RESEARCH

5(17), January - March, 2019

ISSN 2394–8558
EISSN 2394–8566

Climate Change

Scheduling planting dates to manage drought in the northern lake basin, Kenya: An assessment of annual crop performance during drought in northern lake basin, Kenya

Joab Onyango Wamari

It is generally observed that drought affects various stages of all the crops growth cycles and it was also more advantageous to plant early in the south west and north east rainfall regions but a month later after rainfall onset in the south east rainfall region since the off season rains seem to favour late planting in the last region. Drought stress in the early planted crops in the south east frequently occurs in March interfering with the establishment stages but also the peak phases of some crops as well. Later planting foregoes these drought stress problems with relatively few if any stress problems occurring. In the north east drought may affect the peak and sometimes pre and post peak phases of late planted crops although cassava and potatoes are virtually unaffected by any drought stress in this rainfall region. Late planted long maturing crop varieties perform better than short maturing crops. In the southwest, drought stress is worse in the latter planted crops as compared with early planted ones although both plantings may suffer drought stress from the pre peak phase all the way to the end of the season. Cassava and potatoes have better chances of survival in this rainfall region than any of the other seven crops investigated. These inherent establishment phase stress intensities may however be avoided by planting later in the season. In the south west more crops would suffer intense drought stress of the order of some 40 mm of rainfall deficiency from the pre-peak to post-peak phases. It is recommended that, upland rice (i.e. rice that do not require flooding conditions) can by no means be grown particularly at KadengeYala swamp and Bunyala 's second season where otherwise higher water supplements would be required especially in the peak phases of the crop, plant crops in later in April rather than March in the southeast, plant early in March and apply irrigation schedule particularly in the crop establishment phases, planting should be done as early as possible and it is even more advisable to plant dry about half a month before the onset of the rains especially in the south west, fast-track, and if present expanded low water consuming plants, normally associated with C4 carbon pathway, use root crops such as cassava and potatoes should be enhanced in addition to the usual crops especially in the drier south west rainfall region and initiate irrigation programs to absorb the largely unemployed youthful labor force especially in the south western rainfall region.

INTRODUCTION

Agriculture in Kenya is and will for some time remain the backbone of the economy and in general offers employment including informal to the majority, produces food and provides surpluses for export and local industry (Heyer et al, 1976; Sunday Nation, 2nd June 1985). Up to 90% of the population living in rural Kenya depends on it while a further 5% may be directly engaged in processing, storage and distribution of associated agricultural products hence ranking significantly as a contributor to the Gross Domestic Product and has previously given higher returns than manufacturing and retail categories combined (Heyer et al, 1976). Up to about 7,000 hectares is assigned to commercial production whereby cash crops such as sugarcane, cotton, tea, coffee, wheat, sunflower, rice and sometimes maize is produced with the rest assigned to subsistence production. However agricultural production has been lately at crossroads due to drought related reduction and unprecedented large food imports in 1971-1981 period causing policy makers to be acutely aware of imbalance between food supply and demand arising from rapid population especially in high potential areas (Economic Review, 1983). Further, agricultural land availability in NLB which is less than ½ an acre per person (except around Busia) is poor, pathetic and continuously declining especially around Kakamega due to the high population growth rates with the danger of outstripping rational food production. The WMO (1975) agrees that the weather and climate are important especially their relevance to water-soil-crop relationships but these represent human response to space and time through a wide range of physical factors coupled with those of socio-economic nature. Water is however essential for photosynthesis and a decline of this deduces stress affecting this essential process by severing transpiration (Rosenberg, 1961). Although the needs and tolerances of various cultivars differ and depend on adequate supplies of light (solar radiation), heat (temperatures), wind and water use are collectively required for crop production, the impacts of drought can be better

National Agricultural Research Laboratories, Kenya Agricultural and Livestock Research Organisation, Kenya

understood by investigating plant water relationships and essentially implies water/rainfall variations and its effects on crop performance (Brown and Cocheme, 1969; Otengi, 1982; Mwingira, 1980; Vitkevitch, 1960, Nieuwolt, 1973b). Changing planting dates have been applied for management of crop production in various parts of the world.

This study involves an initial division of agricultural into its components of livestock and crop production and considering only the latter in some detail. It is approached by a determination of the nature of rainfall seasonality in the NLB which forms a background used to classify regions justifiable on the basis of the synoptic circulation patterns. Estimation is then made of critical water requirements of nine annual crops (per availability of information). The results are used together with the drought aspects to attempt an assessment of drought effects at two planting date alternatives on general growth stages of these crops at the variously determined rainfall regions. Further recommendations are given to farmers of when to grow the various crops in the different areas.

The outlines of the objectives are summarized as:-

1. Assess the suitability of utilizing early and late planting dates by area from analysis of expected frequencies and intensities of crop stress as induced by drought over the years
2. Recommend by identifying some crops which crops may be grown without much risk of drought stress and corresponding areas and planting dates for growing them.

MATERIALS AND METHODS

Area of Study

Figure 1 Position of NLB (Western Kenya)

Nature and availability of data

The agricultural and climatic data used was based on available monthly rainfall information from the Kenya Meteorological Department in Nairobi. The assessment relied on the use of water balance equation which outlines the outflow of water into the atmosphere whereas monthly climatic data of radiation, temperature, wind-run and where applicable hours of sunshine were assumed in the calculation of the potential evaporation index as advocated in the Penman (1949). The agricultural data collected from literature and the Ministry of Agriculture and various libraries including the University of Nairobias was available for the study area and was related to crop performance.

Table 1 shows the 22 rainfall stations used in this analysis with diverse variation in data availability. The longest record period is of 47 years running from 1938 at Kisumu Airport Meteorological Station. Ten of these stations belong to a 1931-1960 data period and four of these have discontinuity of one form or another while the rest (12) of the stations including Kisumu airport belong to the synoptic and agricultural category (E.A.M.D., 1966). Their data run into recent periods (i.e. 1983-1984) and was available during the field work session in 1986. Nzoia meteorological station had the shortest (i.e. 8 years) while Busia station was slightly shifted with apparent loss of records. Ngirimoru Koru and Mumias Sugar Research stations data were discontinuous for unknown reasons and these inconsistencies are tabulated in table 2. Monthly values has been considered more appropriate than the annual values since the latter do not show periods in the season when the rains fell (Apeldon, 1978). In Kisumu for example, although the first season is high (i.e. 27 inches), optimal crop water requirements are unlikely to be met in 4 out of 10 years during the second season because the chances of satisfying these requirements are quite remote (Manning, 1956).

Agricultural data was located in various centers sometimes considerable distances from each other making both appointments and schedules less productive in terms of disappointments and time consuming exercises. Although the climatic data was at one centre of the Kenya Meteorological Department, Dagoretti corner, they were kept in various and volumes requiring a cumbersome and time consuming process to retrieve and compile. Further only nine stations had adequate climatic data essential for calculating the Penman evaporation hence the limited spatial coverage since the more rainfall stations that were available had to be discarded or not used especially for the crop analyses due to this limitation.

Rainfall deficiency including its variability in predominantly agriculture-based East Africa has been identified as the main and direct cause upsetting the environment on which human communities depend (Sansom, 1965; Nieuwolt, 1978; Muriithi, 1979; Kenworthy and Glover, 1958; Gillman, 1938; Ogallo, 1981, 1982; Okoola, 1978; Alusa and Gwyne, 1978; Alusa, 1978; Manning, 1956b). Nieuwolt (1974a; 1974b) has used seasonal concentration index of 8% of annual rainfall as appropriate for agricultural production and defines a drought month in East Africa as that during which the actual rainfall is less than 50% of the long term mean alongside any month with less than 100 mm of rain. The water demands has previously been expressed as ratios of potential evaporation to potential evapo-transpiration (Et/Eo) and obtained for various stations in East Africa (Sansom, 1954; Woodhead, 1968; Woodhead and Waweru, 1969; Rijks, 1968; Nyenzi, 1980; Obasi and Kiangi, 1973, 1977; Pereira, 1959a, Blackie, 1965; Dagg and Blackie, 1965, 1970; Pereira and McCulloch, 1962). It has been considered necessary to use the Penman method in this study since it is widely used and is generally acceptable and convenient (Koslowsky, 1968; WMO, 1966; Monteith, 1965; McCulloch, 1965). The Penman method as modified by McCulloch (1965) for altitude is used in this analysis because:

1. It has widely been used without much controversy (Dorenbos and Pruitt, 1977; Monteith, 1965; Wallen, 1967).
2. Its formulation includes logical considerations of physical physiological aspects of crop growth
3. It avoids errors involved in measurements of physical and physiological aspects whose relative significance in the evapo-transpiration are not only assumed but are indeed difficult to measure accurately.

Table 1 Location of rainfall stations used in analysis

Number	Station	Registration number	Altitude	Location	Data period	Remarks
1	Ahero Kano irrigation scheme	9034086	1219	0º 08’ S, 34º 56’ E	1962-85	
2	Bukura farm, Kakamega	8934002	1463	0º13’ N, 34º 37’ E	1971-84	
3	Bunyala irrigation scheme	8934139	1145	0º 7’ N, 34º 04’ E	1931-60	
4	Busia cotton research Station	8934139	1220	0º29’ N, 34º 08’ E	1957-84	1971 missing, 1976, 1981 incomplete 1980 estimated position changed in 1974
5	Chemilil sugar company	9035274	1269	0º 04’ S, 35º 08’ E	1971-84	
6	KadengeYala swamp	8934140	1168	0º 8’ S, 34º 56’ E	1971-83	
7	Kakamega district Commissioner’s office	8934001	1515	0º 2’ N, 34º 11’ E	1931-60	
8	Kibos cotton Research Station	9034081	1173	0º17’ N, 34º 45’ E	1952-84	
9	Kibos sugar research Station	9034105	1214	0º 04’ S, 34º 48’ E	1952-83	
10	Kisumu Airport Meteorological station	9034025	1149	0º 02’ S, 34º 49’ E	1938-84	
11	Kisumu Town	9034004	1146	0º 06’ S, 34º 45’ E	1931-60	
12	Koru Coffee research station	9035230	1560	0º 06’ S, 34º 45’ E		
13	Ngirimori, Koru Estate	90351017	1616	0º 35’ S, 35º 17’ E	1931-60	
14	Lugari limited	-	1616	0º 08’ S, 35º 17’ E	1931-60	
15	MiwaniMillls	9034008	1207	0º 03’ S, 34º 57’ E	1931-60	
16	Miwani station	9035032	1220	0º 05’ S, 34º 59’ E	1931-60	
17	Miwani quarters	9034009	1372	0º 03’ S, 34º 57’ E	1931-60	
18	Muhoroni station	9035016	1300	0º 09’ S, 35º 12’ E	1931-60	
19	Mumias St. Marys	8934013	1340	0º19’ N, 34º 30’ E	1931-60	1936, 1939, 1942, and 1953 data incomplete
20	Mumias sugar company	8934133	1302	0º 22’ N 34º 30’ E	1971-84	
21	Nzoia Meteorological station	8934138	1840	0º45’ N, 34º 56’ E	1976-84	
22	West Kano irrigation scheme	9034133	1137	0º 12’ S, 34º 50’ E	1975-84	

Table 2 Nzoia meteorological station rainfall data showing rainy months (i.e. underlined)*

Year	1977	1978	1979	1980	1981	1982	1983	1984	No. of rainy months
J	95.9	34.6	93.3	39.5	21.9	22.7	0.0	60.9	0
F	86.4	76.4	236.6	24.4	64.3	25.3	56.2	16.6	1
M	113.3	126.9	169.1	83.1	289.3	64.5	154.5	65.1	1
A	470.9	517.8	164.6	176.0	376.1	204.1	287.9	190.9	8
M	398.3	339.4	197.4	246.8	269.6	231.6	162.3	127.5	8
J	155.8	153.8	159.2	115.8	116.7	101.9	148.4	87.8	3
J	110.1	110.1	68.7	57.0	451.6	144.8	127.0	138.6	3
A	174.6	174.7	132.0	181.9	276.0	230.0	218.0	120.1	7
S	83.2	83.3	104.4	87.1	273.9	109.0	190.3	36.7	2
O	98.9	100.9	53.2	88.8	61.8	140.4	139.1	64.4	1
N	159.3	120.6	181.5	106.4	270.5	335.3	212.1	167.0	5
D	113.3	95.3	193.4	76.2	66.4	36.4	87.9	84.8	1
Total	2059.7	1933.8	1753.0	1283.0	2538.1	1646.6	1784.5	1160.4	40

*Note the data length limitation earlier mentioned

Table 3 Some environmental requirements of crops used in analysis (Source: Acland, 1972)

Crop	Altitude range (m)	Annual water needs (mm)	Temperature/wind and frost tolerance	Soil requirements	Remarks
Beans *(Phaseolus vulgaris)*	>2100			Requires free draining moist soils throughout growth	Rains at end of season undesirable especially for canning seeds
Bulrush millet *(Pennisetumtyphoidea)*	< 1200	500-625		Performs better under medium to light textured soils	Drought resistant/evading
Cassava *(Mannihot sp.)*	< 1500			Requires free draining soils (Not shallow or stony as this prevent tuber development)	Very drought resistant
Finger millet *(Eleusinecoracana)*	0-2400 but normally grown above 900 m	900		Requires fertile free draining soils	Tolerates dry spells in early stages of growth
Groundnuts *(Arachiahypogenea)*	< 1500			Requires moist fertile and light soils until harvesting	
Maize *(Zea mays)*	0-2500	1800	High night temperatures lead to high respiration rates and limits yields. < 10 ^{o}C, night temperatures and light frost kills crop.	Requires well drained soils with good nutrient supplies	Every 25 mm that falls before sowing leads to about 180 kg/ha yield loss. Optimum of 200 mm of rains required within 2 weeks of sowing
Rice *(Oryza sativa)*	< 1200	Between 910-1070 mm per hectare (e.g. at Mwea)	Sensitive to photoperiod and flowers when day length decreases	Sandy soils support good crop provided there is plenty o water	Varying requirements for paddy rice including soil permeability, length of growing season, rains in growing season, efficiency in water management
Sorghum *(Sorghum vulgare)*	900-1500			Require reasonably fertile soils but performs in exhausted soils	Drought resistant and requires 300-360 mm rains during growing period. Popular in Kano as can withstand short waterlogging periods
Sweet potatoes *(Ipomeabatatas)*	0-2100	750 or more		Performs well in wide range of soils (i.e. From swampy to eroded soils)	

4. The estimate do not vary much from year to year like rainfall so that it is possible to gauge effects of variation from the more variant rainfall aspect, say in drought and non- drought years (Pereira and McCulloch, 1960).

The index of course has its limitations including in East Africa where calculation of the radiation term is often estimated from cloud amounts and/or sunshine hours or otherwise (Woodhead, 1966, 1967; Glover and McCulloch, 1958, Pereira, 1959a). Also estimation of the index by use of a conversion factor from pan readings involves a host of complications ranging from the different pan types whose exposure are subject to interferences by animals which would lead to fallacious and hence incorrect estimates (Dagg, 1969a; Hutchinson and Farbrother, 1956). Further the assumption of constant evaporation is not always true as has been observed for example in cotton where the process begins promptly at 9.00 am but continues until 22.00 pm at night, indicating physiognomy affects either directly or indirectly the nature of water transfer (Lemon et al, 1960). From an agricultural point of view apart from the overall complexities of the plant-atmosphere-water systems, comparisons are at its best only a crude indication of the potential of an area (Stern. 1967). The ratio Et/Eo is considered constant and largely independent of location so values can be used in other parts of the tropical region without serious errors (Nieuwolt, 1978). Nieuwolt (1975) actually provide values that compare well except for sugarcane, although his data sources remain un-informative of how they were obtained (Nieuwolt, 1973b; Blackie, 1965; Woodhead, 1970b).

The use of soil moisture data obtained using the neutron probe on some four soil profiles per treatment were used to calculate estimates of monthly water use for nine crops namely bean, bulrush and finger millet, cassava, groundnut, maize, rice, sorghum and sweet potatoes were used to estimate Eo values for individual stations in the NLB assuming soil and cropping patterns are similar considered appropriate in the study (Wangati et al, 1969). As an example beans had the ratio (Et/Eo) of 0.75 during the first month.

$Et/Eo = 0.75$

Where Et is potential evapotranspiration as measured via the neutron probe (This can be done also using lysimeters (Glover and Forsgate, 1962).

Eo is the potential evaporation of open water as estimated by the Penman equation (See also appendix part 3).

For the NLB the 0.75 will remain unchanged but both Et and Eo will both be different. Values for the NLB were obtained by rearranging the equation so as to make Et the subject as follows.

Et = 0.75*Eo

The values of Eo were then calculated using the Penman formula with the climatic data obtained and substituted in the above equation.

The Eo values were of the main seasons were substituted in the main equation to obtain values for the NLB. As an example the calculated value for West Kano in March when the season begins is 109.6 mm. At Ahero Kano where the season begins in February values are multiplied by either 28 or 29 days depending on whether it is a leap year or not.

Being potential values (i.e. assuming sufficient water supplies) these cannot be directly used as critical and need to be converted to critical values in the light of the rainfall values. Attempts have often used the Eo item and expressed the estimates of crop water needs (e.g. sugarcane) to be 2/3 of Eo (Mungai, 1979; Kibe and Sogomo, 1979). Comparing the 2/3Eto estimate gives very low values of estimated water requirements (estimated Et) and is contradiction to observational evidence and survey analysis and suggest that no drought occurs for the nine crops under investigation. Brown et al (1969) argues for the Eo item exceeds Et by 20% due to higher radiative reflection of plant cover compared with water surface. This implies that

Eo = 1.20 Et

Hence Et = 5/6 * Eo

Thus 0.83 * Eo is the estimated water requirement.

This wouldn't hold throughout since instances in the plant cycle when Et is exceeded by Eo and so 0.83*Eo gives very low estimates of Et for NLB and suggests that rains are invariably sufficient for crop growth except very few months in the South west rainfall region. Recent investigations show that actual evapotranspiration vary between 0.4Eo at early crop stages and 0.8Eo at peak and hence averages 0.6Eo (Jaetzold and Schmidt, 1882). Use of Et would be more appropriately related to crops than Eo since even correlations between the two have been found to be negative since the patterns occur influenced by different physical/physiological conditions (Dagg et al, 1969; Brown et al, 1969). The more realistic ratio of Et that was attempted was 2/5Et (0.4Et) and seem to provide reasonable evaluation of crop stress limit and is in line with a well-remembered drought lasting from late 1979 and into the year 1980 affecting all crops especially maize in the SE NLB can be ascertained (Personal observation). Similarly years such as famine in 1975 were bad in the same area confirming a drought in 1974.

Two planting dates were used the second one given the second month of the rainy season and is supposed to indicate whether or not germination was poor and if this latter date would be more appropriate against a drought (Manning, 1960; Gray, 1970). One year with the least seasonal total was used in this investigation more or less along similar indicators previously carried out (Gibbs and Maher, 1967). The identified year represent the months of highest rainfall deficit over record period and represent the most intense drought years. Whenever the rainfall season was shorter than the period given in these calculations values at the peak were averaged and the result used in place in the first of the two peak months. At Chemelil for example the season is only 3 months long while the maize crop can grow for up to 6 months. The 3rd and 4th peak readings of Eo are averaged to obtain a value which is entered for analysis. It is assumed that when a season is short the crop should be able to complete its cycle within this period and therefore reaches its peak earlier than when the season is long and should probably have a lower peak water demand. This is repeated until the crop fits into the rainy season as indicated in chapter 5. Little emphasis is given for the end of growing cycle since the period does not alter the crop yields and if it does it would not be a direct influence of rainfall availability and in any case most crops require drier periods at this stage (Russel, 1960).

The growth cycles of the nine crops under investigation were divided into 4 phases namely establishment (i.e. from planting/sowing to before pre-peak), pre-peak (between establishment and peak phase), peak (when the water demands are highest) and post peak (the rest of the crop cycle). The post peak was only considered if there was at least two months of the peak phase of the crop and if only one month occurs after the peak, the period is assumed to be used for harvesting when rainfall does not play an absolute role in influencing yields. Certain crops do not show a marked peak period so that stress becomes difficult to classify into the four phases as described above. At Busia for example the groundnut crop in the 1974-1975 seasons with the stress situation in November is referred to as the post peak phase while the December situation is not investigated despite being of higher water demand and is considered a period for harvesting. The NLB was classified into three rainfall regions namely; those stations whose main season begin in March (one case in February), those station whose main season begin in April and those whose season begins between July and September.

RESULTS AND DISCUSSION

The South East region

Only 11 of the 22 stations had adequate data for these computations while estimates had to be made for both Bunyala (station 2) and Nzoia (station 10). March rainfall appears to be inadequate for establishment of most crops with the drought in this month represented by the year 1973 although other years show similar deficiency period. This is noted in west Kano and Kisumu in 1993 and at Ahero in 1984. The Aherokano situation is apparently serious as two consecutive months of deficiency are possible. March is a notoriously rainfall deficient month with its worst effects seen at Kibos Cotton Research Station and Ahero Kano where only 1.2 mm and 4.1 mm of rain fell in March 1973. None of the nine crops could establish unless irrigation is used meaning most subsistence farmers had to re-plant later in April. The other stress month is May though this is relatively more reliable than March and since this coincides with the peak crop requirement period they experienced stress in West Kano in 1973 and 1979, Chemilil and Aherokano in 1984 and Kisumu Airport in 1982. Analyses of specific effects of individual crops now follow (Table 3).

Maize and Sorghum

Early planted maize could not establish at Kisumu, Ahero in 1984 (figures 2a), Chemelil in 1973 and 1984, Kibos and Bunyala in 1973 (fig 3a), wet Kano and Bunyala in 1973 (fig 4a) because of the sometimes grossly inadequate March rains. The crop experienced drought in the peak period in 1984 at Chemilil and pre peak at west Kano in 1983. Although this crop established well at West kano in 1979, Kisumu airport in 1982 and Kibos sugar in 1969, it still suffered stress in the second month at Kibos, the third month at west Kano and the peak phase at Kisumu Airport so reducing expected yields in these areas.Since majority do not irrigate it is assumed a second planting was carried out in the area when the unreliable march rains were replaced by the April rains meaning good establishment of the maize crop in this second attempt. The latter phases were however affected by inadequate rains at Kibos in 1973 and Kisumu airport in 1984 and the pre-peak period, at West kano in 1979 both stresses probably reducing yields. Similar results were obtained for sorghum at the same stations and years. Under supplemented moisture stress still occurred during peak requirements at Chemilil in 1984 and pre-peak at west kano in 1983.Considering the two planting dates poor yields were obtained extensively in his region as indicated in 1973 at Kisumu in the earlier planting while better yields were realized at Chemelil for planting later in this particular year and therefore the effects of drought could have been minimized by planting one month later.

Beans and pigeon peas

At Kisumu the bean was the only crop that seems to have survived in the 1984 drought, although this could be the usual physiological response attributed to continuous rapid canopy development and ground coverage observed under irrigation (Wangati et al, 1970).Generally however, the early planted crop met with widespread failure at establishment at Bunyala (fig 3b), Kibos in 1973, Ahero Kano in 1984 (fig 2b) and Kisumu in 1982 and 1984. At west Kano drought affected not only the establishment of the bean crop in 1983 but also the peak phase as well in 1983 and in 1979.The peak phases were also affected at Chemilil in 1984 and Kisumu while a slight stress was also encountered in 1969 at Kibos in the second month of the growth cycle. The later planted crop also failed to establish at Ahero Kano in 1984 (fig 3b) rendering the year a relatively bad one for the bean crop in this year at the station. The 2nd planted crop also suffered stress at Kibos in 1973, at West Kano, pre-peak at Chemelil in 1984 and at the peak phase at Kisumu in 1984. drought stress has actually been noted to reduce plant heights, shoot dry weight, leaf expansion and if extended in the vegetative phase reduction of node numbers which is essentially potential leaf/flower bearing zones of the plant and pods per plant while in pigeon peas drought favors dry matter in roots as opposed to pods (El Nadi, 1969; Nyabuni, 1980).

The millets

Both bulrush and finger millets could not establish at Kisumu in 1984, Kibos in 1973, Chemilil in 1973 and 1984 and West Kano in 1983. If under supplemented water, the early planted crop was still affected by stress in the peak phase at Chemelil in 1984 and West Kano in 1983, otherwise performing well at Kibos and Kisumu. At Ahero Kano irrigation needed to be administered for two consecutive months at the beginning of the season (fig 2c). Later planted finger millet also suffered drought stress a month after planting at West Kano in 1979 although this did not affect bulrush millet. The later crop therefore by virtue of lower water demand should preferably be grown instead of other grains as a supplementary food source at Ahero Kano. Performances of the millets in the latter planting schedules were more successful than was realized in the earlier attempt.

Cassava and Sweet potatoes

These two crops usually maintain low water requirements throughout their growing life cycle, however planting early were still checked by drought at Ahero (fig 2c) Kisumu in 1984. If this early stage was supplied with irrigation water, there would be no longer any drought experienced in the latter phases. The latter planted crops were widely successful and performed very well in the latter phases as well, suffering very minimal and perhaps insignificant stress at Kibos in the last two months of their life cycle. These two crops can therefore be extensively in this region to supplement food resources in case of devastation by drought on other crops but planting should be carried preferably in April rather than March.

Rice

Rice (upland) is generally grown under irrigation and so it is clear why this crop could not perform well at either Aherokano or West Kano where it is usually grown. Should there be need to consider upland rice (i.e. rain-fed) Ahero Kano should be preferable as the rainfall regime at West Kano was grossly inadequate in the selected drought years. Even at West Kano however, irrigation would be required in March, May and June in drought years. At Ahero Kano, a more continuous irrigation would be necessary otherwise the crop may suffer from defoliation and increase grain weight per plant (Fukoshima, 1985).

The North East rainfall region

This has been represented by the Mumias Sugar company station but consideration is also given of one long season that runs from April to September but with a relatively drier month in July. Crops in a possible second season would be expected to behave in a similar manner as discussed in the previous section. For example, see Figure 5.

Maize, beans and sorghum

These crops performed better than in the SE region as observed at Mumias during the droughts of 1978 and 1972 but if planted early (i.e. April) this stress would be altogether avoided. At Nzoia slight stress occurred for the early planted maize and bean crops in July of 1979 while the latter planted crops performed successfully in their growth life cycles. In 1984, the situation is reversed, the early planted crop suffering no stress problems while the latter planted crop experiencing slight stress in September. Except for the slight stress in 1979, sorghum was not affected by any of the droughts at Nzoia. If the long growing season is utilized at Mumias, the early planted crop may have suffered stress in July and in the latter planting, the pre-peak and peak phases. Arguing that peak water demands are critical for proper yields it could have been safe to recommend later planting of these crops in the region in drought years such as 1978. In 1972 there was apparently no drought effect on any of the crops regardless of when they were planted and it has been reported for example that about 200 mm of optimal rains are required for maize at five weeks after sowing (Acland, 1970).

However, in the NE region generally there is a higher probability that the early planted crops will be successful than the later planted, but if the long maturing crops are preferred then they should give better returns when planted early. Planting early enables the peak requirement phases to be effectively shifted from the drier July as observed at Mumias and Nzoia into a more reliable rainfall month of August. Yields would further be realized with both planting dates in good years (e.g. 1972) at Mumias when the July rains are in actual sense adequate.

The South West rainfall region

This is a region depicting high drought incidences in the main season since the rains basically in the July-November period when the air circulation is not very effective. The rains are not only poorly distributed (e.g. in Busia) but also deficient in amounts.

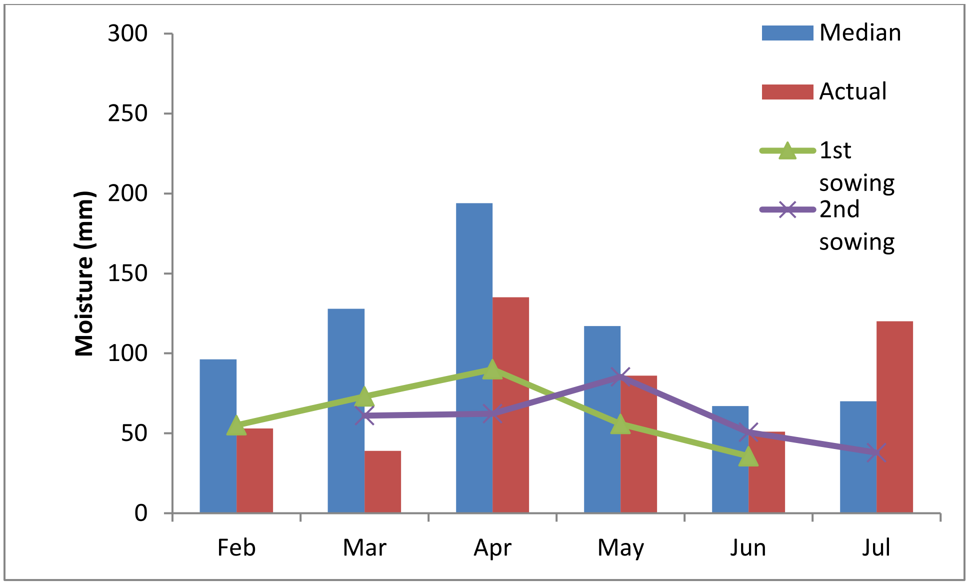

Figure 2a Water use at of beans at Ahero in 1976

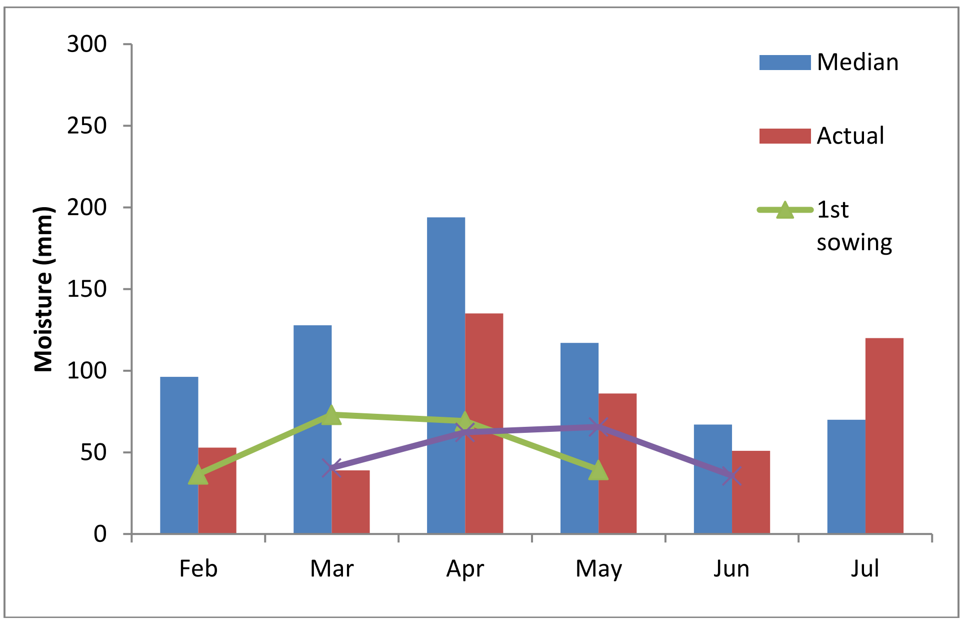

Figure 2b Water use at of bulrush millet at Ahero in 1976

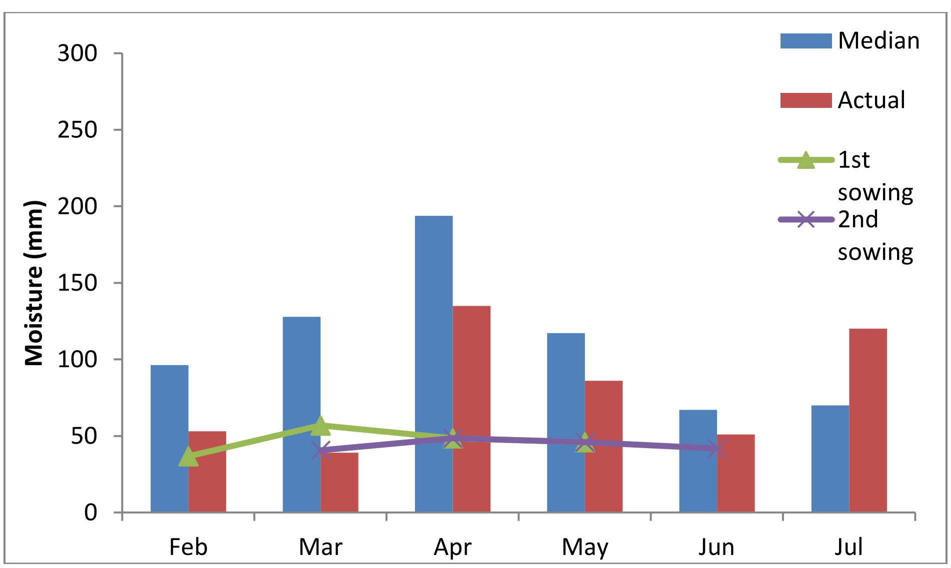

Figure 2c Water use at of cassava/potatoes at Ahero in 1976

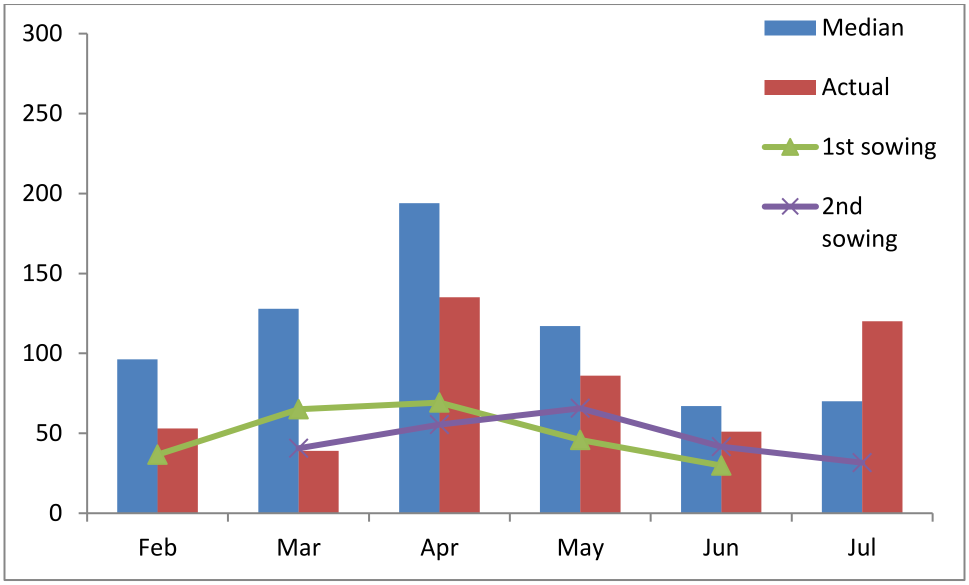

Figure 2d Water use at of finger millet at Ahero in 1976.

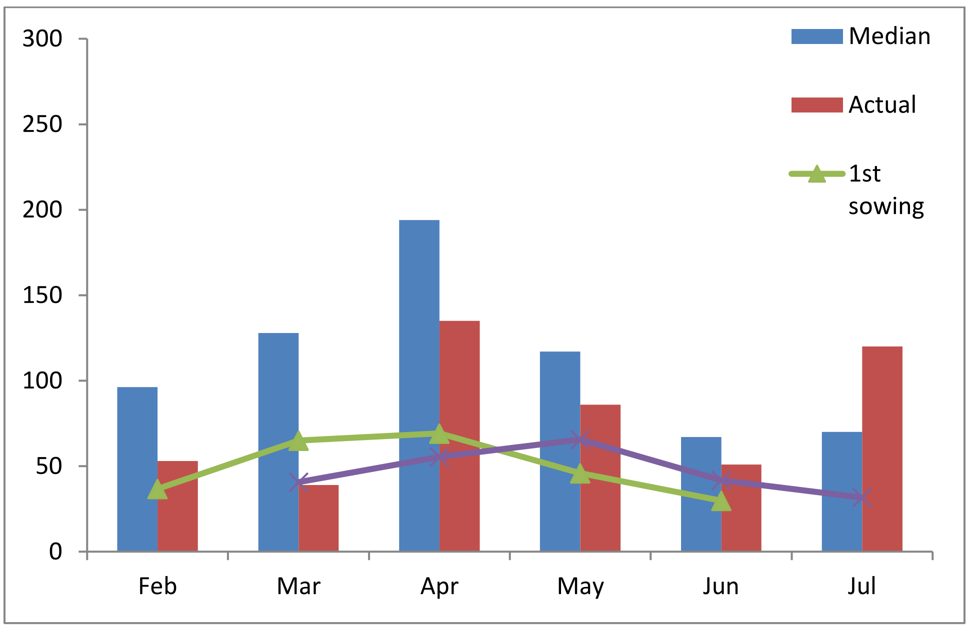

Figure 2e Water use at of groundnuts at Ahero in 1976.

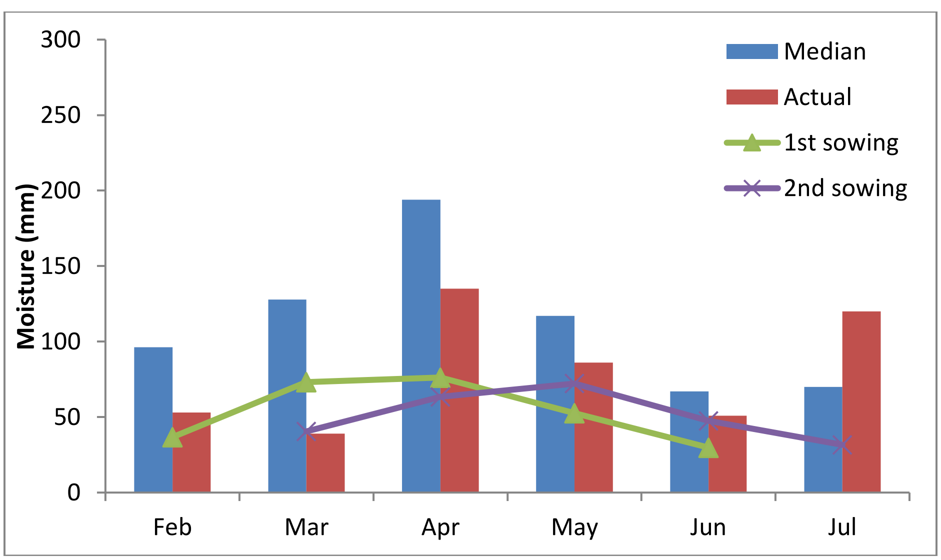

Figure 2f Water use at of maize at Ahero in 1976.

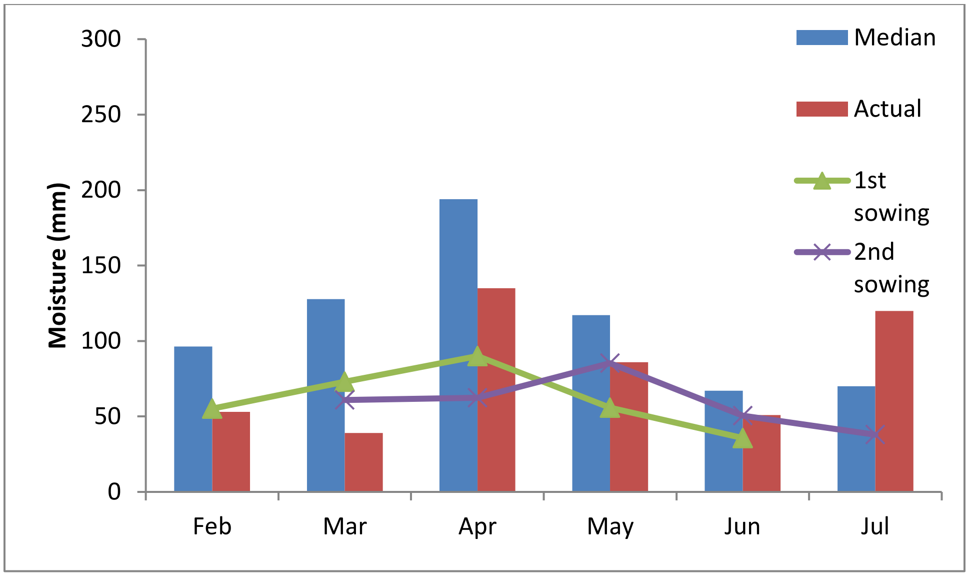

Figure 2g Water use at of rice at Ahero in 1976.

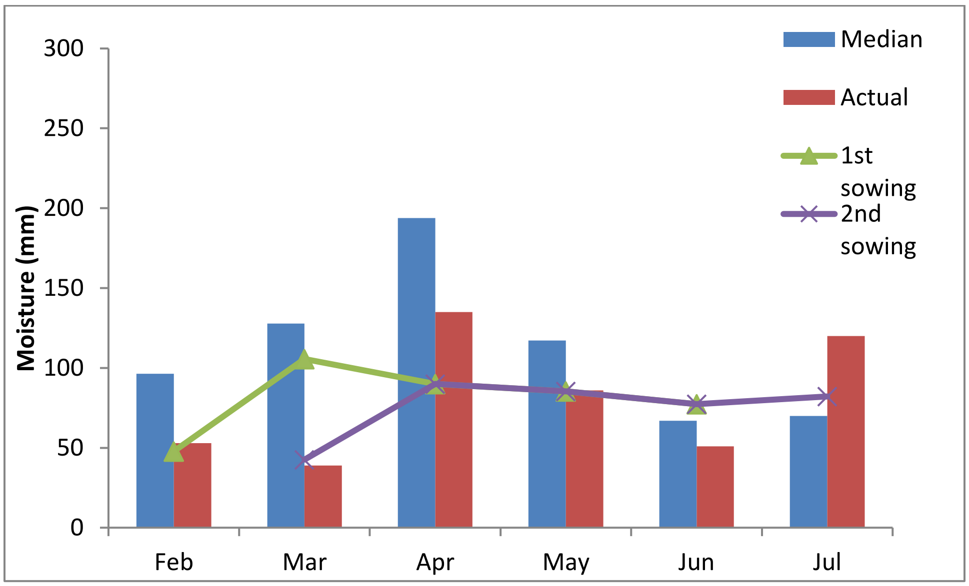

Figure 2h Water use at of sorghum at Ahero in 1976

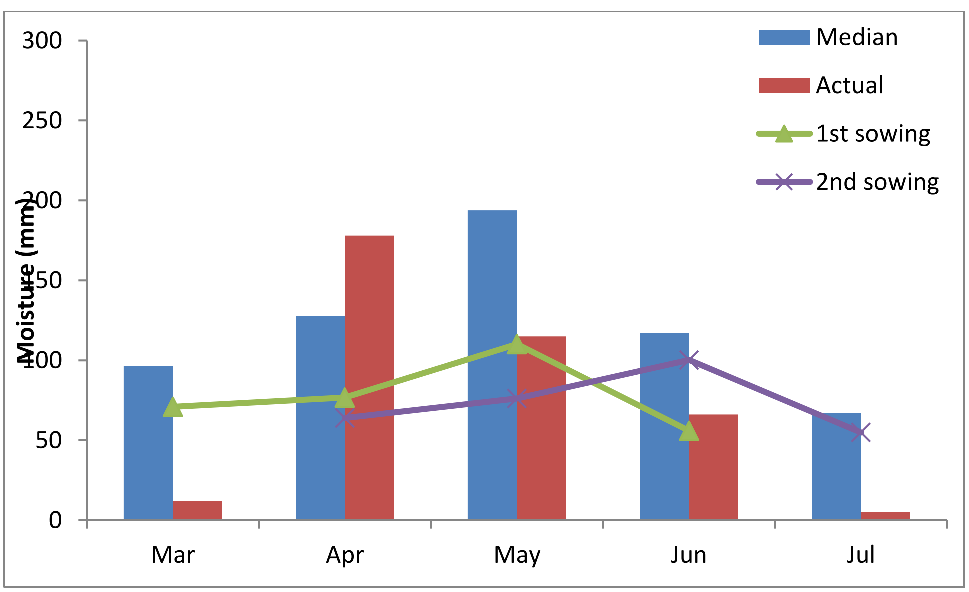

Figure 3a Water use at of beans at Bunyala in 1973

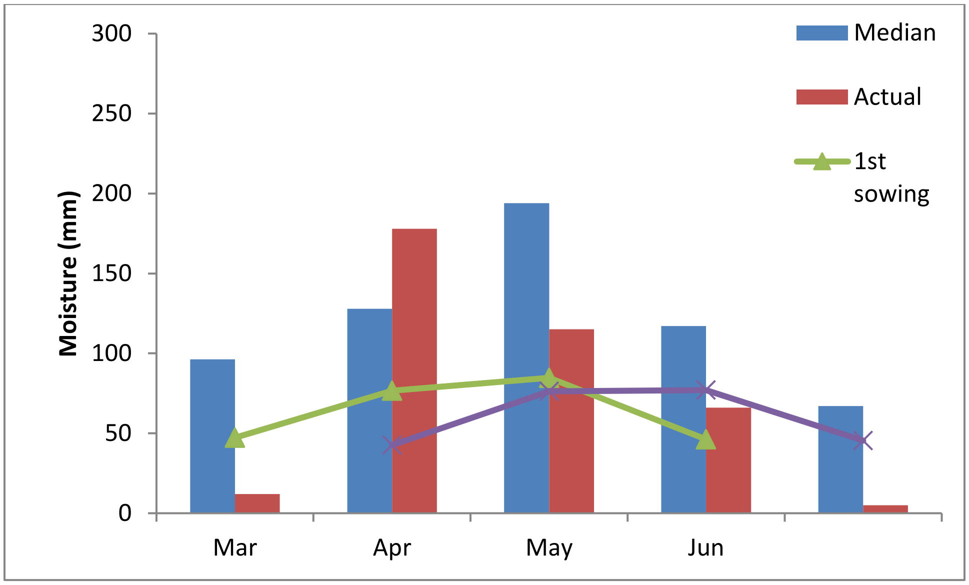

Figure 3b Water use of bulrush millet at Bunyala in 1973

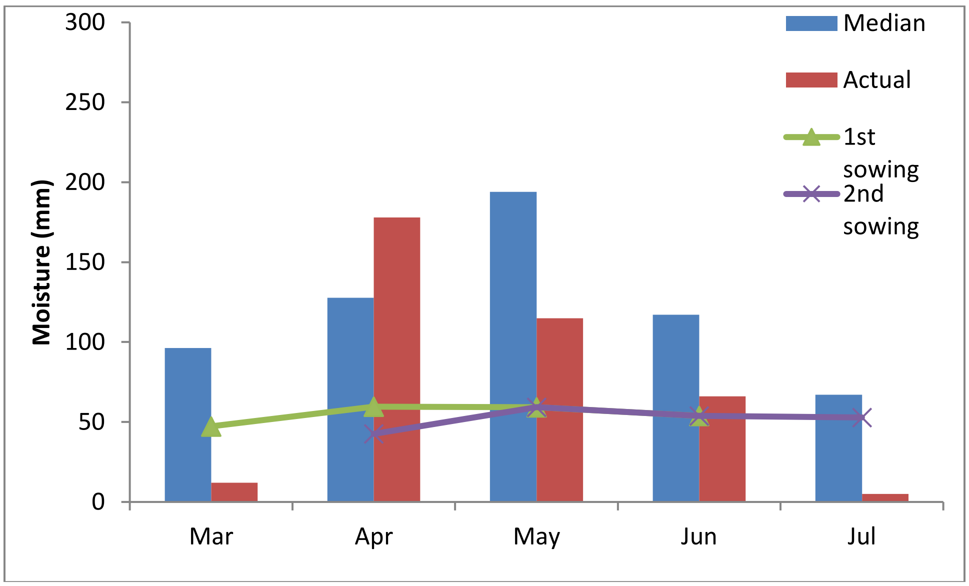

Figure 3c Water use of cassava/potato at Bunyala in 1973

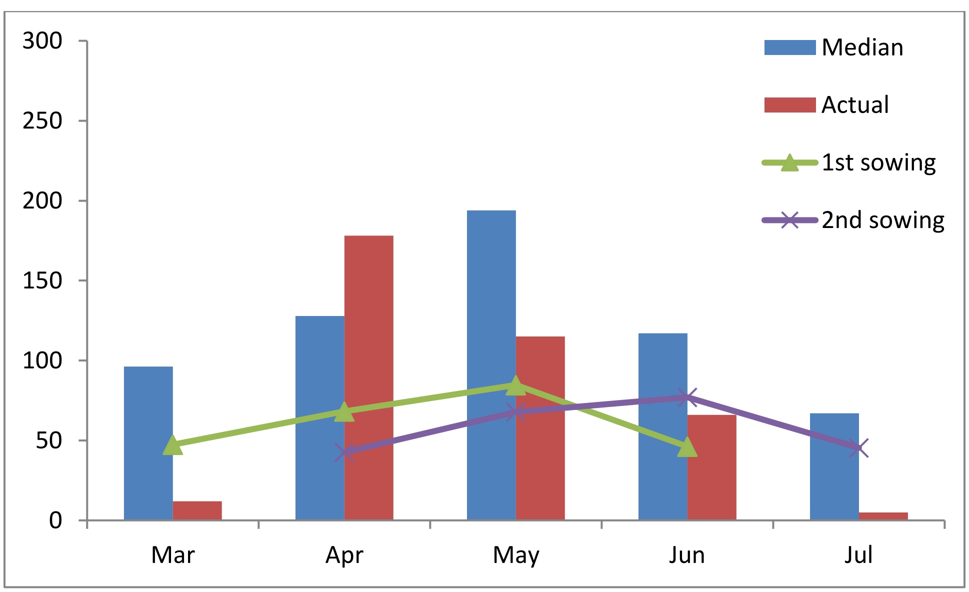

Figure 3d Water use of finger millet at Bunyala in 1973

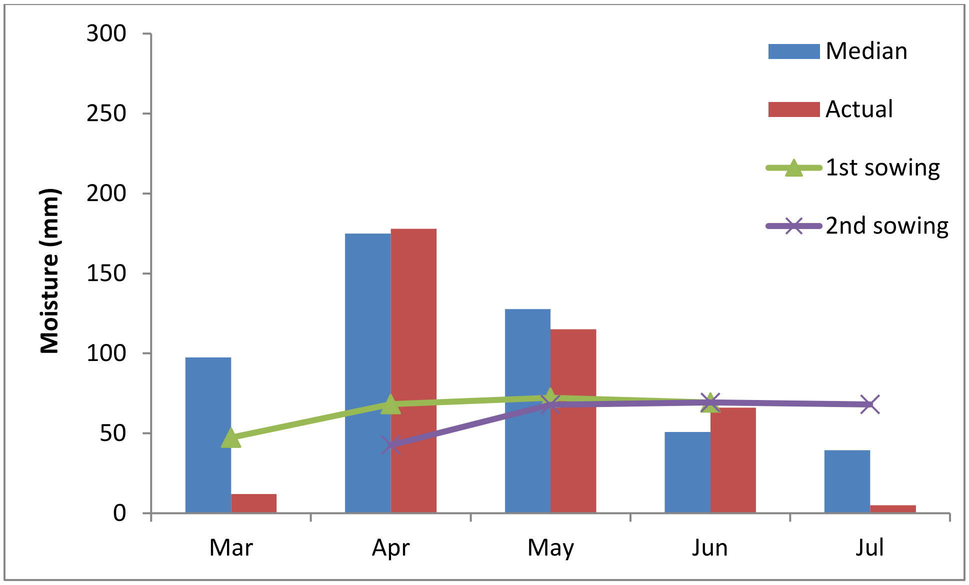

Figure 3e Water use of groundnuts at Bunyala in 1973

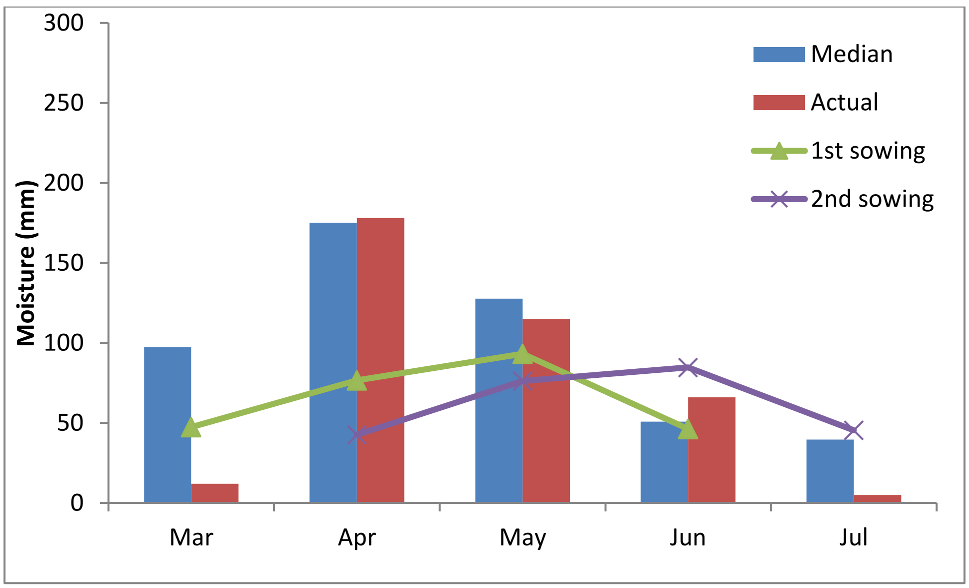

Figure 3f Water use of maize at Bunyala in 1973

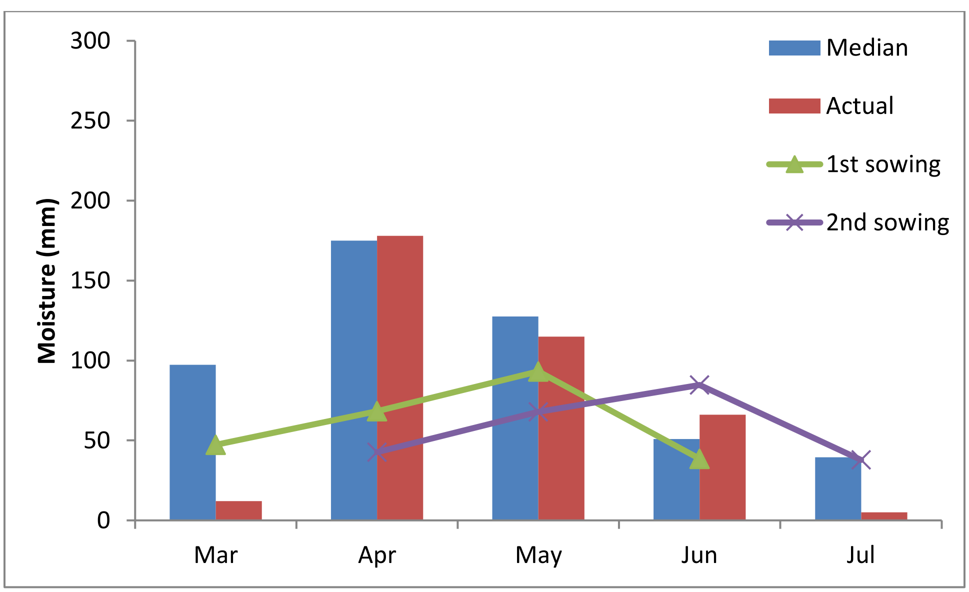

Figure 3g Water use of sorghum at Bunyala in 1973

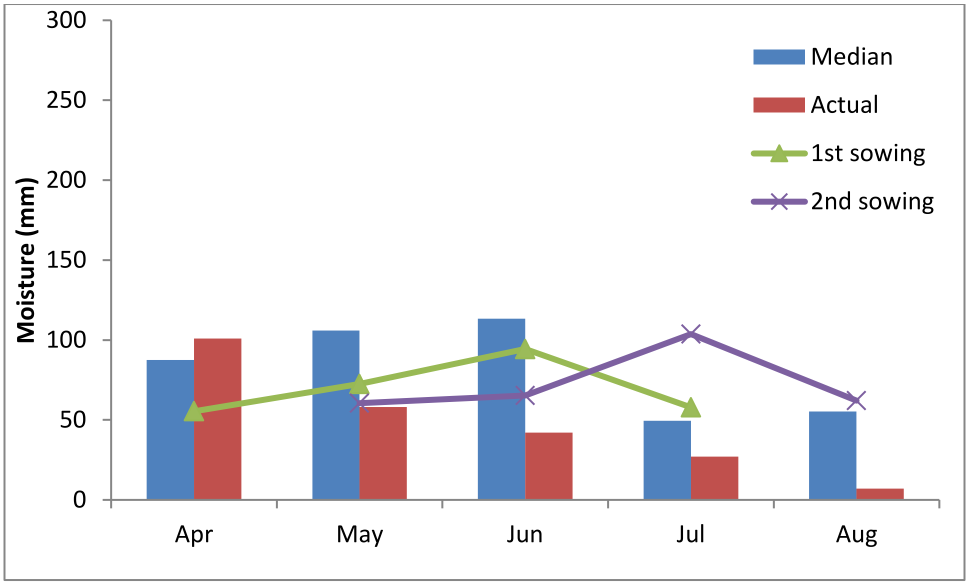

Figure 4a Water use of beans at Kadenge in 1974/75

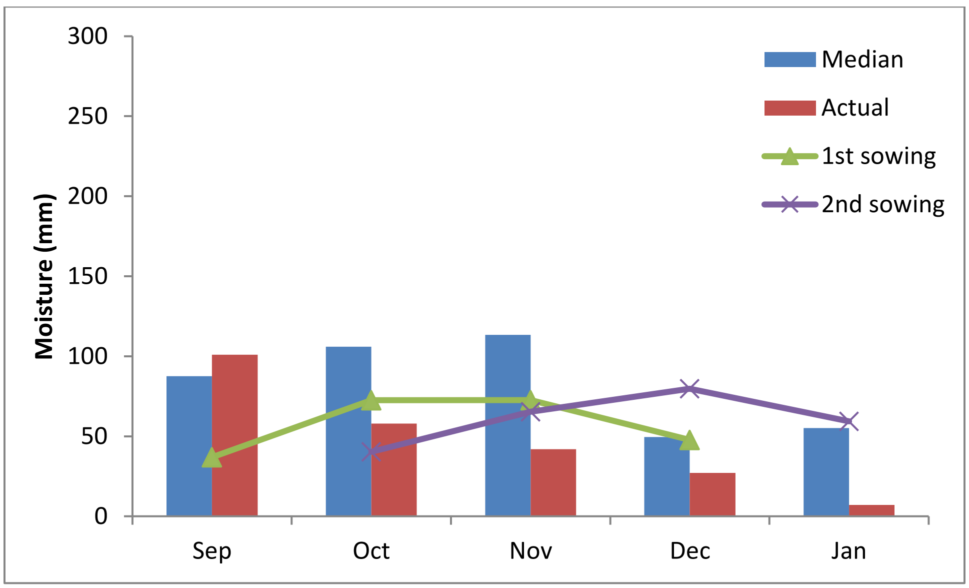

Figure 4b Water use of bulrush millet at Kadenge in 1974/75

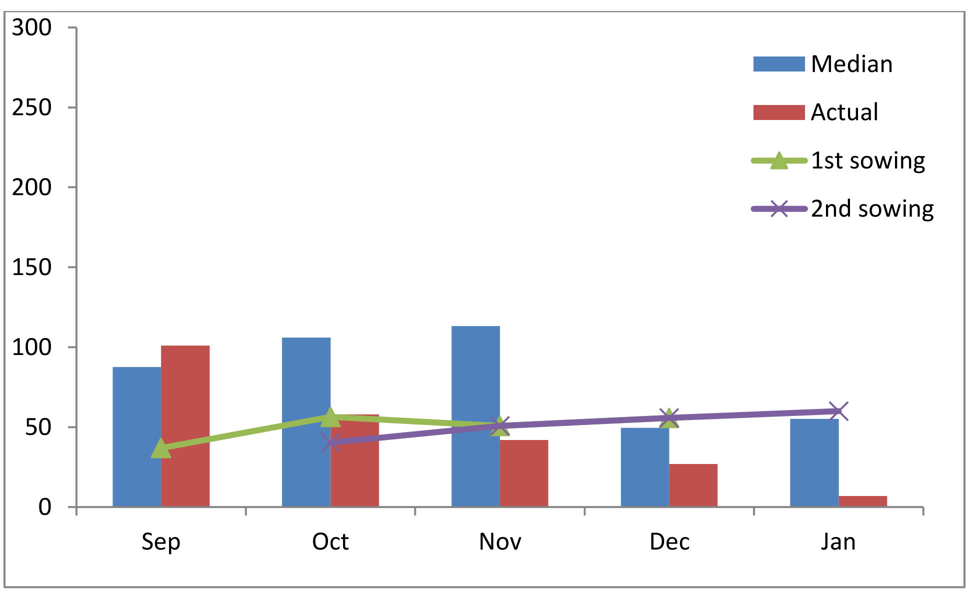

Figure 4c Water use of cassava/potato at Kadenge in 1974/75

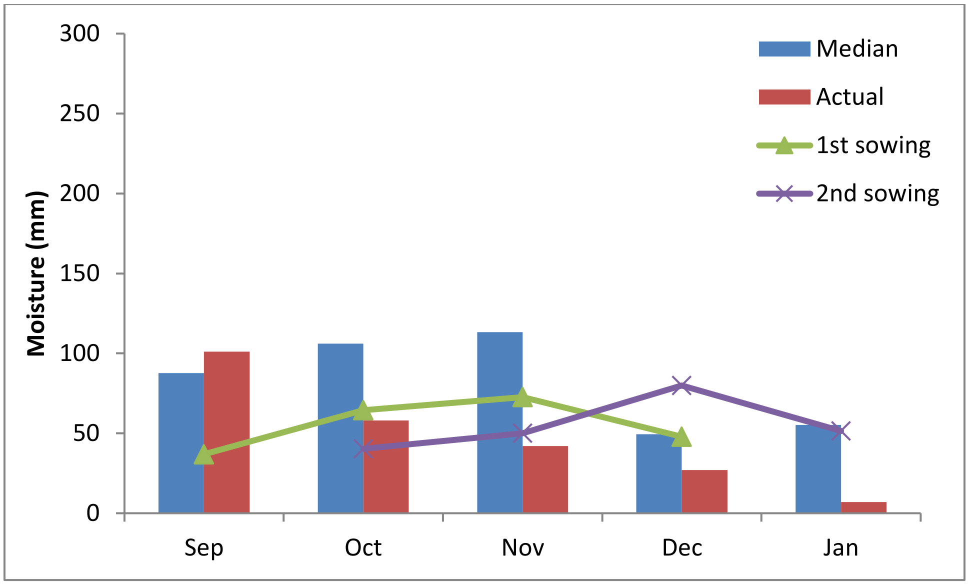

Figure 4d Water use of finger millet at Kadenge in 1974/75

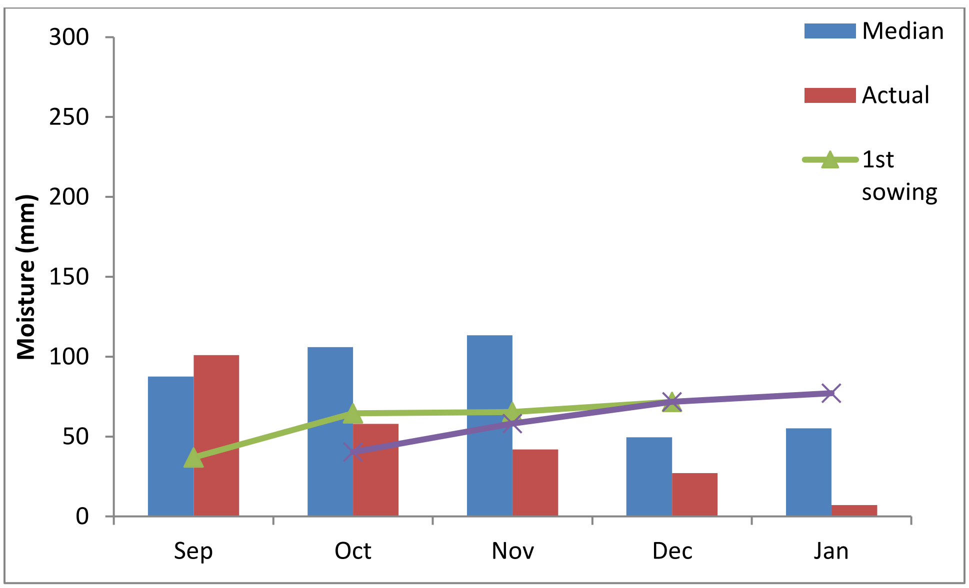

Figure 4e Water use of groundnuts at Kadenge in 1974/75

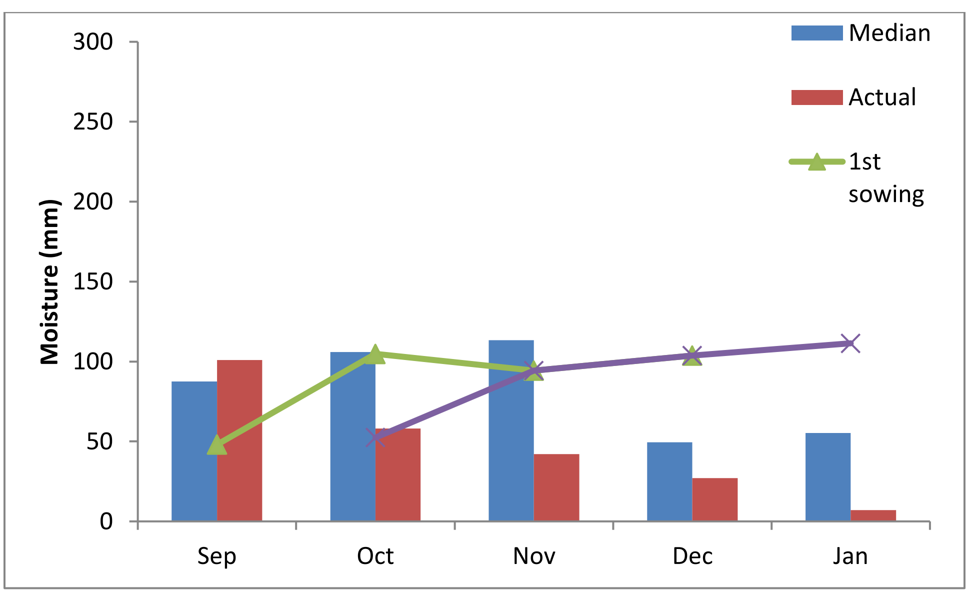

Figure 4f Water use of maize at Kadenge in 1974/75

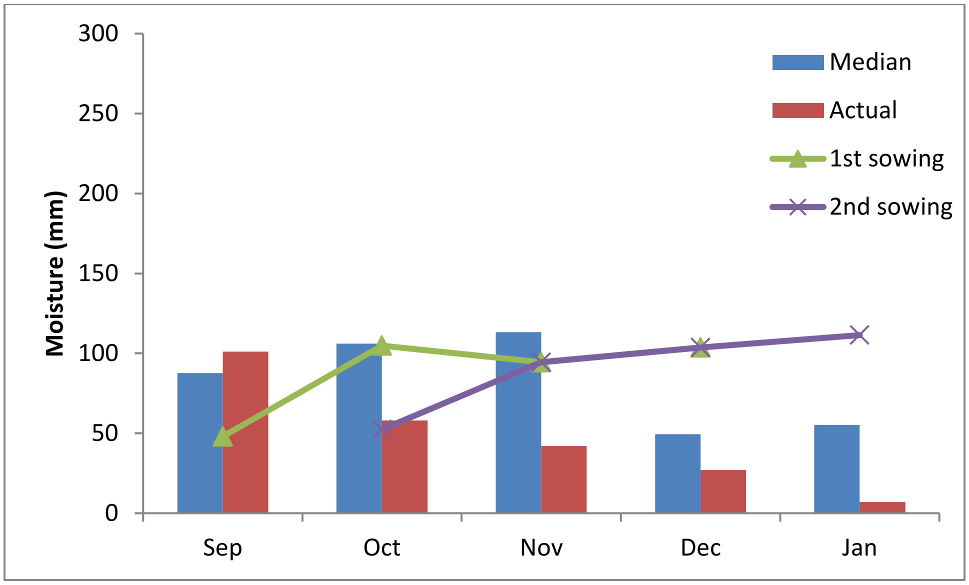

Figure 4g Water use of rice at Kadenge in 1974/75

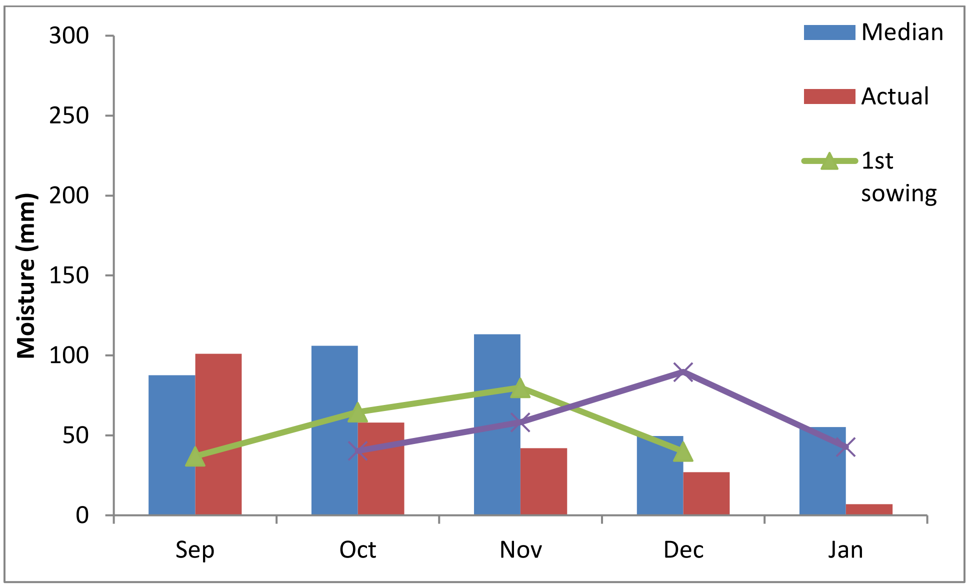

Figure 4h Water use of sorghum at Kadenge in 1974/75

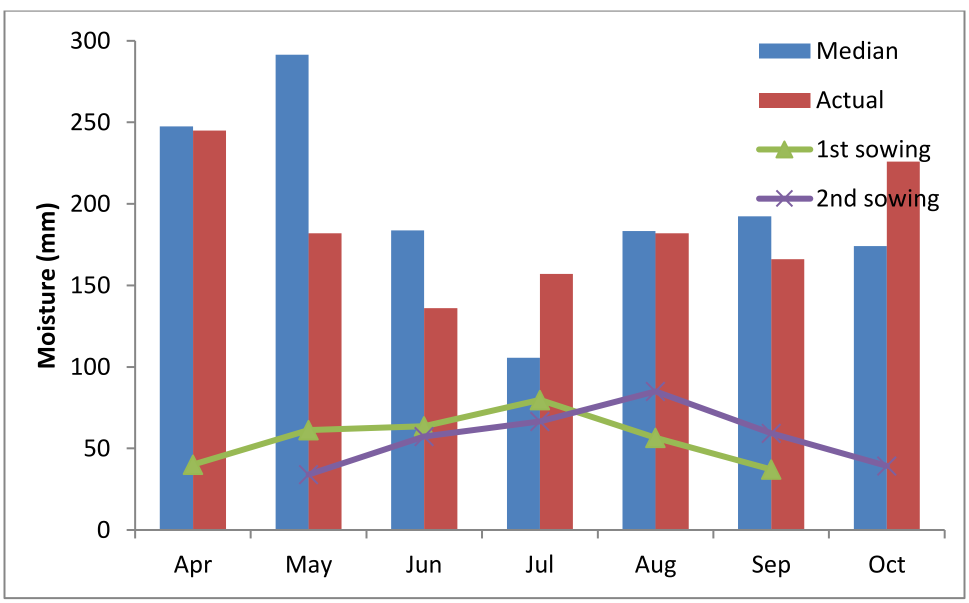

Figure 5 Water use of maize at Mumias in 1972

Maize

The early planted maize at Bunyala could not establish in 1979 and required about two times as much water as was actually available from the rains. If irrigated the crop established, but it still suffered drought stress during the pre-peak to peak demand phases at Kadenge in 1974, in 1974 and 1979 at Busia and in 1974 in Mumias. See for example figure 4f.At Bunyala despite the heavy rains in November and December 1979 these were actually out of season and could not benefit the crops grown earlier (fig 2f), the year standing out as a very bad drought year. Effects of this drought were realized in the notorious "gorogoro*" famine of 1980 in a wide area of this region. See also section 6.4. The year 1974 was also a bad year in the region as shown at Kadenge where although both planting dates were successful the crop underwent severe stress resulting into complete devastation of the crop (fig 4f). This led to a famine well known in the area as "Nyangweso*" in the following year. In 1976 however the situation was partially saved by late planting at Kadenge, and rendered the hurrying early planting farmers a laughing stock by the later planting farmers. Late planting was also a little better at Mumias in 1979 and significantly better in 1984.

Beans

Neither the early nor the later planted crop established leaving the November-December rains fall on parched gardens at Bunyala in 1979 (fig 4a). The situation in 1975 was also bad since none of the essential phases of the crop were marched by adequate rains, thus spelling the inevitable total disaster to the farmers. Although establishment was successful at Busia in 1979 and 1974 and at Kadenge in 1979 (fig 4a), the early planted crop failed entirely in 1974 at both stations and giving poor results in 1976 and 1979. The crop did not establish at Kadenge with traces being completely devastated in the second month of the cycle in 1974 due to lack of rain. The Bunyala situation was severe in 1979 and 1984 when the essential peak phase requirement was not met in the October rains. Dependence on beans in these years could have been from the latter planting which although affected slightly at peak phase perhaps managed to complete the growth cycle at Mumias. The later planted crop at Busia was affected by drought in the pre-peak phase onwards in 1979, with crop completely devastated in both years.

Sorghum

Like maize and beans sorghum failed to establish in both attempts at Bunyala in 1979 (fig 4h) and was severely damaged in 1975. Performance of the early crop was good for the first two months in 1979 or three months in 1974 at Busia, but was badly affected in the pre-peak phase in 1979 and the rest of the growing cycle in 1974. At Kadenge stress occurred from the pre-peak to peak phases in 1976 (fig 4h) and the peak phase onwards in 1974, the first reducing yields considerably and the second completely destroying the crop. At Mumias the crop performed poorly due to inadequate rains in October which coincided with the peak phases in 1979 and 1984. The latter planted crop was however devastated in both 1979 and 1979 due to respective deficiency in rains in the pre-peak and from the pre-peak phase onwards at Busia. Devastation also occurred at Mumias in the pre peak period in 1979 and at Kadenge in 1974 though it performed rather well two years later in 1976 (5h). Performance for the later sorghum crop was also good at Mumias in 1974.

The Millets

Early planted bulrush millet suffered adverse stress in the pre-peak phase at Kadenge in 1976 (fig 4b), the peak phase at Mumias and Busia in 1979 but only slightly in 1984 at Mumias. Performance was good for the early crop s at Busia in 1974 except for the last month when there was some stress. The early crop failed at Kadenge in 1974 (fig 4b) while at Bunyala it altogether failed to establish in 1979 (fig 2b) and after successful establishment in 1975. The late crop performed remarkably well in 1976 at Kadenge (fig 4), in 1984 at Mumias but totally failed after good establishment at Kadenge in 1974 (fig 4b). In 1979 the latter crop suffered stress at Mumias and Busia in the pre-peak phase, in 1974 at Busia from the peak phase onwards and was devastated at Bunyala in 1975 due to inadequate rains during the later phases (fig 4b and d). The finger millet was largely similar to that of bulrush millet especially at Bunyala and Kadenge. The later planted crop however endured extended periods of stress at Busia while at Mumias both early and late planted crops succeeded, reflecting a possibility of obtaining double yields at this station.

Groundnuts

Performance of this crop at Bunyala in both 1975 and 1979 was very poor because it established but failed to proceed properly in its subsequent phases in 1975 (fig 3e) or failed completely in both early and late plantings in 1979. At Kadenge the early planted crop suffered due to stress in the second month in 1976 (fig 4e) and though establishing well 1974, failed to complete its cycle due to inadequate rains in October onwards. The later planted crop however performed well in 1976 at Kadenge (fig 4e) but suffered stress in 1979 at Mumias in the third month. Both planting attempts at Mumias performed well in 1984 although the first attempt performed better than the second since to deficient rains in November affected only the later phase of growth when water was less critical while two consecutive months of stress were realized in the high water demand phases of the later planted crop.

Cassava and Potatoes

Good yields were obtained at Mumias in 1984 and very little stress inflicted on the crops in the latter two months. The Bunyala drought was bad because although 1975 saw the establishment of the early planted crops, there was stress afflicted to the crop in the latter two months of the growing cycle (fig 2c) while the late planted crops were also badly affected due to deficiencies in the latter two months of the growth cycle. In 1979 both planting attempts performed very well although the early crop had some stress in the second month but suffering stress in the last two months when planted early and three months when planted late.

Rice

This has been grown at Bunyala for some time, the possibility of growing it at Kadenge is still under investigation and so the climatic assessment deserves mentioning (Van de Weg and Mbuvi, 1974). However, it appears to be unwise to grow upland rice since the main season at these two stations have very unreliable rains for proper growth (fig 2g). The early crop would have established well at Kadenge in 1974 and 1976 at Kadenge, but would require substantial irrigation in most of the latter growth phases without which the crop would clearly fail. The drought effects in the latter planted rice would be worse since even establishment cannot be assured in most years.

DISCUSSIONS

Critical water levels calculated agree well and are significantly correlated (95%) to those by Woodhead (1968) although his data periods are different (i.e. Ahero-kano (1963-1965, Busia cotton (1965), Kibos (1963-65; Kisumu Meteorological station (1939-62) and Kisumu railway (1939)). The low correlation in Busia may be attributed to the short data period in the Woodhead (1968) data readings. The significant correlations and other independent daily estimates for Kisumu (6.5 mm/day) and annual computations for Winam (e.g. Eo – 2000-2200 mm) imply that any of the periods may safely be used in analysis with insignificant errors (Kuria, 1977; Baker, 1977). Thornthwaites (1948) index however give values which are on average 40% less than those of Penman but this is about 60% on highland areas.

Otengi (1982) and Gwyne (1948) contend that it is not total rainfall amounts but whether it is enough to cover the growing stages of the crop even if grown on well fertilized soils. In the Kano plains rainfall probabilities and the magnitude of their depletion from the mean were observed to have repercussions on cotton yields and the expected minimum rains is only theoretically sufficient when well distributed during the growing season since there are departures from this rule of thumb arising from high evaporation rates (Obara,.1983). It is important to observe appropriate planting schedules as this has been determined to pose considerable risks due to probable consequent low rainfall and harvests for crops such as cotton (Manning, 1950). The precise moisture required for maximum growth rates varies with plant species, its stage of growth and other soil parameters such as soil texture (Webster and Wilson, 1966; Acland, 1971). Further, late planting of cotton reduced the grade of cotton by subjecting this to grain damage at Ukirunguru, Tanzania and elsewhere subjected sorghum to falling-off of the germ seed due to dry periods in the season (Peate and Brown, 1960; Jowett, 1965; Unger, 1984). Although about 500 to 750 mm per year of well distributed rains are adequate for cotton timely sowing to enable maximum requirements to coincide with peak rainfall is key to obtaining maximum yields in cotton (Brown and Cocheme, 1972). Also a simple mistake such as delaying bean plantation until after first weeding of maize (about 10 days) may reduce the bean yields to zero (Owuor, 1977). The root to shoot ratio for maize has been determined to vary between 33% in dry soils to 12.9% in wet soils but it increases sharply when the moisture exceeds 80% of pore spaces probably due to anaerobic respiration (Nye, 1977). The advantages noted in Kakamega when maize was planted at the same time with beans were more than when beans were planted 5 days later and included protection by the maize from early hailstorms and hence increased chances of harvesting the beans (Owuor, 1977). Also, flower shedding in beans (Vicia fava) was aggravated when a wet treatment was delayed and applied during flowering while a short day length reduced vegetative growth and imbalances the root/shoot ratio and eventual tuber yields (El Nadi, 1969; Rayner, 1945).

As for potatoes and cassava become very useful crops that would provide supplementary food reserves during and after drought, dry matter deposition have been recorded to favour the roots of plants such as pigeon peas at the expense of shoots (Nyambuni1980). Additionally, these two crops mature quickly and have relatively low water requirements but cassava which can survive 4-6 months of drought has especially been reported to produce more than 50% of calorific requirements for 2 million people in Africa (Courier Magazine, 1983). The importance of use of cowpeas, yams and vegetables after previous drought is also evident from the list and has been shown for example, in cowpeas which is adaptable and can grow in any soil type and is resistant to both heat and drought (Wamari, 1984). Further, cowpeas are significantly important to the farming communities in the NLB and is notably grown in both Kakamega (46%) and Siaya (30%) districts of the region (Wamari, 1984). While the case of rice can be appreciated the beans response is explained to be due to rapid development of full canopy in response to irrigation all the way to senescence (Wangati et al, 1970). In cotton high moisture consumption has been observed to reduce yields in cotton via inducing flower shedding (Njogu (1977). This was also observed at Kibos where high intensities of rain were however found to be inefficient in wetting the soils due to poor infiltration capacity which in turn checked cotton root growth at about 20 to 30 cm below the soil surface while they grew deeper at Tabora (Njogu 1977).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It is generally observed that drought affects various stages of all the crops growth cycles and it was also more advantageous to plant early in the south west and north east rainfall regions but a month later after rainfall onset in the south east rainfall region since the off season rains seem to favour late planting in the last region. The late planted bulrush millet at Ahero Kano in 1973 for example performed better than the early planted crop but in the south west this was not common as shown in the 1974-1975 season at Busia and Kadenge and second main season at Bunyala. The Bunyala rainfall regime however provides similarities with stations in the south east while in the north east the main season is more reliable as shown at Mumias, although late planted beans and beans grown in the single long season would still suffer stress as occurred in 1978. Potatoes and cassava also appear to perform well at Bunyala (e.g. in 1973).At Ahero Kano all the nine crops would suffer stress at establishment to pre-peak phases if early planted while the least droughts would be at Chemilil and Mumias where all the crops with an exception of rice (i.e. at Chemelil), would perform well when planted later in the season. Most crops would generally suffer more intense drought stress in the south east, notably in Ahero Kano, Chemilil and Kibos when early planted.

Drought stress in the early planted crops in the south east frequently occurs in March interfering with the establishment stages but also the peak phases of some crops as well. Later planting foregoes these drought stress problems with relatively few if any stress problems occurring. In the north east drought may affect the peak and sometimes pre and post peak phases of late planted crops although cassava and potatoes are virtually unaffected by any drought stress in this rainfall region. Late planted long maturing crop varieties perform better than short maturing crops. In the southwest, drought stress is worse in the latter planted crops as compared with early planted ones although both plantings may suffer drought stress from the pre peak phase all the way to the end of the season. Cassava and potatoes have better chances of survival in this rainfall region than any of the other seven crops investigated. These inherent establishment phase stress intensities may however be avoided by planting later in the season. In the south west more crops would suffer intense drought stress of the order of some 40 mm of rainfall deficiency from the pre-peak to post-peak phases.

Recommendations

1. Upland rice (i.e. rice that do not require flooding conditions) can by no means be grown particularly at KadengeYala swamp and Bunyala 's second season where otherwise higher water supplements would be required especially in the peak phases of the crop.
2. It is advisable to plant crops in later in April rather than March in the southeast, or plant early in March and apply irrigation schedule particularly in the crop establishment phases.
3. In the south west planting should be done as early as possible and it is even more advisable to plant dry about half a month before the onset of the rains.

4. Drought resistant experimentation including drought resistant cassava and potatoes should be fasttracked, and if present expanded), or low water consuming plants, normally associated with C4 carbon pathway plants emphasized.
5. Since dry matter deposition favors the roots (of some plants) at the expense of roots, the use of root crops such as cassava and potatoes should be enhanced in addition to the usual crops especially in the drier south west rainfall region.
6. Irrigation schedule programs should be initiated to not only to absorb the largely unemployed youthful labor force especially in the south western rainfall region.

REFERENCES

1. Acland, J.D., 1971: East African crops; An introduction of field crops. FAO/Longman.
2. Adams R. et al, 1978: Dry lands. Man and plants. Architectural Press Limited, London.
3. Alusa, A.L. and Gwyne, P.M., 1978: The occurrence of dry spells during the East African long rains. Research Report no. 2/78. East African Institute of Meteorological Training and Research, Nairobi.
4. Alusa, A.L., 1978: A note on the onset of the rains in East African. Research Report no. 3/78. East African Institute of Meteorological Training and Research, Nairobi.
5. Baker, S.J.K., 1977: A background to the study of drought in east Africa. African environmental special report, Vol 6 Pp. 74-82
6. Blackie J.R., 1965: A comparison of methods of estimating evaporation in east Africa. Proceedings of the 3rd specialist meeting on applied meteorology in East Africa, E.African Agricultural and Forestry Organization, Muguga Kenya.
7. Brown, L.H. and Cocheme, J. 1969: A study of the agroclimatology of the highlands of east Africa. FAO/WMO Integrated Project, FAO/UN Rome.
8. Da Costa, V.P,F.X. 1973. Characteristics and interpretation of soils of the Kano plains for irrigated agriculture. MSc Thesis University of East Africa.
9. Dagg, M. 1965: A rational approach to the selection of crops for areas of marginal rainfall in East Africa. East African agricultural and forestry Journal, Vol 30. Pp.295-300
10. Dagg, M.. 1969a Factor affecting the use of evaporation pan data in East Africa. East African agricultural and forestry Journal, Vol 53. Pp. 203-210.
11. Dagg, M..1969b. Water requirements of crops in East Africa. In: East Africa its peoples and resources by Morgan W.T. W (Ed). Oxford University Press.
12. Dagg, M..and Blackie, J.R. 1965. Study of the effects of changes in land use on the hydrological cycle in East Africa by means of experimental catchments. Bulletin of the International Association of scientific hydrology, Vol 1V, no. 13. Pp. 63-75
13. Dagg, M. and Blackie, J.R., 1970; Estimates of evaporation in East Africa in relation to climatic classification. Geographical journal, Vol 136, Pg. 227
14. Dagg, M. and Wangati, F.J., 1964: Estimating evaporation in East Africa. East African academy, 2nd Symposium, Nairobi
15. Dagg, M. et al, 1969.Crop water use. Record of research for 1968.East African Agricultural and Forestry Organization.
16. Denmead O.T. and Shaw, R.H., 1962. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. Agronomy journal, Vol 45: Pp. 385-390.
17. Dogget, H and Jowett, B. 1966.Yields of maize and sorghum hybrids in East African lowlands. Journal of agricultural science. Vol. 67: Pp31-39
18. Dorenbos, J and Pruitt.W.M. 1977.Crop water requirements. Irrigation and drainage paper no. 24. FAO, Rome.
19. Downey, L.A. 1971. Water use by maize at three plant densities. Experimental agriculture. Vol. 7 Pp. 161-170.
20. El Nadi, A.H. 1969: Water relations of beans: Effects of stress on growth and flowering. Experimental agriculture. Vol. 5 Pp. 195-209.
21. Gehart, J. 1975: The diffusion of hybrid maize in Western Kenya. Ministry of Agriculture Report. Nairobi
22. Gibbs, W. J. and Maher, J.V., 1967: Rainfall deciles as drought indicators. Commonwealth Bureau of Meteorology, Melbourne.
23. Gillman, C. 1938: Man, land and water in East Africa. East African agricultural and forestry Journal, Vol 3.
24. Glover, J. 1948: Water demands by maize and sorghum. East African agricultural and forestry Journal, Vol 30.P 171.
25. Glover, J. 1957: The relationships between total seasonal rainfall and yields of maize in Kenya highlands. Journal of Agricultural Science, Vol. 49, Pp. 285-290.
26. Glover, J. and Forsgate, J.A. 1962. Measurement of evapo-transpiration from large tanks of soil. Nature, Vol. 195.P 1330.
27. Glover, J. and McCulloch, J.S.G. 1958. The empirical relation between solar radiation and hours of sunshine. Quarterly Journal of Royal Meteorological Society. Vol. 84 Pp. 172-175
28. Goldson, J.B., 1963: The effect of time of planting on maize yields. . East African agricultural and Forestry Journal, Vol. 29. Pp. 160-163.
29. Government of Kenya, 1970.National Atlas of Kenya.Survey of Kenya.
30. Government of Kenya, 1983.Economic review. Kenya Bureau of Statistics, Nairobi.
31. Gray, R.W. 1970: The effect on maize yields of time of planting of maize in south west Kenya. East African agricultural and Forestry Journal, Vol. 35.No. 3. Pp. 291-298.
32. Gwynne, M.D. 1964: Plant characteristics that make them suited to areas of low and erratic rainfall. Special meeting on crops of low and erratic rainfall, Item 2 of agenda.East African Agricultural and Forestry Organization.
33. Heyer, J. et al, 1976. Agricultural development in Kenya.An economic assessment. Oxford University Press, Nairobi.
34. Hutchinson, (Sir) J. B. and Farbrother, H.G., 1956: On the estimation of water losses by evaporation under equatorial conditions. Empire cotton growing review, no. 3.
35. Hutchinson, (Sir) J. B. et al, Crop water requirements of cotton.Journal of Agricultural Science. Vol. 51 Pp. 177-188.
36. Jackson, I.J. 1968. As quoted in “The effects of rainfall on fruiting and yields of four genotypes of cotton in Kenya” by Njogu, N. 1977. See below.
37. Jackson, I.J. 1982. Climate water and agriculture in the tropics. Longmans.
38. Jaetzold R. and Schmidt, H. 1982. Farm management handbook of Kenya.Vol. 2 Natural conditions and farm management information. Part A Western Kenya (Nyanza nd Western Provinces), Ministry of Agriculture.
39. Jowett, D. 1965. The grain structure of sorghum related to water uptake and germination. East African agricultural and forestry Journal, Vol. 31 Pp. 25-30.
40. Kenworthy, J.M., 1964: Rainfall and the water resources of East Africa. In: Geographers and the Tropics, Liverpool Essays. Longman, London.
41. Kenworthy, J.M. and Glover, J. 1958: The reliability of the main rains in Kenya. East African agricultural and forestry Journal, Vol. 23 no. 4 Pp. 267-280.
42. Kiangi, P. 1981. Physical and wind-flow characteristics of the atmosphere over Eastern Africa during the 1967 and 1972. As quoted in Garcia, R.V. (Ed) See below.
43. Kosllowski, T.T. (Ed.) 1968a Water deficits and plant growth.Vol. 1.Development control and Measurement. Academic Press, New York, London.
44. Kosllowski, T.T. (Ed.) 1968a Water deficits and plant growth.Vol. 2.Plant water consumption and response. Academic Press, New York, London.

45. Kuria, P.E. N.K., 1977. Water management study in sugarcane block in West Kano pilot scheme. Postgraduate Diploma in Agricultural Engineering, U.O. Nairobi.
46. Lemon E.R. et al, 1960: Some effects of the relationship of soil plant and meteorological factors in evapo-transpiration proceedings. Soil Science Society of America, Vol. 21 Pp. 464-468.
47. Lenga, F.K., 1979: Water use by eight annual crops at Kabete Kenya. M Sc. Thesis U.O. Nairobi
48. Manning, H.L. 1949: Planting date and cotton production in the Buganda province of Uganda. Empirical Journal of Experimental Agriculture, Vol. 17 Pp. 245-258.
49. Manning, H.L. 1956a: Calculation of confidence limits of monthly rainfall. Journal of Agricultural Science, Vol. 47. Pp. 154-156.
50. Manning, H.L. 1956b: The statistical assessment of rainfall probability and its application in Uganda agriculture. Proceedings of the Royal Society of London. Vol. 144 Pp. 460-480.
51. Manning, H.L. 1960: Cotton potential and rainfall expectation in Uganda. WMO/Munitalp Symposium, Nairobi. Pp. 402-414.
52. Mbithi, P.M. 1972: Drought, welfare and rural development. Two progress reports and provisional recommendations arising from joint study of drought in Kenya.
53. Mbithi P.M. and Wisner, B. 1972: Drought and famine in Kenya: Magnitude and attempted solutions. Discussion paper no. 144, IDS, U.O. Nairobi (revised version of Working paper no. 46).
54. Mbithi P.M. and Wisner, B. 1974: Drought in Eastern Kenya. Nutritional status and farmer activity. In: Natural Hazards by White G. (Ed) Pp. 87-97.
55. McCulloch, J. S.G., 1961: Evaporation pans in East and Central Africa. East African Agricultural and Forestry Organization/ Inter Africa Conference on hydrology, Nairobi.
56. McCulloch, J.S.G. 1965: Tables for the rapid calculation of the Penman estimate of evaporation. East African Agricultural and Forestry Journal, Vol. 30 Pp. 268-295.
57. Ministry of Agriculture, 1972: Annual report of the scientific research division. Government Printer, Nairobi.
58. Ministry of Agriculture, 1974.Crop production annual reports. Government Printer, Nairobi.
59. Monteith, J.L. 1965: Radiation and crops. Experimental Agriculture, Vol. 1 Pp. 241-251.
60. Monteith, J.L. 1966: Photosynthesis and transpiration of crops. Experimental Agriculture, Vol. 2 Pp. 1-14.
61. Muchena, F.N. 1976: The soil resources of Maseno division, Kisumu district. A preliminary investigation.Site Evaluation no. 27, Kenya Soil Survey.
62. Mungai, D.N. 1979: As quoted by Sogomo. See below.
63. Muriithi, 1979. Forward to " Diurnal variation of precipitation in East Africa" In: Asnani, G.C. 1977: Circulation over Lake Victoria. Lecture delivered at the second training Course in computer application for water resources management, Nairobi.
64. Nganga, J.K. 1984: Why there is no rain despite all the clouds. Focus on weather column in "The Daily nation, 9th August, 1984.
65. Nieuwolt, S. 1973b: Rainfall and evaporation in Tanzania. Bureau of Resource Assessment and Land Use Planning. Paper no. 24. U.O. Dar es Salaam.
66. Nieuwolt, S. 1974a: Seasonal rainfall distribution in Tanzania and its cartographic representation. Erdkunde, Vol. 28 Pp. 186-194.
67. Nieuwolt, S. 1974b: Seasonal droughts in East Africa. East African Agricultural and Forestry Journal. Vol. 43 no. 3 Pp. 208-222.
68. Nieuwolt, S. 1978. Rainfall variability and drought frequencies in East Africa.Erdkunde, Vol. 32 Pp. 81-88.
69. Njogu, N. 1977: The effect of rainfall on the fruiting and yield of genotypes of cotton in Kenya. MSc. Thesis U.O. Nairobi.
70. Nyambuni, J.O. 1980: A study of drought resistance in pigeon peas. MSc Thesis U.O. Nairobi.
71. Nyenzi, B.S. 1980: The distribution of actual evaporation and evapo-transpiration over East Africa. Research Report no. 7/80. East African Institute of Meteorological Training and Research, Nairobi.
72. Obara, D.A. 1983: Environmental and agronomic factors influencing variations in small holding cotton yields in the Kano plains, Kisumu District West Kenya. PhD Thesis U.O. Nairobi
73. Obasi, G.O. P. and Kiangi, P.M.R. 1973: Water balance in Kenya. Paper presented at the 5th Specialist Meeting on Applied Meteorology in September, Nairobi.
74. Obasi, G.O. P. and Kiangi, P.M.R. 1977: Monthly distribution of water balance components in Kenya. Technical Memorandum no. 24, Kenya Meteorological Department P 23 (The Observer newspaper 25h April 1984).
75. Ogallo, L. J. 1981. Reliability of rainfall in East Africa. Research Report no. 5/81. East African Institute of Meteorological Training and Research, Nairobi.
76. Ogallo, L. J. 1982: The persistence of the monthly rainfall over East Africa. Research Report no. 3/82. East African Institute of Meteorological Training and Research, Nairobi.
77. Okoola, R.E.F., 1978: Spatial distribution of precipitation in the Mombasa area, Kenya. Research Report no. 1/78. East African Institute of Meteorological Training and Research, Nairobi.
78. Onyango, J.W., 1983: The applicability of Von Thunen's agricultural land use model in Siaya district, Kenya. A spatial crop analysis. Unpublished dissertation for partial fulfillment of the BSc degree, University of Nairobi.
79. Otengi, S.B.B. 1982. The reliability of the pentad rainfall in Kenya. Research Report no. 2/82. East African Institute of Meteorological Training and Research, Nairobi.
80. Owuor, J. O. 1977: Mixed cropping of maize with beans with special reference to relative times of planting of two crops in western Kenya. MSc Thesis, U.O. Nairobi.
81. Peat J.E. and Brown, K.J., 1960: Effects of management on increasing crop yields in the Lake province of Tanganyiaka. East African Agricultural and Forestry Journal, Vol. 26 Pp.103-109.
82. Penman, H.L. 1960.Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society, A, Pp. 120-145.
83. Penman, H.L. 1949.The dependence of transpiration on weather and soil conditions. Journal of soil science, Vol. 1 P 74.
84. Penman, H.L. 1962: Weather and crops. Quarterly Journal of Royal Meteorological Society. Vol. 88 Pp. 209-219.
85. Pereira, H.C. 1957: Field assessment of water use for irrigation in Kenya coffee. Journal of Agricultural Science, Vol. 49 Pp. 459-466.
86. Pereira, H.C. 1959a: Practical field instruments for estimation of radiation and evaporation. . Quarterly Journal of Royal Meteorological Society. Vol. 85 Pp. 253-261.
87. Pereira, H.C. and McCulloch, J.S.G. 1960: The energy balance of tropical land surfaces. WMO/Munitalp Symposium Nairobi Pp. 318-326.
88. Pereira, H.C. and McCulloch, J.S.G.. 1962: Water balance requirements of East African crops. In: The natural resources of east Africa by Rusell, E.W. (Ed).
89. Rayner, R.W. 1945: Notes on the effect of day-length on potato yields. East African Agricultural and Forestry Journal, Vol. 2 Pp. 25-28.
90. Russell, E.W. 1956: Effects of very deep ploughing and of sub-soiling on crop yields. Journal of Agricultural Science, Vol. 48, Pp. 129-144.
91. Russell E.W. 1960: The agricultural uses of meteorological data. WMO/Munitalp symposium, Nairobi Pp. 390-401.
92. Sambroek, W.G. 1980: Exploratory soil map and agro-climatic zone map of Kenya. Report no. E1 Kenya Soil Survey.
93. Sansom, H.W. 1954a: Measurement of evaporation in East Africa. Technical memorandum no. 5. East African Meteorological Department, Nairobi.
94. Sansom, H.W. 1954b : The climate of East Africa based on Thornthwaites classification. Memoirs Vol. III no. 2 East African Meteorological Department, Nairobi

95. Standard (the) Newspaper, 6th March, 1984.
96. Stern, W.R. 1967: Seasonal evapo-transpiration of irrigated cotton in low latitude environment. Australian Journal of Agricultural Resources, Vol. 18 no. 2 Pp. 256-269.
97. Sunday (The) Nation, 5th May and 2nd June, 1985: Presidential address during the 22ndMadaraka day celebrations on 1st June 1985.
98. Swynnerton, R.M.J. 1954: A plan to intensify the development on African agriculture in Kenya. Ministry of Agriculture, Nairobi.
99. Thornthwaite, C.W. 1948: An approach toward a rational classification of climate. Geographical Review, Vol. 38 Pp. 55-94.
100. Thornthwaite, C.W. and Mather, J.R. 1957. Instructions and tables for computing potential evaporation and water balance. Publications in Climatology, Vol. 10 Pp. 185-311.
101. Times and Sunday (the) Newspaper, 29th September, 1985, 13th October, 1985.
102. Turner, D.J. 1966: An investigation into the causes of low yields in late planted maize. East African agricultural and forestry Journal, Vol. 31 Pp. 249-260
103. Van De Weg, R.F. and Mbuvi, J.P., 1974: A preliminary evaluation of soils around Nyangoma mission, Bondo division Nyanza province. Site Evaluation Report no. 19 Kenya Soil Survey.
104. Wallen, C.G. 1967: Aridity definitions and their applicability. Geographisca Annaler, Vol. 49 a, nos. 2-4, Pp. 367-384.
105. Wamari, P.A., 1984: Studies on Ascomyccyta blight of cowpeas (Vignaungiculata L. Walp) and characterization of of its causal organism (Aschocytaphaseolorumacea). MSc. Thesis U.O. Nairobi.
106. Wangati, F.J. et al, 1969: As quoted in Crop water use by Dagg, M. et al, (Ed). See above.
107. Williamson, R.E. 1963: Response of corn and grain sorghum to different water depths. In: Yields of cereals in East Africa by Dogget H. and Jowett, D. (Ed). See above.
108. Woodhead, T. 1968: Studies of potential evaporation in Kenya. . East African Agricultural and Forestry Organization, Ministry of Natural Resources, Republic of Kenya.
109. Woodhead, T. 1970b: Mapping potential evaporation for tropical East Africa; The accuracy of the Penman estimate derived from indirect assessment of radiation and wind-speeds. Proceedings of Reading Symposium of World Water Balance, International Association of Scientific Hydrology, Pp. 233-241.
110. Woodhead, T. and Waweru, E.S. 1970: Variability of potential evaporation in East Africa. Experimental Agriculture, Vol. 6. Pp. 51-55.
111. Woodhead, T., Waweru, E.S. and Lawes, E. T. 1970: Expected rainfall and Kenya agriculture; Confidence limits for large areas at minimum cost. Experimental Agriculture, Vol. 6. Pp. 87-97.
112. World Meteorological Organization, 1966: Measurement and estimation of evaporation and evapo-transpiration. WMO Technical Report no. 83 Pp. 1-121, Geneva Switzerland.

Acknowledgements

I should like to thank Professor R.B. Ogendo who together with my supervisor Dr. Graham N. Sumner, presented a united front and initiated the possibility of carrying out this study in the United Kingdom, DrsBasnayake and Rajotte and the St. David's Postgraduate Committee for respectively recommending me for, and accepting to offer me a college grant for the study. Special thanks go to Dr. Graham for his unswerving efforts to impartially supervise the work and further acquisition of a travel grant for the field work in Kenya the computing skills he taught me which went a long way towards reaching the timely completion of the work. Further, the computer staff for the help and advice they gave me, but particularly Mr Alan Rogers for writing valuable programmes, I acknowledge the librarians at Kabete Campus, Institute of Development studies, Chiromo Campus, Gandhi Wing library all of the University of Nairobi, the Kenya Soil Survey, the Kenyan (Dagoretti Corner) and United Kingdom (Bracknell) Meteorological Departments for their urge to help and permission to use their libraries. I further extend my appreciation to the Interlibrary Loans Department which was so vital in acquiring the numerous articles necessary for the study. Also acknowledged are the numerous generous financial contributions from my countrymen and women without which the very idea of studying in the UK could materialize especially members of staff of the Geography Department, University of Nairobi, teaching staff at Sega Girls' Secondary School and indeed members of my family who rallied behind me in attempts to make the *harambee* project a success.

Note

Thesis submitted for the degree of Masters' of Arts, Department of Geography, University of Wales, United Kingdom, 1986
Personal Supervisor: Dr. Graham N. Sumner
Departmental Supervisor: Dr David Kirby

Article History

Received: 23 August 2018
Accepted: 18 September 2018
Published: January - March 2019

Citation

Joab Onyango Wamari. Scheduling planting dates to manage drought in the northern lake basin, Kenya: An assessment of annual crop performance during drought in northern lake basin, Kenya. *Climate Change*, 2019, 5(17), 10-28