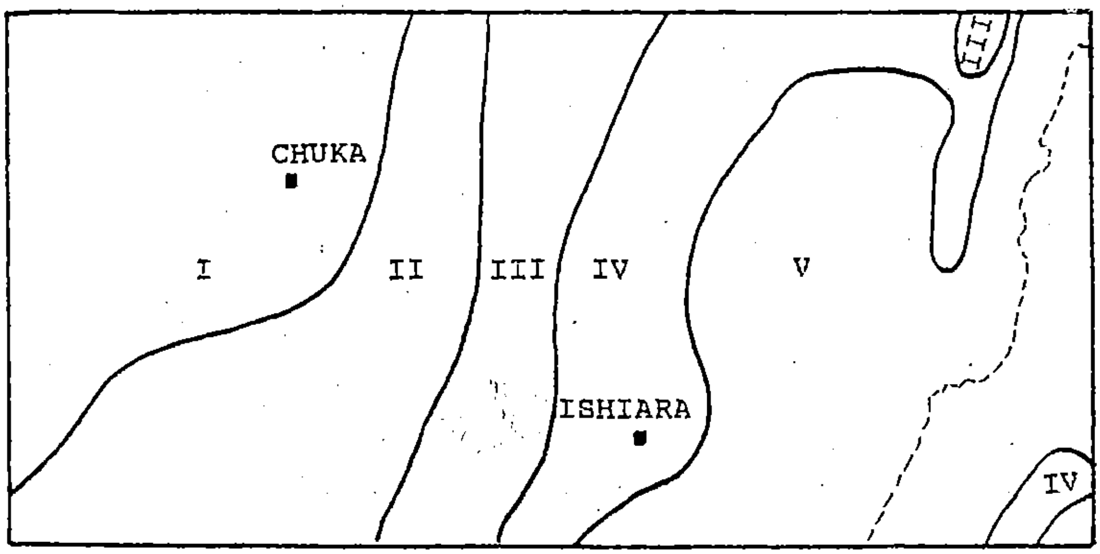


Figure 4. Moisture availability zones based on the ratios of precipitation and potential evaporation. V = 25-40% (semiarid), IV = 40-50% (semihumid to semi-arid), III = 50-65% (semihumid), II = 65-80% (subhumid) and I = >80% (humid).

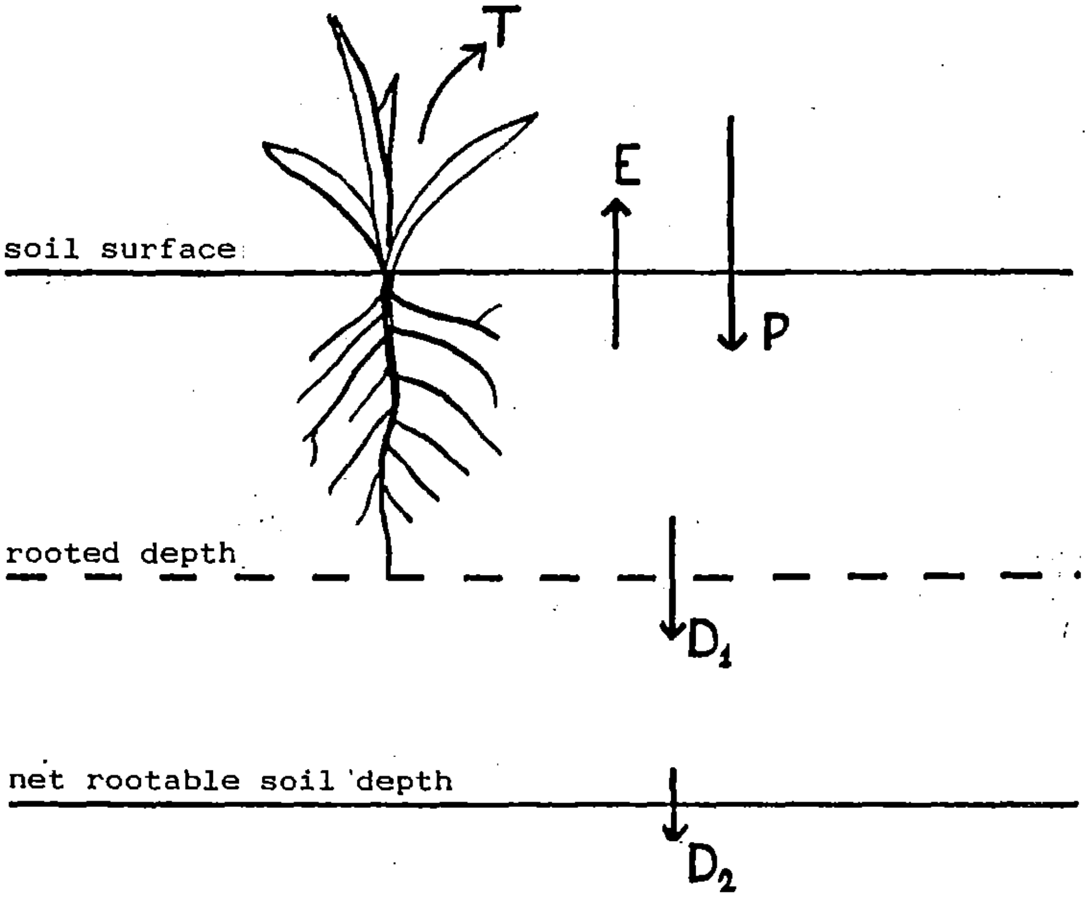


Figure 5. Soil layers and moisture flows in the model. E = evaporation from the upper soil, P = precipitation, D1 = drainage of rooted layer to subsoil, D2 = drainage out of the subsoil.

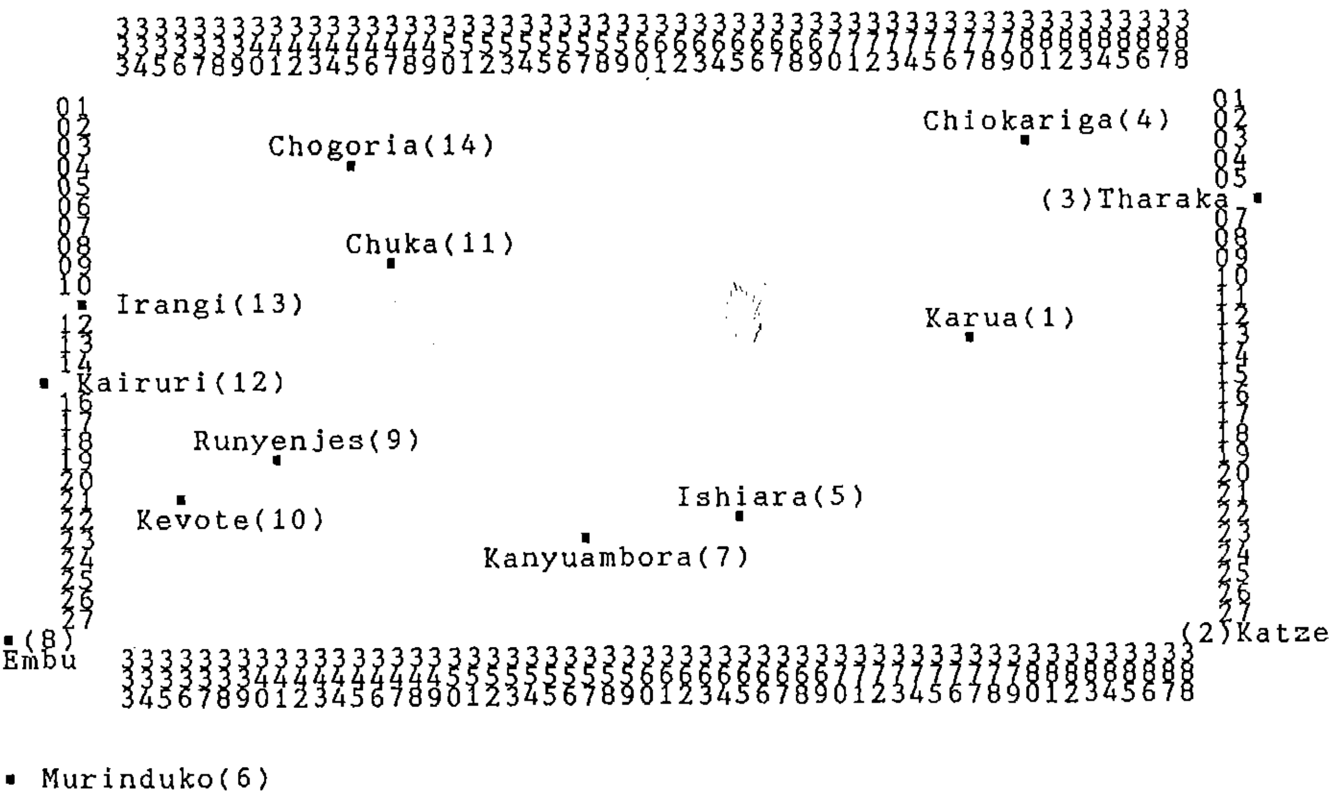


Figure 6. Location of meteorological gauging points, inside and outside the study area, and the number of years with complete data.

Figure 7. Distribution of climatic zones, with different rainfall and cloudiness regimes, in the Chuka area.

```
    33333333333333333333333333333333333333333333333333333333
    33333334444444444555555555566666666667777777777888888888
    34567890123456789012345678901234567890123456789012345678

01  DDDDDDDDDDDDDCCAAAA000998888887776664444444444444676322 2  01
02  DDDDDDDDDDDDDCCCAA0009999888877766664444444444444776322 2  02
03  DDDDDDDDDDDDDCCAAA0009999888877766664444444444444664222 2  03
04  DDDDDDDDDDDDCCAAA00099999888877766664444333333334643222 2  04
05  DDDDDDDDDDDDCCCAA00099988888877666444444333333333443222 2  05
06  DDDDDDDDDDCCCCAAA00099988888777666444444333333333643222 2  06
07  DDCCCCCCCCCCAAAAA0099988888777666444443333333333464322 22  07
08  CCCCCCCCCCCCAAAA0009998888877766644443333333333346432 222  08
09  CCCCCCCCCAAAAAAA00009998888777666444333333333333463222 22  09
10  CCCCCCCCCAAAAAAAA00099988877766644433333332222334632222 2  10
11  CCCCCAAAAAAAAAAA0009998888777666644433333322222344322222   11
12  CCCCCBBAAAAAA00000999988887777665553333333222223462222 22  12
13  CCCCBBBAAAAA000000999988887666655553333333211123432222 22  13
14  CCBBBBBB000000000099998888766655555333333321122332222 222  14
15  CBBBBBB00000000999999888777665555553333333222223222222 22  15
16  CCBBBBB00000099999888887777665555555333333222222222222 22  16
17  CCBBB000099999999988888777766555555333333322222222222222   17
18  CCCB0099999999998888887777776555555333333322222222222222   18
19  BBBBB09999999999888888777777665555533333333222222222222 2  19
20  BB00099999999998888888777777665555553333333222222222222 2  20
21  00009999998888888888877777776655555533333332222222222232   21
22  00009999998888888888877777766655555533333332222222222333   22
23  00099998888888888888877777766655555333333332222222222353   23
24  00999998888888888888877777665555555333333332222222233555   24
25  99999888888888888888877777665333333333333332222222335566   25
26  99998888888888888888877776666553333333333333322222233556 66  26
27  99998888998888888887776666555333333333333222222223355667   27

    33333333333333333333333333333333333333333333333333333333
    33333334444444444555555555566666666667777777777888888888
    34567890123456789012345678901234567890123456789012345678
```

Zone	Symbol	Frequency	%
1	1	5	0.3
2	2	221	15
3	3	238	16
4	4	88	6
5	5	90	6
6	6	99	7
7	7	104	7
8	8	185	12
9	9	138	9
10	0	94	6
11	A	62	4
12	B	34	2
13	C	81	5
14	D	73	5

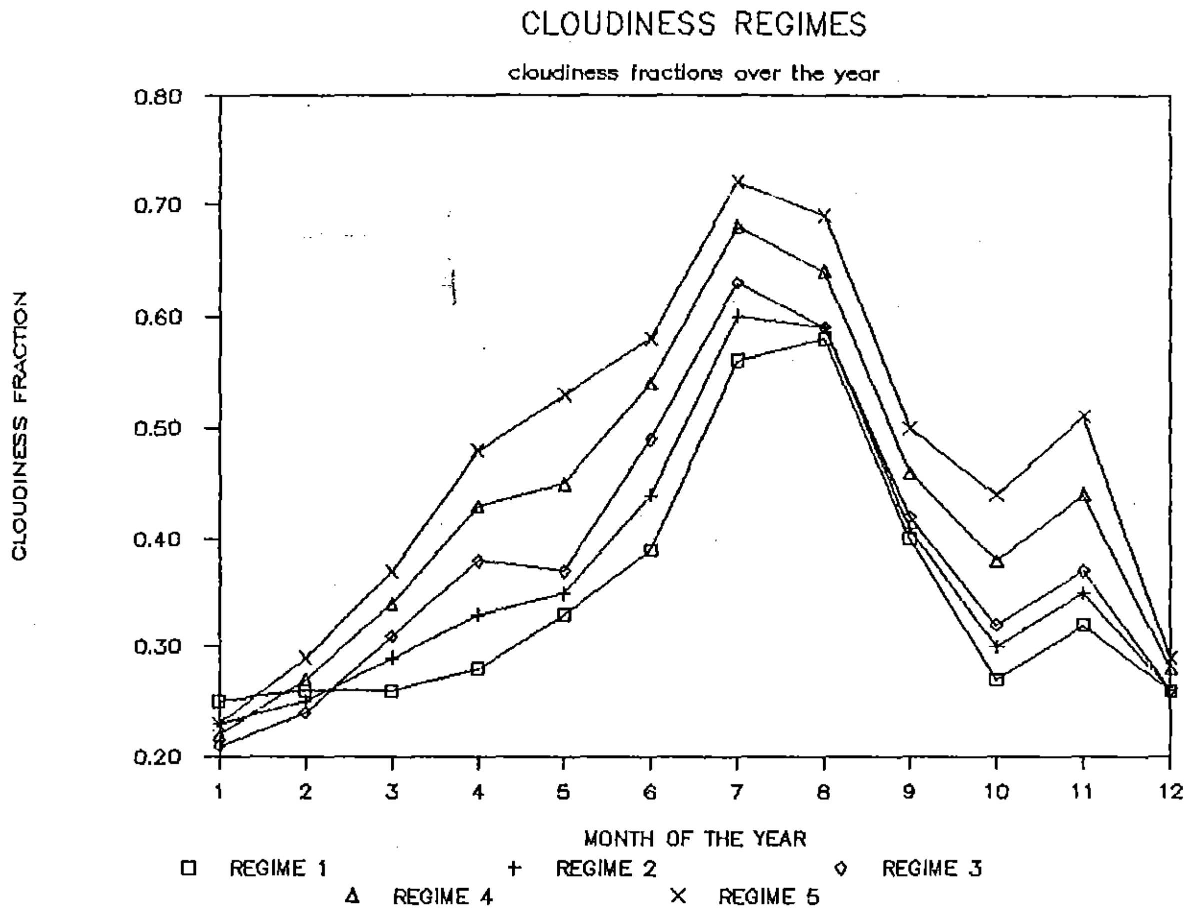


Figure 8. Values of cloudiness fractions in different regimes during the year.

Figure 9. Distribution of soil types over the Chuka area.

```
   33333333333333333333333333333333333333333333333333333333
   33333334444444444555555555566666666667777777777888888888
   34567890123456789012345678901234567890123456789012345678

01 11111221111111111112111112222224444434234664466444444644 01
02 11111112211111111121122222222222644333324644666444444644 02
03 11111111112211111111111112212222662444363246666444446444 03
04 11111111111122222222222111222222266433334634666664446444 04
05 12121111111111111111111122212222226434443246666644464464 05
06 11111211111111111111111122222222663333443336666444444444 06
07 11111221111111111111111222222224436634334442664444444644 07
08 21111111221111111111111112222666633334434442666444464444 08
09 12111111112111111111111122222664663333333446666444444444 09
10 11211111111211111111111122222226622333343434466664464444 10
11 11122111111111111111112122222224433333333443644446444444 11
12 11111211111121111112221222224444333333643443664444444444 12
13 11111112211111211111111222444444333336633643364444446444 13
14 11111111112111122211111222444333333366346446664444444444 14
15 21111111111121111211211112243336666666666466664444444444 15
16 22211111111111211112111222224366633366664466664444444444 16
17 12221111111111121111212222222633636666444666646444444444 17
18 22222111111111112212222222224266662266444466666644444444 18
19 22244411111111111221222222224466666664444466666444444444 19
20 22114111111111111112222222222244666664466446666644444444 20
21 11111111111111111112222222222224666444466466666444444444 21
22 11111111111111121222222222222224666444444666466444444444 22
23 11111112221111111122222222244244444444444664664444444444 23
24 11111112222222222222222222444444444444444666644444444444 24
25 11111112222222222222224444444444444444444666644444444444 25
26 11111112242222222222222244444644444444446666644444444444 26
27 11111111244222222222222244444464444444666666444444444444 27

   33333333333333333333333333333333333333333333333333333333
   33333334444444444555555555566666666667777777777888888888
   34567890123456789012345678901234567890123456789012345678
```

Soil type	Description	Frequency	%
1	clay (Volc. Footridges)	462	31
2	clay (Volc. Plateau)	323	21
3	clay (Basement System)	91	6
4	sandy clayloam (,,)	435	29
6	sa. cl.loam to clay (,,)	201	13

Figure 10. Map of the effective rootable soil depth classes in the Chuka area.

```
   33333333333333333333333333333333333333333333333333333333
   33333334444444444555555555566666666667777777777888888888
   34567890123456789012345678901234567890123456789012345678

01 -----++------------+-----+==+==*****-*=**++************* 01
02 -------++---------+--++++=++=+=++**----*=*+**+********** 02
03 ----------++-------------++-+=++++****-+*=*+++********** 03
04 ------------+++++++++++----==+==*++*---*+**++*********** 04
05 -+-+--------------------+++-++*+**+*-****=*+**********=* 05
06 -----+-------------------+==*****++----*****+*********** 06
07 -----++----------------++=*==****+++-+--***+=********=** 07
08 +-------++--------------****=+++=+----++-**+=*********** 08
09 -+--------+------------=====*++*++--------*+**=********* 09
10 --+--------+-----------=+++**=++==----*-*-*+************ 10
11 ---++----------------=-+==*==+*=**--------*+-*********** 11
12 -----+------+-------===-*===****-------=*-*+-*********** 12
13 -------++-----+--------===******-----==--=*--*******=*** 13
14 ----------+----+++-----*+=***-------=+-+=**+************ 14
15 =-----------+----+--+----++*---=====+++==*++************ 15
16 ===-----------+----+---**+*+*-=++---++==+*++************ 16
17 -====----------+----+-***+*++=--+-+++*=++*+++*********** 17
18 =====-----------++-+---++-*#**++++**==++**++++********** 18
19 ===***-----------++-+--+-+-#**+++++==+++**+++++********* 19
20 ==--*--------------++-----++#**+*+==++++**+++++********* 20
21 -------------------+-++----**#*+==++++++*+++++********** 21
22 ---------------=---------+*+++#*===+++++++++*++********** 22
23 -------***------=----==----**#++++++++++*++*++********** 23
24 -------***---=------------+++++++++++++++++************* 24
25 -------**------=------=++**++*+*++++++++++++************* 25
26 -------***------=-=----=+++++=**++++++++++************** 26
27 --------***--------======***++*=*++++++++*************** 27

   33333333333333333333333333333333333333333333333333333333
   33333334444444444555555555566666666667777777777888888888
   34567890123456789012345678901234567890123456789012345678
```

Depth class		Symbol	Frequency
very shallow	< 25	#	6
shallow	26 - 50	*	462
moderately deep	51 - 80	+	305
deep	81 - 120	=	118
very deep	121 - 150	-	621

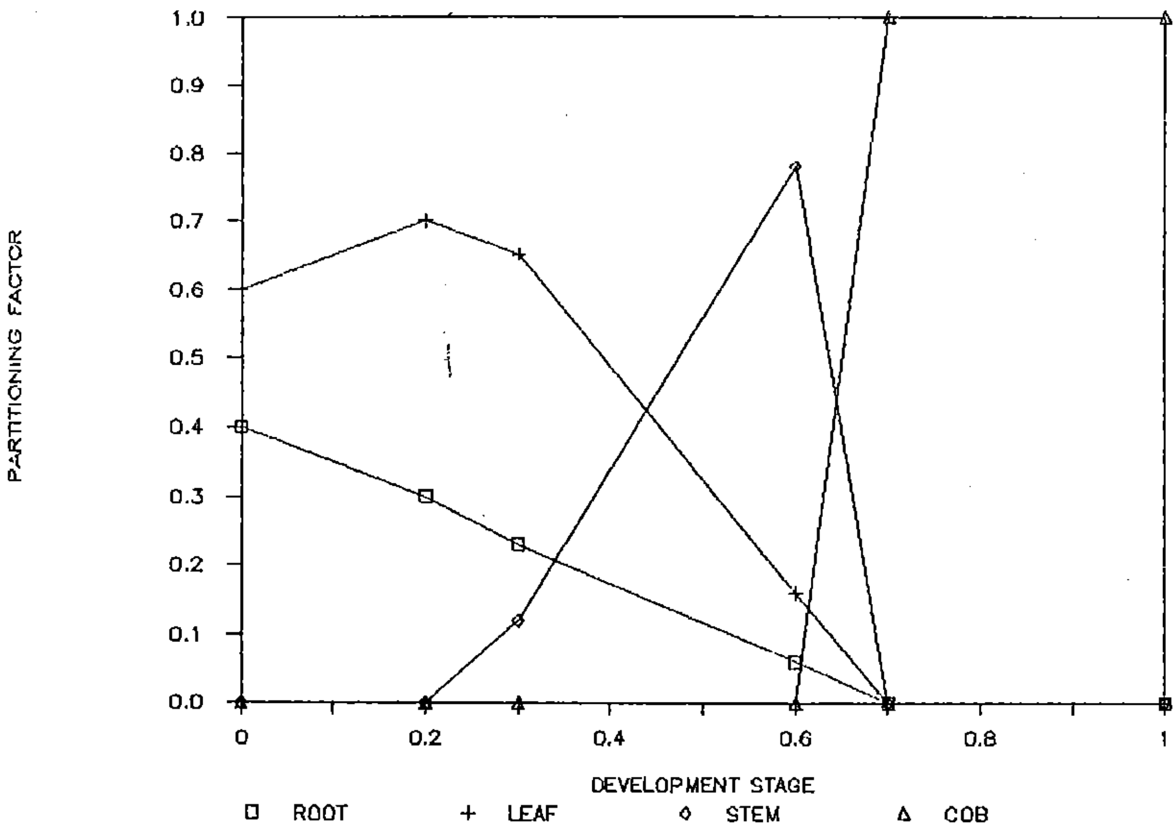


Figure 11. Partitioning factors for maize.

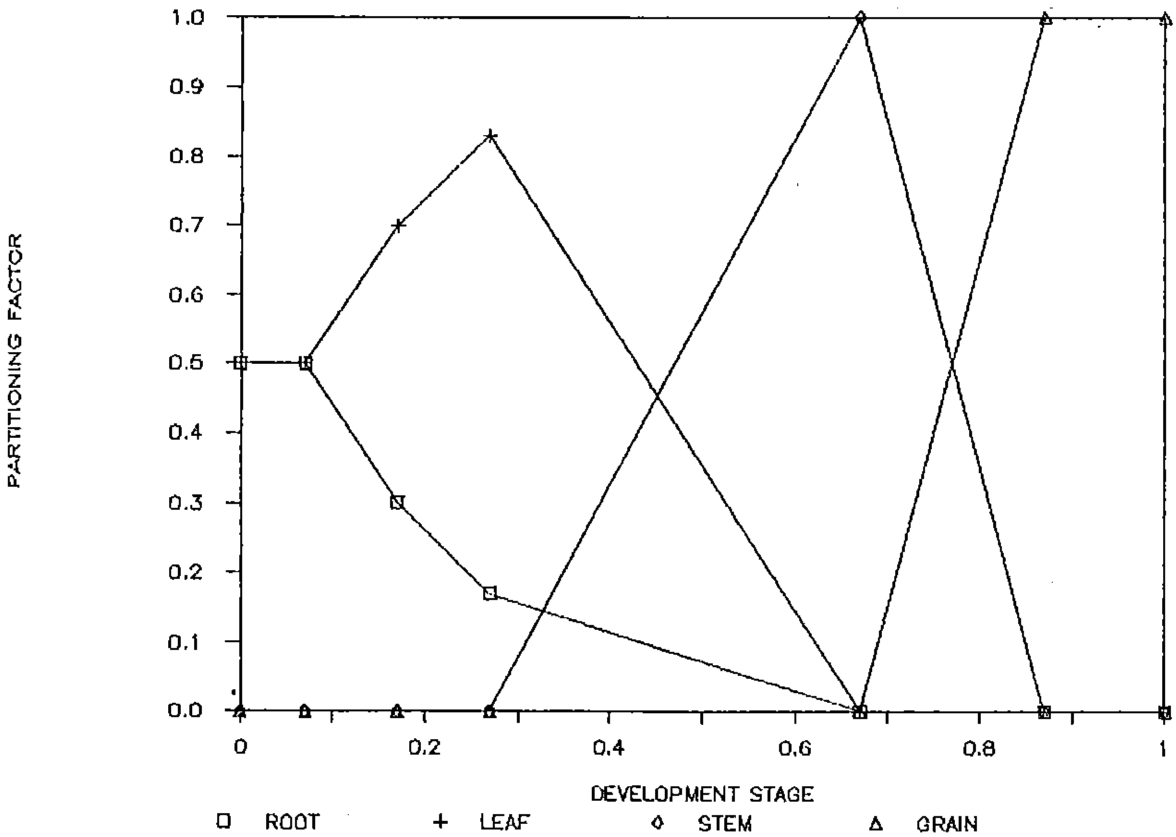


Figure 12. Partitioning factors for bulrush millet.

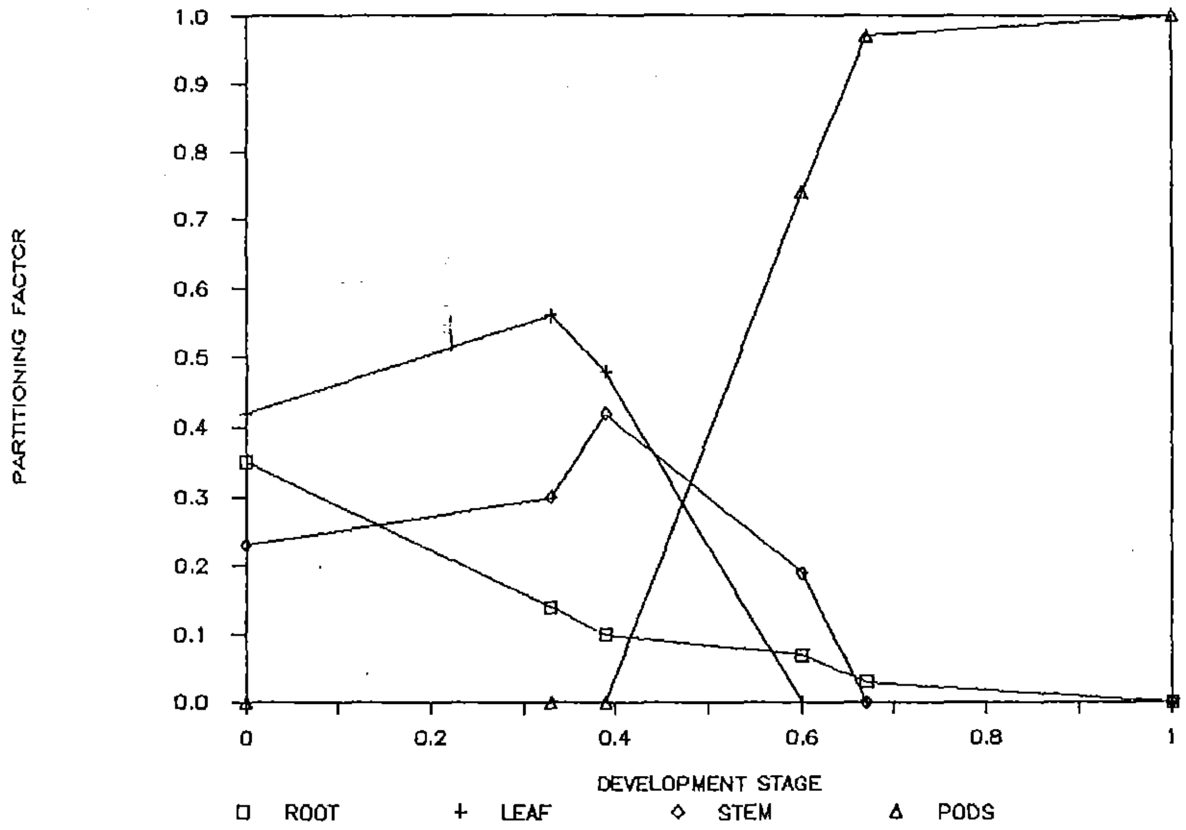
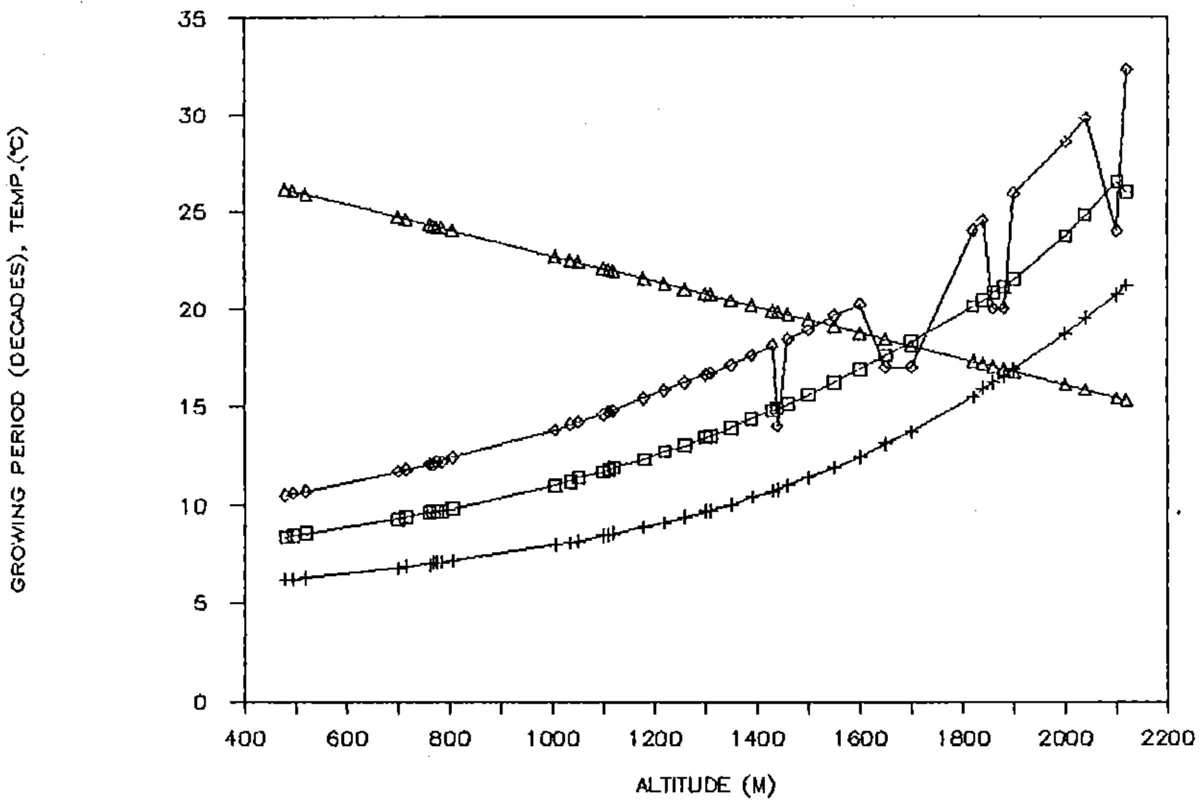
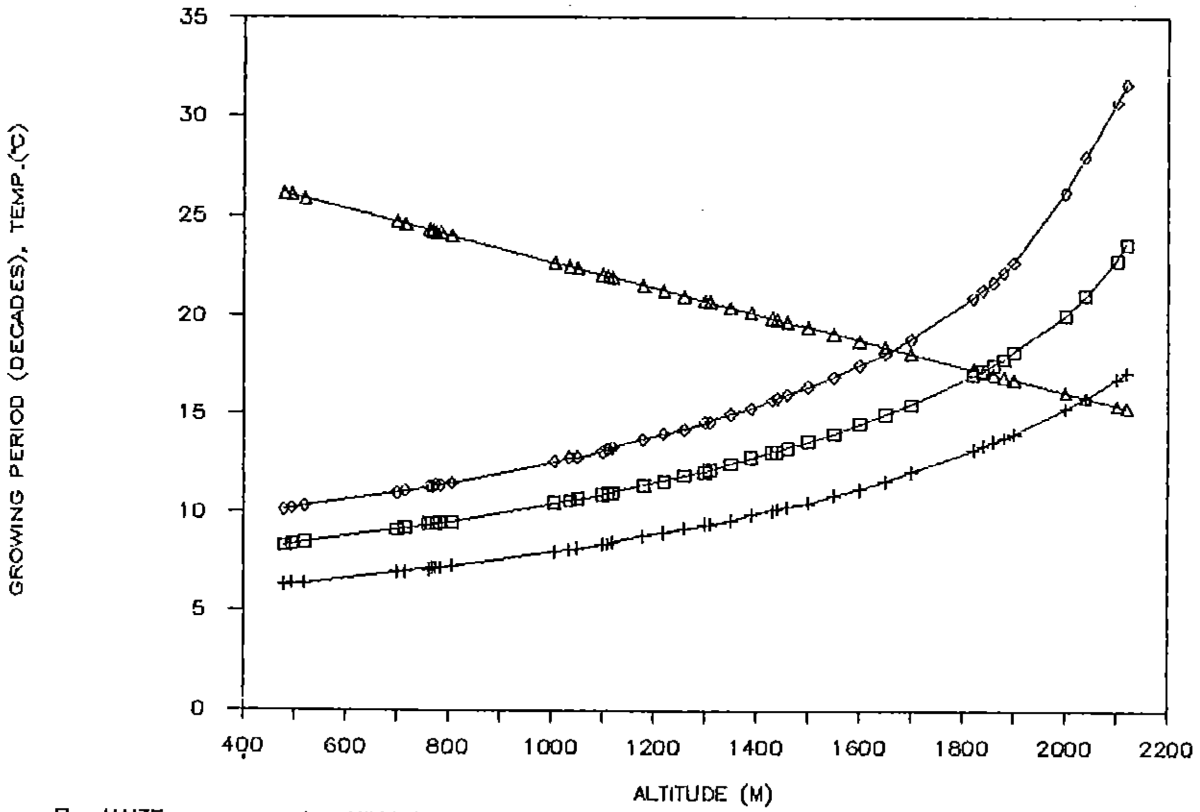


Figure 13. Partitioning factors for mungbean.



□ MAIZE + MILLET ◇ MUNGBEAN △ ANN. TEMP.

Figure 14. Relation between altitude and the length of the growing period for maize, millet and mungbean when emerged at the 10th decade.



□ MAIZE + MILLET ◇ MUNGBEAN △ ANN. TEMP.

Figure 15. Relation between altitude and the length of the growing period for maize, millet and mungbean when emerged at the 31st decade.

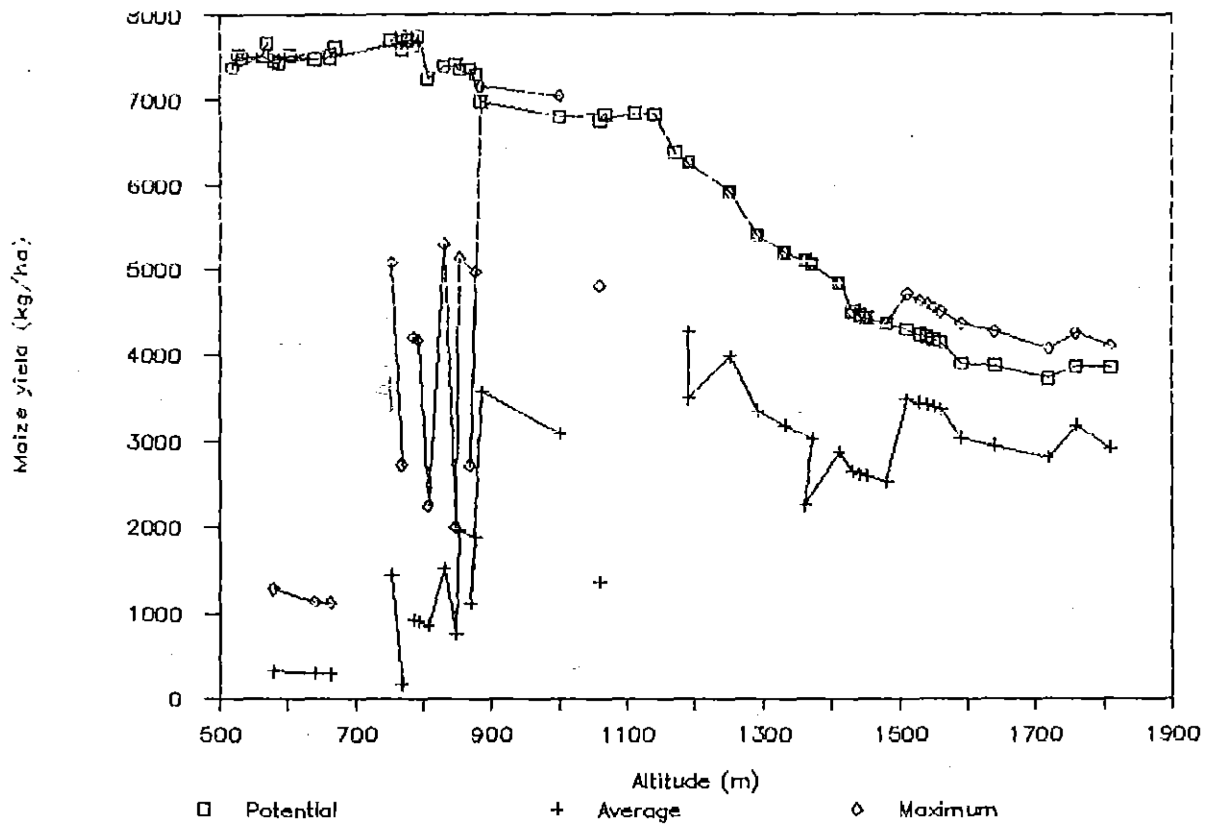


Figure 16. Potential, average water limited and maximum water limited maize yield when emerged at the 10th decade for row coordinate 17.

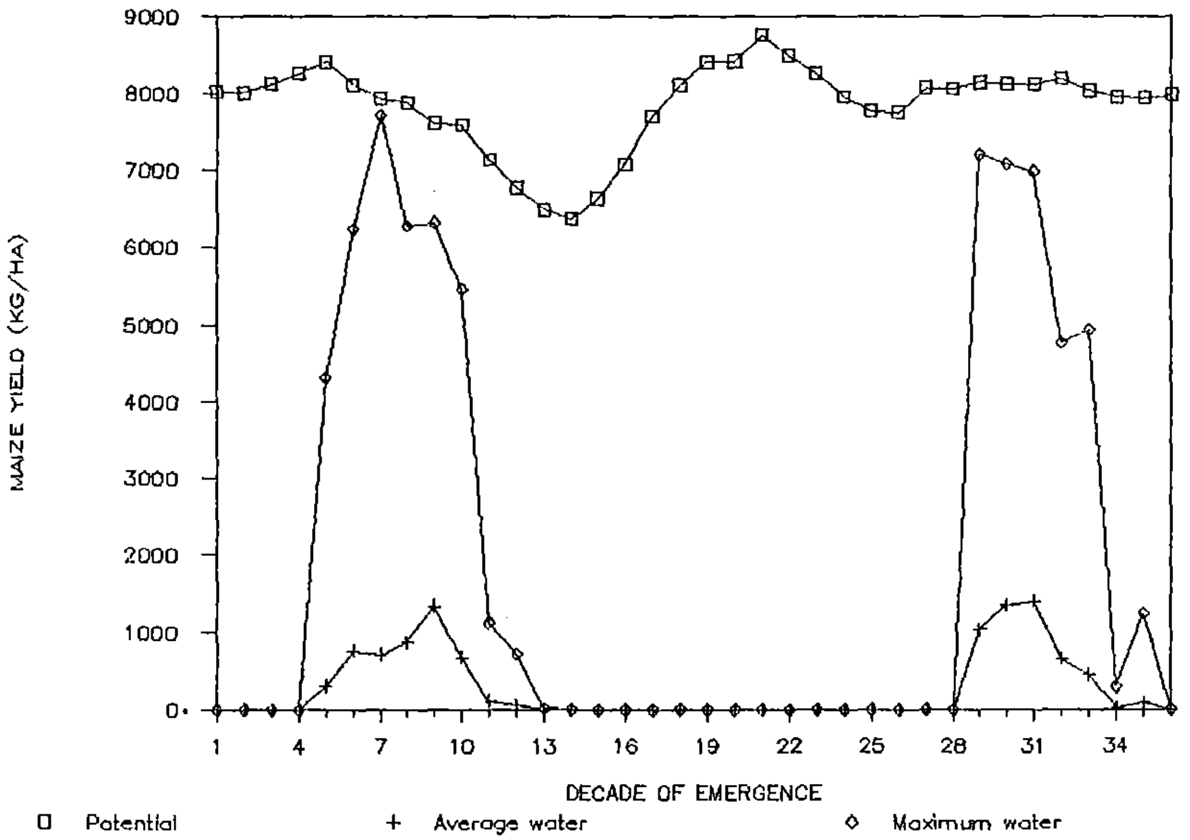


Figure 17. Maize yields at location 13/377 (Karua) for different decades of emergence.

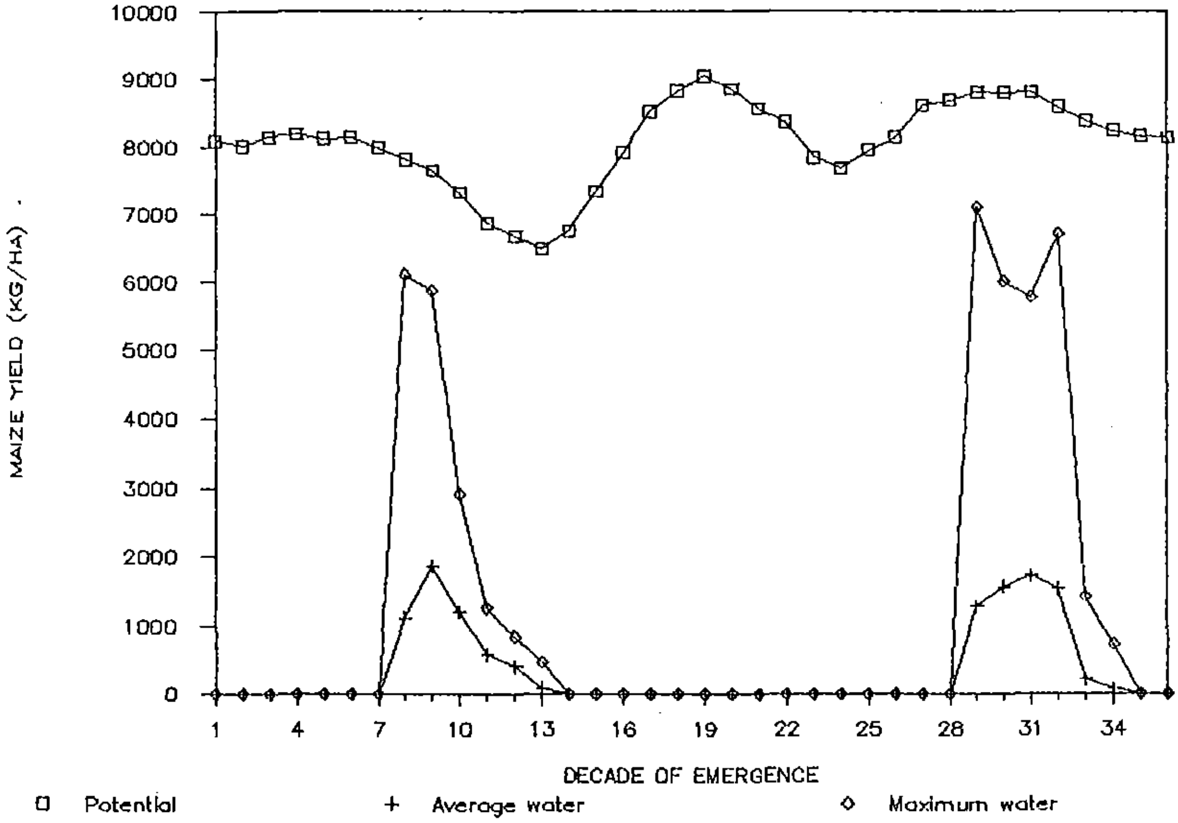


Figure 18. Maize yields at location 22/365 (Ishiara) for different decades of emergence.

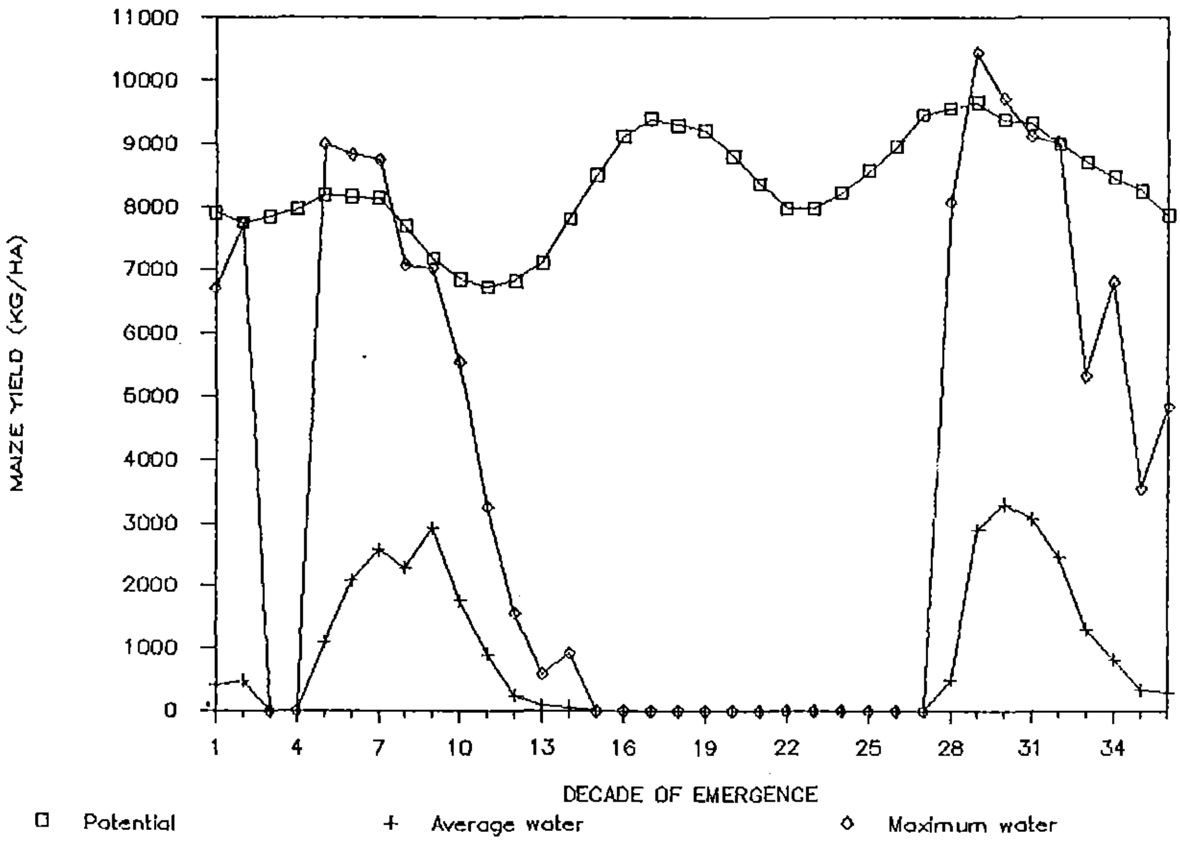


Figure 19. Maize yields at location 23/357 (Kanyuambora) for different decades of emergence.

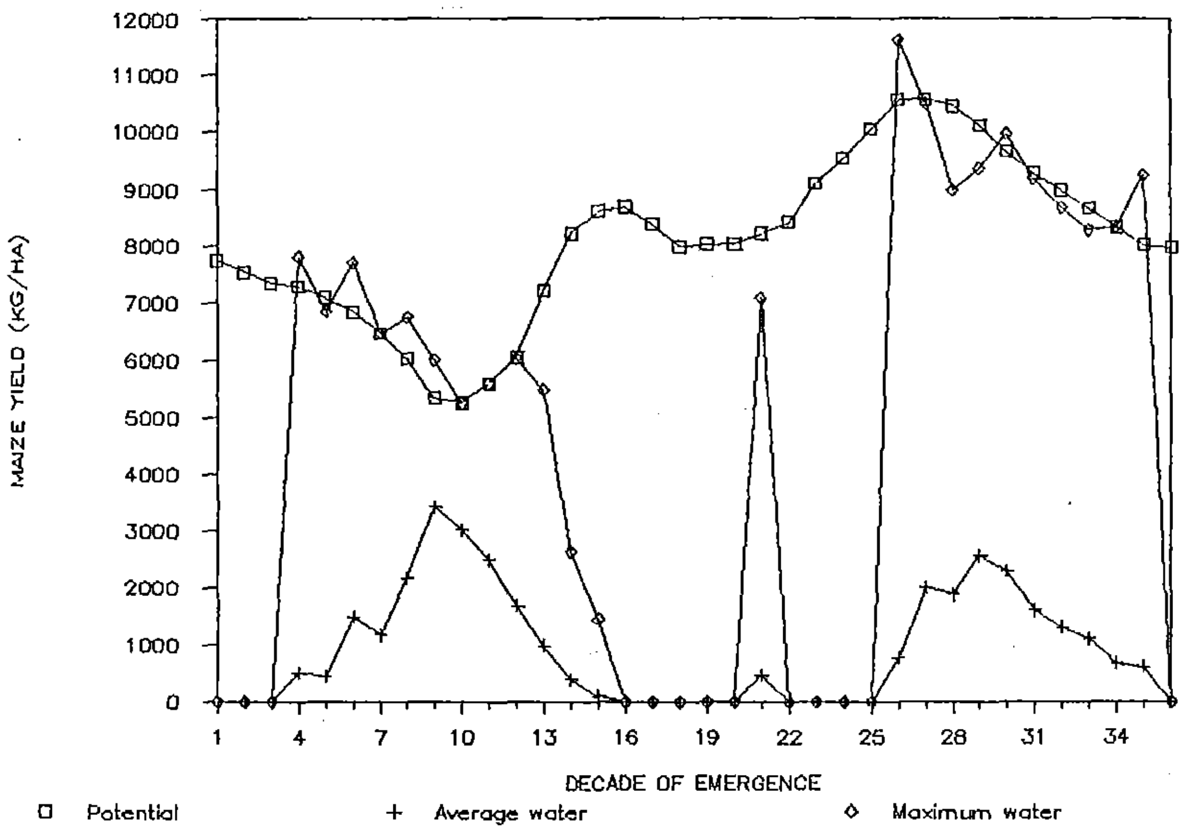


Figure 20. Maize yields at location 19/341 (Runyenjes) for different decades of emergence.

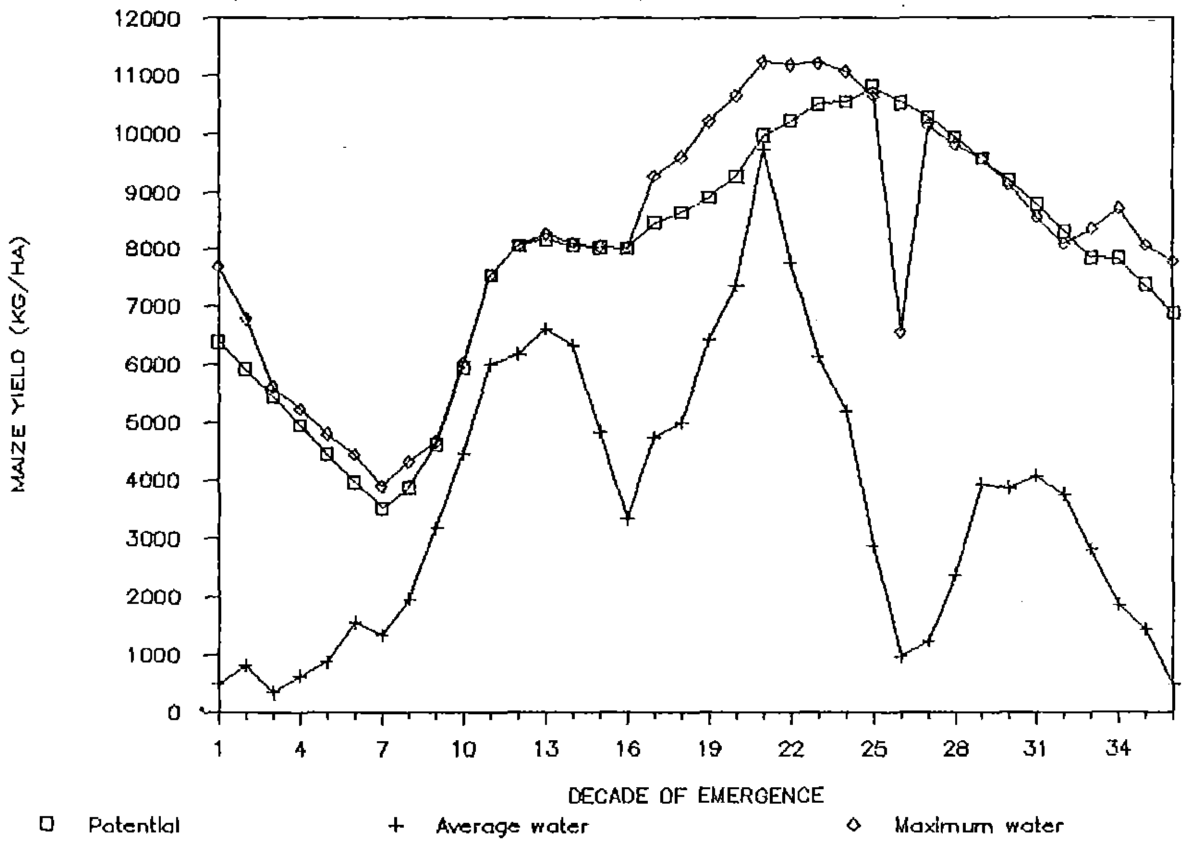


Figure 21. Maize yields at location 10/333 (Irangi) for different decades of emergence.

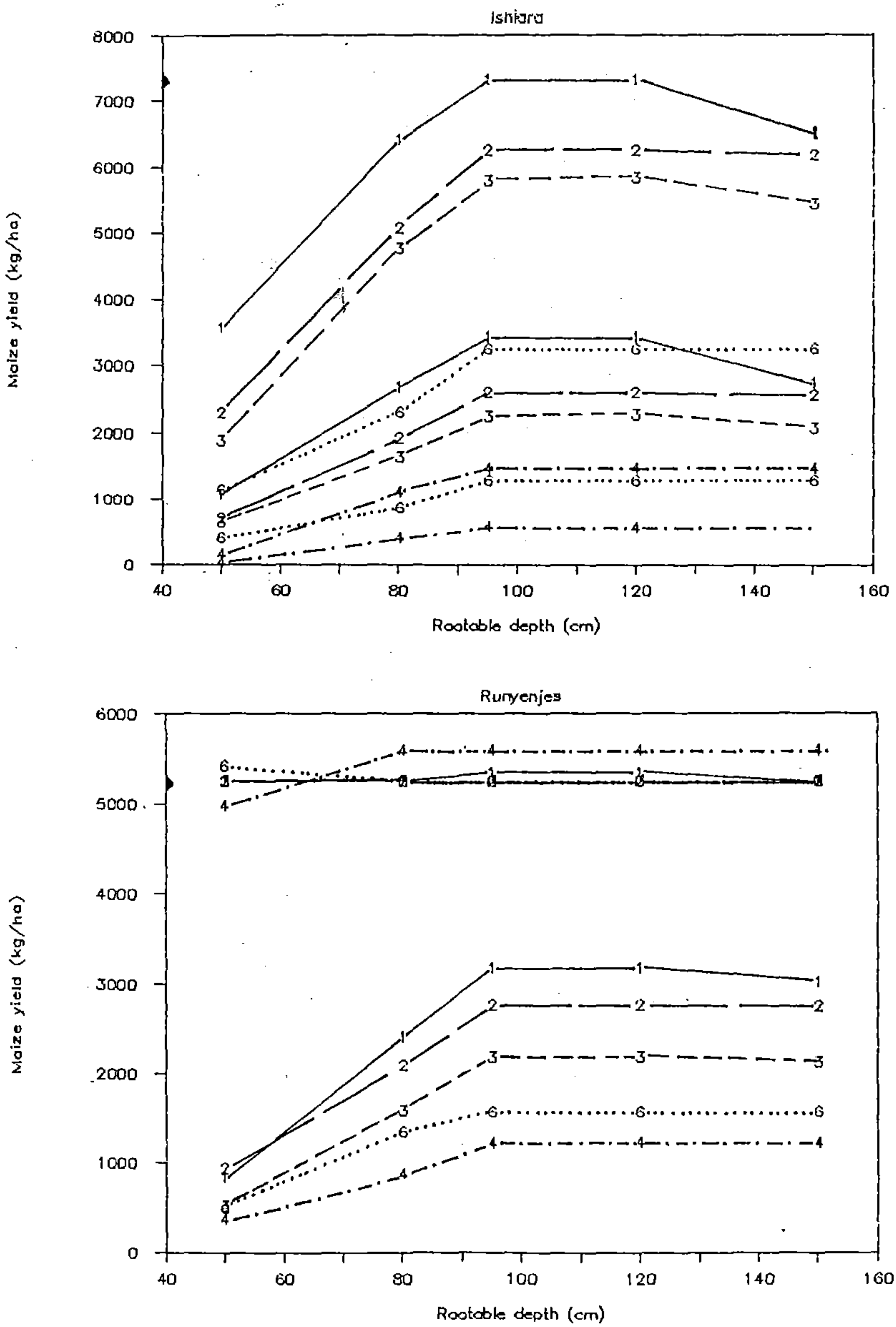


Figure 22. Influence of soil type and depth on the maximum and average maize yields at Ishiara (a) and Runyenjes (b). Each soil type has two lines of which the upper represents the maximum yield, and the lower the average water limited yield. Emergence is at the 10th decade. The mark at the vertical axis gives the potential maize yield.

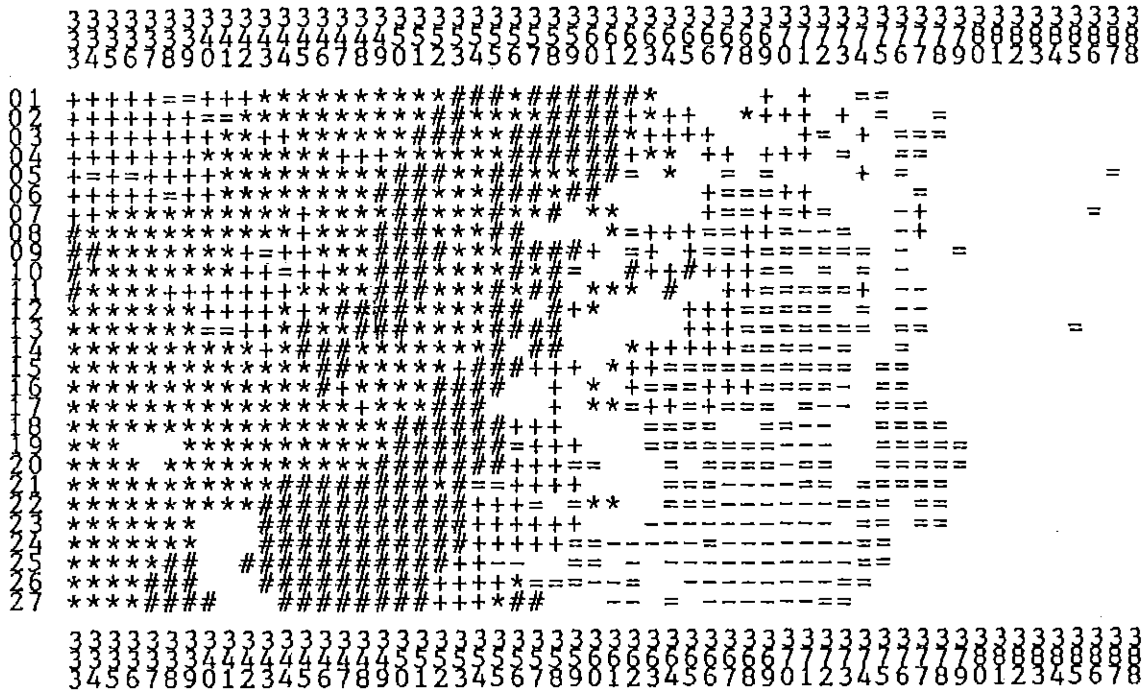


Figure 23. Yield classes for water limited maize yields with emergence at decades 8 to 10. Class size is 1085 kg/ha.

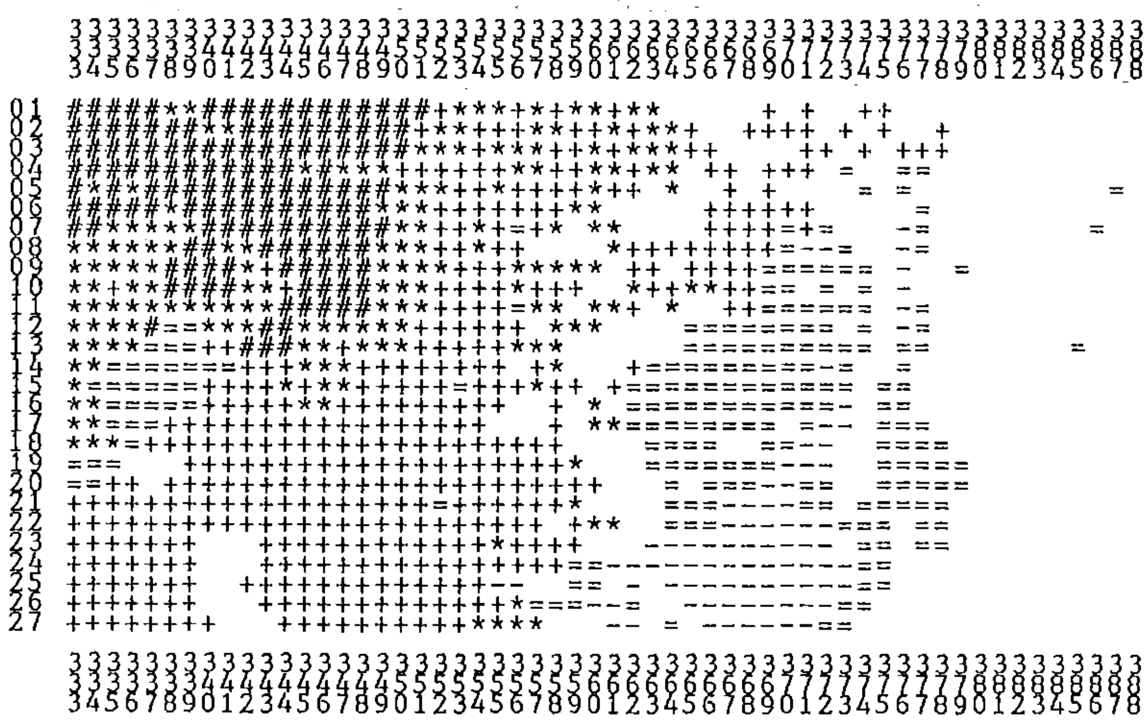


Figure 24. Yield classes for water limited maize yields with emergence at decades 29 to 31. Class size is 1125 kg/ha.

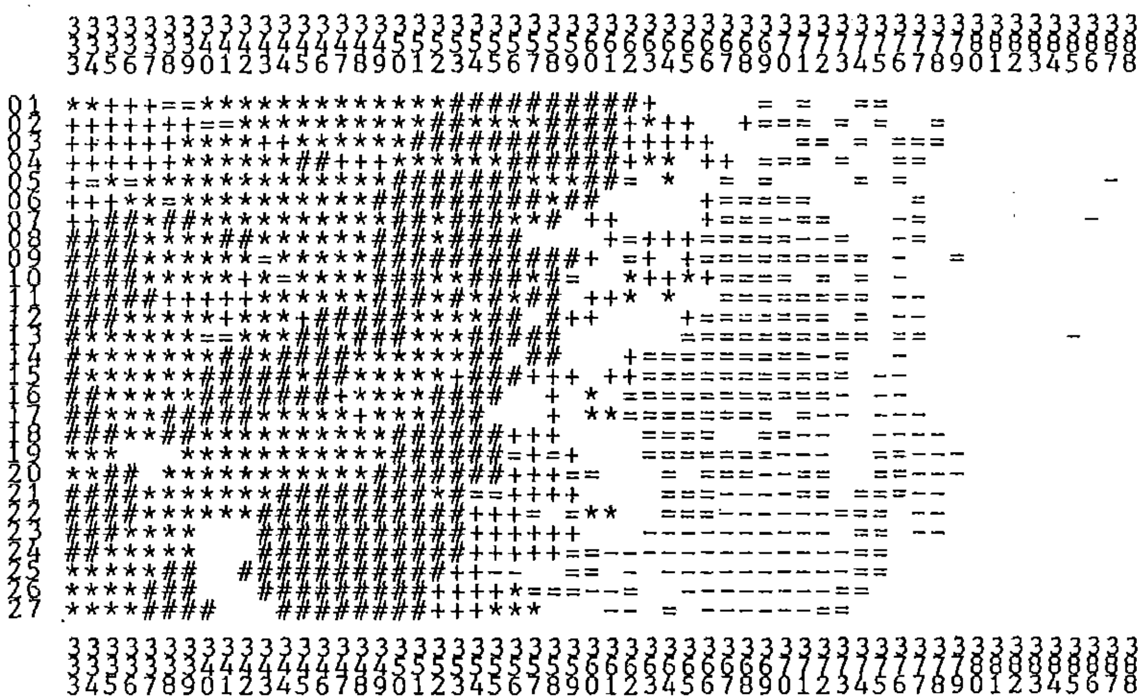


Figure 25. Yield classes for maize in the first rains when the cloudiness regime is 3 throughout the whole area. Class size is 1150 kg/ha.

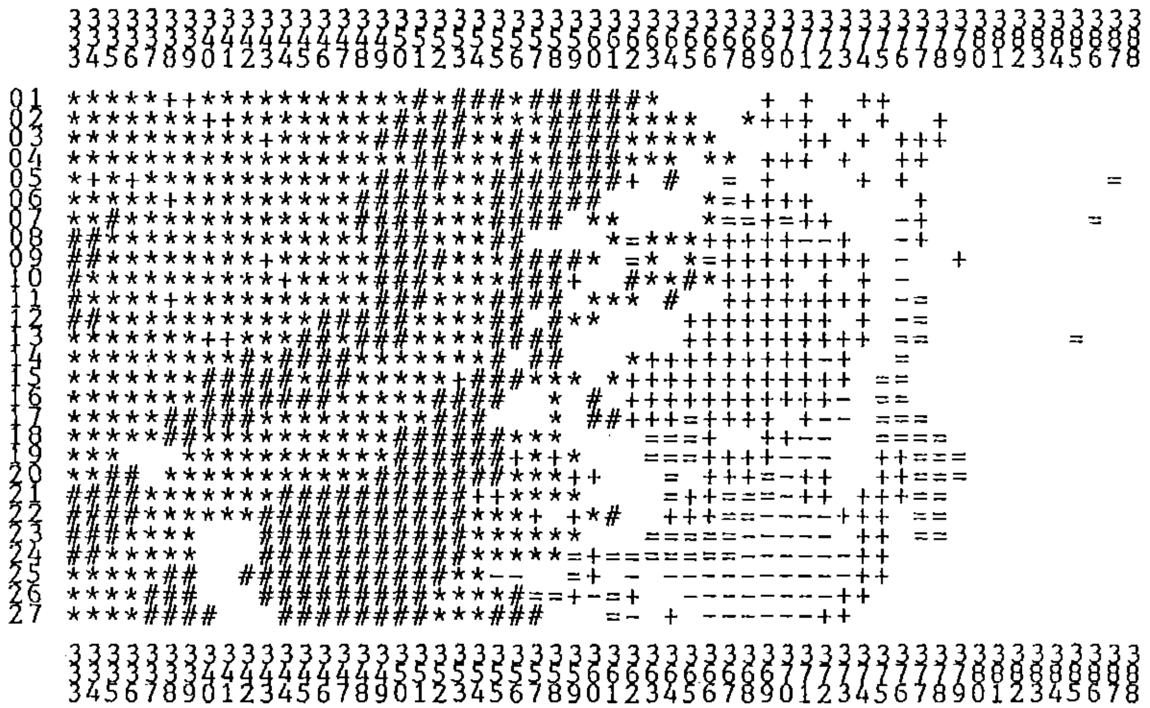


Figure 26. Yield classes for rainfed maize emerged at decades 8 to 10 and with evaporation 10% lower. Class size is 1140 kg/ha.

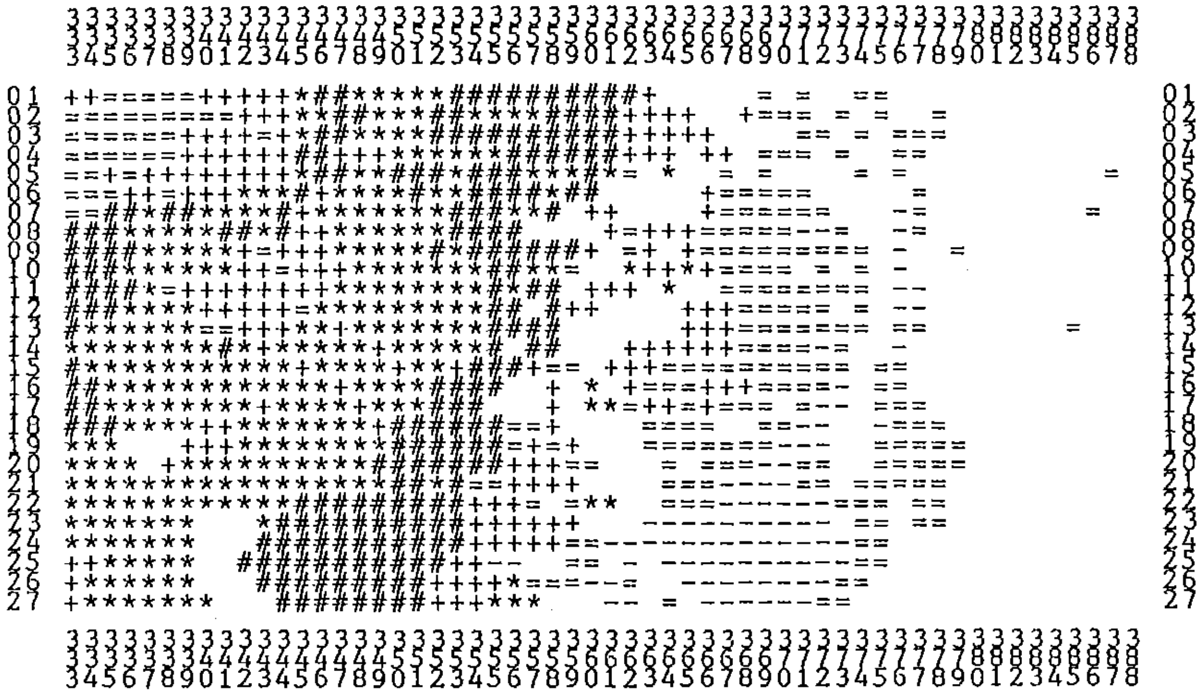


Figure 27. Yield classes for rainfed maize emerged at decades 8 to 10 and with evaporation 10% higher. Class size is 975 kg/ha.

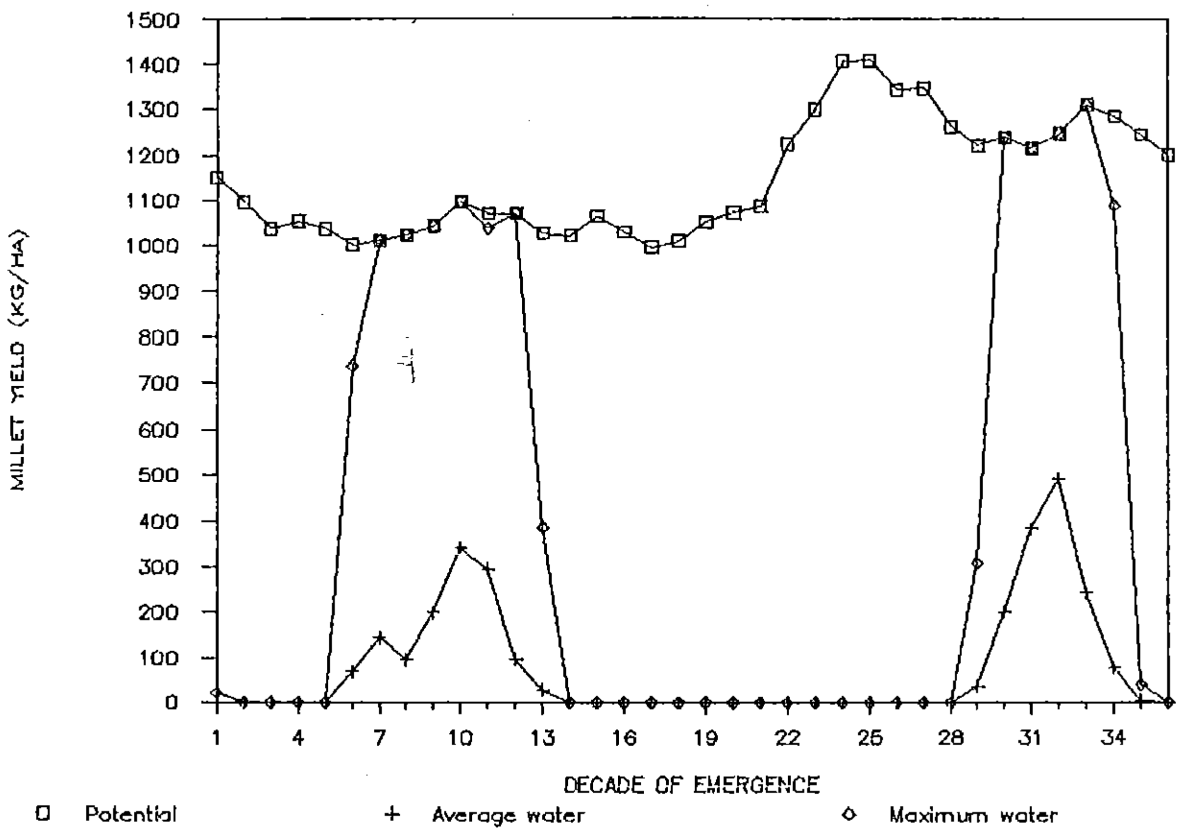


Figure 28. Bulrush millet yields at location 13/377 (Karua) for different decades of emergence.

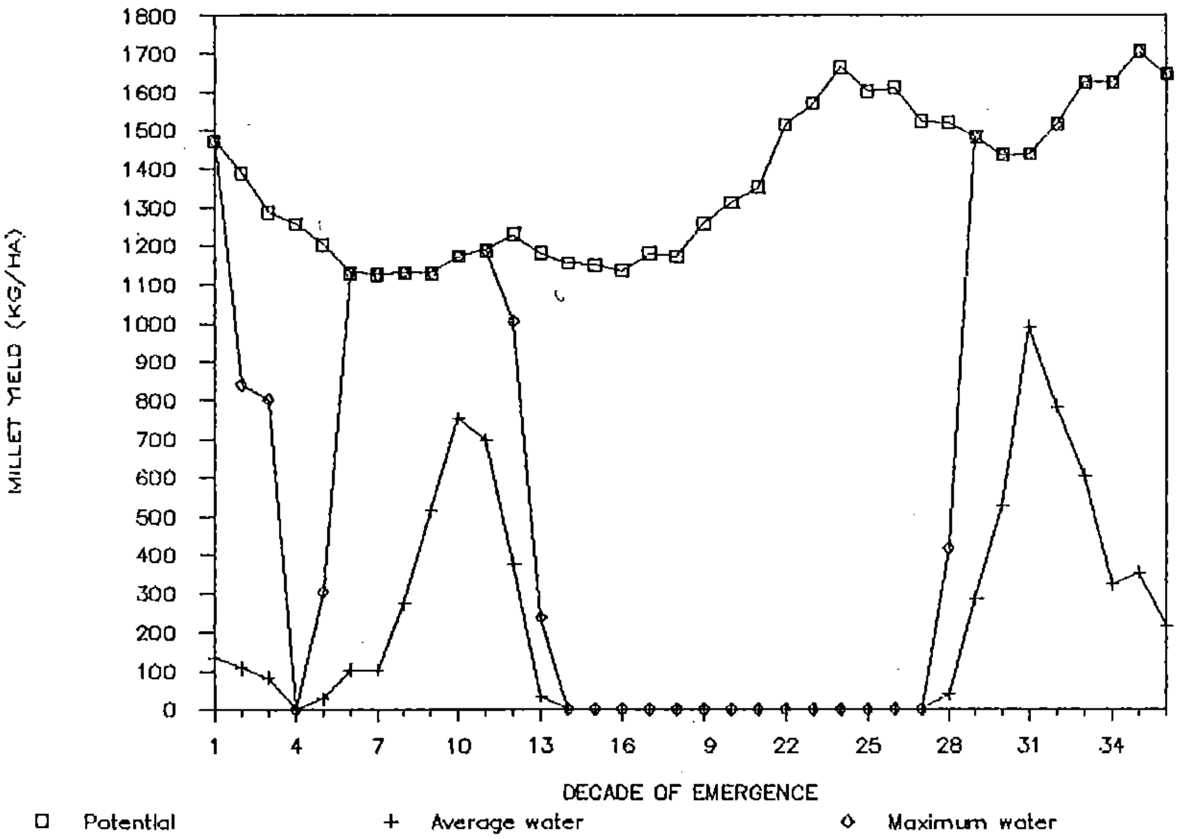


Figure 29. Bulrush millet yields at location 3/378 (Chiokariga) for different decades of emergence.

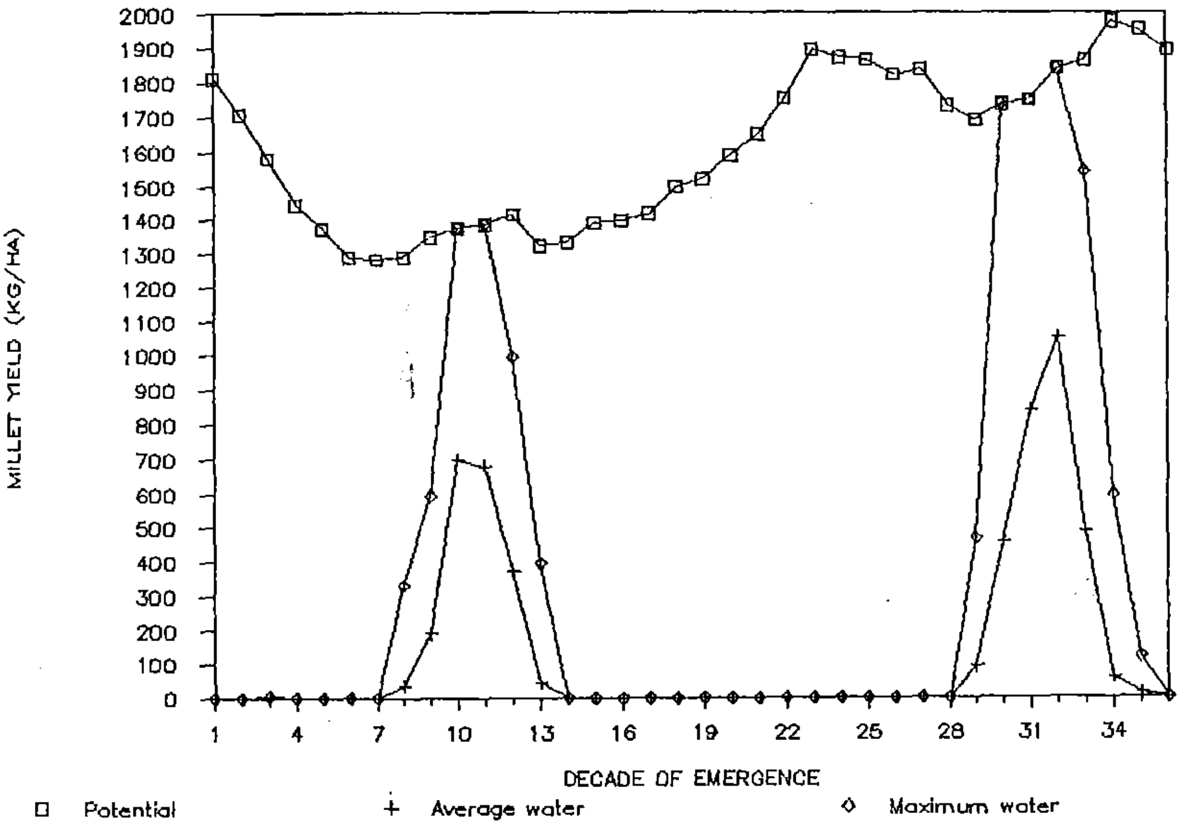


Figure 30. Bulrush millet yields at location 22/365 (Ishiara) for different decades of emergence.

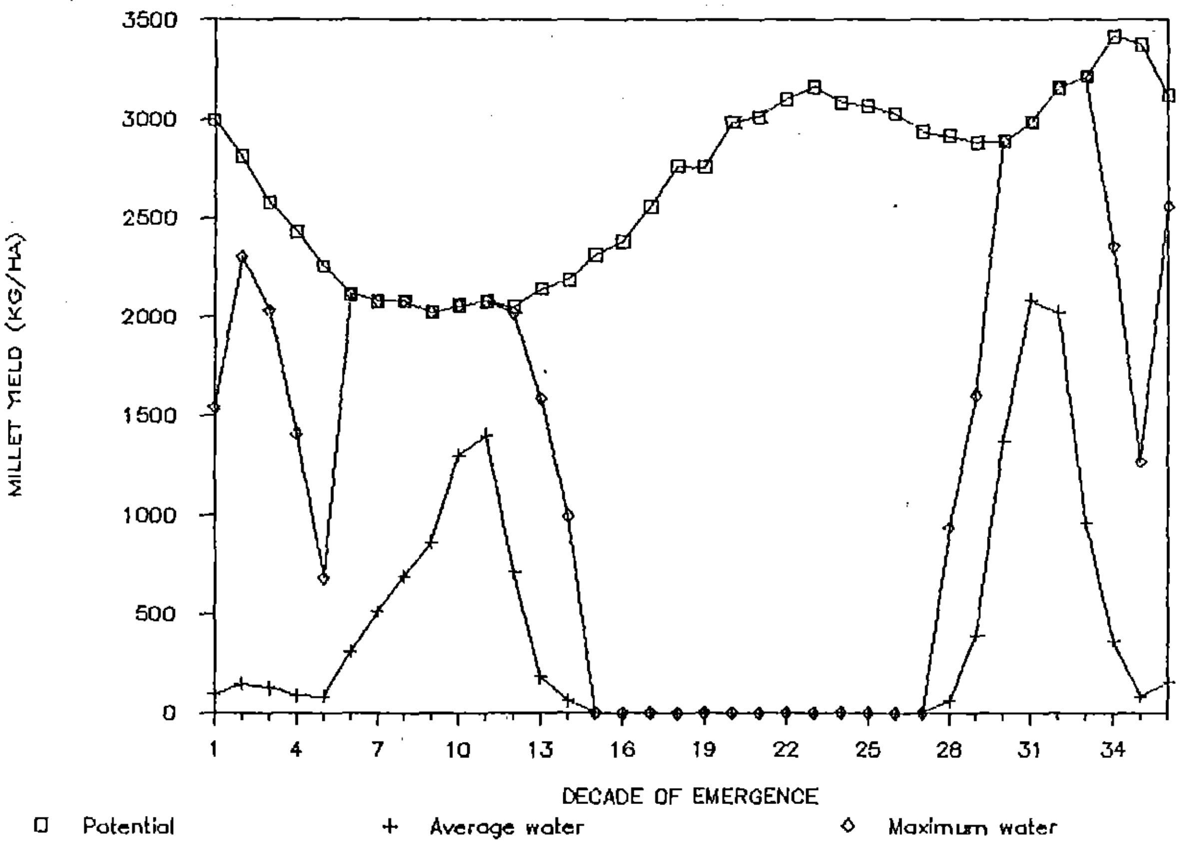


Figure 31. Bulrush millet yields at location 23/357 (Kanyuambora) for different decades of emergence.

Figure 32. Yield classes for rainfed bulrush millet with emergence at decades 10 and 11. Class size is 340 kg/ha.

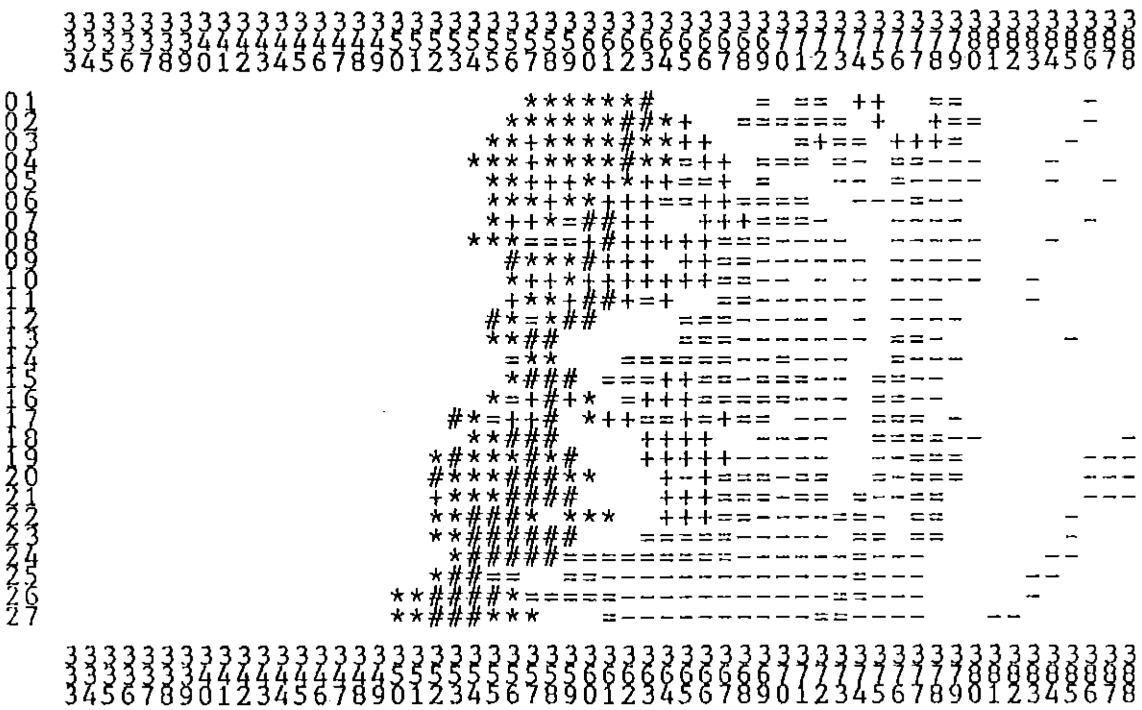


Figure 33. Yield classes for rainfed bulrush millet with emergence at decades 31 and 32. Class size is 485 kg/ha.

Figure 34. Rainfed yields for bulrush millet as a percentage of the potential yield; emergence at decades 10 and 11. Class size is 16.4%.

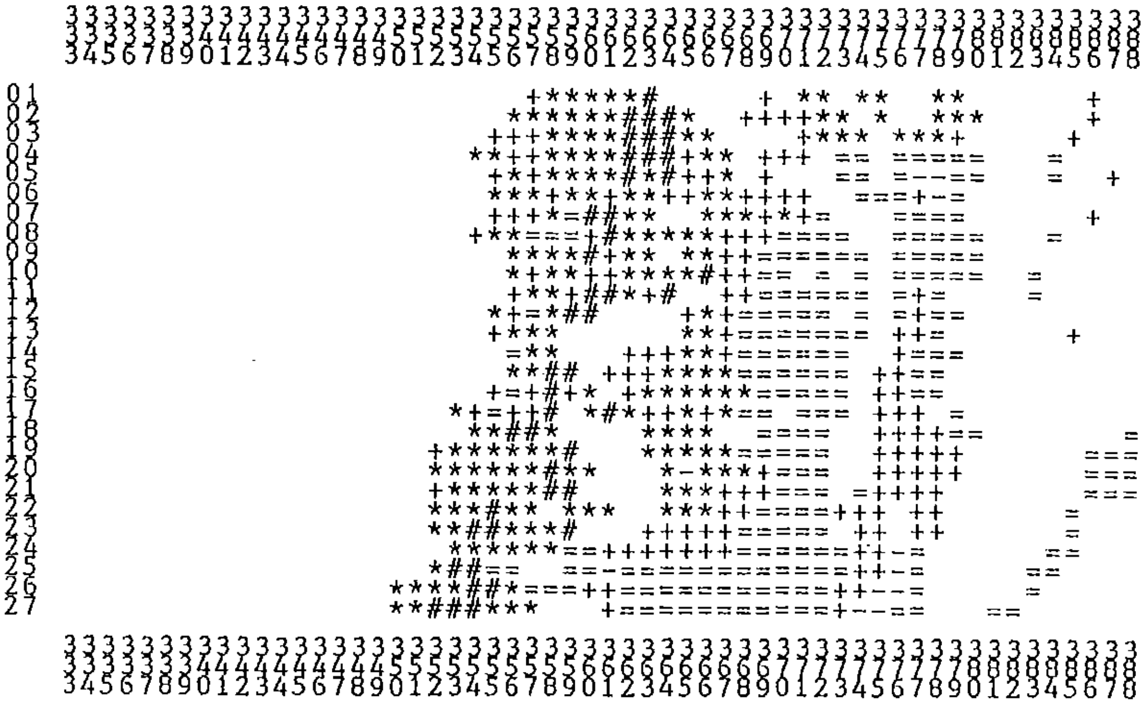


Figure 35. Rainfed yields for bulrush millet as a percentage of the potential yield; emergence at decades 31 and 32. Class size is 16.6%.

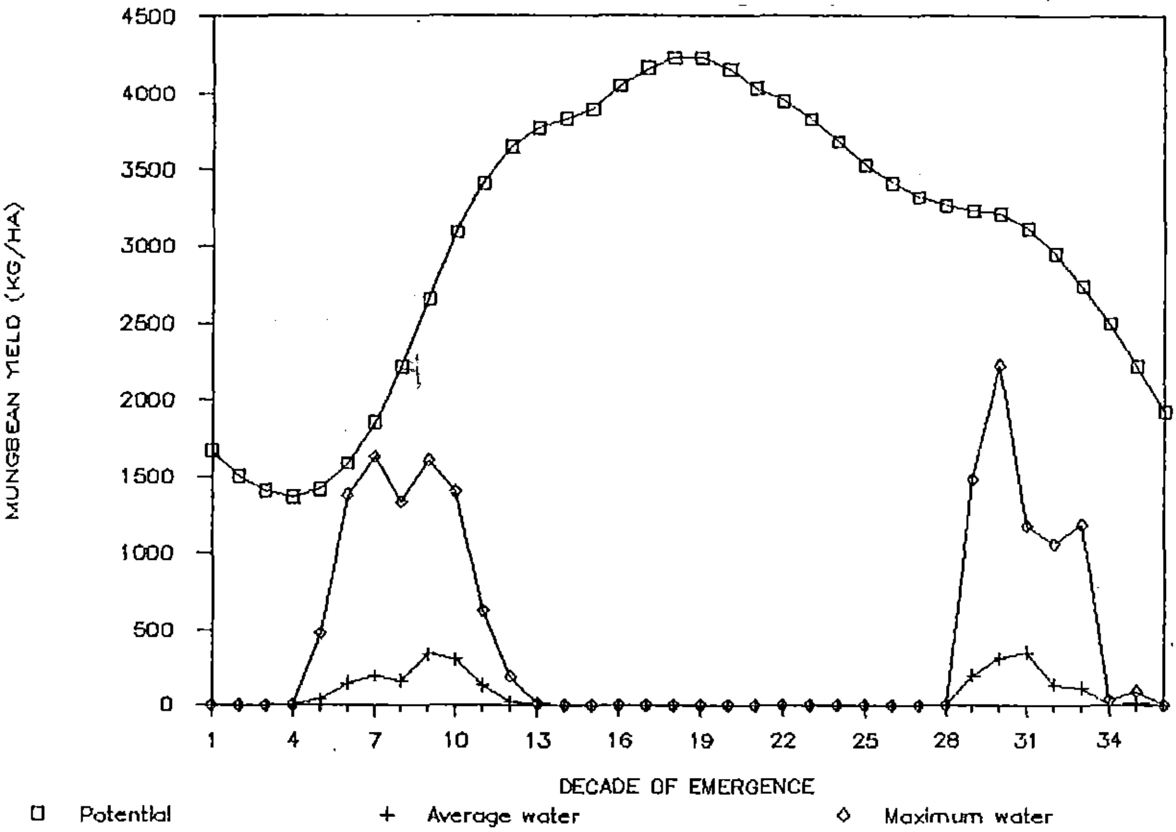


Figure 36. Mungbean yields at location 13/377 (Karua) for different decades of emergence.

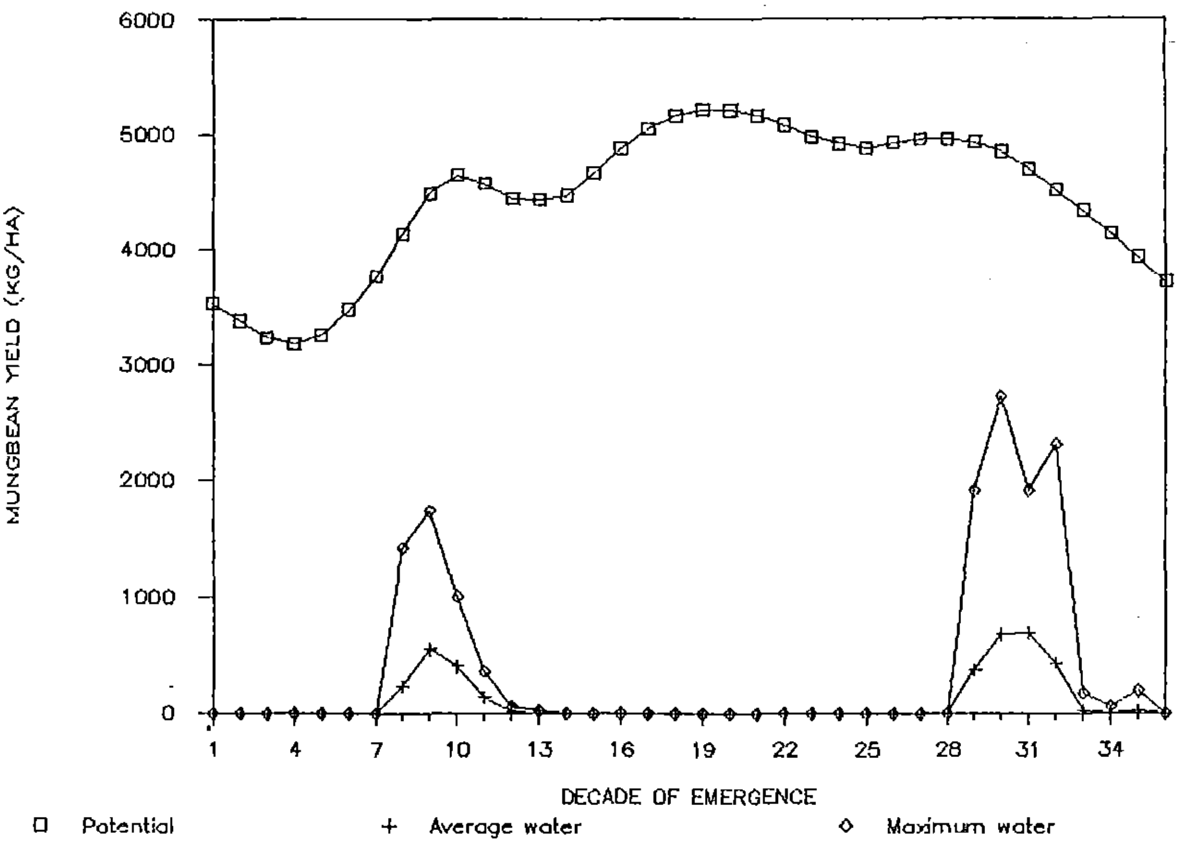


Figure 37. Mungbean yields at location 22/365 (Ishiara) for different decades of emergence.

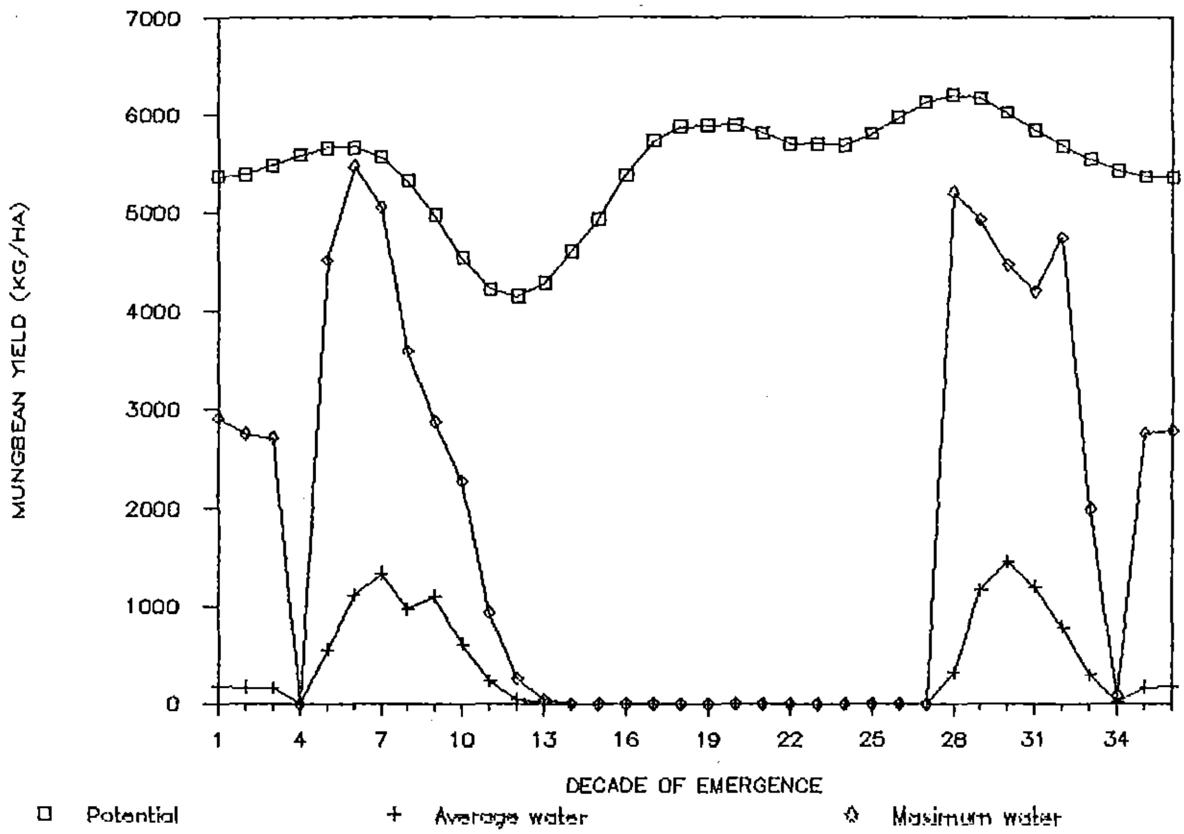


Figure 38. Mungbean yields at location 23/357 (Kanyuambora) for different decades of emergence.

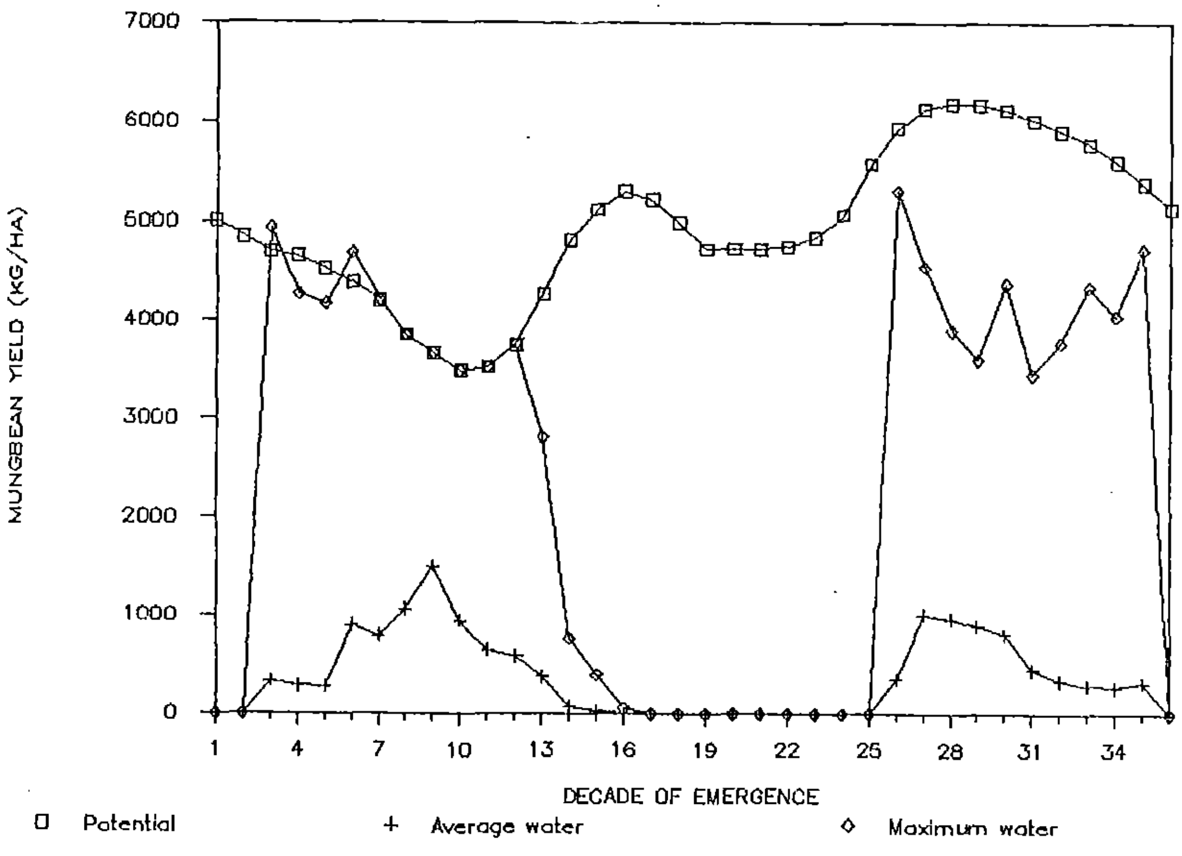


Figure 39. Mungbean yields at location 19/341 (Runyenjes) for different decades of emergence.

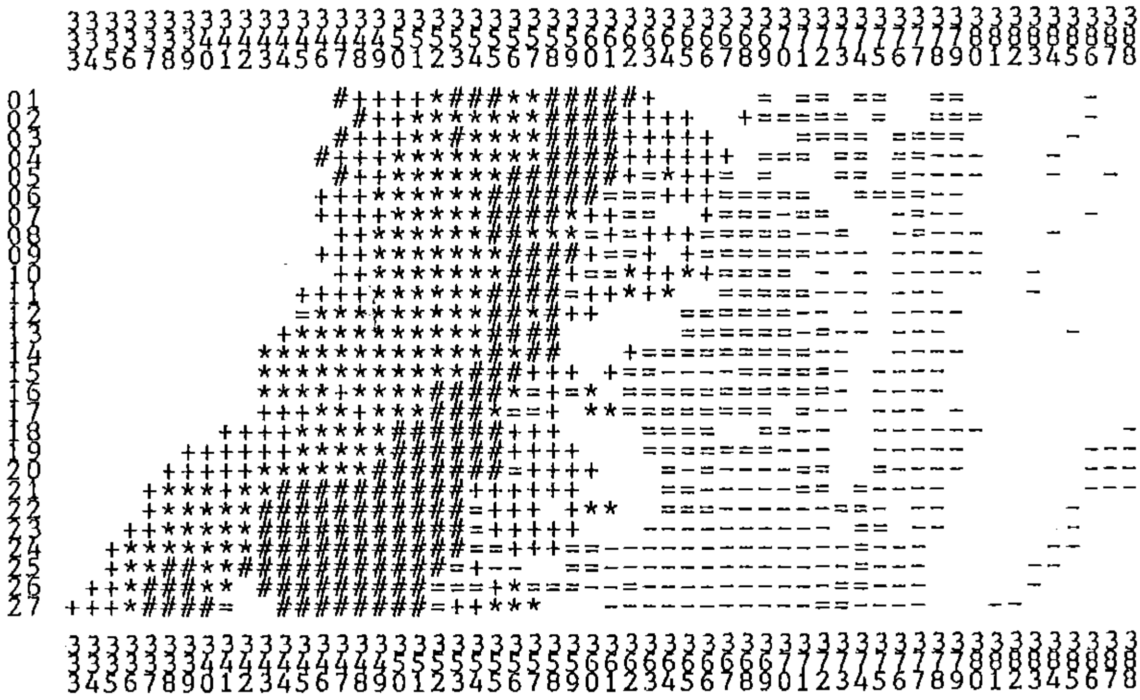


Figure 40. Yield classes for rainfed mungbean with emergence at decades 8 to 10. Class size is 530 kg/ha.

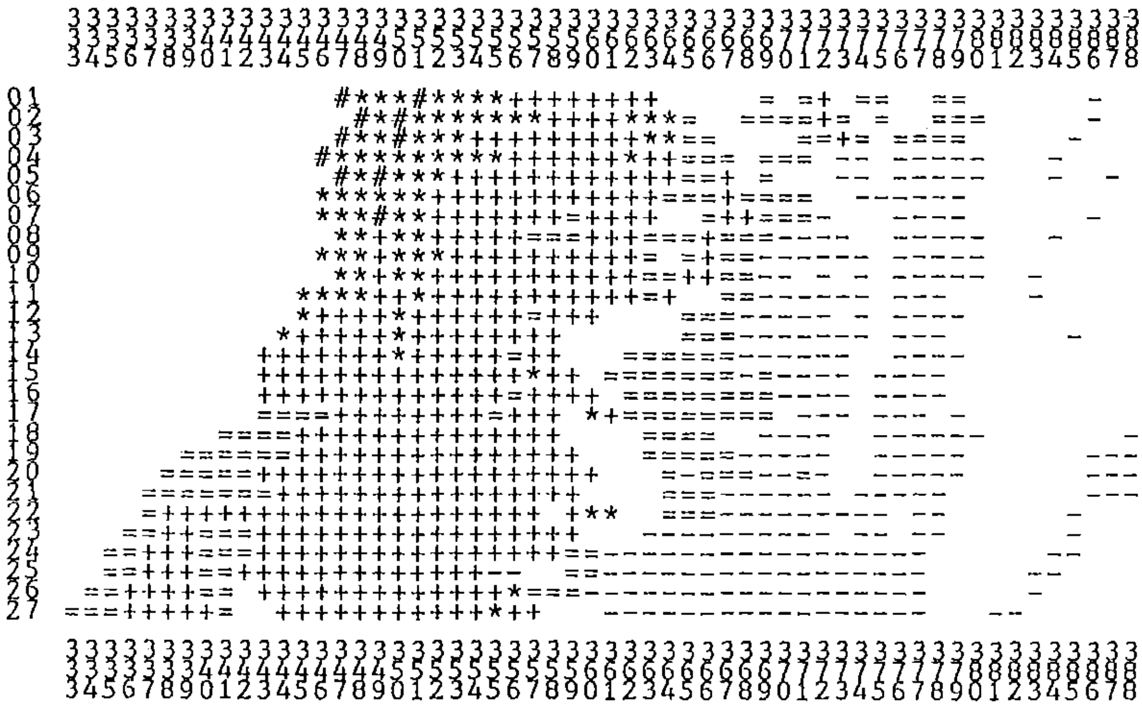


Figure 41. Yield classes for rainfed mungbean with emergence at decades 29 to 31. Class size is 525 kg/ha.

ANNEX A. CLIMATE

Monthly relationships on temperature were derived from data (KMD, 1975) on the same 20 stations Braun (1986) used for assessing the annual temperature - altitude relationships in Eastern Kenya. The monthly relationships have correlation coefficients within the range -0.959 to -0.984 and are listed in Table 9.

Table 9. Intercepts and slope gradients of monthly relationships between minimum or maximum temperature and altitude in Eastern Kenya, and the percental distribution of annual evaporation over the months.

Month	Minimum temperature		Maximum temperature		evaporation %
1	23.526	-0.00721	36.055	-0.00616	8.9
2	24.355	-0.00747	37.312	-0.00632	8.8
3	25.438	-0.00734	37.407	-0.00658	9.8
4	24.886	-0.00649	35.637	-0.00655	8.5
5	23.997	-0.00638	34.485	-0.00655	8.0
6	22.520	-0.00656	33.450	-0.00645	7.0
7	21.778	-0.00655	32.884	-0.00664	6.8
8	21.934	-0.00658	33.307	-0.00660	7.4
9	22.510	-0.00682	34.574	-0.00623	8.8
10	23.758	-0.00670	35.346	-0.00615	9.7
11	23.996	-0.00653	34.811	-0.00646	8.0
12	23.765	-0.00697	34.766	-0.00617	8.3

Cloudiness fractions can be estimated with data on radiation or sunshine duration (KMD, 1985) and both estimations must give (near to) identical values. Only three locations were used for estimating cloudiness fractions for other stations gave improbable values or showed inconsistency between radiation and sunshine duration. The stations used are Kindaruma Fisheries, Tebere C.R. Station and Thika Horticultural Res. Station. Estimations for Kimakia (see Figure 1) at 2439 m were only slightly differing from the Thika values. In the whole study area five cloudiness regimes are distinguished and assigned to the 14 climatic zones (see Table 10). The actual values can be found at the listing of average rainfall data for each station.

Table 10. Description of cloudiness regimes and to which climatic zones they are assigned.

Regime	Description	Climatic zone(s)
1	Kindaruma - values	1, 2 and 3
2	average of Kindaruma and Tebere	4 and 5
3	Tebere - values	6 and 7
4	average of Tebere and Thika	8
5	Thika - values	9, 10, 11, 12, 13 and 14

Table 11. Indicative gross CO_2 assimilation rate (kg CO_2/ha.d) of a closed canopy of a C3 crop, on clear (Fcl) and overcast (Fov) 15th day of months (Goudriaan, 1978).

Lat		J	F	M	A	M	J	J	A	S	O	N	D
0	Fcl	727	752	768	760	736	720	728	753	768	761	737	720
	Fov	306	319	328	324	311	302	306	320	328	324	311	302
10	Fcl	785	784	765	720	667	638	652	701	748	779	786	784
	Fov	335	336	327	305	277	262	270	295	319	334	336	333
20	Fcl	829	802	745	665	583	542	562	634	713	783	820	834
	Fov	355	343	316	276	236	216	226	261	300	334	351	356
30	Fcl	858	804	708	591	481	429	454	549	659	768	839	869
	Fov	366	341	295	239	187	163	175	219	271	324	357	371
40	Fcl	873	788	652	497	364	304	333	445	586	737	843	892
	Fov	368	329	264	193	133	107	120	169	233	304	354	377
50	Fcl	877	757	574	384	234	172	202	324	491	686	833	904
	Fov	363	307	224	140	77	52	63	114	187	275	343	375
60	Fcl	875	708	474	255	102	39	68	191	375	615	813	915
	Fov	351	277	175	83	25	8	15	57	132	236	323	368

Table 12. Indicative gross CO_2 assimilation rate (kg CO_2/ha.d) of a closed canopy of a C4 crop, on clear (Fcl) and overcast (Fov) 15th day of months (Goudriaan, 1978).

Lat		J	F	M	A	M	J	J	A	S	O	N	D
0	Fcl	958	993	1018	1007	971	947	959	995	1017	1007	973	947
	Fov	325	340	351	346	331	321	326	341	350	346	331	321
10	Fcl	1037	1038	1012	949	873	832	852	922	989	1032	1039	1035
	Fov	357	359	349	324	294	277	285	313	340	357	358	356
20	Fcl	1097	1062	983	870	755	698	726	827	937	1035	1086	1103
	Fov	379	366	336	292	248	226	237	276	319	356	375	381
30	Fcl	1134	1060	927	765	613	542	577	707	860	1011	1109	1149
	Fov	391	363	313	251	195	170	182	229	287	345	381	396
40	Fcl	1150	1033	845	633	452	372	410	562	755	962	1108	1175
	Fov	392	349	278	201	138	110	123	176	245	322	377	402
50	Fcl	1145	982	733	477	278	198	236	397	620	885	1086	1183
	Fov	384	324	234	145	78	53	65	117	194	289	362	398
60	Fcl	1129	905	591	301	109	40	71	220	460	779	1046	1182
	Fov	369	290	181	85	25	8	15	58	136	246	340	388

With data from Kindaruma, Marimant, Mariene and Tebere (see Figure 1) Penman calculations were done according to the method presented by Frere and Popov (1979) to assess the average distribution of annual evaporation over the different months. The monthly percental values are given for each location in Table 13, the average values in the most right column of Table 9.

Table 13. Average distribution of evaporation over the year at 4 locations.

Location	Alt.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Marimanti	587	8.1	8.2	9.4	8.6	8.3	7.2	7.2	8.0	9.3	10.0	7.8	7.7
Kindaruma	792	8.9	8.8	9.8	8.6	7.9	7.1	6.7	7.2	8.6	9.8	8.2	8.5
Tebere	1159	9.8	9.4	10.0	8.4	7.8	6.6	6.2	7.0	8.3	9.4	8.2	8.8
Mariene	1615	8.9	8.8	9.8	8.5	8.1	7.0	6.9	7.5	9.0	9.4	7.9	8.2

The absolute values of monthly evaporation from these calculations could not be used as estimates for because use ot this method for this purpose would require non average data. Another result taken from these calculations is the ratio of potential evapotranspiration and evaporation which amounts to 0.80. Multiplication of the Woodhead equation (1968) on potential evaporation with this factor leads to équation (8) for potential evapotranspiration.

$$Eo\ (mm) = 2422 - 0.358 \cdot Altitude\ (m) \qquad (7)$$

$$ETo\ (mm) = 1938 - 0.286 \cdot Altitude\ (m) \qquad (8)$$

Linear regression of average annual rainfall and altitude at 13 locations in/near the study area with more than 15 years of (monthly) recordings since 1961, resulted in the relationship :

$$P\ (mm) = -204 + 1.154 \cdot Altitude\ (m) \qquad (9)$$

with a correlation coefficient of 0.926, meaning that 86 % of the variation in annual rainfall can be explained by altitude. Stations with less years of data, such as Ishiara and Chiokariga, were estimated a long term average annual rainfall by extrapolation from other locations.
Now for each grid cell annual rainfall was estimated with equation (9), after which the difference between estimated and actual value at each climatic station was interpolated with squared inverse distances as weighing factor. Thus is accounted for the influence of location on average rainfall. The rainfall map is shown in Figure 3.

The 14 stations in Table 14 are selected to be representative for zones with a comparable amount of annual rainfall. Locations 4 and 5, as well as 10 and 11 are considered to have an equal annual amount.

Table 14. Different climatic zones, KMD - code, location, altitude, average annual rainfall, coordinates South and East and the number of years with complete data on rainfall.

Nr.	Code	Location	Alt.	Prec.	Coord.S/E		Yr
1	9037232	Karua Muthonga River	650	570	0°22'	37°54'	14
2	9038000	Katze Dispensary	762	670	0°30'	38°05'	15
3	9038006	Tharaka Chief's Camp	914	830	0°18'	38°02'	16
4	9037187	Chiokariga D.O.'s Office	810	890	0°16'	37°56'	11
5	9037161	Ishiara	840	890	0°27'	37°47'	10
6	9037103	Murinduko Experimental Farm	1378	1060	0°34'	37°27'	20
7	9037133	Kanyuambora	1120	1170	0°28'	37°43'	16
8	9037050	Embu Prov. Agric. Trade Ct.	1508	1314	0°30'	37°27'	20
9	9037122	Runyenjes D.C.'s Office	1480	1480	0°26'	37°34'	15
10	9037053	Kevote Catholic Mission	1520	1570	0°26'	37°32'	16
11	9037034	Chuka County Council Farm	1490	1700	0°20'	37°38'	15
12	9037134	Kairuri Ngandori Location	1676	1720	0°23'	37°28'	12
13	9037077	Irangi Forest Station	1935	1920	0°21'	37°29'	16
14	9037123	Chogoria Forest Station	1600?	2050	0°17'	37°37'	18

A disadvantage of the procedure that was followed is that the average annual rainfall for average monthly data and for complete years of data may be different. The largest difference is 7 % (150 mm) for zone 13.
Measured annual rainfall at Ishiara is 60 mm less than at Tharaka which equals the amount at Chiokariga.

Average monthly data on rainfall, the number of rainy days and the cloudiness fractions for 14 representative climatic stations (KMD, 1986). Rainfall is in mm/month.

1 Karua Muthonga River				2 Katze Dispensary			
1	19	1.1	0.25	1	43	2.1	0.25
2	17	1.1	0.26	2	27	1.5	0.26
3	89	3.7	0.26	3	80	4.8	0.26
4	134	7.5	0.28	4	145	7.9	0.28
5	31	2.1	0.33	5	36	2.3	0.33
6	4	0.3	0.39	6	4	0.1	0.39
7	1	0.3	0.56	7	0	0.1	0.56
8	0	0.0	0.58	8	0	0.1	0.58
9	4	0.1	0.40	9	1	0.1	0.40
10	64	3.7	0.27	10	67	2.7	0.27
11	148	8.0	0.32	11	191	10.8	0.32
12	57	3.1	0.26	12	75	5.5	0.26

3	Tharaka		
1	35	1.6	0.25
2	27	1.3	0.26
3	88	3.2	0.26
4	229	7.4	0.28
5	61	2.6	0.33
6	6	0.4	0.39
7	0	0.0	0.56
8	5	0.1	0.58
9	6	0.2	0.40
10	70	2.6	0.27
11	217	8.2	0.32
12	83	3.9	0.26

4	Chiokariga D.O.'s Office		
1	36	3.1	0.23
2	28	1.8	0.25
3	103	4.8	0.29
4	243	10.4	0.33
5	49	3.4	0.35
6	4	0.3	0.44
7	0	0.1	0.60
8	3	0.3	0.59
9	6	0.4	0.41
10	117	5.1	0.30
11	218	11.3	0.35
12	88	5.0	0.26

5	Ishiara		
1	33	2.8	0.23
2	28	2.1	0.25
3	83	5.0	0.29
4	251	11.8	0.33
5	54	4.8	0.35
6	9	0.8	0.44
7	3	0.5	0.60
8	2	0.5	0.59
9	11	0.9	0.41
10	90	4.9	0.30
11	217	12.5	0.35
12	62	5.3	0.26

6	Murinduko Exp. Farm		
1	24	2.7	0.21
2	32	2.5	0.24
3	91	6.4	0.31
4	261	14.7	0.38
5	147	10.9	0.37
6	18	3.6	0.49
7	23	4.3	0.63
8	21	4.9	0.59
9	21	3.0	0.42
10	147	9.5	0.32
11	208	13.9	0.37
12	65	5.4	0.26

7	Kanyuambora		
1	35	2.6	0.21
2	42	2.6	0.24
3	128	6.2	0.31
4	348	12.3	0.38
5	98	5.3	0.37
6	7	0.5	0.49
7	3	0.5	0.63
8	9	0.8	0.59
9	13	0.7	0.42
10	115	4.8	0.32
11	288	13.5	0.37
12	82	4.7	0.26

8	Embu Prov. Agric.Trade Ct		
1	27	3.4	0.22
2	34	2.9	0.27
3	109	8.1	0.34
4	309	17.1	0.43
5	204	14.1	0.45
6	32	5.2	0.54
7	53	8.1	0.68
8	43	8.9	0.64
9	48	5.2	0.46
10	183	11.5	0.38
11	221	14.7	0.44
12	51	6.2	0.28

9 Runyenjes D.C.'s Office

1	28	1.9	0.23
2	42	2.5	0.29
3	128	6.8	0.37
4	400	16.2	0.48
5	185	9.4	0.53
6	28	2.8	0.58
7	44	4.4	0.72
8	39	4.8	0.69
9	26	3.0	0.50
10	212	9.2	0.44
11	282	13.4	0.51
12	64	4.9	0.29

10 Kevote Catholic mission

1	36	2.9	0.23
2	45	3.2	0.29
3	132	8.8	0.37
4	378	16.7	0.48
5	235	11.6	0.53
6	29	3.3	0.58
7	57	8.2	0.72
8	66	8.6	0.69
9	33	3.9	0.50
10	229	11.2	0.44
11	286	15.3	0.51
12	68	5.1	0.29

11 Chuka County Council Farm

1	52	4.2	0.23
2	47	2.8	0.29
3	119	6.4	0.37
4	422	17.0	0.48
5	161	8.8	0.53
6	19	2.3	0.58
7	43	5.1	0.72
8	28	4.9	0.69
9	34	4.1	0.50
10	277	10.9	0.44
11	381	16.5	0.51
12	113	8.7	0.29

12 Kairuri Ngandori Location

1	20	2.6	0.23
2	41	2.7	0.29
3	96	7.4	0.37
4	412	16.4	0.48
5	292	15.5	0.53
6	66	6.9	0.58
7	76	11.2	0.72
8	79	12.3	0.69
9	56	6.0	0.50
10	256	12.4	0.44
11	251	14.1	0.51
12	73	5.4	0.29

13 Irangi Forest Station

1	41	3.6	0.23
2	44	3.4	0.29
3	131	9.0	0.37
4	373	16.9	0.48
5	327	15.6	0.53
6	75	7.5	0.58
7	113	13.0	0.72
8	117	14.6	0.69
9	72	7.8	0.50
10	250	12.8	0.44
11	304	16.7	0.51
12	78	6.8	0.29

14 Chogoria Forest Station

1	63	5.4	0.23
2	50	3.9	0.29
3	159	9.3	0.37
4	484	19.3	0.48
5	270	14.5	0.53
6	40	4.8	0.58
7	66	8.7	0.72
8	57	10.0	0.69
9	44	5.8	0.50
10	305	13.3	0.44
11	382	18.2	0.51
12	129	10.4	0.29

The actual measured amounts of rainfall during all decades are given on the following pages for all representative stations. Sometimes two years with partly missing data are used to make one year complete.
The first column contains the year for which the following 36 figures represent the rainfall during consecutive decades (mm). The figure at each location is the KMD-code for that location, the figure between brackets represents the amount of years without missing data.

9037232 KARUA MUTHONGA RIVER (14)
1971 0 0 0 0 0 0 0 0 38 45 62 49 21 31 31 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 5 15 1 1 0
1972 1 0 0 2 0 0 0 4 0 2 0 0 34 19 6 0 0 0 0 0 0 0 0 0 0 11 0 0 8 12 6 20 18 11 4 23 11
1973 0 0 0 4 3 0 0 0 10 0 17 15 0 0 0 0 0 10 0 0 0 0 0 0 0 0 0 1 0 0 0 33 10 10 0 0 1
1974 1 0 0 21 0 0 6 0 122 77 58 47 0 4 0 0 0 5 2 6 0 0 0 0 0 0 0 0 0 0 104 144 67 0 0 60 24
1975 0 0 0 0 0 0 0 0 83 29 82 173 20 72 0 0 0 4 2 0 2 0 0 0 0 0 0 0 6 0 86 0 174 28 66 0 0
1976 0 0 0 0 0 0 0 0 0 12 60 37 0 0 0 0 33 0 0 1 0 0 0 0 0 0 0 0 29 0 11 49 71 53 1 36 30
1977 6 25 0 0 0 3 2 8 13 171 13 47 17 0 0 0 0 0 0 0 0 0 0 0 0 46 0 0 0 0 228 96 62 24 105 12
1978 0 86 0 0 25 69 89 27 33 51 12 42 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 54 144 32 132 97 55 51 0
1979 44 12 87 1 0 1 0 111 0 90 105 22 13 0 56 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 16 161 53 0 0 43 11
1980 0 0 0 0 0 0 10 0 53 32 32 0 39 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 34 165 1 1 0 0 0
1981 0 0 0 0 0 0 11 128 140 125 62 18 67 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 34 3 45 25 51 0 3
1982 0 0 0 0 0 0 0 16 0 0 65 1 1 17 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 103 78 46 39 149 68 8 0
1983 0 0 0 1 0 0 0 0 1 0 27 104 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 17 43 22 13 0 42 0 36
1985 0 20 0 17 0 102 165 95 155 75 39 45 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 28 10 17 50 28 0 0

9038000 KATZE DISPENSARY (15)
1962 82 0 0 0 0 0 0 92 25 71 30 243 76 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 37 102 1 16 122 48 27 0
1964 0 0 0 36 0 0 4 8 76 36 62 66 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 13 0 17 16 39 43 73 28
1965 0 13 0 0 0 0 0 0 13 24 47 22 3 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0 168 10 80 16 62 25 25 0
1966 0 0 16 0 11 3 36 60 110 31 104 0 17 0 11 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 121 60 0 0 3 0 0
1967 0 0 0 0 0 0 0 0 3 49 77 9 9 5 23 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 239 71 79 224 0 0 0
1968 0 0 0 0 0 130 137 38 34 138 53 166 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 7 95 108 260 123 3 0
1969 0 15 21 0 0 47 95 0 45 0 31 5 70 0 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 34 30 102 50 0 0 6
1972 36 0 0 90 0 0 0 17 0 0 0 0 46 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 29 168 115 49 4 54 7 0
1973 106 81 0 4 30 0 0 0 12 0 86 60 0 0 9 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 139 12 8 62 0 62
1974 4 0 0 3 0 0 0 0 199 198 0 14 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 20 104 95 0 0 46 12
1977 30 35 0 0 0 13 10 54 39 118 34 5 15 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 163 94 56 42 87 9
80/79 0 0 0 0 0 0 0 0 19 4 10 35 87 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 112 86 0 1 73 38
1981 0 0 0 0 0 0 1 29 65 93 7 10 45 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 7 13 19 28 1 27
1982 54 0 0 0 0 0 0 0 10 66 48 10 19 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 202 80 0 161 122 63 12 0
1983 0 0 0 0 0 0 0 0 0 0 17 73 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 9 13 3 9 41 13 23

9038006 THARAKA CHIEF'S CAMP (16)
1961 0 0 0 5 0 0 0 0 16 278 115 11 0 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 23 328 151 278 268 0 3 13
1962 33 0 0 0 0 0 0 30 113 43 21 84 0 16 0 0 0 0 0 0 0 0 0 0 53 0 0 0 0 89 79 5 19 112 33 23 27
1963 0 1 3 8 0 9 4 52 33 50 199 20 4 36 33 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 11 29 113 75 179 43 39
1964 39 0 1 18 0 0 0 0 55 38 216 41 0 0 0 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 22 18 70 44 9
1965 0 0 1 0 0 0 0 9 24 0 48 14 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 125 1 32 5 74 0 0 0
1966 0 0 0 0 20 3 4 82 62 0 236 66 56 0 0 8 0 0 0 0 0 0 0 0 0 0 0 0 0 6 0 32 122 7 2 0 0 0
1967 0 9 0 0 0 0 24 0 23 98 107 29 84 22 6 46 0 0 0 0 0 0 0 0 0 0 0 0 0 0 119 0 0 0 0 0 0
1968 0 0 0 0 0 0 0 0 0 557 304 246 0 0 0 13 0 13 0 0 0 0 0 0 0 0 0 0 0 19 25 114 199 695 350 4 0
1969 0 3 187 8 8 181 232 0 137 91 0 67 201 0 28 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 25 25 53 124 46 0 0 11
1970 0 11 85 0 0 0 93 0 255 96 50 53 0 0 31 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 79 103 3 32 0 3
1971 0 0 0 0 0 0 0 0 0 7 114 63 124 28 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 160 10 10 0
1972 32 0 0 31 0 0 0 46 0 0 0 0 32 31 0 14 0 0 0 0 0 0 0 0 0 2 0 0 2 63 27 142 11 1 21 30 0
1973 11 0 0 0 40 0 0 0 0 0 112 71 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 50 0 0 0 53 30 1 31 0 0
1974 0 0 0 0 0 0 11 0 80 122 11 84 10 0 0 0 0 0 0 0 0 0 0 0 31 0 0 0 0 31 0 72 51 0 0 60 0
1978 121 0 0 0 20 61 111 61 51 191 0 101 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 91 91 0 140 52 30 31 0
1981 10 0 0 0 0 0 0 0 30 91 140 30 21 65 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 111 206 0 0 50 0 43

9037187 CHIOKARIGA DO'S OFFICE (11)
1975 0 0 4 0 0 0 0 0 81 51 123 90 2 55 0 0 0 5 3 0 0 0 0 0 8 0 0 15 0 112 0 180 28 8 0 1
1976 6 0 0 4 0 9 5 0 0 49 59 51 5 46 12 0 30 0 0 0 0 0 2 0 0 0 0 21 15 15 117 69 75 7 61 9
1977 26 51 0 0 0 0 0 55 100 141 124 156 28 104 0 0 0 0 0 0 0 0 0 0 0 0 51 0 0 20 240 233 130 17 183 31
1978 0 110 0 0 136 75 140 8 84 177 20 117 0 0 0 0 0 0 0 0 0 0 0 0 0 0 7 35 152 11 62 82 145 25 0
1979 62 88 32 56 0 0 0 147 0 155 121 92 21 0 41 7 0 0 0 0 0 0 30 0 0 0 0 9 0 22 293 116 15 0 72 45
1980 0 0 0 0 0 0 0 0 77 121 143 73 53 0 6 0 0 0 0 0 0 0 0 0 0 0 0 34 102 136 22 16 24 6 0
1981 16 0 0 0 3 0 9 50 101 59 50 23 39 44 0 0 0 0 0 0 0 0 0 5 0 0 0 3 52 31 95 16 22 0 39
1982 0 0 0 0 0 0 0 0 73 60 87 34 18 2 0 0 0 0 0 0 0 0 0 0 0 0 61 133 204 82 21 79 51 7 0
1983 0 0 0 0 0 0 0 0 0 0 25 146 32 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 30 13 0 56 0 0
1984 0 0 0 0 0 0 0 0 0 60 74 48 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 24 100 73 46 44 0 0 0 0
1985 0 0 0 0 0 20 39 112 52 54 67 22 22 0 0 0 0 0 0 0 0 0 0 0 0 0 0 22 27 44 20 35 39 49 54

9037161 ISHIARA (10)
1971 0 0 0 0 0 0 0 0 53 31 104 177 83 53 0 0 7 0 0 0 0 0 0 0 0 0 0 0 12 63 21 18 158 7 7 0
1972 86 0 0 24 0 0 5 60 0 0 1 0 47 12 0 30 0 0 2 0 0 0 0 0 11 0 7 0 117 89 115 35 55 39 11 0
1973 44 3 0 0 25 0 0 17 0 0 89 82 0 0 19 0 0 0 0 0 10 0 0 0 0 0 14 0 5 0 84 28 25 0 0 16
1974 4 0 0 31 9 0 0 0 135 107 101 95 6 0 0 0 0 0 0 0 0 0 7 0 0 0 0 0 45 99 51 0 0 39 41
1975 0 0 5 0 0 0 0 0 71 25 243 82 2 73 0 0 0 0 11 0 9 0 0 0 15 4 0 2 6 73 0 256 39 14 0 0
1976 0 0 0 54 7 8 0 0 6 62 31 10 7 10 1 0 70 7 0 0 0 0 0 0 0 0 0 33 5 0 75 39 53 38 39 29
1977 7 16 0 0 0 5 0 34 19 293 35 54 21 3 3 0 0 0 0 0 0 0 12 0 0 51 0 0 0 0 172 192 104 23 103 1
1979 36 3 128 8 0 0 0 78 20 141 143 91 22 0 23 2 0 0 0 0 0 0 4 0 0 0 0 0 0 38 177 122 0 0 44 15
1982 0 0 1 0 0 0 0 0 88 135 157 42 59 39 0 0 0 1 0 0 1 0'0 0 0 0 14 1 208 71 73 111 60 70 13 0
1983 1 0 0 0 12 0 0 0 27 0 45 222 25 0 3 0 3 1 0 0 1 0 2 0 0 0 0 23 3 20 26 0 1 68 3 50

9037103 MURINDUKO EXPERIMENTAL FARM (20)
1961 0 9 0 4 0 0 0 19 54 161 57 73 55 66 0 0 6 9 0 6 7 8 2 6 14 27 5 10 172 325 233 266 199 9 27 34
1962 41 0 0 0 0 0 8 30 12 27 157 59 74 102 0 0 1 0 0 13 10 3 63 30 4 1 22 2 36 46 2 42 41 1 20 15
1963 0 20 19 31 0 38 15 20 41 22 96 196 38 74 81 17 0 11 1 0 11 1 3 5 0 0 43 4 19 70 31 138 34 40 14 25
1964 0 0 0 7 0 4 45 13 114 96 185 74 18 4 6 0 0 0 7 3 3 17 4 6 3 10 1 0 53 90 21 12 92 88 23 5
1965 35 6 7 0 0 0 1 0 49 88 96 24 16 12 4 1 11 1 0 8 4 0 16 0 0 3 1 7 24 24 191 69 29 7 11 0
1966 0 43 12 5 7 1 3 24 163 100 95 25 17 3 45 1 4 4 0 1 18 3 1 1 0 0 1 13 2 119 194 0 10 1 0 0
1967 0 3 0 3 0 0 54 0 15 55 50 162 476 33 74 15 1 6 1 20 9 13 11 4 21 0 10 2 45 120 100 32 100 0 0 0
1968 0 0 0 0 19 166 100 25 59 82 66 137 49 0 52 16 2 1 2 5 14 9 9 1 0 0 0 7 59 38 37 135 157 151 0 0
1969 0 0 7 6 46 92 96 2 86 31 3 10 146 4 19 2 0 0 0 0 7 35 6 8 3 2 4 6 64 68 34 85 39 14 0 1
1970 1 35 21 0 0 0 2 7 142 148 13 168 46 65 59 0 2 2 0 0 11 0 6 25 1 0 1 8 8 2 127 31 0 37 2 4
1971 0 0 0 0 0 0 0 0 71 74 106 75 61 77 25 0 12 10 7 3 4 3 1 3 4 1 0 15 0 31 0 14 86 0 43 0
1972 36 0 8 4 6 0 4 5 0 28 3 15 102 65 32 44 0 9 5 4 1 1 4 0 20 11 16 11 223 146 63 167 10 18 9 1
1973 31 30 0 0 12 0 0 0 13 0 83 44 10 2 44 0 8 0 0 0 22 3 8 0 0 1 23 1 23 4 73 100 23 5 1 0
1974 0 0 0 11 3 0 1 0 42 66 85 69 36 4 45 22 17 16 135 11 6 16 12 6 10 1 0 0 0 74 104 36 0 1 20 19
1977 0 0 0 0 0 88 28 62 22 130 66 201 151 28 0 21 7 0 0 11 7 3 12 0 0 51 0 8 27 19 134 96 110 5 53 11
1978 0 29 4 0 39 35 38 102 53 194 101 104 10 3 1 0 7 6 19 11 7 4 9 5 29 3 10 7 77 205 17 58 42 31 23 0
1979 16 20 77 14 0 0 0 94 5 142 42 77 66 0 111 25 0 0 7 2 4 0 10 0 14 0 0 20 13 68 172 44 2 0 35 20
1981 1 0 0 16 0 0 0 97 91 129 244 15 152 127 4 2 1 0 0 7 0 2 8 9 0 11 0 3 15 90 16 58 43 25 76 192
1982 0 1 3 0 0 0 0 0 86 121 62 112 106 54 4 0 2 8 2 0 11 5 4 5 0 5 22 19 395 49 18 35 100 28 1 21
1983 4 0 0 6 7 0 0 0 6 6 102 255 28 11 53 2 2 16 1 0 7 0 9 3 18 0 0 74 5 41 58 0 1 55 0 48

9037133 KANYUAMBORA (16)
1965 0 19 0 0 0 0 2 0 31 95 103 85 67 9 0 0 0 0 0 0 0 10 36 0 0 0 0 0 43 44 177 111 124 0 68 6
1966 0 19 5 9 5 11 41 75 135 222 215 27 25 0 37 3 0 0 0 0 0 0 0 0 0 0 11 0 168 111 0 0 57 16 0
1967 0 16 0 4 0 0 48 0 20 90 155 133 249 10 104 0 0 0 0 0 8 18 0 0 19 0 0 0 29 236 150 22 205 0 0 0
1968 0 0 0 8 0 187 146 22 43 177 125 229 0 0 25 8 0 0 0 11 0 0 0 0 0 0 0 41 91 47 118 356 200 0 0
1969 0 0 9 0 57 41 116 44 62 0 65 23 117 0 16 5 0 0 0 0 7 9 0 1 0 0 35 4 0 103 104 168 97 84 0 8
1970 0 48 90 0 0 0 13 4 312 265 32 145 19 0 24 0 0 0 0 0 0 6 20 17 0 0 0 0 0 0 139 52 14 30 0 3
1971 0 0 0 0 0 0 0 5 32 59 135 124 100 104 0 0 10 0 0 0 0 0 0 0 0 0 0 0 74 28 55 147 18 42 0
1972 109 0 16 18 0 0 2 46 0 0 13 20 62 39 11 27 0 0 0 0 0 0 0 0 18 0 14 0 87 126 117 99 100 34 9 0
1973 48 0 0 0 24 0 8 0 0 13 188 134 6 0 32 0 0 0 0 0 8 0 0 0 0 0 26 0 21 0 111 34 23 2 0 0
1974 0 0 0 40 18 0 0 18 169 80 212 96 0 0 1 0 0 0 6 0 0 0 0 0 0 0 0 0 0 30 119 55 0 0 46 0
1976 0 0 0 26 0 24 0 0 25 45 46 8 13 5 15 0 36 0 0 0 0 0 0 0 0 0 0 49 58 0 78 22 43 49 60 31
1977 25 22 0 0 0 19 32 44 103 327 91 22 53 22 0 0 0 0 0 0 0 10 16 0 0 59 0 0 0 0 375 361 138 22 106 20
1978 10 31 0 0 64 56 38 69 120 207 19 145 22 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 20 96 21 99 148 71 48 5
1979 24 35 99 27 0 38 0 155 0 141 72 114 91 0 35 7 0 0 6 0 0 0 0 0 0 0 0 0 0 74 232 120 0 0 61 25
1982 0 0 0 6 0 0 0 0 95 162 106 116 81 67 6 0 0 0 0 0 0 0 0 0 0 0 12 12 316 50 20 148 96 94 20 0
1983 10 0 0 6 7 0 0 0 9 5 125 348 10 8 4 8 0 0 0 0 0 0 0 0 0 0 2 28 0 48 80 32 0 99 10 53

9037050+9037202 EMBU (20)
1961 0 6 0 26 0 0 11 9 67 132 90 68 133 71 36 2 7 23 4 11 17 14 10 3 22 26 13 25 267 311 271 236 196 16 23 16
1962 46 0 0 0 0 0 2 71 7 33 74 100 131 158 10 0 0 3 5 12 28 9 71 47 11 1 3 15 81 38 4 34 16 1 25 25
1963 0 26 39 22 2 63 25 20 49 46 269 271 39 86 107 15 11 17 3 1 21 19 9 19 3 1 15 28 45 79 54 142 36 54 19 55
1964 10 0 0 5 0 23 34 21 108 157 200 92 90 14 13 12 1 0 19 11 7 60 12 3 4 16 1 3 74 130 23 58 106 77 41 9
1965 29 6 4 0 0 0 0 1 35 65 138 107 90 20 5 0 12 2 0 17 11 4 27 1 2 7 1 6 53 64 217 53 27 0 1 0
1966 0 9 17 18 15 2 44 30 129 174 95 56 32 11 37 1 0 6 2 9 35 8 4 3 5 31 0 31 5 166 218 0 4 25 5 0
1967 0 4 0 0 0 0 48 1 11 59 51 63 659 79 47 20 2 8 6 26 8 16 28 10 37 0 1 0 59 132 112 57 77 0 0 0
1968 0 0 0 11 0 145 147 21 55 101 91 131 120 17 81 37 42 3 13 12 36 25 27 3 1 16 1 7 76 115 75 133 175 165 5 10
1969 0 0 2 13 40 81 63 6 88 7 23 112 142 6 19 8 0 0 42 2 197 64 21 22 16 3 56 7 84 43 43 70 100 9 0 1
1970 15 29 35 0 0 0 3 23 136 167 13 115 19 32 57 0 7 6 6 1 38 9 10 44 155 1 101 21 48 7 116 46 0 21 1 4
1971 0 1 0 13 0 0 0 2 87 97 141 56 124 90 34 0 6 18 51 49 26 6 3 10 5 0 1 0 25 39 3 10 78 0 22 4
1972 23 0 18 7 0 2 3 0 0 50 20 35 140 110 33 16 0 14 8 17 5 2 6 4 32 30 26 4 231 157 137 150 14 10 9 11
1973 49 5 0 0 16 0 10 0 11 1 83 92 11 0 49 0 6 3 0 1 29 6 17 7 0 18 16 0 34 27 72 111 22 6 0 0
1975 0 0 8 0 0 0 1 0 43 18 159 125 5 86 30 2 2 23 10 10 19 10 14 11 14 35 18 25 0 75 0 83 10 19 2 4
1977 2 0 0 0 0 57 4 66 25 136 44 243 138 29 20 0 14 0 5 25 15 10 21 0 0 53 0 41 11 15 219 102 88 11 18 27
1978 3 39 0 0 63 50 45 33 101 139 162 125 45 15 3 0 19 14 20 15 26 12 40 0 34 5 31 12 85 164 58 72 21 43 2 0
1979 32 11 97 17 0 0 0 86 52 139 41 118 118 14 117 40 0 1 10 8 12 13 18 2 0 1 0 49 13 73 181 48 0 1 21 8
1981 4 0 0 5 0 0 8 113 85 72 271 51 189 103 7 15 4 1 0 12 1 8 12 21 8 12 0 8 14 90 23 30 32 23 4 15
1982 0 3 3 0 0 0 0 48 127 139 87 105 154 94 16 0 17 12 2 0 12 4 8 13 2 16 39 8 342 104 27 34 71 30 1 6
1983 1 0 0 1 19 0 0 0 29 13 67 283 90 19 44 2 1 31 1 2 20 1 2 9 66 0 0 99 0 39 120 5 2 67 0 57

9037122 RUNYENJES DC'S OFFICE (15)
1961 0 18 0 4 0 0 0 18 121 233 68 153 95 45 0 0 0 10 0 10 8 27 0 0 47 0 7 53 240 451 318 249 139 27 0 43
1962 43 0 0 0 0 0 0 83 6 21 52 251 143 99 0 0 0 0 5 19 31 14 48 32 6 10 0 34 97 57 8 28 38 0 30 10
1963 0 2 29 41 1 53 56 51 31 66 436 234 64 89 146 18 10 19 4 0 0 0 0 0 0 0 29 52 0 75 68 226 40 158 29 51
1964 50 0 0 5 4 0 27 0 178 187 220 52 57 28 7 43 0 0 59 18 0 18 10 18 0 38 0 0 71 198 34 32 196 102 20 19
1965 0 6 0 0 0 0 0 0 72 97 177 108 105 10 0 8 0 0 0 25 6 12 36 0 7 0 0 0 30 57 204 85 38 20 50 0
1967 0 6 0 0 0 0 49 0 0 94 83 248 626 15 93 6 0 0 0 42 11 15 20 0 20 0 0 0 87 220 155 108 98 18 0 11
1968 0 0 0 0 0 147 118 78 42 164 91 197 57 0 87 33 21 53 16 13 54 37 0 0 0 0 0 0 0 0 0 361 227 38 0 0
1969 0 0 0 46 57 56 128 23 54 0 71 0 95 19 13 11 0 0 0 0 27 41 15 6 18 0 38 28 72 43 67 99 52 3 0 0
1970 0 90 35 0 0 0 10 35 159 221 41 32 51 13 6 0 0 0 0 0 47 0 6 59 4 1 0 0 37 24 140 68 0 38 0 4
1971 0 0 0 0 0 0 0 16 31 111 281 167 149 192 7 0 28 8 24 18 0 25 3 10 10 0 0 32 25 57 0 69 135 0 39 0
1972 42 0 0 20 0 14 0 12 0 64 28 30 137 170 25 27 0 7 0 0 25 3 6 11 14 19 39 52 190 255 107 163 68 13 4 9
1973 75 0 0 13 11 0 0 0 9 2 166 94 15 0 45 0 6 0 0 0 40 6 9 20 0 0 0 0 0 0 36 151 12 4 0 0
1975 0 0 4 0 0 0 0 6 32 28 202 113 2 94 11 3 0 19 13 11 10 13 22 20 7 26 12 48 0 110 0 71 16 0 0 0
77/76 0 0 40 0 0 40 0 55 67 97 63 245 213 16 2 20 10 0 12 11 16 9 0 0 0 0 59 74 47 0 60 42 50 0 80 17
1982 0 0 0 0 0 0 0 0 151 201 93 136 140 127 10 6 17 16 4 0 10 9 6 5 0 6 39 89 313 135 76 118 54 46 17 0

9037053 KEVOTE CATHOLIC MISSION (16)
1961 0 29 0 17 0 0 10 14 113 216 84 108 156 84 4 0 1 16 2 10 14 40 0 6 33 20 20 52 247 473 286 266 131 38 0 43
1962 52 0 0 0 0 0 2 70 5 38 57 183 238 127 0 0 0 8 3 13 36 27 36 32 8 5 5 14 99 69 8 26 37 0 21 10
1963 0 0 32 32 3 40 49 28 46 78 421 282 53 130 124 27 26 36 4 1 36 33 9 14 2 1 34 41 18 46 84 167 66 100 23 61
1964 17 0 0 8 9 2 32 5 145 235 182 60 69 46 6 18 2 0 11 11 11 74 27 5 8 32 2 3 77 150 18 25 152 116 22 25
1965 10 8 1 0 0 0 0 4 69 163 152 128 81 21 4 0 7 4 0 31 8 12 33 4 8 4 7 4 36 48 246 96 30 13 30 0
1966 0 13 13 34 5 7 41 38 174 158 114 96 20 4 48 0 0 8 5 14 56 7 7 6 0 0 10 45 4 247 242 0 0 25 5 0
1967 0 10 0 3 0 0 41 0 12 46 77 257 520 26 110 29 0 0 0 43 9 21 22 0 34 0 9 3 113 244 144 48 83 0 0 0
1968 0 0 0 7 12 205 107 39 41 107 117 181 93 15 100 36 54 0 0 14 54 43 36 6 0 0 0 6 62 151 102 165 186 232 0 0
1969 0 0 17 0 44 36 51 29 44 0 32 0 171 16 105 11 0 0 12 11 23 264 41 33 28 8 41 12 46 50 52 71 108 8 0 1
1970 11 59 39 0 0 0 4 48 184 188 55 94 66 24 42 0 9 9 9 1 46 19 14 47 7 0 0 13 35 13 127 38 0 39 0 4
1971 0 0 0 0 0 0 0 14 45 97 251 143 125 192 15 0 32 8 30 15 17 15 3 13 10 3 0 25 21 79 19 40 109 0 73 5
1972 35 1 0 21 0 13 0 7 0 67 24 39 256 150 54 23 0 4 19 21 10 0 4 3 30 30 19 70 198 241 40 197 75 9 0 35
1973 73 11 0 4 11 0 0 0 25 18 175 128 39 0 41 0 19 5 0 0 56 21 18 12 13 0 14 0 81 59 121 106 34 0 0 0
1977 21 0 0 0 0 35 1 37 85 174 43 192 281 30 3 0 20 0 0 20 26 2 37 0 0 49 0 61 119 14 273 153 53 0 26 14
1978 3 67 0 0 40 81 35 92 165 209 145 155 89 30 9 0 31 0 34 10 54 17 45 0 30 0 0 22 117 289 48 84 69 48 31 10
1979 0 0 87 61 0 0 0 129 28 200 105 92 134 14 75 0 0 0 0 60 0 0 0 0 3 0 0 44 2 81 195 62 0 0 19 0

9037034 CHUKA COUNTY COUNCIL (15)
1961 0 22 0 0 0 1 0 53 98 188 98 0 230 50 0 2 19 3 7 0 7 14 4 0 45 16 0 16 332 589 386 366 186 19 0 42
1962 6 0 0 0 0 0 0 0 89 56 102 228 109 46 0 0 0 0 1 169 117 0 53 25 20 13 5 5 176 115 0 14 66 18 45 8
1963 0 2 44 0 0 58 19 50 45 74 253 239 38 50 45 36 3 24 3 0 0 0 39 7 0 0 20 75 82 26 100 322 52 124 78 66
1964 59 0 0 0 0 0 42 0 150 117 284 143 46 36 0 49 1 0 7 5 2 26 16 5 4 17 1 0 113 80 84 62 109 167 46 55
1965 51 0 12 0 0 0 0 6 58 92 115 92 221 1 0 0 6 0 0 31 2 29 39 4 8 39 4 5 51 60 289 156 84 0 61 0
1966 0 8 15 138 58 0 57 47 185 195 217 58 16 30 8 0 0 0 18 53 28 0 0 0 0 0 0 0 114 199 114 57 151 41 2 0
1972 53 0 14 14 0 11 0 45 2 16 72 205 260 63 6 0 3 0 7 9 3 3 3 5 44 14 103 43 166 391 239 218 116 24 24 12
1975 3 0 8 0 6 0 7 0 15 22 162 121 11 96 9 0 0 11 12 6 10 9 13 1 19 25 8 60 4 176 0 179 46 22 7 7
1976 0 7 0 41 9 17 0 0 16 47 112 173 0 34 36 30 28 3 11 5 5 6 2 3 0 0 8 35 96 1 165 99 57 17 114 26
1977 45 21 3 0 3 37 12 64 146 235 93 236 98 63 0 5 14 0 0 12 9 0 13 0 0 8 0 9 3 0 254 166 174 13 83 7
1979 57 41 246 77 0 0 0 143 11 110 117 268 139 0 54 3 0 0 5 1 4 8 6 3 0 0 0 11 0 105 360 79 0 0 54 23
1981 0 0 0 20 0 0 7 108 171 169 344 77 218 106 2 0 3 1 0 2 0 3 15 6 39 15 2 11 43 114 77 151 38 47 41 30
1982 0 0 0 8 0 0 0 0 52 240 127 89 128 56 20 0 3 0 0 5 4 2 4 2 2 10 30 16 281 142 160 120 80 68 57 4
73/78 57 41 246 77 0 0 0 0 16 0 21 8 32 0 33 27 2 2 0 0 37 9 7 4 3 9 7 11 132 440 34 115 115 77 184 9
80/74 0 0 11 0 0 0 5 0 79 161 83 52 131 60 59 0 0 0 3 0 0 17 2 6 12 6 0 0 1 77 195 67 7 1 63 28

9037134 KAIRURI NGANDORI LOCATION (12)
1965 5 0 0 0 0 0 0 0 16 51 127 229 150 13 25 0 19 0 33 59 63 57 49 5 5 19 0 57 59 74 363 191 1 70 27 0
1968 0 0 0 5 0 174 134 35 43 87 113 111 184 16 147 55 79 3 106 8 84 45 27 31 26 7 0 12 159 180 37 111 192 213 4 0
1969 0 0 6 0 25 74 69 7 53 0 101 0 197 150 48 27 1 0 15 4 50 127 43 30 25 8 29 26 54 79 63 49 122 0 0 0
1970 29 8 25 12 27 5 17 30 159 306 73 215 25 53 36 0 193 14 0 9 7 66 36 89 0 4 3 0 96 25 69 37 0 0 5 0
1971 3 0 0 0 0 0 0 0 42 65 208 45 130 134 31 2 42 14 21 7 11 31 0 11 3 0 3 20 28 62 0 21 72 0 52 23
1972 11 0 8 10 0 62 0 5 0 63 56 20 318 49 84 25 0 0 30 28 13 4 8 10 39 47 19 104 250 223 68 183 28 8 4 0
1973 25 12 0 4 41 0 18 0 10 3 226 178 112 20 81 0 7 4 0 1 54 23 26 17 8 1 69 4 194 66 124 73 25 1 0 0
1974 2 0 0 18 9 0 10 3 87 135 79 126 49 7 57 85 37 40 130 39 9 26 42 9 30 12 3 8 2 96 117 35 0 8 44 5
1977 6 5 0 0 0 79 0 52 69 233 208 212 256 147 16 6 13 0 1 17 36 37 61 0 0 57 0 98 51 35 267 155 29 10 14 4
1981 0 0 0 0 0 0 8 49 65 129 480 192 257 176 15 33 5 2 5 31 8 27 18 11 15 34 0 22 42 146 57 90 55 28 29 6
1982 0 0 0 0 0 0 0 0 86 203 117 123 204 164 41 0 30 14 5 3 32 15 28 37 0 30 69 13 397 110 38 54 51 41 2 10
1983 0 0 0 3 30 0 0 0 0 53 156 381 186 57 222 11 15 38 11 8 23 4 15 11 69 17 0 140 4 136 308 17 4 77 0 85

9037077 IRANGI FOREST STATION (16)
1961 0 6 0 22 0 10 0 71 57 220 81 183 232 48 9 0 9 39 8 36 75 79 35 45 98 69 46 93 330 475 309 194 160 65 30 20
1962 53 0 17 0 0 0 1 7 42 54 66 126 319 148 7 5 17 8 39 36 37 34 85 56 54 33 19 52 75 122 17 48 59 0 25 24
1963 0 17 38 50 9 18 72 43 57 60 290 304 156 331 114 27 18 16 84 0 32 60 12 37 18 10 34 26 21 18 42 167 41 80 53 32
1964 66 3 0 6 0 33 42 4 85 143 178 122 104 97 28 33 5 0 30 72 57 174 84 16 25 42 0 14 120 139 71 43 128 190 32 20
1965 80 4 4 0 0 0 0 0 27 111 186 239 76 35 5 0 18 2 0 52 52 54 8 17 21 10 6 29 49 101 281 126 65 8 72 0
1966 0 0 26 9 18 4 26 42 156 183 148 192 116 0 0 15 17 32 21 49 71 28 14 11 19 5 12 63 3 233 330 21 1 30 19 0
1967 0 6 0 11 0 0 36 11 5 32 66 179 509 70 75 40 13 21 41 58 57 33 36 10 66 8 15 55 121 187 220 199 92 16 0 0
1968 0 0 0 0 17 201 151 49 120 70 157 165 169 64 303 46 33 14 46 25 76 81 64 8 0 12 8 11 54 205 104 155 235 131 31 0
1969 0 0 12 16 26 121 63 5 61 6 16 0 158 74 25 0 0 0 7 25 101 21 55 15 65 25 42 65 134 93 77 50 70 6 0 1
1970 32 57 32 0 0 0 53 36 121 35 0 0 59 0 6 18 55 56 60 3 133 34 76 109 28 4 12 2 100 52 94 37 38 10 0 8
1971 4 41 0 0 0 0 0 0 48 71 243 106 127 193 79 4 60 55 45 74 59 38 68 36 70 14 9 71 83 54 32 34 80 0 61 20
1972 5 0 0 28 2 10 0 5 8 33 67 27 194 95 49 115 40 48 22 49 7 13 26 19 60 74 28 102 219 198 95 243 57 0 3 0
1973 29 29 0 5 22 0 11 0 12 3 240 156 117 38 77 0 45 26 0 2 60 88 77 0 7 0 13 1 83 52 48 154 90 0 0 2
1977 9 0 8 0 0 46 7 80 105 232 132 317 271 144 50 0 52 34 0 41 67 27 72 11 2 0 0 67 151 51 236 187 153 0 29 4
1978 0 62 6 0 18 60 31 201 82 143 239 179 170 58 21 0 42 69 38 57 26 45 55 17 39 20 21 6 104 186 39 31 39 46 77 0
1979 48 24 113 19 12 0 0 104 40 146 56 126 231 82 198 97 5 3 67 27 43 38 53 12 29 8 4 22 89 107 175 42 0 0 69 11

9037123 CHOGORIA FOREST STATION (18)
1961 0 13 0 40 5 0 5 51 129 280 75 262 262 11 0 0 39 1 4 17 30 44 9 7 81 47 14 62 687 594 351 341 227 73 32 55
1962 101 0 12 0 0 0 0 0 46 80 136 260 249 98 0 0 0 0 8 4 2 12 43 42 13 26 1 56 110 29 40 53 43 6 20 19
1963 15 11 20 15 7 27 42 56 46 176 322 140 87 86 32 127 0 0 118 56 0 0 0 6 0 0 13 14 19 15 79 140 44 150 72 30
1964 97 0 0 54 0 30 51 13 132 87 234 107 101 16 7 30 1 0 30 1 0 39 7 2 3 2 0 10 121 65 111 55 24 10 9 32
1965 44 4 0 0 0 0 0 9 73 48 210 32 124 9 3 0 4 0 0 52 43 54 54 17 27 0 1 13 70 33 133 83 44 34 46 2
1966 0 9 45 39 42 5 59 58 119 316 92 118 81 11 7 20 19 18 1 13 20 8 0 4 5 0 13 31 0 173 243 0 12 27 17 0
1967 0 0 0 10 0 0 95 8 0 174 308 437 522 126 79 53 19 0 57 73 14 22 37 0 23 14 23 39 137 208 244 111 31 50 0 20
1970 50 111 99 0 0 0 33 22 126 186 103 161 105 29 61 6 9 6 2 2 18 10 14 43 17 0 1 38 136 81 227 63 14 33 43 11
1972 71 0 0 44 0 40 0 16 12 21 125 15 205 152 66 15 0 5 10 13 3 0 10 2 34 24 44 57 223 286 268 326 87 20 42 1
1973 67 46 0 3 17 0 0 0 16 17 143 130 84 25 21 0 14 0 0 1 29 26 16 9 8 1 17 14 136 11 230 124 60 18 0 3
1974 9 0 1 46 23 0 20 29 172 203 133 235 27 16 61 28 5 26 120 40 5 26 14 6 22 5 0 1 10 139 332 65 9 0 75 23
1975 2 0 10 0 8 0 3 15 31 46 265 127 61 216 12 6 0 37 6 16 19 7 18 0 12 14 25 41 9 158 0 204 68 51 3 12
1976 0 0 0 29 6 33 0 0 6 76 245 212 5 62 138 46 45 10 5 23 6 13 0 6 5 11 28 71 106 14 231 80 56 24 116 48
1977 30 12 26 5 0 93 11 100 98 346 94 177 185 147 31 3 18 4 1 26 14 4 24 1 0 53 0 76 122 20 341 172 123 28 50 21
1978 10 54 5 0 22 87 120 199 192 273 215 154 134 19 4 0 21 13 5 15 21 4 27 0 38 25 25 45 58 311 131 146 98 95 185 121
1981 0 0 0 37 11 0 17 146 212 180 321 119 220 105 0 36 1 0 7 16 2 6 19 11 9 2 3 18 21 180 141 187 59 37 56 38
1982 0 13 5 11 2 0 0 0 81 249 163 251 195 116 56 5 9 10 0 0 23 4 9 12 0 36 63 14 414 233 99 93 53 179 32 22
1983 8 0 0 30 37 0 3 0 0 2 128 411 132 15 49 0 0 19 5 0 15 2 4 16 6 5 13 95 37 117 213 60 20 103 76 133

ANNEX B. MAPPING UNITS AND SOILS

Listing of soil mapping unit descriptions from the legend of the soil map of Chuka-South (de Meester, revision November 1987).

Mountains and major scarps (relief intensity > 300 m, slopes > 30%)

MQC

Complex of well drained, brown to reddish brown soils of varying depth, texture and stoniness (orthic LUVISOLS, eutric REGOSOLS, CAMBISOLS and LITHOSOLS).

MBP

Somewhat excessively drained, shallow to moderately deep, dark brown to dark reddish brown, sandy loam to sandy clay loam (eutric REGOSOLS and LITHOSOLS).

Hills and minor scarps (relief intensity > 100 m, slopes 8 - 30 %)

HGC

Complex of well drained, dark reddish brown to red, friable soils of varying depth, texture and rockiness (chromic ACRISOLS, partly lithic phase).

HQC

Complex of somewhat excessively drained, strong brown to dark reddish brown, friable soils of varying depth, texture, stoniness and rockiness (eutric CAMBISOLS, chromic LUVISOLS, eutric REGOSOLS and LITHOSOLS).

HUC

Complex of well drained, brown to dark reddish brown, gravelly, soils of varying depth, texture, stoniness and rockiness (eutric and dystric CAMBISOLS, chromic LUVISOLS, eutric REGOSOLS and LITHOSOLS).

HIC

Complex of well drained, very shallow to deep, brown to dark reddish brown, friable, sandy clay loam to sandy clay, in places very gravelly or rocky (dystric CAMBISOLS, dystric REGOSOLS and LITHOSOLS).

HBC

Complex of somewhat excessively drained, shallow to moderately deep, dark brown to dark reddish brown, gravelly soils of varying texture, stoniness and rockiness (eutric and calcaric REGOSOLS, and LITHOSOLS).

HPC

Complex of well drained, brown to dark red, friable clay soils of varying depth, with an acid humic topsoil of varying thickness (dystric NITISOLS and chromic and orthic ACRISOLS).

Footridges (dissected middle slopes of volcanic mountains, relief intensity 50 - 100 m, slopes on crests 0 - 5 %, slopes on valley sides 5 - 16 %)

RP1h

Well drained, very deep, dark reddish brown to yellowish red and dark red, friable clay with acid humic surface soil (dystric and humic NITISOLS, in places dystric ACRISOLS).

RP2

Well drained, very deep dark reddish brown, friable clay (dystric and chromic CAMBISOLS).

Plateaus (relief intensity < 50 m, slopes 0 - 8 %)

LP1

Well drained to moderately well drained, very deep, dark reddish brown, friable clay (chromic and humic ACRISOLS, in low areas ferric ACRISOLS).

LP2P

Excessively drained, very shallow, dark brown, friable, very gravelly, stony and rocky, sandy loam to sandy clay loam (LITHOSOLS, pisoferric phase).

LPC

Complex of excessively drained, brown to dark reddish brown, very gravelly, sandy clay loam to sandy clay soils of varying depth, consistency, stoniness and rockiness (dystric CAMBISOLS, pisoferric and partly lithic phase).

LIC

Complex of brown to dark reddish brown, friable, very gravelly, sandy clay loam to sandy clay soils of varying depth, stoniness and rockiness (dystric CAMBISOLS, LITHOSOLS and rock outcrops).

LB

Well drained, deep, dark reddish brown to red, gravelly and stony, sandy clay loam to clay (ferric ACRISOLS, in places pisoferric phase).

High level uplands, volcanic origin (altitude > 900 m, relief intensity < 50 m, slopes 0 - 16 %)

U1P1h

Well drained, very deep, dark reddish brown to dark red, friable clay, with acid humic topsoil (dystric and humic NITISOLS).

U1P2

Well drained, moderately deep to deep, dark reddish brown to dark red, friable clay (chromic ACRISOLS).

U1PC

Complex of somewhat excessively drained, brown to dark reddish brown, gravelly sandy clay to clay of varying depth, stoniness and rockiness (dystric CAMBISOLS, ferric ACRISOLS, partly lithic phase, and LITHOSOLS).

Lower level uplands, Basement system (altitude < 900 m, relief intensity < 50 m, slopes 0 - 16 %)

U2Q1P

Well drained, shallow, dark reddish brown, gravelly and stony, sandy clay loam to clay, in places rocky (chromic LUVISOLS, in places lithic phase, and LITHOSOLS).

U2Q2P

Well drained, shallow, dark reddish brown, gravelly and stony, sandy clay loam to clay, in places rocky (chromic LUVISOLS, in places lithic phase, and LITHOSOLS).

U2QC1

Complex of well drained, dark reddish brown to red, gravelly, sandy clay loam to clay soils, of varying depth, stoniness and rockiness (orthic and chromic LUVISOLS, and eutric REGOSOLS, partly lithic phase).

U2F1

Well drained, deep to very deep, dark reddish brown to dark red, friable, sandy clay to clay, in places gravelly (orhtic and chromic LUVISOLS).

U2F2p

Well drained, moderately deep, dark brown to dark red, friable sandy clay loam to clay, in places fairly gravelly and stony or calcareous; occasionally rock outcrops (orthic and chromic LUVISOLS, partly calcic LUVISOLS).

U2F3P

Well drained, shallow, dark reddish brown to red, friable sandy loam to sandy clay loam, in places fairly stony and rocky (chromic LUVISOLS and partly LITHOSOLS).

U2FC1

Complex of strong brown to dark red, gravelly sandy clay loam to clay soils of varying depth, stoniness and rockiness (orthic, chromic and calcic LUVISOLS, and humic and feric ACRISOLS).

U2FC2

Complex of well drained, very gravelly, stony and rocky soils of varying depth, colour, consistency and texture (eutric REGOSOLS, CAMBISOLS and LUVISOLS, partly lithic phase and LITHOSOLS).

U2UC

Complex of somewhat excessively drained, dark reddish brown to red, very gravelly loamy to clayey soils of varying depth, stoniness and rockiness (chromic LUVISOLS, eutric REGOSOLS, in places lithic phase, and LITHOSOLS).

U2XC

Complex of well drained, dark brown to red, gravelly, very stony and bouldery clay soils of varying depth (chromic and ferric LUVISOLS, ferric ACRISOLS and eutric REGOSOLS, in places lithic phase).

U2Ap

Well drained, moderately deep to deep, dark reddish brown to red, slightly gravelly, sandy clay loam to clay, in places calcareous (ferric and chromic LUVISOLS, in places vertic and calcic LUVISOLS).

Plains (relief intensity < 10 m, slopes 0 - 5 %)

PPC

Complex of well drained, dark brown to dark reddish brown, rocky, friable sandy clay soils of varying depth and stoniness (orthic LUVISOLS and LITHOSOLS).

Major valleys (relief intensity 50 - 100 m, slopes of valley sides 8 - 30 %)

V1PC

Complex of well drained, dark reddish brown, friable clay soils of varying depth and rockiness (dystric NITISOLS, humic and chromic ACRISOLS, chromic LUVISOLS, partly petroferric phase, LITHOSOLS and rock outcrops).

Minor valleys (relief intensity < 50 m, slopes of valley sides 8 - 30 %)

V2P

Well drained, deep, dark reddish brown to dark red, friable clay, in places rock outcrops (dystric and humic NITISOLS, and humic ACRISOLS).

V2PC

Complex of well drained, dark reddish brown, friable clay soils of varying depth, stoniness and rockiness (chromic, ferric and calcic LUVISOLS, partly lithic phase, and rock outcrops).

Table 15. Soil types, their moisture fractions at saturation, field capacity, permanent wilting point, air dry, initial, Available Soil Moisture Fraction (ASMF = SMfc - SMpwp), saturated conductivity and a description.

Type	SM0	SMfc	SMpwp	SMa	SMi	ASMF	Ks	Description
1	0.61	0.48	0.25	0.08	0.26	0.23	3.5	clay (Volc. Footridges)
2	0.61	0.41	0.21	0.07	0.21	0.20	3.5	clay (Volc. Plateau)
3	0.46	0.31	0.13	0.04	0.09	0.18	3.5	clay (Basement System)
4	0.41	0.19	0.10	0.03	0.07	0.09	23.5	sandy clay loam (,,)
5	0.45	0.10	0.04	0.01	0.02	0.07	12.0	sandy loam (,,)
6	0.44	0.25	0.12	0.04	0.08	0.13	13.5	sandy cl.loam to clay(,)

Table 16. Gravel content classes and depth classes used for the reconnaissance soil map.

Gravel content classes		Depth classes	
non gravelly	< 0.02	very shallow	< 25
slightly gravelly	0.02 - 0.10	shallow	25 - 50
gravelly	0.10 - 0.40	moderately deep	50 - 80
very gravelly	0.40 - 0.80	deep	80 - 120
gravel	> 0.80	very deep	120 - 150

The classes derived from the classes in Table 16 and knowing the occurrence of intermediates in the mapping unit descriptions are:

Classes	0	1	2	3	4	5	6	7	8	9
Grav.fraction	0	0.02	0.06	0.10	0.25	0.40	0.60	0.80	0.90	1.00
Depth	0	25	38	50	65	80	100	120	135	150

Table 17. Mapping units, codes, soil types, gravel content and rooting depth classes, predefined suitability (0 = not suitable), are occupied in grid cells (km²) and in percentages of the whole area.

UNIT	CODE	SOIL	GRAV	DEPTH	SUIT	GRIDS	PERC.
MQC	10	4	4	4	0	76	5.03
MBP	11	4	4	4	0	7	0.47
HGC	20	4	4	4	0	12	0.80
HQC	21	4	4	4	0	8	0.53
HUC	22	4	4	4	0	18	1.20
HIC	23	6	4	4	0	1	0.07
HBC	24	4	4	4	0	41	2.72
HPC	25	2	0	6	1	17	1.13
RP1h	30	1	0	9	1	402	26.59
RP2	31	1	0	9	1	31	2.06
LP1	40	2	0	9	1	78	5.16
LP2P	41	2	6	1	1	6	0.40
LPC	42	2	6	4	1	6	0.40
LIC	43	2	6	4	1	3	0.20
LB	44	2	4	7	1	6	0.40
U1P1h	50	1	0	9	1	29	1.92
U1P2	51	2	0	6	1	38	2.52
U1PC	52	2	4	4	1	40	2.65
U2Q1p	60	6	4	3	1	6	0.40
U2Q2P	61	6	4	3	1	11	0.73
U2QC1	62	6	4	4	1	43	2.85
U2F1	65	3	3	8	1	81	5.36
U2F2p	66	6	2	5	1	104	6.88
U2F3P	67	4	2	3	1	25	1.66
U2FC1	68	4	4	5	1	91	6.02
U2FC2	69	4	6	4	1	29	1.92
U2UC	70	4	6	4	1	128	8.47
U2XC	71	3	4	4	1	8	0.53
U2Ap	72	6	2	6	1	36	2.39
PPC	80	3	2	4	1	2	0.14
V1PC	91	2	0	5	1	85	5.63
V2P	92	2	0	7	1	21	1.39
V2PC	93	2	2	4	1	23	1.53

At four places in the area ring infiltrometer measurements have been done using a single ring of 11 cm diameter. From the data on cumulative infiltration at different times the saturated conductivity is calculated using equations (10) and (11) from Koorevaar (1983) :

$$Icum = S \cdot \sqrt{t} + A \cdot t \tag{10}$$

$$Ks = 3/2 \cdot A \tag{11}$$

The measurements were done in different soil catena's in the so_called tea zone, coffee, mango and livestock/millet zone at altitudes of approximately 1800, 1500, 1200 and 850 m respectively. The calculated average (!) saturated conductivities were 350, 720, 500 and 120 cm/day respectively. These values are clearly not in proportion with a model that uses 10 day intervals.

ANNEX C. CROPS

Explanation of symbols for crop data :

assim	assimilation type of crop	(C3 or C4)
airduc	presence (1) of airducts in roots	
tsum1	temperature sum before anthesis	(°C·day)
tsum2	temp. sum from anthesis to maturation	(°C·day)
tsum	total temperature sum	(°C·day)
tmin	threshold temperature	(°C)
itdw	total dry weight at emergence	(kg/ha)
span	life span of leaves	(days)
sla	specific leaf area	(m^2/kg)
exc	extinction coefficient for visible light	
rdi	initial rooting depth	(cm)
rrg	rate of root growth	(cm/day)
rdm	maximum rooting depth	(cm)
LWmax	maximum number of decades with waterlogging	
Dmax	maximum number of decades with a drought	
RDmin	minimum required rootable soil depth	(cm)
conversion efficiencies	efficiency of conversion of assimilates into plant structural dry matter	
respiration rates	rate of respiration of plant parts	(kg/kg)
dying fractions	relative dying rate of roots and stems after anthesis	(kg/kg)
depletion factors	depletion factors at a transpiration rate from 0.2 cm/day to 1.0 cm/day	

```
Maize          <
C4 0 810 540 1350 10   (assim airduc tsum1 tsum2 tsum tmin)
20 60 18 0.7   (itdw span sla exc)
10.0 1.2 135   (rdi rrg rdm)
    1      1     50    (LWmax Dmax RDmin)
  ROOT  LEAF  STEM ORGAN
 0.720 0.720 0.690 0.730  (conversion efficiencies)
 0.010 0.030 0.015 0.010  (respiration rates)
 0.020       0.020        (dying fractions)
 0.400 0.600 0.000 0.000 0.000  Partitioning factors at development stages
 0.300 0.700 0.000 0.000 0.200     F_root F_leaf F_stem F_organ Dvs.
 0.230 0.650 0.120 0.000 0.300        |      |      |      |     |
 0.060 0.160 0.780 0.000 0.600        v      v      v      v     v
 0.000 0.000 0.000 1.000 0.700
 0.000 0.000 0.000 1.000 1.000
 0.885 0.800 0.700 0.600 0.550 0.515 0.465 0.430 0.400 (depl. factors)
```

```
Bulrush millet <
C4 0 680 340 1020 10   (assim airduc tsum1 tsum2 tsum tmin)
6 60 21 0.5   (itdw span sla exc)
10.0 4.0 120   (rdi rrg rdm)
     1     1     30    (LWmax Dmax RDmin)
  ROOT  LEAF  STEM ORGAN
 0.720 0.720 0.690 0.730  (conversion efficiencies)
 0.010 0.030 0.015 0.010  (respiration rates)
 0.020       0.020        (dying fractions)
 0.500 0.500 0.000 0.000 0.000
 0.500 0.500 0.000 0.000 0.070
 0.300 0.700 0.000 0.000 0.170
 0.170 0.830 0.000 0.000 0.270
 0.000 0.000 1.000 0.000 0.670
 0.000 0.000 0.000 1.000 0.870
 0.000 0.000 0.000 1.000 1.000
 0.885 0.800 0.700 0.600 0.550 0.515 0.465 0.430 0.400 (depl. factors)

Mungbean        <
C3 0 650 1000 1650 10   (assim airduc tsum1 tsum2 tsum tmin)
10 35 30 0.6   (itdw span sla exc)
10.0 1.2 75   (rdi rrg rdm)
     1     1     30    (LWmax Dmax RDmin)
  ROOT  LEAF  STEM ORGAN
 0.720 0.720 0.690 0.660  (conversion efficiencies)
 0.010 0.030 0.015 0.010  (respiration rates)
 0.020       0.020        (dying fractions)
 0.350 0.420 0.230 0.000 0.000
 0.140 0.560 0.300 0.000 0.330
 0.100 0.480 0.420 0.000 0.390
 0.070 0.000 0.190 0.740 0.600
 0.030 0.000 0.000 0.970 0.670
 0.000 0.000 0.000 1.000 1.000
 0.800 0.700 0.600 0.500 0.450 0.430 0.380 0.340 0.300 (depl. factors)
```

ANNEX D. PROGRAM CODE OF SIMULATION PART

```
(**********************************************************************)
(* Procedure : WATER.                                                 *)
(* Purpose   : to calculate the water reduction factor WRF and        *)
(*             update the moisture status of the soil and rooted      *)
(*             depth.                                                 *)
(* Interface : see PROCEDURE declaration part.                        *)
(**********************************************************************)
PROCEDURE WATER(VAR SOIL : SOILDATA; CROP : CROPDATA;
  VAR WRF, DEPTH : REAL; MAXDEP, LAI, BRF : REAL; Dt : INTEGER;
  ROOTGROWTH : BOOLEAN; P, E0, ET0 :REAL; IRRIG : BOOLEAN;
  VAR IRR : REAL; VAR LW, DRY, PI, EAT, D : INTEGER);

(**********************************************************************)
(* Procedure : DRAIN - DRAINage of water                              *)
(* Purpose   :adjust moisture content of layer with incoming          *)
(*             water from upper layer and determine loss to lower     *)
(*             layer.                                                 *)
(**********************************************************************)
PROCEDURE DRAIN( VAR SM, LOSS : REAL; FC, K, WIDTH : REAL;
  NR : INTEGER);
BEGIN
  SM := SM + LOSS / WIDTH;
  LOSS := (SM - FC ) * WIDTH;
  LIMIT ( 0, K * NR, LOSS);
  SM := SM - LOSS/WIDTH
END; (* DRAIN *)

VAR
  SMcr,                 (* critical soil moisture content              *)
  IM,                   (* infiltration rate (cm/day)                  *)
  Em,                   (* maximum evaporation from the soil surface   *)
  Ea,                   (* actual evaporation                          *)
  Tmax,                 (* maximum crop transpiration (cm/day)         *)
  T,                    (* actual crop transpiration                   *)
  DEPL,                 (* depletion factor                            *)
  ADD,                  (* added water in case of irrigation (cm)      *)
  LOSS,                 (* Loss of water lower layers                  *)
  DEPTHINCR : REAL;     (* Increase in rooted depth (cm)               *)
  I :         INTEGER;
BEGIN
  WITH SOIL DO
  BEGIN
    LOSS := 0; P := P / 10; ET0 := ET0 / 10; E0 := E0 / 10;
    Em := E0 * EXP(-0.4*LAI);
    Ea := Em * (SM-SMa)/(SM0-SMa); LIMIT(0, Em, Ea);
    IM := P - Ea;
    Tmax := BRF*(ET0-0.1*E0);
    WITH CROP DO
    BEGIN
      I := TRUNC(10*TMAX) - 1;
```

```
  IF I IN [1..8] THEN
    DEPL := (DEPLFCT[I+1] - DEPLFCT[I]) * FRAC(10*TMAX) + DEPLFCT[I]
  ELSE IF I < 1 THEN
    DEPL := DEPLFCT[1]
  ELSE
    DEPL := DEPLFCT[9]
END;
SMcr := (1 - DEPL)*(SM0 - 0.04 - SMpwp) + SMpwp;
IF IRRIG THEN
  T := Tmax
ELSE
BEGIN
  IF SM > SM0-0.08 THEN
    WRF := (SM0-0.04-SM)/0.04
  ELSE
    WRF := (SM - SMpwp)/(SMcr - SMpwp); LIMIT(0,1, WRF);
  T := WRF * Tmax
END;
SM := SM + Dt * (IM - T) / DEPTH;
IF DEPTH < MAXDEPTH {!} THEN
BEGIN
  DRAIN( SM, LOSS, SMfc, Ks, DEPTH, Dt);
  DRAIN( SMsub, LOSS, SMfc, Ksub, MAXDEPTH - DEPTH, Dt);
  IF ROOTGROWTH THEN
  BEGIN
    DEPTHINCR := CROP.RRG * Dt;
    IF DEPTH + DEPTHINCR > MAXDEP {!} THEN
      DEPTHINCR := MAXDEP - DEPTH;
    SM := (SM * DEPTH + SMsub * DEPTHINCR);
    DEPTH := DEPTH + DEPTHINCR; SM := SM/DEPTH
  END; (* IF *)
END
ELSE
  DRAIN( SM, LOSS, SMfc, Ksub, MAXDEPTH, Dt);
IF SMsub > SM0 THEN
BEGIN
  SM := SM + (SMsub - SM0) * (MAXDEPTH - DEPTH) / DEPTH;
  SMsub := SM0
END;
ADD := 0;
IF IRRIG THEN
BEGIN
  IF SM < SMfc THEN
  BEGIN
    ADD := 10 * DEPTH * (SMfc - SM);
    IRR := IRR + ADD; SM := SMfc
  END;
  IF SM > SM0-0.08 THEN
    WRF := (SM0-0.04-SM)/0.04
  ELSE
    WRF := (SM - SMpwp)/(SMcr - SMpwp); LIMIT(0,1, WRF);
END;
LIMIT( 0, SM0, SM);
```

```
    IF (SM > SM0 - 0.04) AND (CROP.AIRDUC = 0) THEN
      LW := LW + 1
    ELSE
      LW := 0;
    IF (SM < SMpwp) THEN DRY := DRY + 1 ELSE DRY := 0;
    PI := ROUND(P*10*Dt+ADD);          (* Rainfall + irrigation          *)
    EAT := ROUND(10*(Ea+T)*Dt);        (* evaporation + transpiration    *)
    D := ROUND(LOSS*10);               (* drainage losses from soil      *)
  END; (* WITH *)
END; (* PROCEDURE WATER *)

(*************************************************************************)
(* Procedure : DEVELOP - concerning the DEVELOPment stage.              *)
(* Purpose   : determine the daily increase in development stage        *)
(*             of a crop at a certain DECADE with its temperature.      *)
(* Interface : DECADE, CROP, DVS, TEMPROW, TEMP, Dt, DVSINC.            *)
(*************************************************************************)
PROCEDURE DEVELOP(DECADE : INTEGER; CROP : CROPDATA; DVS : REAL;
  TEMPROW : ROW2_36; VAR TEMP : TEMPDATA; VAR Dt : INTEGER;
  VAR DVSINC:REAL);
BEGIN
  WITH TEMP DO
  BEGIN
    MIN := TEMPROW[1,DECADE]; MAX := TEMPROW[2,DECADE]; MEAN := (MIN + MAX)/2;
    IF MEAN > CROP.TMIN THEN
      DVSINC := (MEAN-CROP.TMIN)/CROP.TSUM
    ELSE
      DVSINC := 0;
    IF DVS + Dt * DVSINC > 1.0 THEN
      Dt := ROUND((1.0-DVS)/DVSINC + 0.5)
  END
END; (* DEVELOP *)

(*************************************************************************)
(* Function  : TEMPRED - TEMPerature REDuction factor.                  *)
(* Purpose   : determine how TEMP reduces the CROP growth.              *)
(* Interface : TEMP, CROP, TEMPRED.                                     *)
(*************************************************************************)
FUNCTION TEMPRED( TEMP:TEMPDATA; CROP:CROPDATA; TPCOEF:PAIRS):REAL;
VAR TP, TRF : REAL;
BEGIN
  TP := TPCOEF[1] * TEMP.MIN + TPCOEF[2] * TEMP.MAX;
  IF CROP.ASSIM = 'C3' THEN
    IF TP < 25 THEN TRF := (-5 + TP)/10 ELSE TRF := (35 - TP)/10
  ELSE IF CROP.ASSIM = 'C4' THEN
    IF TP < 30 THEN TRF := (-8 + TP)/12 ELSE TRF := (40 - TP)/10
  ELSE
    ERROR('Unknown assimilation type for '+CROP.NAME);
  LIMIT(0, 1, TRF); TEMPRED := TRF
END;
```

```
(***********************************************************************)
(* Procedure : PERFORM - crop PERFORMance.                             *)
(* Purpose   : calculate dry matter production by crop growth          *)
(*             simulation in intervals and write calculations to       *)
(*             OUTPUT or LST.                                          *)
(* Interface : see PROCEDURE declaration part.                         *)
(***********************************************************************)
PROCEDURE PERFORM ( TEMPROW,      (* Tmin and Tmax in decades          *)
   CO₂ASS:ROW2_36;                (* Gross assimilation in decades     *)
   DEC : INTEGER; CROP : CROPDATA;(* decade of emergence               *)
   PRDTYP:INTEGER;                (* type of production simulation     *)
   SOIL:SOILDATA; CLIM : CLIMDATA;
   VAR TDW, WSO:REAL;             (* total dry weight, yield wght.     *)
   EVRIJ, ETRIJ : ROW36;          (* evapo(transpi)ration              *)
   PERC:REAL;                     (* percolation fraction of rain      *)
   YEAR:INTEGER;                  (* year of measured rainfall         *)
   MSRROW : MSRRAIN;              (* data on measured rainfall         *)
   IRRIG : BOOLEAN;               (* irrigation ?                      *)
   VAR IRR:REAL;                  (* irrigation requirement            *)
   VAR SCREEN, PRINTER :BOOLEAN;  (* output to screen/printer ?        *)
   VAR GRWLEN : INTEGER;          (* length of growth period           *)
   TPCOEF : PAIRS);               (* coefficients process temp.        *)
VAR
  DVS,  DVSINC,                   (* (increase of) development stage   *)
  LAI,                            (* leaf area index (m²/m²)           *)
  Fgc,                            (* gross canopy assimilation (CO₂)   *)
  Fgass,                          (* gross assimilation (kg CH2O/ha)   *)
  RESP,                           (* maintenance respiration rate      *)
  Fnet,                           (* net assimilation rate             *)
  INCR,                           (* dry weight increase of parts      *)
  WRF, TRF, LRF,                  (* water, temperature, leaf red.fct. *)
  DEPTH,                          (* actual rooted depth               *)
  MAXDEP,                         (* maximum rooting depth             *)
  PREC,                           (* effective rainfall in decade      *)
  LVLOSS : REAL;                  (* loss of leaves due to stress      *)
  DECADE,                         (* interval decade                   *)
  Dt,                             (* interval length                   *)
  PAST,                           (* present day minus life span       *)
  LW, DRP,                        (* counters for logged/dry intervals *)
  DECBEFORE,                      (* decade before emergence           *)
  PI, EAT, D : INTEGER;           (* moisture flows to output.         *)
  TEMP : TEMPDATA;                (* data on temperature               *)
  ORGAN : PLANTORGANS;
  LDW,                            (* living dry weight of parts        *)
  PARTFACT : ORGANROW;            (* partitioning factors of parts     *)
  LVFORMED : ARRAY[0..600] OF REAL; (* weight of leaves formed         *)
  RAINROW : ROW36;                (* decadal rainfall figures          *)
  ROOTGROWTH : BOOLEAN;           (* rootgrowth ?                      *)
```

```
BEGIN
  IF PRDTYP <> 1 THEN
  BEGIN
    DEPTH := CROP.INIDEPTH;
    IF  0.7 * CROP.MAXDEPTH > SOIL.MAXDEPTH  THEN
      MAXDEP := SOIL.MAXDEPTH
    ELSE
      MAXDEP := CROP.MAXDEPTH * 0.7;
    DEPTH := DEPTH * (1 - SOIL.GRAVFR);
    CROP.RRG := CROP.RRG * (1 - SOIL.GRAVFR);
    MAXDEP := MAXDEP * (1 - SOIL.GRAVFR);
    WITH CLIM DO
      IF PRDTYP = 2 THEN
        RAINGEN(RAIN,DAYS,DIST,RAINROW)
      ELSE
        RAINROW := MSRROW[YEAR];
    WITH SOIL DO
    BEGIN
      SM := SMi; SMsub := SMi; DECBEFORE := DEC - 1;
      Ks := Ks * (1 - GRAVFR); Ksub := Ksub * (1 - GRAVFR);
      IF DECBEFORE < 1 THEN DECBEFORE := DECBEFORE + 36;
      WATER(SOIL,CROP,WRF,DEPTH,MAXDEP,0,0,0,10,FALSE,
                RAINROW[DECBEFORE]*PERC/10,EVRIJ[DECBEFORE],
                ETRIJ[DECBEFORE],IRRIG,IRR,LW,DRP,PI,EAT,D)
    END;
  END
  ELSE
  BEGIN
    SOIL.SM := 0; PREC := 0
  END;
  DECADE := DEC; ROOTGROWTH := TRUE;
  LW := 0; DRP := 0; DVS := 0; GRWLEN := 0; TDW := CROP.TDW;
  FOR ORGAN:=ROOT TO STOR DO
    LDW[ORGAN]:=CROP.PARTFCT[0,ORGAN]*TDW;
  LVFORMED[0] := CROP.PARTFCT[0,LEAF] * TDW;
  WHILE (DVS<1.0) AND (LDW[LEAF]>0) AND (LW<CROP.LWmax) AND (DRP<CROP.Dmax) DO
  BEGIN
    Dt := 10;
    DEVELOP(DECADE,CROP,DVS,TEMPROW,TEMP,Dt,DVSINC);
    TRF:=TEMPRED( TEMP, CROP, TPCOEF);
    LAI:=LDW[LEAF] * CROP.SLA * 0.0001;
    LRF := 1 - EXP(-CROP.EXC * LAI);
    Fgc := (CO2ASS[1,DECADE] * (1 - CLIM.CLF[DECADE])+CO2ASS[2,DECADE] *
        CLIM.CLF[DECADE]);
    IF PRDTYP = 1 THEN
      WRF := 1.0
    ELSE
    BEGIN
      PREC := RAINROW[DECADE] * PERC;
      WATER(SOIL, CROP, WRF, DEPTH, MAXDEP, LAI, LRF, Dt,
                ROOTGROWTH, PREC/10, EVRIJ[DECADE], ETRIJ[DECADE],
                IRRIG, IRR, LW, DRP, PI, EAT, D);
      LVLOSS := (1-WRF) * CROP.FDIE[LEAF] * LDW[LEAF] * Dt;
```

```
        LDW[LEAF] := LDW[LEAF] - LVLOSS;
        PAST := GRWLEN - ROUND(CROP.SPAN);
        LVFORMED[PAST] := LVFORMED[PAST] - LVLOSS;
        WHILE LVFORMED[PAST] < -0.0001 DO
        BEGIN
          PAST := PAST + 1;
          LVFORMED[PAST] := LVFORMED[PAST] + LVFORMED[PAST-1];
          LVFORMED[PAST-1] := 0
        END;
      END; (* PRDTYP <> 1 *)
      Fgass:=Fgc * TRF * LRF * WRF * 30/44;
      RESP:=0;
      FOR ORGAN := ROOT TO STOR DO
        RESP := RESP+LDW[ORGAN] * CROP.RESP[ORGAN];
      Fnet:=Fgass - RESP * TRF;
      IF DVS > 1 - CROP.TSUM2/CROP.TSUM THEN
      BEGIN
        LDW[ROOT] := LDW[ROOT] - CROP.FDIE[ROOT] * LDW[ROOT]*Dt;
        LDW[STEM] := LDW[STEM] - CROP.FDIE[STEM] * LDW[STEM]*Dt
      END;
      ROOTGROWTH := Fnet > 0;
      WHILE Dt > 0 DO
      BEGIN
        GRWLEN := GRWLEN + 1;
        IF Fnet > 0 THEN
        BEGIN
          PARTITION(DVS + DVSINC/2,CROP,PARTFACT);
          FOR ORGAN:=ROOT TO STOR DO
          BEGIN
            INCR := Fnet * PARTFACT[ORGAN]*CROP.CONV[ORGAN];
            IF ORGAN = LEAF THEN
              LVFORMED[GRWLEN] := INCR;
            LDW[ORGAN] := LDW[ORGAN] + INCR;
            TDW := TDW + INCR
          END (* FOR - ORGAN *)
        END (* IF - Fnet *)
        ELSE
          LVFORMED[GRWLEN] := 0;
        DVS := DVS + DVSINC;
        PAST := GRWLEN - ROUND(CROP.SPAN);
        IF PAST >= 0 THEN
        BEGIN
          LDW[LEAF] := LDW[LEAF] - LVFORMED[PAST]; LVFORMED[PAST] := 0
        END;
        Dt := Dt - 1
      END; (* WHILE *)
      IF LDW[LEAF] < 0 THEN LDW[LEAF] := 0;
      IF DECADE < 36 THEN DECADE := DECADE + 1 ELSE DECADE := 1
    END; (* WHILE *)
    WSO := LDW[STOR]
  END; (* PERFORM *)
```