USE AND IMPROVEMENT of POORLY DRAINED LAND

with particular reference to Lelmolk farm,

Uasin Gishu District, Kenya

H.M.H.Braun

April, 1985

International Institute for Land Reclamation and Improvement/ILRI,
Wageningen, The Netherlands

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Report by H.M.H.Braun (ILRI, Wageningen)

1 INTRODUCTION

The International Institute for Land Reclamation and Improvement (ILRI) is the back-stopping agency of several Land and Water projects supported by the Netherlands Directorate for International Cooperation (DGIS) in Kenya. In the context of regular visits to Kenya, the coordinating officer at ILRI, Ir. H.M.H. Braun, was requested by the Provincial Irrigation Unit of Rift Valley Province in Nakuru, to pay a visit to Lelmolk farm and south-central Uasin Gishu district in order to assess the nature and extent of poorly drained soils and the possibilities to improve these soils for arable use by smallholders, particularly in relation to the experiences with similar soils and land use, before and after drainage improvement, in other parts of Kenya.

The Lelmolk settlement farm is located south of the Kerita river, west of the murram road from Cheptiret to Lessos lake, some 20 km south from Eldoret in Uasin Gishu district. Three years ago this former large-scale farm was subdivided in settlement plots of 4 acres each, irrespective of soil conditions. The majority of farmers obtained plots consisting of well drained soils, while about 70 of them received plots consisting of poorly drained soils. The former are extensively used as arable land, the latter are hardly used for cultivation of crops because the growing conditions are considered unsuitable. The occupants of these poorly drained soils requested the District Agricultural Officer (DAO) for help to improve their soils. This request was passed on to the Provincial Irrigation Unit (PIU) in Rift Valley. The PIU undertook a topographical survey and commissioned a preliminary soil survey of the poorly drained areas of the Lelmolk farm to the Kenya Soil Survey (KSS). The present study is a follow-up of the KSS survey of which the report (van Engelen 1984) was used during the field trip in November 1984 and during the preparation of the draft of this report. The topomap of the farm unfortunately was neither available during the field trip nor during the preparation of this report. The District Agricultural Officer in Eldoret and the Provincial Irrigation Engineer in Nakuru were briefed on the preliminary findings after the field visit. A draft of the report was circulated and the comments received, from the Irrigation and Drainage Branch, the PIU Rift Valley, the Netherlands Soil Survey Institute (Stiboka) and others, have been incorporated.

2 ITINERARY OF FIELD VISITS

Tuesday 13 November 1984	Discussion at PIU, Nakuru (Knops, Mwathe, Braun); Travel to Eldoret (Knops, Braun), discussion with acting DAO (Muiru, Knops, Braun, Waithuki); field visit Soy-Kaaboi-Kiplombe-Plateau-Eldoret (Waithuki, Knops, Braun).
Wednesday 14 November	Field visit Lelmolk farm and Kesses-Cheptiret area (Omwenga, Muiru, Kamau, Braun); discussion at DAO (Ibeere, Muiru, Omwenga, Braun).
Thursday 15 November	Field visit Namancharara area near Kitale and Chepterit swamp area near Kapsabet, return to Eldoret through Lessos and Cheptiret (Omwenga, Braun).
Friday 16 November	Field visit Eldoret-Cheptiret-Lelmolk farm (Omwenga, Braun); return to Nakuru and discussion at PIU (Knops, Moejes, Braun).
Thursday 22 November	Field visit Eldoret-Plateau-Kerita farm-Cheptiret (Braun).
Friday 23 November	Discussion at PIU (Knops, Braun); field visit Kinangop area, i.e. Naivasha-North Kinangop-South Kinangop-Limuru (Braun).
Sunday 24 Nov.	Field visit western part of Kinangop plateau (Braun).

3 SOIL CONDITIONS

In Uasin Gishu the majority of soils are well drained, shallow (<50 cm) to moderately deep (50-80 cm), red clays with murram and/or rock in the subsoil (Sombroek et al, 1982). A considerably smaller, but still quite substantial, part of the district consists of poorly drained, shallow to moderately deep, grey-brown and mottled clays with murram in the subsoil. A relatively small part of the district consists of poorly drained, deep (>120 cm), grey and mottled clays with a dark and humic topsoil. An impression on the location of the smaller areas with poorly drained soils can be obtained from inspecting the 1:50,000 topographic maps of the Survey of Kenya. The location of these poorly drained areas is as follows:

A (with generally deep soils): Alluvial valleys of the small rivers and (semi)-permanent swamps which are indicated on the 1:50,000 and topographical maps with the symbol 'papyrus swamp, marsh, bog', varying in size from 1 ha to 100 ha.

B (with generally deep soils): Bottomlands of 50-500 ha in extent, scattered throughout the district except in the extreme southern and eastern parts. Such areas are indicated with a symbol for seasonal swamp on the scale 1:50,000 topographical maps of the Survey of s Kenya (sheets 89/1-89/4, 103/1, 103/2, 103/4). The total extent of these areas can be assessed by planimetration or by counting on a dot screen which is superimposed on the 1:50,000 maps. The difference between A and B (i.e. between alluvial valley and bottomland) is clear on the maps but sometimes not in the field.

A large contiguous area with poorly drained soils is not indicated on the topographic maps, however. In crude outline it is indicated on the Exploratory Soil Map (Sombroek et al 1982) with the same code as the bottomlands proper referred to above under B. It concerns the 'Cheptiret Land System Area', an area of some 5000 ha, geographically situated around Cheptiret Market. It forms part of the Eldoret plateau and some of the parts with poorly drained soils are no proper bottomlands. The soils are generally shallow or moderately deep. Further details on the distribution of the soils in this area can be

found on the preliminary soil map which is attached as an appendix to this report.
The four major soil units described by Sombroek et al. (1982) are the following:

L24 well drained, moderately deep to deep, dark red, friable clay over petroplinthite; with inclusions of small bottomlands of unit B2 (rhodic FERRALSOLS, petroferric phase)

B2 poorly drained, moderately deep, dark grey to grey, mottled, firm clay, with a humic topsoil; in many places over petroplinthite (mollic GLEYSOLS, partly petroferric phase)

Uh3 well drained, extremely deep, dark reddish brown, friable clay (eutric NITISOLS)

R2 well drained, extremely deep, dusky red to dark reddish brown, friable clay, with an acid humic topsoil (humic NITISOLS)

These unit descriptions, with slight modifications, fit the units of the map attached to this report: L24 = CPR; B2 = CPG; Uh3 + R2 = UR; note that in the description of unit L24 the depth is moderately deep to deep over petroplinthite, while in CPR the depth is described as shallow to moderately deep over rock; similarly B2 is described as moderately deep over petroplinthite, while CPG gives the description shallow to moderately deep over rock. In both the CPR (L24) and CPG (B2) units there is a horizon of petroplinthite (locally more commonly known as murram) but it is thin and immediately underlain by rock.

For the poorly drained areas of the Lelmolk farm, Kenya Soil Survey carried out a preliminary soil survey (van Engelen 1984). The map of that report shows 4 bottomland units. The most extensive unit (BI2P) is similar in description to the CPG unit of the map attached to this report; one other unit (BI2p) is similar in profile characteristics but deeper. Deep units like BI1 and BI3, which cover relatively small areas, might be of similar occurrence elsewhere in the Cheptiret Land System Area. No deep soils were found during the field survey in which over 50 observations, scattered throughout the area, were made.
All the soil maps referred to in this Chapter are of a preliminary nature. They provide a first picture of the distribution of soils in

Kenya, south-central Uasin Gishu district and Lelmolk farm respectively. Neither of the three maps should be used for direct project planning (at national, district or farm level). Instead, they can and should be used for the planning of further surveys and investigations. It is emphasized therefore that a detailed soil survey should be carried out as a matter of urgency in case drainage improvements at Lelmolk farm are envisaged.

4 LAND USE

Major forms of estate land use in Uasin Gishu district are cattle grazing, wheat cultivation and wattle plantation. Smallholders' major forms of land use are cattle grazing and maize cultivation. Cultivation of maize, which is increasingly replacing the main crop wheat, is generally done on the well drained soils. Yields are good to reasonable, except on shallow soils, where particularly maize does not thrive (the poorest maize of the whole district was seen on the shallow red soils of the former Lewa Downs farm, alongside the road from Eldoret to Soy). Most of the poorly drained areas are used for grazing, and in the areas described in the previous section under A and B, hardly any cultivation was noticed. In the Cheptiret Land System area, the better drained and/or deeper soils were, and still are, generally used for wheat cultivation. The poorer drained and /or shallower soils were generally used for grazing, i.e those areas which were thought or proven unfit for wheat, were left as grassland. In recent years, i.e. after former large farms were subdivided among smallholders, the cultivation of maize has increased. Though for climatic and soil reasons maize is less suitable than wheat, the maize performs reasonably well on the deeper and/or better drained soils, but it does not do well on shallow and/or poorly drained soils.

Maize: altitude, rainfall pattern and amount, together with limited soil depth make most of Uasin Gishu moderately to marginally suitable for maize growing, the latter particularly on soils which are shallow and/or poorly drained.

Wheat is well suited to the climate and altitude conditions in most of Uasin Gishu. The crop can cope (much) better than maize with unfavourable soil depth or drainage conditions.

Rice: In principle poorly drained areas might be suitable for the cultivation of rice. The high altitude and consequent low temperatures of all the land in Uasin Gishu district precludes the cultivation of rice, however.

Grassland: Nearly all grasslands are natural grasslands (i.e. no improvement measures like ploughing and reseeding have taken place). The grasslands occupy those parts of the Uasin Gishu landscape where soils are too shallow, too rocky or too poor in drainage condition to allow for (mechanised) wheat cultivation. In all cases where conditions in wheat fields and nearby grasslands were compared, the latter had the shallower soils and/or poorer drainage condition.

Land use on the poorly drained areas of Lelmolk farm is in large majority grazing of unimproved grassland. Some of the new settlers have tried to grow crops, maize in particular, and these attempts have been resonably successful on the deep soils of units BI1, BI3 and AI1 of the Kenya Soil Survey map (van Engelen 1984). Crop performance on the moderately deep soils of unit BI2p was fair to poor, while the few attempts to grow maize on the shallow soils of unit BI2P resulted in virtual or complete crop failure.

5 TOPOGRAPHY AND DRAINAGE

Few of the poorly drained areas are flat. The slopes are generally 1 to 2%. The poor drainage is caused by lack of internal drainage, i.e. the water cannot move downwards because of an impermeable layer of clay or rock. The poor drainage is apparent from the mottling which occurs in these soils. It leads to a so-called perched water table. In the rainy season the water table will be quite often close to the soil surface and under such conditions non-adapted plants or crops are unable to grow properly. Many of the poorly drained areas receive run-off water from higher lying areas and this aggravates the drainage problem.

6 SOIL WATER RETENTION

Many of the poorly drained soils are shallow, particularly so at the Lelmolk farm. The shallowness has as a consequence that only a small amount of moisture can be stored in the soil profile. By coincidence this feature could be observed during the field visit: the rain which fell the night of 14/15 November filled up the dry soil profiles up to 35 or even 45 cm depth i.e. the not excessive rainfall of one night (probably in the order of 35 mm) nearly fills up the whole moisture storage capacity of the soil. Any further rain might have caused saturation conditions in the soil profile and still further amounts might have caused run-off. The low amount of moisture which can be stored in shallow soils causes that the plants growing on such soils will suffer from lack of an adequate moisture supply quicker than on deeper soils where the amount of stored soil moisture is larger.

7 USE OF POORLY DRAINED AREAS IN OTHER PARTS OF KENYA

Most of the poorly drained areas are used for grazing. Examples are the Chepterit swamp area near Kapsabet, the Kinangop plateau (Nyandat 1984), the bottomlands of Bomet (Braun & Okwaro 1974), Kisii (Wielemaker & Boxem 1982; Braun 1984; van der Wal 1979), Ndeiya Karai (van der Wal 1980; Braun 1983), Busia (Michieka & Rachilo in prep.), Meru (Michieka 1981) and Nyanza/Western Province (Rachilo 1984), the Molo/Mau Summit area, parts of the Laikipia plateau and parts of the Athi/Kaputei plains (Touber et al. in print). Some poorly drained areas are used for crop production. Examples are the peaty clay bottomlands in Kisii, the Namancharara swamp area north of Kitale, parts of the Kinangop plateau area and some parts of the clay bottomlands in Nyanza and Western Provinces.

The Namancharara swamp area was formerly covered with grassland (Gelens et al. 1976), but it is now extensively cultivated with maize. To alleviate the drainage problems cambered beds and a surface drainage system were developed by the farmers (squatters ?) in this area of deep soils. On the Kinangop plateau only a small proportion (5-10%) of the land surface of poorly drained deep soils is used for crop production. For improving the drainage and for increasing the rootable depth of these soils, which consist of a loam or silt loam topsoil on a heavy clay subsoil (Planosol), use is made of cambered beds which are often ridged. Potatoes, and to a lesser extent also peas, cabbage and onions do quite well under such conditions, though nearby well drained soils invariably have better crops. Maize is not growing well on Kinangop, probably largely due to the climate (i.e. too cold: maize was not doing well on well drained soils either). Another area where crops, in particular wheat, are said to be grown on poorly drained soils improved by bedding, is the Mau Narok area. However, on a field visit to this area (in March, 1985), the cambered bedding seen occurred in grasslands only, and few examples were seen of the use of poorly drained soils for crop production.

8 METHODS FOR IMPROVING THE AGRICULTURAL PRODUCTIVITY OF POORLY DRAINED AREAS

Many poorly drained areas in Kenya and elsewhere are left under natural vegetation or are in use as unimproved grazing land. Whether it is useful or worthwhile to improve such areas depends on local conditions like land pressure, possibilities and cost/benefit ratio of improvement measures of the existing agriculture and the possibilities and the cost/benefit ratio of improvement of the poorly drained areas. In a case like the poorly drained areas issued to settlers on the Lelmolk farm there is not much choice, but even then it is very necessary to make an assessment whether the efforts and costs of any improvements for the growth of crops, forage or trees are in balance with the benefits accruing from such improvements. The author is rather pessimistic on the possibilities for improvement of the poorly drained areas on the Lelmolk farm, particularly because of the shallowness of the soils in that area (and in most of the remainder of the Cheptiret area). A proper assessment can only be made however, when some improvement experiments or trials are carried out.

The major methods of improvement are the following:

1 cultivation of adapted crops, trees or forage plants (particularly rice, Eucalyptus and elephant grass);
2 interception/diversion of run-off water from higher lying areas;
3 surface drainage) with or without maintaining
4 sub-surface drainage) a particular
5 pumped-well drainage) groundwater level
6 bedding (cambered beds) or piling (heaps) of the soil;
7 sub-soiling (ripping);
8 deep ploughing;

Generally these methods are not used singly but in combination, for instance a combination of adapted crop, diversion of run-off water from higher lying areas, surface drainage, ripping and bedding (i.e. methods 1+2+3+6+7). Methods 4 and 5 are mentioned for completeness sake, though they seem of little relevance for Kenyan conditions. All the other ones have been used in Kenya. Which combination should be used depends on alternatives, costs and benefits. That the effects of the various methods cannot be predicted (and may also vary according to climatic variations from year to year) is shown by the results of trials on the Kinangop plateau area (Nyandat 1984).

Rice is in principle a most appropriate crop. In many poorly drained areas in Kenya, and probably in the whole of Uasin Gishu district, it cannot be used because of temperature restrictions. Some further data on rice in relation to temperatures is given in annex 1.

Cambered beds can be made in various ways (see for instance Robinson et al. 1955; or Smedema & Rycroft 1983). Construction of a cambered bed generally has as a consequence that growing conditions on one part of the area improve while on another part of the area the conditions deteriorate. Cambered beds can be made mechanically by ploughing (towards a centre-line with a disc or mouldboard plough or by making gullies with a V-shaped plough) or by hand with shovel and spade. The latter is feasible in Planosol areas which have relatively light topsoils, but it is hardly feasible in heavy clay soils.

Subsoiling and deep-ploughing require heavy machinery and therefore these methods are expensive. They should be carried out when the soils are rather dry, in order to avoid the bad effects of smearing. Because of the shallowness of the soils, it seems doubtful whether these methods are of importance for improvement of the poorly drained soils on the Lelmolk farm.

9 CONCLUSIONS

1 There are two types of poorly drained lands in Uasin Gishu district:

a. bottomlands proper, scattered over most of the district, with deep clay soils in general; not cultivated

b. the Cheptiret land system area with generally shallow or moderately deep clay soils over rock; partly cultivated: wheat and increasingly also maize, the latter with poor results on shallow soils.

2 The preliminary soil survey of the Lelmolk farm (by the Kenya Soil Survey) provides a general outline of the soil conditions in that area. Any improvement plans for the poorly drained area should be based on more detailed information (i.e. a detailed soil survey in which particular attention is paid to soil depth and texture should be carried out prior to any further developments).

3 In various parts of Kenya there are more or less successful attempts to improve the drainage conditions of poorly drained areas particularly on peaty clay soils (Kisii) and heavy clay soils with a silt loam or sandy loam topsoil (Kinangop, Namancharara: Planosols).

4 Because of the shallowness and heavy texture of most of the soils in the Cheptiret land system area, the prospects for improvement are more unfavourable than in most other areas.

5 The soils under grassland in the Cheptiret land system area are shallower than the soils under arable crops (or: the better soils are used for arable crops while the poorer ones remain under grassland).

6 The prospects for maize cultivation in the Cheptiret land system area are thought to remain marginal even after improvement of the drainage. However, experiments with cambered beds and a surface drainage system are necessary to make a proper assessment of the viability or unviability of such improvements.

10 RECOMMENDATIONS

1 With regard to the Lelmolk farm and other Cheptiret area poorly drained soils, study soil water relations in the wet season. Preferably a person should be on the spot, particularly to study the influence of run-off from higher ground during periods of continued rainfall, i.e. to observe the duration and depth of inundation.

2 To study the effects of drainage improvements (surface drainage, cambered beds, ridging, singly or in combination) on the performance of crops (maize, and wheat for comparison, potatoes, peas), trees or forage plants.

3 Carry out or commission a detailed soil survey at a scale of 1:5,000 approximately of the poorly drained parts of Lelmolk farm, paying particular attention to soil depth and texture. To assess the influence of soil conditions on crop yields a crop performance survey and study should be carried out simultaneously with, and/or as a follow-up of, the detailed soil survey.

4 Unless it has been proven that the poorly drained areas can be used as arable land they should, when large farms are subdivided, not be given out as arable land.

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ANNEX 1

Temperature conditions for rice

The best option to develop poorly drained lands at lower altitudes in the wet or moist tropics is not drainage but the cultivation of rice, either irrigated or non-irrigated. This possibility seems very worthwhile exploring for those areas where there are no temperature limitations for rice growth. The general guideline with regard to temperature is that rice should be grown below 1500 m in Kenya (Ackland 1971; Jaetzold & Schmidt 1982). Grist (1975) is rather vague about altitude and related temperatures. ILACO (1981) mentions that temperatures should not fall below 10°C. According to Tenhave (pers. comm.) minimum temperatures should not fall below 7°C. In IRRI (1976) the many effects of temperature on various aspects of rice growth are mentioned, though no critical values are given for mean minimum or absolute minimum temperatures. From the contributions by Chang & Oka, Vergara, Nishiyama, Munakata, Satake and Murata it can be concluded that the rice productivity decreases sharply when the average temperature drops below 20°C approximately; in all cases the average seasonal temperatures are above 20°C though average temperatures at the beginning and end of the season may be as low as 15°C. Low night temperatures are not harmful as long as they are compensated by high day temperatures. At high latitudes the daily period of insolation (and high temperature) is much longer than at the equator. Cold tolerant varieties are not day-length sensitive.

In Hokkaido (Japan) yields decrease sharply (Ishizuka et al. 1973) when the mean temperature during July and August, which is the sensitive period, drops below 19°C: for 13 seasons with an average temperature below 19°C the average yield is in the order of 1200 kg/ha and for 27 seasons with an average temperature above 19°C 3600 kg/ha; the average temperature in this July-August period is 19.7°C.

In Annex 2 some temperature data are given for various sites in Kenya (data derived from EAMD 1975). The data sets for sites in Western and Eastern Kenya are separated. Also separate equations have been derived for the annual mean maximum, annual mean mimimum, mean annual, absolute mimimum, coolest and warmest month' mean temperatures in relation to altitude for Western and Eastern Kenya sites (see tables 1A/1B, 2A/2B, 3A/3B and 4A/4B). The equations provide a means to estimate seasonal temperatures at various altitudes in Kenya. When also the temperature limits of a particular rice variety are known, then the areas which might be climatically suitable for rice-growing can be estimated on the basis of contour maps (e.g. for a temperature of 20°C the equation for the warmest month in western Kenya gives an altitude of 1750 m or 5750 ft; the 1760 m (or 5800 ft) contour then separates areas with a higher and lower average temperature in the period February-March; in July-August the relevant contour is 1500 m (5000 ft), still in western Kenya; for eastern Kenya the values are 1660 m (5400 ft) in February-March and 1100 m (3600 ft) in July-August).

Based on the references quoted at the beginning of this annex one can assume that the temperature limit even for tolerant varieties is in the order of 20°C. If this assumption is correct then it is estimated that in areas like Mwea, which is at 1160 m, at least one out of every three July-August seasons will result in cold damage.

The main conclusion from the data presented here is that for a particular altitude there is a temperature difference of 2.5 to 3°C between west and east Kenya in the cool season July-August and 0.5 to 1°C in the warm season February-March. Consequently temperature-sensitive crops like rice can be grown at higher altitudes in western Kenya than in the eastern part of the country (400 m higher in July-August and only 100 m higher in February-March).

ANNEX 2

Temperature data Kenya

Table 1A. Altitude, mean maximum, mean minimum, average annual* and absolute minimum temperatures of some stations in western Kenya (Source: EAMD 1975).

	alt (m)	mean max	mean min	average	abs. min
Ahero	1220	30.0	15.9	23.0	9.8
Busia	1220	28.0	16.0	22.0	9.0
Eldoret	2080	24.0	9.3	16.7	1.6
Kibos	1170	29.0	15.5	22.3	10.0
Kisii	1710	26.0	12.5	19.3	5.5
Kisumu	1160	29.4	17.0	23.2	11.0
Kitale	1890	25.0	11.5	18.3	6.4
Koru	1560	28.1	13.5	20.8	6.9
Lodwar	510	34.7	23.6	29.2	14.6
Marigat	1070	32.4	16.8	24.6	10.2
Molo	2480	20.7	7.0	14.9	0.6
Equator	2760	18.3	8.0	13.2	3.5

correlation and regression (n = 11, omitting Equator):

mean max = 38.1 - 0.0069 × alt r = - 0.9734

mean min = 26.0 - 0.0079 × alt r = - 0.9852

annual mean = 32.1 - 0.0074 × alt r = - 0.9895

abs. min = 18.5 - 0.0073 × alt r = - 0.9771

* In these tables and the text average and mean are used as synonyms; average annual is the sum of mean maximum and minimum divided by two; all temperatures in centrigrade (°C).

Table 1B. Altitude and temperatures in Eastern Kenya (and Narok)

	alt (m)	mean max	mean min	average	abs. min
Mwea	1160	27.8	15.5	21.7	7.2
Garissa	140	34.3	22:6	28.5	13.9
Hola	90	33.1	21.9	27.5	14.0
Isiolo	1100	30.2	16.8	23.5	9.0
Kiambu	1730	24.7	12.9	18.8	5.2
Kimakia	2440	18.0	7.9	13.0	0.6
Kitui	1090	26.5	14.2	20.4	4.5
Machakos	1570	25.1	12.2	18.7	3.7
Makindu	1000	28.6	16.5	22.6	8.8
Mandera	230	34.3	23.3	28.8	12.0
Moyale	1110	27.1	17.4	22.3	10.6
Muguga	2100	20.9	10.8	15.9	1.9
Nairobi	1800	23.3	11.8	17.6	2.5
Nanyuki	1950	23.5	8.6	16.1	0.7
Narok	1890	24.5	8.5	16.5	0.3
Ruiru	1700	24.9	13.0	19.0	4.0
S. Kinangop	2590	17.7	5.4	11.6	- 2.2
Thika	1550	25.1	13.7	19.4	5.6
Voi	560	30.5	19.3	24.9	9.6
Wajir	240	33.6	22.1	27.9	14.5

n = 20

mean max = 35.0 - 0.0064 × alt r = - 0.9795

mean min = 23.5 - 0.0068 × alt r = - 0.9769

annual mean = 29.3 - 0.0066 × alt r = - 0.9887

abs. min = 14.6 - 0.0064 × alt r = - 0.9556

Regression for Western and Eastern Kenya combined:

n = 31

mean max = 35.7 - 0.0063 × alt r = - 0.9476

Table 2A. Western Kenya; calculated temperatures for altitudes 1200 - 1800 m

alt (m)	mean max	mean min	average	abs. min
1200	29.7	16.5	23.2	9.7
1300	29.1	15.7	22.5	9.0
1400	28.4	14.9	21.7	8.2
1500	27.7	14.1	21.0	7.5
1600	27.0	13.3	20.3	6.8
1700	26.3	12.5	19.5	6.0
1800	25.6	11.7	18.8	5.3

Table 2B. Eastern Kenya; calculated temperatures for altitudes 1200 - 1800 m

alt (m)	mean max	mean min	average	abs. min
1200	27.3	15.4	21.4	7.0
1300	26.7	14.7	20.7	6.3
1400	26.1	14.1	20.1	5.7
1500	25.4	13.4	19.4	5.1
1600	24.8	12.7	18.8	4.4
1700	24.1	12.0	18.1	3.8
1800	23.5	11.4	17.5	3.2

Table 3A. Average temperature of coldest and warmest month in Western Kenya

	alt (m)	average temperature coldest month	warmest month	coldest period	warmest period
Ahero	1220	22.3	23.8	June - Aug	Feb - Mar
Busia	1220	21.2	22.9	July - Aug	Feb - Mar
Eldoret	2080	15.6	18.0	July - Aug	Mar - Apr*
Kibos	1170	21.4	23.2	July - Aug	Feb - Mar
Kisii	1710	18.5	20.1	July - Aug	Feb - Mar
Kisumu	1160	22.0	24.1	June - Aug	Feb - Mar
Kitale	1890	17.4	19.5	July - Aug	Feb - Mar
Koru	1560	20.0	21.8	July - Aug	Jan - Mar
Lodwar	510	28.3	30.1	July - Aug	Feb - Mar**
Marigat	1070	23.6	25.7	July - Aug	Mar - Apr*
Molo	2480	12.7	14.9	July - Aug	Mar - Apr*

mean temp coldest month = 31.3 - 0.0075 × alt   r = - 0.9899

mean temp warmest month = 32.8 - 0.0073 × alt   r = - 0.9868

The average temperature difference between the warmest and coldest month is 1.9 ± 0.2 (95% conf. lim.)

* The average temperature in April is higher than in February but the mean maximum temperature in April is lower than in February (and the mean minimum is higher than in February).

** also October

Table 3B. Average temperature of coldest and warmest month in Eastern Kenya

	alt (m)	average temperature coldest month	warmest month	coldest period	warmest period
Mwea	1160	20.0	23.1	July - Aug	Feb - Mar**
Garissa	140	26.6	30.4	July - Aug	Mar - Apr
Hola	90	25.3	29.5	June - Aug	Feb - Mar
Isiolo	1100	22.3	24.7	Nov - Dec***	Feb - Mar**
Kiambu	1730	16.3	20.5	July - Aug	Feb - Mar
Kimakia	2440	11.0	14.4	July - Aug	Mar - Apr*
Kitui	1090	18.1	22.2	July - Aug	Mar - Apr*
Machakos	1570	16.0	20.5	July - Aug	Mar - Apr
Makindu	1000	20.1	24.6	July - Aug	Feb - Mar
Mandera	230	27.8	31.0	July - Aug	Feb - Mar
Moyale	1110	19.7	25.1	July - Aug	Feb - Mar
Muguga	2100	13.5	17.7	July - Aug	Feb - Mar
Nairobi	1800	15.2	19.2	July - Aug	Mar - Apr*
Nanyuki	1950	15.0	17.1	July - Sept	Mar - Apr*
Narok	1890	14.8	17.7	July - Aug	Mar - Apr*
Ruiru	1700	16.9	20.4	July - Aug	Mar - Apr*
S. Kinangop	2590	10.3	13.0	July - Aug	Mar - Apr*
Thika	1550	17.4	20.8	July - Aug	Feb - Mar
Voi	560	22.6	27.1	July - Aug	Feb - Mar
Wajir	240	26.2	29.9	July - Aug	Feb - Mar

average temp coldest month = 27.3 - 0.0066 × alt   r = - 0.9803

average temp warmest month = 31.4 - 0.0069 × alt   r = - 0.9882

The average temperature difference between the warmest and coldest month is 3.7 ± 0.4 (95% conf. lim)

* See note under Table 3A

** also October

*** also July

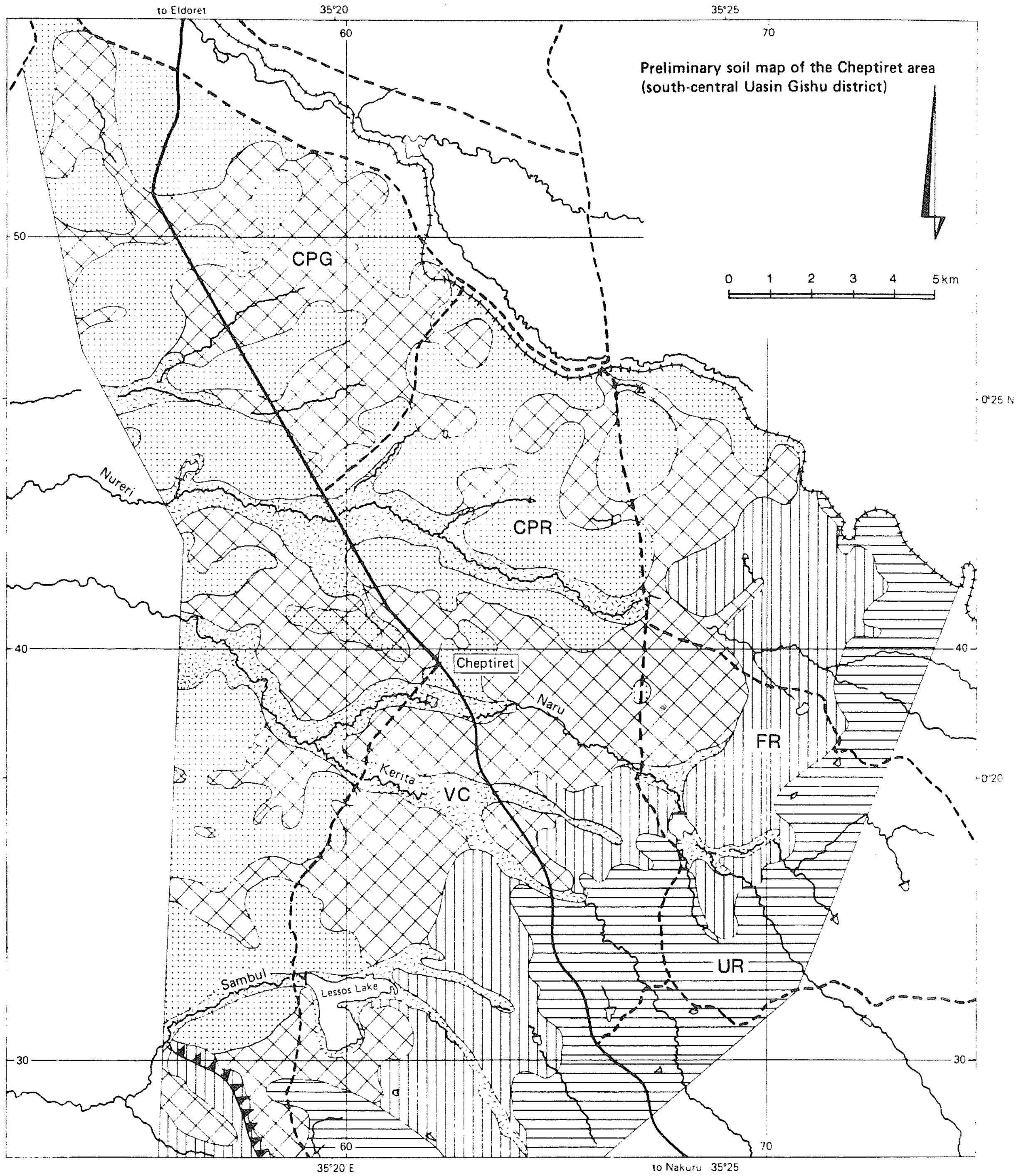
Table 4A. Calculated mean monthly temperatures for coldest and warmest month in Western Kenya

	coldest	warmest
1200	22.3	24.0
1300	21.5	23.3
1400	20.8	22.6
1500	20.0	21.8
1600	19.3	21.1
1700	18.5	20.4
1750	18.1	20.0
1800	17.8	19.7

Table 4B. Calculated mean monthly temperatures for coldest and warmest month in Eastern Kenya (and Narok)

	coldest	warmest
1100	20.0	23.8
1200	19.4	23.1
1300	18.8	22.5
1400	18.1	21.8
1500	17.5	21.1
1600	16.8	20.4
1650	16.4	20.0
1700	16.1	19.7
1800	15.5	19.0

Appendix I

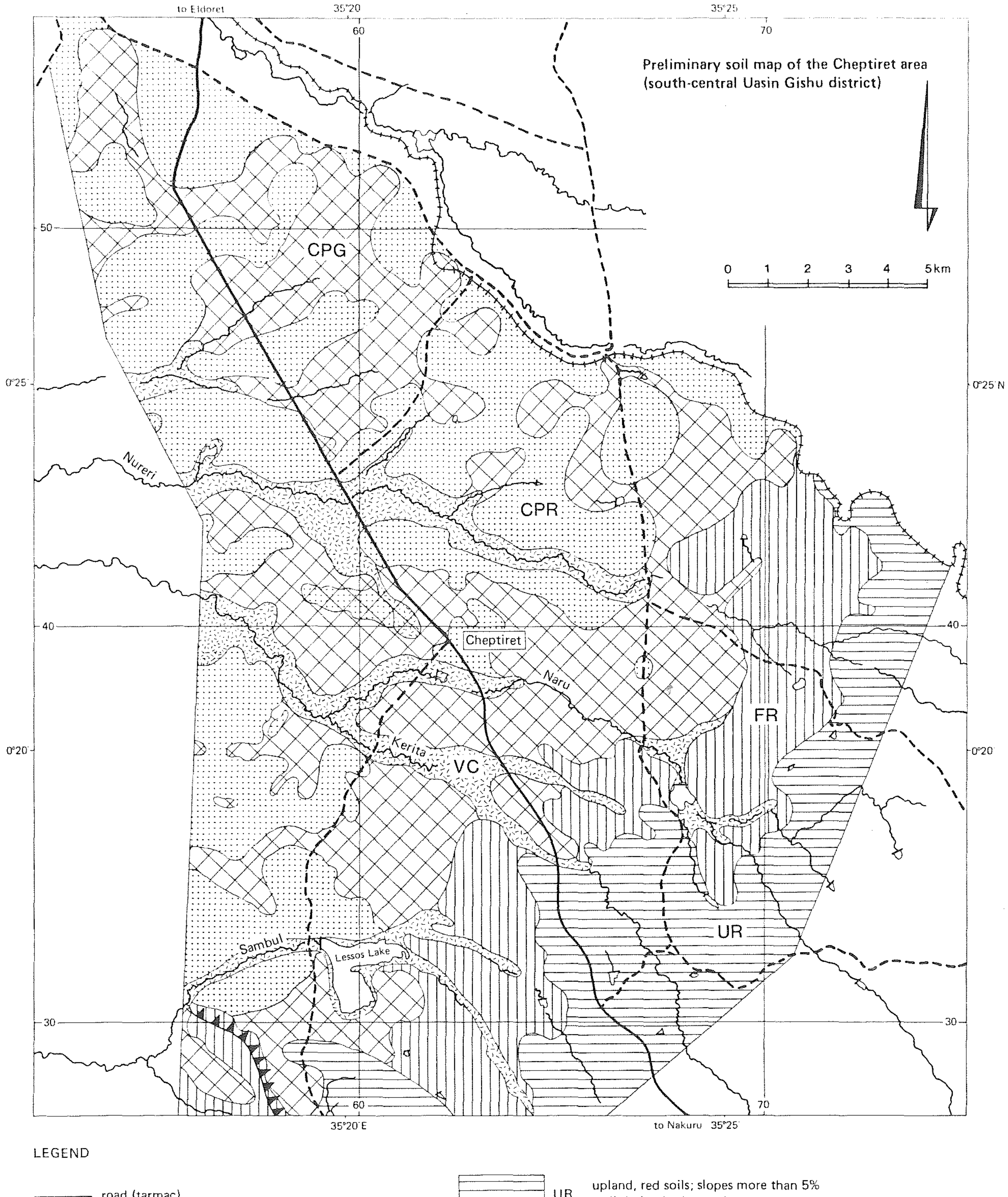


LEGEND

- road (tarmac)
- road (murram)
- railway
- river
- scarp
- soil boundary
- UTM grid (10 km interval)

UR	upland, red soils; slopes more than 5% well drained, deep, clay
FR	footslope or transition zone, red soils; slopes 2-5% well drained, moderately deep to deep, clay
CPR	Cheptiret plateau, red soils; slopes 0-5% well drained, shallow to moderately deep, clay over rock
CPG	Cheptiret plateau, grey, mottled soils (Gleysols), slopes 0-2%: imperfectly to poorly drained, shallow to moderately deep, clay over rock
VC	valley complex; variable slopes complex of soils of various drainage condition, colour and depth

Appendix I



LEGEND

- road (tarmac)
- road (murram)
- railway
- river
- scarp
- soil boundary
- —70— UTM grid (10 km interval)

UR	upland, red soils; slopes more than 5%	well drained, deep, clay
FR	footslope or transition zone, red soils; slopes 2-5%	well drained, moderately deep to deep, clay
CPR	Cheptiret plateau, red soils; slopes 0-5%	well drained, shallow to moderately deep, clay over rock
CPG	Cheptiret plateau, grey, mottled soils (Gleysols); slopes 0-2%	imperfectly to poorly drained, shallow to moderately deep, clay over rock
VC	valley complex; variable slopes	complex of soils of various drainage condition, colour and depth