REPUBLIC OF KENYA

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KENYA SOIL SURVEY

SOME CHARACTERISTICS AND ALTITUDE RELATIONSHIPS OF TEMPERATURES IN KENYA

by

H.M.H. Braun

Miscellaneous Paper No. M18, 1986

Kenya Soil Survey, Nairobi

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SUMMARY

Knowledge on temperatures, particularly in agriculture, is important. Because Kenya straddles the equator, it can be expected that temperatures are closely correlated with altitude, except at the coast. This is confirmed by data and derived equations.

The main purpose of this report is to make the available information better accessible to the users. Published data and derived equations have been reworked to enable the reader to make as accurate as possible estimates of: mean maximum, mean minimum and average temperatures per month or annum and absolute minimum and maximum temperatures per annum for any location in Kenya (Chapters 2, 3, 4, 9).

Some attention is also given to the following aspects of temperature:

- Altitudinal and regional differences in the month of occurrence of the lowest and highest mean maximum, mean minimum and average temperature (Chapter 5);
- The regional difference in monthly average temperature between the warmest and coolest month of the year (Chapter 6)
- Regional variations in the difference between the mean maximum and mean minimum temperature (Chapter 7).

1 INTRODUCTION

Because of its influence on plant growth, temperature is an important aspect of climate. In Kenya the variation in temperatures over the country is large: at any time during the day there may be a difference of 30°C between the coldest and hottest place in the country. Data on absolute and mean temperatures, maximum and minimum, monthly and annual, for 160 stations in Kenya are given in a publication of the East African Meteorological Department (EAMD 1970). For the estimation of the monthly and annual average, mean maximum and mean minimum temperatures of stations above 500ft, the EAMD 1970-publication gives equations relating the temperatures in centigrade (°C) to the altitude in feet.

In this report some additional information, derived from the same data source, is given. It concerns the following aspects:

1) Conversion of feet-centigrade equations to metres-centigrade equations;
2) Temperatures at altitudes below 500 ft;
3) Relationship between altitude and absolute maximum and minimum temperature;
4) The distribution of the mean maximum, mean minimum and average temperatures in time and space;
5) The range in the monthly average temperature (highest minus lowest monthly average temperature);
6) The mean daily temperature range (annual mean maximum minus annual mean minimum);
7) Differences in temperature between east and west Kenya.

2 CONVERSION OF FEET-CENTIGRADE TO METERS-CENTIGRADE EQUATIONS

Altitude data in Kenya are still largely in feet though gradually more maps are being issued with altitudes in meters. In the East African Meteorological Department's report on temperatures in Kenya (EAMD 1970), various equations are given for the relationships between altitude (in feet) and temperature (in °C = Celsius = centigrade). By multiplying the lapse rate (= regression coefficient or slope of the regression line) by 3.2808 (= 1000 meter/1000 feet), the equations given in the EAMD report for altitudes in feet (EAMD 1970) can be transformed for use with altitudes in meters. Thus the equations for the annual mean maximum, mean minimum and average annual temperatures in feet and meters are as follows:

feet	meters
mean max.= 35.5°C - 0.00181 xf	mean max.= 35.5°C - 0.00594 xm
mean min.= 24.8°C - 0.00215 xf	mean min.= 24.8°C - 0.00705 xm
average = 30.2°C - 0.00198 xf	average = 30.2°C - 0.00650 xm

The equations for each month are given in Annex I. In Chapter 8 and Annex III further information is given on temperature differences between eastern and western Kenya.

Note: the sum of the mean maximum and mean minimum temperature, either per day, per month or per year, divided by two is called the mean or average temperature. For easier differentiation we will use the term average in this report.

3 ESTIMATION OF THE MEAN MAXIMUM, MEAN MINIMUM AND AVERAGE TEMPERATURE FOR ALTITUDES BELOW 500 FEET

The equations given in the East African Meteorlogical Department's report on temperatures (EAMD 1970) can only be used for altitudes above 500 feet, for which the following reason is forwarded:

> "In Kenya much of the land below 500 ft is influenced by the land and sea breezes and is not expected to conform to the general pattern for other stations. For this reason all the stations below the 500 ft level are excluded and the equations may only be used above this level".

The choice of the 500 ft contour seems rather inappropriate because this contour is as close as 10 kilometers from the coastline in the vicinity of Mombasa while it is as far inland as 200 km near Lamu. It seems more realistic to assume that the influence of the sea breezes, which suppress the maximum temperatures, is related to the distance from the coast. Barry and Chorley (1976) mention that these winds may penetrate 50 km inland. Somewhat arbitrarily it will be assumed here that the cooling effect of the sea breezes decreases proportionally with the increasing distance from the coast and becomes nil at a distance of 100 km from the coast.

From EAMD (loc.cit.) data for 13 stations at the coast, the following averages and standard deviation have been calculated for the mean maximum, mean minimum and the average (or mean) temperature:

annual mean maximum temperature	= 29.5°C +/- 0.5
annual mean minimum "	= 22.8°C +/- 0.8
annual average "	= 26.2°C +/- 0.4

From the same publication the following equations for the mean maximum, mean minimum and average temperature in relation to altitude in meters were derived in the previous chapter:

sufficiently accurate to calculate the monthly values as a percentage of the annual values. From the 13 stations at the coast the calculated monthly percentages are given in Table 1.

Table 1. Monthly mean maximum, mean minimum and average temperatures as a percentage of the annual values for 13 stations at the coast

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean max. temp.	104	106	108	104	98	95	92	93	96	99	102	104
mean min. temp.	102	104	107	106	101	97	94	93	95	99	101	103
average temp.	103	105	108	105	99	96	93	93	95	99	101	103

Example: annual mean maximum temperature 28.2°C; mean maximum July is 92% of 28.2 = 25.9°C

4 THE RELATIONSHIP BETWEEN ALTITUDE AND THE ABSOLUTE MINIMUM AND MAXIMUM TEMPERATURES

Minimum temperatures

From the 69 stations with 10 or more years of data in EAMD (loc.cit.), the following regression, with a correlation coefficient r = -0.94, was calculated between altitude (range 10 to 9200 feet) and absolute minimum temperature (range +19.7 to -1.1°C):

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absolute minimum temperature = 16.2°C - 0.002 xf
= 16.2°C - 0.00656 xm

(xf = altitude in feet; xm = altitude in meters)

According to the above equation the average height above which frost can be expected is 16.2/0.002 = 8100 ft or 2470 m. Five stations below this altitude have recorded temperatures below 0°C and two above the altitude of 8100 ft have minimum temperatures above freezing point. The specific data are as follows:

	feet	meters	°C		feet	meters	°C
Rumuruti	5800	1770	-0.6	Ainabkoi	8750	2670	2.8
Kericho	6800	2070	-1.1	Equator	9060	2760	3.5
Eldoret	7000	2130	-1.1				
Kakoe For.St.	7100	2160	-1.1				
Ol Joro Orok	7800	2380	-1.3				

The conclusion one can draw from these data is that although there is a good correlation between the absolute minimum temperature and the altitude, in practice there can be important deviations from the calculated regression. In terms of 95% confidence limits, 1.5°C could be added or subtracted to the calculated temperature that occurs at a

5 THE DISTRIBUTION OF THE MEAN MINIMUM, MEAN MAXIMUM AND AVERAGE TEMPERATURE IN TIME AND SPACE

Minimum temperatures

The graphs of the monthly mean minimum temperatures in relation to altitude which are given in the East African Meteorological Department Report (EAMD 1970) suggest that the minimum in July at sea level is gradually replaced by a minimum in January - February when going to higher altitudes. To a lesser extent the tendency of a gradual shift of the minimum from low altitudes to higher altitudes can also be seen from table 2: the percentage in January increases from 7 to 22%, while July -August decreases from 86 to 40%. Note however that September increases from 7 to 26%.

Table 2. The distribution (expressed as a percentage) of the lowest monthly mean minimum temperature over the months of the year for 179 sites divided in three altitude classes

	Jan	Feb	Jun	Jul	Aug	Sep	Oct	Nov	Dec	n
0 - 2500 ft	7	-	-	37	49	7	-	-	-	27
2500 - 5000 ft	12	-	6	36	43	3	-	-	-	33
above 5000 ft	22	4	3	25	15	26	1	1	3	119
all data	18	3	3	18	26	19	1	1	2	179

The occurrence of three maxima (i.e. January, July and September) in the class above 5000 ft suggests that this class might be a mixture. Because it is known that west and east Kenya experience different temperature conditions (e.g. Griffiths 1962, 1969, 1972, see also chapter 8), the class above 5000 ft was subdivided in a western and eastern sub-class along the line Loita Hills- Longonot- Kimakia- Kerugoya- Isiolo- Lokitaung, see Table 3.

Average temperatures

The lowest monthly average temperatures occur in July (at 64% of all stations) and August (32%) while the highest occur in March (66%), February (21%) and April (10%).

A summary of the lowest and highest monthly mean minimum, mean maximum and average is given in table 4. It is worth noting that March is the month with the largest percentage for the highest monthly average temperature, though April has the largest percentage for the highest minimum and February has the largest percentage for the highest maximum.

Table 4. The distribution (expressed as a percentage) of the lowest and highest monthly mean minimum, monthly mean maximum and monthly average temperatures over the months of the year; only percentages higher than 5 are reported

	Jan	Feb	Mar	Apr	May	Jul	Aug	Sep
lowest minimum temp.	20					25	19	25
lowest maximum "						71	25	
lowest average "						64	32	
highest minimum temp.			20	56	12			
highest maximum "	7	60	31					
highest average "		21	66	10				

6 THE RANGE IN THE MONTHLY AVERAGE TEMPERATURE

The range in the monthly average temperature, by which is meant the difference between the highest and lowest monthly average temperature, or the difference in monthly average temperature between the warmest and the coolest month (in general between March and July respectively), varies from 1.1 to 5.5°C. For stations east of the line Loita Hills- Longonot- Kimakia- Kerugoya- Isiolo- Lokitaung the average range is 3.9°C (with n = 65 and a standard deviation of 0.5), while west of that line the average range is 2.3°C (with n = 90 and s.d. 0.6), i.e. in eastern Kenya there is more temperature difference between the warm and cool season than in western Kenya.

7 THE MEAN 24-HOUR TEMPERATURE RANGE

The mean 24-hour temperature range, by which is meant the difference between the mean maximum and the mean minimum temperature, varies seasonally and geographically, as can be seen from table 5. At the coast the difference between the mean maximum and the mean minimum is not even half the difference occurring in the Central "Rift" part of Kenya.

Table 5. The smallest and largest monthly 24-hour temperature range and the average 24-hour temperature range for 4 areas in Kenya; for more extensive data see Annex II

	smallest	largest	average	n
coast	5.7°C	8.2°C	6.9°C	5
north and east	10.0	14.0	11.5	27
west	11.4	14.7	13.5	12
central	12.7	18.9	15.6	10

Notes: the smallest difference generally occurs in May or July; the largest difference occurs in February or January

coast = 100 km wide strip along the coast,

north and east = from coastal strip up to the line Magadi- Muguga-Kinangop- Isiolo- Lodwar

west = west of the line Kapenguria- Molo- Kisii

central = the area between north & east and west

8 TEMPERATURE DIFFERENCES BETWEEN WESTERN AND EASTERN KENYA

In the chapters dealing with the average, the mean minimum, the mean maximum and the absolute minimum temperatures, no differentiation was made for the long-known systematic differences between temperatures at a particular altitude in Western and Eastern Kenya (Griffiths 1962). For a recent report (Braun 1985), dealing amongst others with temperature conditions for rice, the author derived seperate temperature equations for Eastern and Western Kenya (east of Moyale- Nanyuki- South Kinangop- Muguga- Narok, excluding the coastal strip and west of Lodwar- Marigat- Molo- Kisii respectively). The tables and text of Annex IIIA and B give data, calculations and interpretations. A summary of the equations is given below.

GENERAL equations; from EAMD (1970) equations or data (see Chapter 2 and 4); xm is the altitude in meters:

annual mean maximum temperature	= 35.5 °C	- 0.0059 xm
annual mean minimum	"	= 24.8	- 0.0071 xm
annual average	"	= 30.2	- 0.0065 xm
absolute minimum	"	= 16.2	- 0.0066 xm

Equations for east and west Kenya; from EAMD (1975) data (see Annex IIIA):

EAST			
annual mean maximum temperature	= 35.0 °C	- 0.0064 xm
annual mean minimum	"	= 23.5	- 0.0068 xm
annual average	"	= 29.3	- 0.0066 xm
absolute minimum	"	= 14.6	- 0.0064 xm
WEST			
annual mean maximum temperature	= 38.1 °C	- 0.0069 xm
annual mean minimum	"	= 26.0	- 0.0079 xm
annual average	"	= 32.1	- 0.0074 xm
absolute minimum	"	= 18.5	- 0.0073 xm

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ANNEX I

REGRESSION EQUATIONS FOR FSTIMATING THE MONTHLY MEAN AND ANNUAL MAXIMUM, MINIMUM AND AVERAGE TEMPERATURE (in°C) FROM THE ALTITUDE IN FEET (xf) OR METERS (xm);data source EAMD 1970

	mean maximum		mean minimum		average	
January	36.7 - 0.00174 xf		25.0 - 0.00227 xf		30.8 - 0.00201 xf	
February	37.4	176	25.8	232	31.6	204
March	37.6	176	26.3	230	31.9	203
April	35.8	175	26.1	215	30.9	196
May	34.6	179	25.1	208	29.9	193
June	33.9	178	23.8	203	28.9	191
July	33.5	183	22.8	194	28.2	188
August	33.7	186	23.2	197	28.5	191
September	35.4	184	24.1	215	29.7	199
October	36.4	187	24.8	217	30.6	202
November	36.2	196	25.2	216	30.7	206
December	35.5	179	25.1	221	30.3	200
year	35.5	181	24.8	215	30.2	198
January	36.7 - 0.00571 xm		25.0 - 0.00745 xm		30.8 - 0.00659 xm	
February	37.4	577	25.8	761	31.6	669
March	37.6	577	26.3	755	31.9	666
April	35.8	574	26.1	705	30.9	643
May	34.6	587	25.1	682	29.9	633
June	33.9	584	23.8	666	28.9	627
July	33.5	600	22.8	636	28.2	617
August	33.7	610	23.2	646	28.5	627
September	35.4	604	24.1	705	29.7	653
October	36.4	614	24.8	712	30.6	663
November	36.2	643	25.2	709	30.7	676
December	35.5	587	25.1	725	30.3	656
year	35.5	594	24.8	705	30.2	650

Example: altitude 7300 feet.

January mean max. = 36.7 - 7300 x 0.00174 =

36.7 - 12.7 = 24.0°C

altitude 2200 meters.

December mean min. = 30.3 - 2200 x 0.00656 =

30.3 - 14.4 = 15.9°C

ANNEX II

THE SMALLEST, LARGEST AND AVERAGE 24-HOUR TEMPERATURE RANGE IN °C FOR 54 STATIONS IN KENYA (DATA SOURCE EAMD 1975)

	smallest/month		largest/month		average
NORTH and EAST					
Moyale	7.4	May	12.3	February	9.7
Kimakia	7.5	July	13.2	February	10.1
Muguga	8.2	May	11.5	February	10.1
Nairobi Kabete	8.7	May	13.6	February	10.8
Mandera	9.8	July	13.2	January	11.0
Lodwar	9.6	July	13.4	January	11.1
Nairobi NAL	9.6	May	13.7	February	11.1
Katumani	9.0	Nov.	13.3	September	11.2
Hola	9.8	June	12.7	February	11.2
Voi	9.8	May	12.8	February	11.2
Thika	9.2	Nov.	14.0	February	11.4
Wajir	10.4	May	13.6	February	11.5
Nairobi Dag.	9.8	May	14.4	February	11.5
Nairobi Eastl.	9.6	May	14.5	February	11.6
Magadi	9.9	May	13.5	February	11.7
Garissa	11.0	Dec.	13.2	February	11.7
Kiambu	9.3	June	14.6	February	11.8
Ruiru	10.0	May	15.1	February	11.9
Nairobi Wilson	10.1	May	14.4	February	12.0
Marienne	10.8	July	14.0	February	12.1
Makindu	11.0	April	13.6	September	12.1
Kinangop	10.4	April	16.4	February	12.3
Mwea	10.0	July	16.1	February	12.3
Kitui	10.1	April	13.9	January	12.3
Machakos	11.1	April	15.2	February	12.9
Nairobi Airport	11.1	May	15.3	February	13.0
Isiolo	12.1	May	16.0	February	13.4
Average north & east	10.0		14.0		11.5

ANNEX III A

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 centigrade (°C).

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 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

ANNEX III B

TEMPERATURE CONDITIONS FOR RICE

The general guideline in Kenya with regard to altitude is that rice should be grown below 1500 m (Acland 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 Ten Have (pers. comm.) minimum temperatures should not fall below 7°C. In the IRRI publication "Climate and Rice" (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 productivity decreases sharply when the average temperature drops below approximately 20°C. In all the cases reported on, the average seasonal temperatures were above 20°C, though average temperatures at the beginning and end of the season were as low as 15°C. Low night temperatures did not appear to be harmful as long as they were compensated by high day temperatures. Whether this is also the case at tropical latitudes, is not clear. It seems important, however, to keep in mind that at high latitudes the daily period of insolation (and high temperature) is much longer than at the equator.

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 was of the order of 1200 kg/ha; for 27 seasons with an average temperature above 19°C the average yield was 3600 kg/ha. The average temperature in this July - August period was 19.7°C.

In Annex III A 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 minimum, annual average, absolute minimum, 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 in Annex III A).