

Assessment of the Growing Season over the Unimodal Rainfall Regime Region of Tanzania

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Abstract

Most part of Tanzania experiences unimodal rainfall. The characteristics of rainfall such as its onset and cessation dates, dry and wet spell lengths, frequency and number of rainy days can be used to determine the nature of growing season; length of growing season, end of season and its geographical variation both latitudinally and longitudinally. This justifies the assessment of the crop growing season under unimodal rainfall regime by this category in order to adapt agricultural practices, which result in increased crop productivity. A water balance model was used to determine the end of growing season. The method of Sivakumar (2002) was used to evaluate dry spell of different lengths and their frequencies. The results show that on the mean the growing season starts in the first week of December in most of the region except in Kigoma where the season starts earlier in the second week of November. The growing season ends in April in most of the years. Similarly, the length of the season was found to range between 131 and 150 days in Mbeya and Songea in the south and Kigoma to the west. In Dodoma and Iringa, the growing season is as short as 93 to 97 days. Variations of starting dates for the growing season with latitude were not statistically significant, but longitudinal variations in the mean starting dates of the growing season revealed some statistical significance. These results form a good basis for explaining the characteristics of the growing season in the study region.

Key words: Agrometeorology, dry spells, growing season, Tanzania, unimodal rainfall

Introduction

Determination of the effective crop growing season is important for rainfed agriculture. The late planting, occurrence of dry spells within a growing season and early cessation of rainfall reduce the length of the season which in turn reduces crop yields. These are the contributing factors of crop failure and thus food insecurity in the country. A study by Lomas (1998) in eastern Kenya shows that a delay in planting by 10 days leads to yield loss by of 20%. The variability of growing seasons has caused frequent crop failure and forced society to live under a recurring threat of famine. Prolonged dry spells in 2002/03 (July-June) left 320,000 households (nearly 2 million people) spread across 47 districts in 16 regions highly food insecure (FEWS Net, 2003). Dry spells are becoming increasingly commonplace in our rainy seasons. Dry spells occurring at different developmental stages cause water stress in crops. Long dry spells may cause stress and

disrupt the phenological stages of most crops resulting in low crop yields. The effect of soil moisture stress to a crop depends on the type of crop and the phenological stage at which the stress occurs. Long duration varieties suffer less yield damage than short duration varieties as long vegetative period could help the plant to recover when water stress is relieved. Late planting will frequently lead to water stress at the end of the growing season, and the crop yield will be reduced (Lomas, 1998).

The best sowing time depends largely on climatic conditions, and in tropical regions with uniform temperature, the occurrence of rainfall is decisive (Mwandosya *et al.*, 1998). Alusa and Mushi (1974) and Alusa (1978) used pentad rainfall to predict the mean onset and cessation of rains in East Africa. Stern *et al.* (1982) discussed the use of daily rainfall to obtain the start and end of the season. In another study, Mhita and Nassib (1988) used the weekly rainfall to determine the

variability and the onset and end of rains in Tanzania.

Rainfall alone however, cannot adequately determine the wetness or dryness of a place because in the tropics rainfall is the most variable of all climatic elements (Idow and Gbuyiro, 2002). Alusa and Gwage (1979) suggested the examination of dry spells in which a rainy (wet) day is defined as a day with at least 5 mm of rainfall or with rain exceeding the potential evapotranspiration (PET) for the region. Mahoo *et al.* (1999) defines the start of the growing season as the first period with running total of at least 20 mm of rain in four consecutive days with at least two days being wet and no dry spell of more than 10 days in the next thirty days. The growing period for most crops continues beyond the rainy season and, to a greater or lesser extent, crops often mature on moisture reserves stored in the soil profile. When the rains start early the season is likely to be longer, however, early rainfall (November) over unimodal areas is variable (Mhita and Nassib, 1988). Gomme and Houssiau (1982) developed the rainfall variability zones in Tanzania based on the risk of crop failure. In their study, it was found that the length of the growing season in the southern and western regions was between 130 – 160 days, and 90 days for central region.

The main objective of this paper was to examine the characteristics of the growing season with a view to determine the start of the effective growing season over the unimodal rainfall regime of Tanzania.

Materials and Methods

Study area and its climatology

The study area covers the unimodal rainfall regime region as developed by Gomme and Houssiau (1982) as shown in Table 1 and Figure 1. The seven stations together with their coordinates and altitudes that were considered in this study area are presented in Table 1. In the unimodal rainfall regime, the seasonal rains “*mvua za mwaka*” start in December and end in April (Mhita and Nassib, 1988). The unimodal regime is experienced in southern, south western, central, and western parts of the country. Central Tanzania is a semi - arid region with some parts receiving annual rainfall of less than 400 mm. The major annual crops grown in the unimodal

rainfall region include cereals (maize, millet, and sorghum) and pulses (beans). Millet and sorghum are grown in semi-arid areas of central Tanzania, where rainfall amount and distribution are limiting for maize.

Table 1: Latitude, longitude and altitude of the stations used in the study

Station	Latitude (°S)	Longitude (°E)	Altitude (m)
Kigoma	4.86	29.63	885
Tabora	5.08	32.83	1182
Dodoma	6.12	35.77	1120
Iringa	7.3	35.2	1428
Mbeya	8.93	33.47	1759
Mtwara	10.35	40.18	113
Songea	10.67	35.58	1036

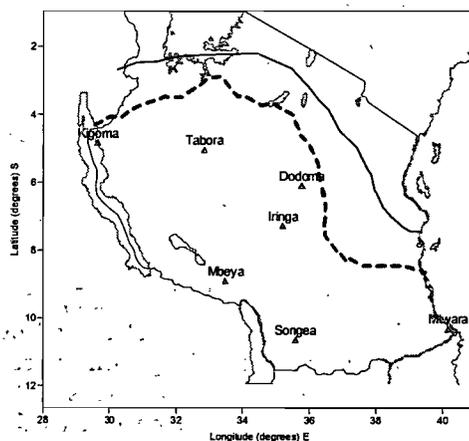


Figure 1: Map of Tanzania showing rainfall patterns (Modified from Gomme and Houssiau, 1982)

The climate of Tanzania depends on the movement of the Inter-Tropical Convergence Zone (ITCZ). Intrusion of moist westerly airstreams over western Tanzania from the Congo basin during southern summer brings seasonal rainfall over south - western and western parts of the country. Because the coastline and the highland areas of Tanzania are meridionally - oriented, the winds are much more meridional

than zonal, and the main convergence zone suffers considerable displacement and distortion. Highland areas act as high-level heat sources and, combine with orographic lifting of the air, resulting in intensification of rain producing mechanisms in mountain areas. Diurnally modified climates in East Africa are areas near coastlines, lakes, escarpments and mountain ranges (Brown and Cocheme, 1973). The modified pressure gradient between tropical Indian and Atlantic Oceans and enhanced easterlies prevent the meridional branch of the ITCZ from expanding to the east over East Africa, hence delaying the rainy season onset (Camberlin and Okoola, 2003).

Data source, handling and analysis

Daily rainfall data covering a period of 21 years from 1980 to 2000 was obtained from the Tanzania Meteorological Agency (TMA).

The analysis carried out included the following:

- Determination of the statistical characteristics of rainfall over the unimodal rainfall regime
- Determination of the dry spell length and frequency
- Determination of the date of start of the effective growing season
- Determination of the length of the effective growing season
- Latitudinal and longitudinal variation in the mean start of the effective growing season

Long term seasonal rainfall analysis

To determine the characteristics of rainfall over the growing season, the long-term seasonal rainfall was analyzed using standard statistical formulae for the mean, standard deviation and the coefficient of variation (CV).

Length and frequency of dry spells

Daily rainfall records were used to analyse dry spell length and frequency using the INSTAT program at threshold rainy day of 5.0 mm. Monthly and dekadal dry spell frequencies of various lengths including 1 day, 2 days, 3 days, ..., and 20 days were determined. A dekad was defined as a period of 10 days between the 1st and 10th and the 11th and 20th of each month, the last dekad of the month having 8, 9, 10 or 11 days (WMO, 1966). To enable monthly and dekadal

analysis of dry spells, the method used by Alusa and Gwage (1979) was adopted, where a dry spell which continues into another month or dekad was broken into two. In this study the dry spell frequencies, F , were determined by the formula of Sivakumar (2002), given as in equation 1.

$$F = \frac{N(D_i)}{m} \times 100\%$$

.....(Equation 1)
where $N(D_i)$ is the number of occurrences of dry spell length D , for example 5 days, 6 days, ... > 20 days for the prescribed period i , and m is the number of years (seasons) of data.

$$N(D_i) = \sum_{j=1}^m f_{ij} \quad (\text{Equation 2}) \text{ and}$$

f_{ij} is the frequency of the length of dry spell of period, i , for the month j . The spatial extent of dry spells lasting at least 1 day, 3 days, 5 days, 7 days, 10 days, 15 days, and 20 days were presented as seasonal average cumulative frequency in Fig. 2. For each station dekadal analysis of dry spell frequency of length of 5 days or longer and 10 days or longer was determined as percentages of their occurrences for the study period.

Start and end of the growing season

The start of the growing season was taken to be the first occasion after 1st October (day 275) with running total of at least 20 mm of rain in four consecutive days with at least two days being wet and no dry spell of more than 10 days in the next thirty days beginning within the next five days. In this case, a rainy day was defined as a day with more than 5.0 mm of rainfall. The end of the season (cessation date) was determined based on the simple water balance as was derived by Dennett *et al.* (1983). Here amount of water in the soil on day $i+1$ is given by equation 3.

$$W_{i+1} = W_i + P_i - E \quad \text{.....(Equation 3)}$$

Where P_i is the daily rainfall and E is daily evapotranspiration, taken here as 5.0 mm per day throughout the season. W_i is the amount of water in the soil on day i . Maximum water storage capacity of the soil was taken to be 100 mm. The end of the season was defined as the first day that W_i becomes zero and remains at zero for more than five days. Values of mean, standard deviation, coefficient of variation (C.V) at

probability levels of 20, 50, and 80 percent were also determined for onset and end of the season.

Length of the growing season

Complete growing season duration (length) was determined based on the method used by Segele and Lamb (2003) where the effective growing season is the period between onset and cessation dates. The cessation dates derived from water balance, takes care of the dry spells that occur during the season.

Latitudinal and longitudinal variation in the mean start of the season

In determining the variation in the mean start of the growing season with latitude and longitude, seven stations with their mean starting dates of the growing season were arranged in ascending order of magnitudes of either latitudes or longitudes. The correlation coefficients (r) between the mean starting day (date) of the effective growing season (in Julian days) and latitudes or longitudes were determined using the standard Pearson correlation formula found in most statistical text books and in Okoola and Salano (2002). Positive correlation coefficients indicate late onset of the season with increase in latitude southwards, while the negative values of r indicate early onset with increasing latitude southwards. For longitudes, the positive values of r, indicate the late onset of the season with increasing longitudes, and vice-versa for negative values of r. To determine if the correlation coefficients were statistically significant the

critical values t_c from Student t-test were compared with table values at 95% confident level and n-2 degrees of freedom.

Results and Discussion

Long term seasonal rainfall characteristics

Means, standard deviations and coefficients of variation (CV) were obtained from the long-term seasonal rainfall for the stations studied, that is, Kigoma, Tabora, Mbeya, Songea, Iringa, Dodoma and Mtwara (Table 2). Seasonal mean rainfall ranged from 581 mm (Iringa) to 1035 mm (Songea). The lowest values (less than 600 mm) were observed over Iringa (581 mm) and Dodoma (589 mm), while other stations (Kigoma, Tabora, Mbeya, Songea, and Mtwara) receive mean rainfall of above 700 mm. Rainfall values at Iringa and Dodoma are quite low in meeting the seasonal water requirements for a crop like maize, which requires about 750 mm. This amount may be sufficient for crops like millet and sorghum, which are tolerant to drought, although farmers in these areas prefer planting maize. The CV values in Table 2 represent the variability of the seasonal rainfall. The CVs ranged from 14.3% (Kigoma) to 29.2% (Dodoma), while at Mtwara it was 26.4%. The high values of CV over the growing period imply a high uncertainty in rainfall hence in crop yields (Mahoo *et al.*, 1999).

Table 2: Means, standard deviations and coefficients of variation for long-term rainfall at stations used in the study

Station	Kigoma	Tabora	Mbeya	Songea	Iringa	Dodoma	Mtwara
Mean	944.8	924.7	743.7	1035.2	580.8	589.1	1008.3
Std. deviation	135.0	212.1	152.9	183.1	120.9	172.0	266.5
Coefficient of variation (%)	14.3	22.9	20.6	17.7	20.8	29.2	26.4

days, 15 days, and 20 days; and high frequency of short duration of dry spells that last at least 1 day and 3 days over central Tanzania (Dodoma). It also

The length and frequency of dry spells

Figure 2 shows the spatial distribution of the average frequency of dry spells of various lengths (or durations) at threshold rainy day of 5.0 mm. The results from Figure 2 show low frequency of dry spells of long duration of at least 7 days, 10

shows that there is a general decrease of frequency of dry spells of short durations (1 day or longer and 3 days or longer) from west to east, for example, from Kigoma (34.6) to Dodoma (23). Another increase for 1 and 3 days or longer dry spells is from Dodoma (23) to Mtwara (28.7).

There is an increase of frequency of dry spells of durations of 5, 7, and 10 days or more, from Songea to Dodoma across the longitudes (Fig. 2). Minimum average frequency of dry spells lasting 20 days or more were 0.3 (Kigoma) and 0.6 (Mtwara), compared with maximum value of 2 observed over Dodoma. The two stations Kigoma and Mtwara are located near water bodies, namely, Lake Tanganyika and the Indian Ocean, while Dodoma in the central part of the country. These results reveal the association of high frequency of short duration dry spells with Congo airmass and presence of water bodies in the vicinity. This is to be expected as convective activity may result in scattered rain resulting in many short dry spells. On the other hand, dry spells of long duration are found in drier areas (i.e. Dodoma). These observations are similar to what Alusa and Gwage (1979) observed over Mandera, Kenya and Dodoma Tanzania. Who hypothesized that the drier areas get their rains from more organized synoptic scale systems with a few short dry spells occurring during the time of the rains.

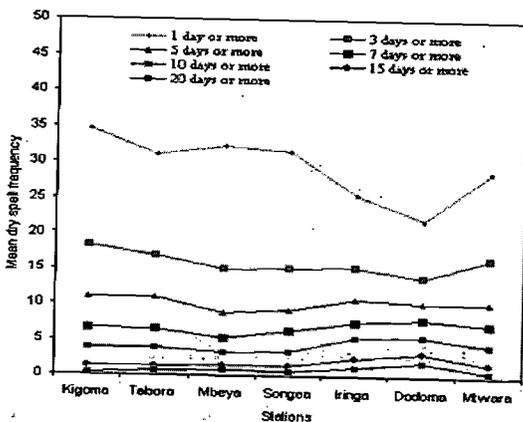


Figure 2: Seasonal frequency distribution of the dry spells of various lengths at a threshold rainy day of 5.0 mm

Figure 3 shows the occurrence of dry spells for the period during the rainy season at four (Kigoma, Dodoma, Mbeya and Mtwara) of the seven stations studied. Similar results, but not presented here for lack of space, were obtained for

the other three (Iringa, Songea and Tabora) stations. Some dry spells overlapped in two or more times. The results show that periods of rainfall during early rainy season (November) are frequently accompanied by dry spells which may last 5 or 10 days or longer. During first dekad of November, the stations experience between 80 and 100% dry spells of 5 days or longer. Kigoma indicated the minimum record (5%) of dry spells that last either ten days or longer during the first dekad of November. Increase of dry spells is observed during third dekad of January and February and early March as shown in Fig. 3. In Kigoma, 10 day or longer dry spell starts during the third dekad of February, Mbeya (first and second dekads of March), and during the first dekad of March for Dodoma, and Mtwara. These widespread dry spells that influence the region between January and March are due to modification of the ITCZ, resulting from large-scale circulation systems rather than the local influences. The study by Camberlin and Okoola (2003) observed a late onset of long rains over East Africa during March. They suggested that the modified pressure gradient between the tropical Indian and Atlantic oceans, and enhanced easterlies prevent the meridional branch of the ITCZ from expanding to the east over East Africa, hence delaying the onset of long rains. While the condition leads to late onset of long rains over bimodal regions of Tanzania, over unimodal region it leads to the observed dry spells.

The high frequency of dry spells during the onset of rainy season during November indicates unreliability of early rains in the region and therefore rainfall in that time cannot be used for planting but for land preparation. Where dry seeding is practiced, particularly in semi-arid areas of central Tanzania replanting may be required because these early rains may be enough to cause germination of the seeds. The crop may die due to prolonged dry spells during this stage. These observations are similar to what Mhita and Nassib (1988) observed on early rainfall (November) over unimodal areas. However, in Kigoma where the dry spells are of lower frequency early rains may lead to long growing season.

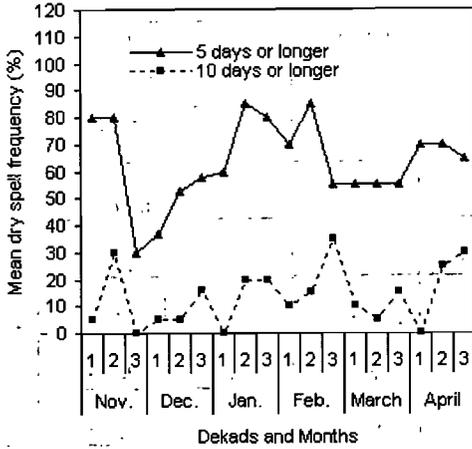


Figure: 3a. Kigoma

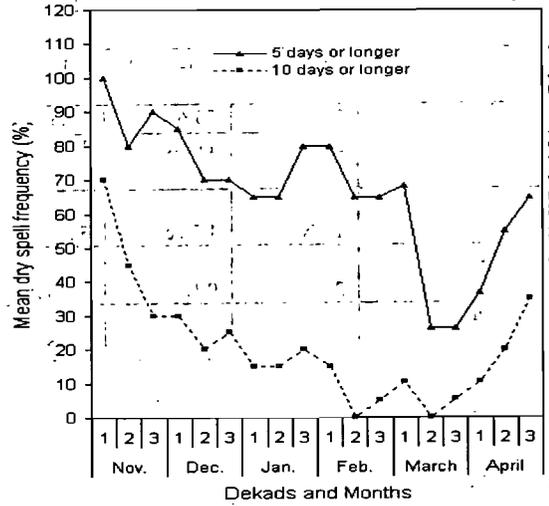


Figure: 3d. Mtwara

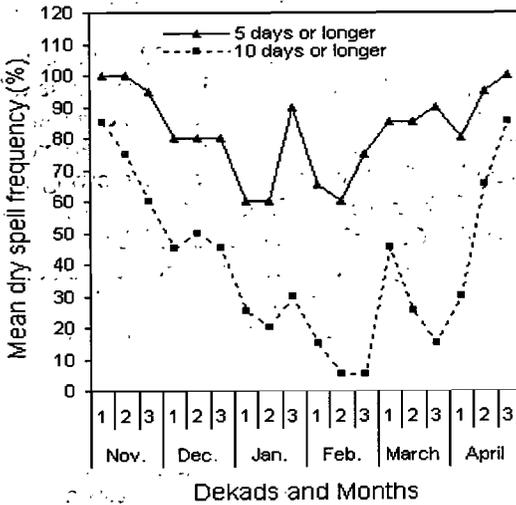


Figure: 3 b. Dodoma

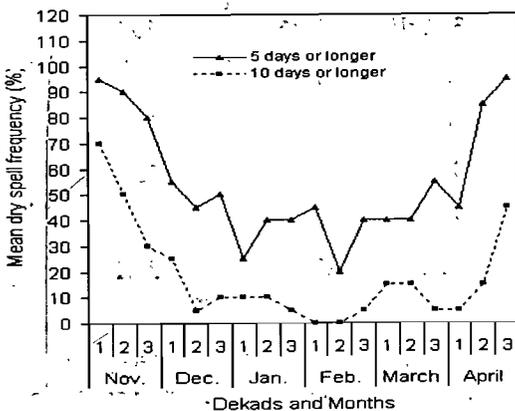


Figure: 3c. Mbeya

Figure 3: The percentage mean dry spell frequency for (a) Kigoma, (b) Dodoma (c) Mbeya and (d) Mtwara

Start and end of the growing season

In Kigoma the season may start as early as late October to as late as late November, while the end of season is early April to early May (Table 3). In Tabora the season may start as early as the third week of November to as late as first week of January, and end as early April to as late as early May. In Mbeya the season may start as early as late November to as late as the fourth week of December, and ends at early April to as late as early May. In the other stations (except Dodoma, where the season starts after mid December) the results show that the season starts early December to as late as early February. The end of the season in Iringa and Dodoma is more certain and occurs in April, latest being the start of the fourth week of the month. The probable start of growing season varies from 18 days (Mbeya and Songea) to 37 days (Mtwara) as compared to the mean cessation dates, which vary from 10 days (Dodoma) to 21 days (Mtwara) (Table 3). The CVs for the mean start of the season ranged from 3.3 to 5%, while that of the end of the season were between 9 and 17.2%. In semi-arid areas high CVs were observed during the onset of the rains and during the cessation of the rains (Ngana, 1990). The high coefficient of variation implies high uncertainty in the crop yield (Hatibu and Mahoo, 2000).

Table 3: Dates of onset and cessation of the growing season at the stations studied

Station	Onset dates at different probabilities				Cessation dates at different probabilities			
	20%	50%	80%	s.d.	20%	50%	80%	s.d.
Kigoma	30-Oct	11-Nov	1-Dec	20	1-Apr	9-Apr	2-May	19
Tabora	18-Nov	1-Dec	5-Jan	22	2-Apr	24-Apr	8-May	17
Mbeya	24-Nov	9-Dec	27-Dec	18	5-Apr	1-May	8-May	15
Songea	3-Dec	18-Dec	31-Dec	18	16-Apr	27-Apr	7-May	11
Iringa	6-Dec	31-Dec	2-Feb	33	1-Apr	5-Apr	21-Apr	11
Dodoma	21-Dec	4-Jan	26-Jan	21	1-Apr	5-Apr	23-Apr	10
Mtwara	1-Dec	13-Dec	1-Feb	37	27-Apr	13-May	31-May	21

Length of the growing season

The minimum lengths vary from 42 days over Iringa to 94 days over Kigoma (Table 4). The maximum lengths vary from 126 days (Dodoma) to 219 days (Mtwara). However, on average the growing season is longest over Kigoma (150 days), while the central region (Dodoma) and Iringa experience the shortest growing season of 93 and 97 days respectively. A study by Gommes and Houssiau (1982) found that the length of the growing season

southern Tanzania was between 130 – 160 days, and average of 90 days in central Tanzania. These values by Gommes and Houssiau (1982) are comparable to what was observed in this study. The coefficients of variation (C.V) for the length of the growing season ranged from 16.1% (Mbeya) to 33.1% (Mtwara). The high C.V values were observed for the length of the growing season over the central region and Mtwara and to a great extent they contribute to crop failure and hence high uncertainty in crop yields.

Table 4. Lengths of the growing seasons at various stations used in the study

	Kigoma	Tabora	Mbeya	Songea	Iringa	Dodoma	Mtwara
Season	4.86°S 29.63°E	5.08°S 32.83°E	8.93°S 33.46°E	10.66°S 35.48°E	7.78°S 35.7°E	6.16°S 35.76°E	10.35°S 40.18°E
Min length	94	85	90	76	42	47	48
Max length	196	175	181	169	145	126	219
Mean	150	134	139	131	97	93	137
Std. deviation	25	27.8	22	22	29	19	45
C.V (%)	16.7	20.7	16.1	17.1	30.2	20.8	33.1

Length of the season and the critical periods for crop water stress

Dekadal rainfall distribution over Kigoma (Fig. 4a) is above 40 mm with a maximum of 70 mm during the third dekad of November. Rainfall at Kigoma goes below 40 mm during the third dekad

of January, and second and third dekads of February, when the crop is at late vegetative and reproductive stages. Dekadal rainfall distribution over Tabora is above 50 mm with a maximum of 80 mm during the second dekad of December (Fig. 4b). Rainfall at Tabora goes below 50 mm

during the first dekad of January, and second and third dekads of February, when the crop is at vegetative and reproductive growth stages, thereby affecting its growth. Mbeya has high rainfall between 60 - 70 mm per dekad during the period between the second dekad of December and February, and third dekad of March (Fig.4c). Low values, between 40 - 55 mm per dekad, on the other hand, are common during the period between the third dekad of February and second dekad of March. Hence a crop of maize can hardly grow successfully. For Songea (Fig. 4d), there is a distinct dekadal rainfall characteristic with January being the wettest month receiving about 95 mm of rainfall per dekad. The dry period (third dekad of February) during intermediate season receives between 60 and 80 mm of rainfall.

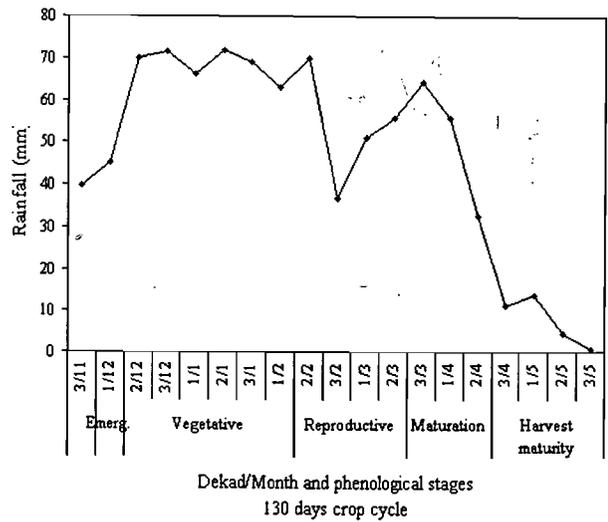


Figure 4 (c): Mbeya

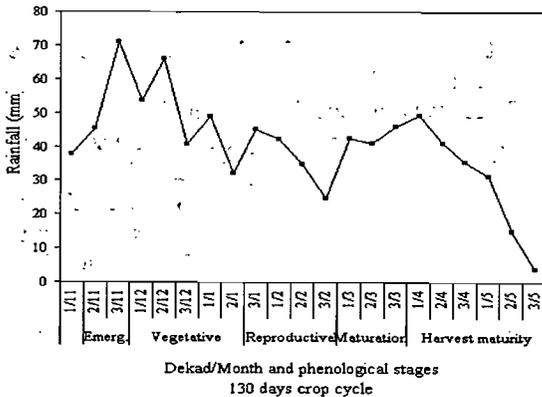


Figure 4(a): Kigoma

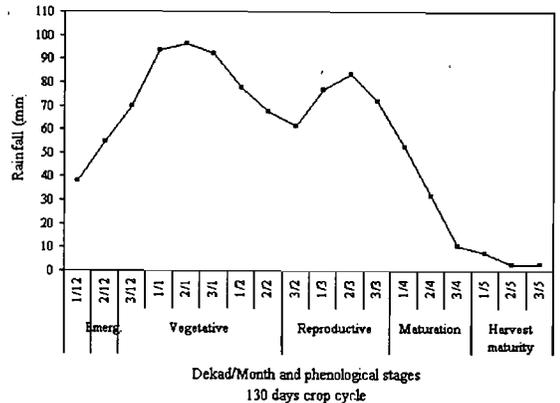


Figure (d): Songea

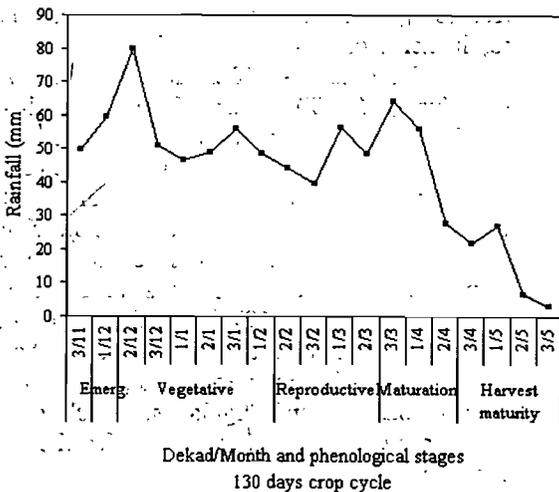
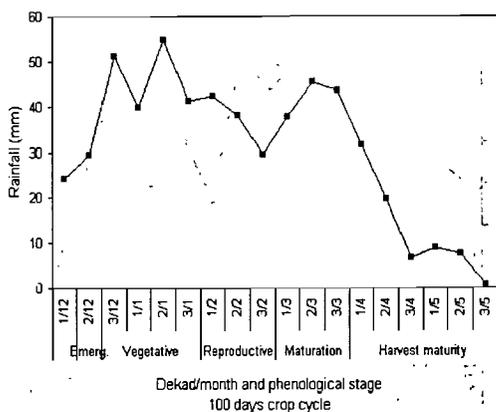


Figure 4 (b): Tabora

Figure 4: Rainfall distribution during different phenological stages of maize with crop cycle of 130 days for (a) Kigoma, (b) Tabora, (c) Mbeya and (d) Songea. Phenological phases are based on fractional crop cycle; vegetative phase (0.42), reproductive phase (0.33), and maturation phase (0.25). After maturation phase the crop starts drying and can be harvested (FAO, 1986)



5 Figure (a) :Iringa

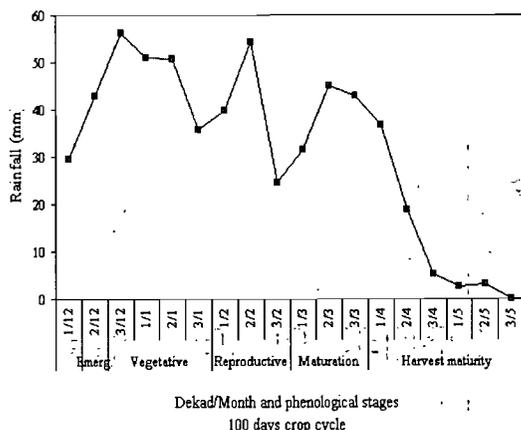


Figure 5b: Dodoma

Figure 5: Rainfall distribution during different phenological stages of millet/sorghum with crop cycle of 100 days for (a) Iringa and (b) Dodoma. Phenological phases are based on fractional crop cycle; vegetative phase (0.42), reproductive phase (0.33), and maturation phase (0.25). After maturation phase the crop starts drying and can be harvested (FAO, 1986)

Iringa and Dodoma exhibit similar rainfall patterns, with the wet period receiving about 50 mm of rainfall per dekad (Fig. 5a and 5b). During the period between the second dekad of February and first dekad of March, rainfall at Iringa is less than 40 mm per dekad. The observation was experienced during the third dekad of January and February, and first dekad of March when the millet/sorghum is at

its vegetative, reproductive, and early maturation stages. The dry spell disrupts its growth cycle.

The observed decrease in rainfall associated with high frequency of dry spells of longer durations during reproductive stage (flowering and grain formation) for maize and millet/sorghum could lead into yield reduction and hence affect the economy of the farmers; most of whom rely on crop production for their income. However, in areas with long growing seasons, say 150 days or more, long duration maize varieties and millet/sorghum could be grown since they suffer less yield damage than short duration varieties as long vegetative period could help the plant to recover when water stress is relieved. Late planting will frequently lead to drought stress at the end of the growing season, and the crop yield may be reduced by 20% (Lomas, 1998).

Latitudinal and longitudinal variations in the mean start of the season

There was a positive correlation ($r = 0.41$) between the mean starting date of the season and latitude, though not significant. Positive and significant correlation ($r = 0.83$) was observed between the mean start of the growing season and longitude. This indicates that the variation in the mean start of the growing season is from north to south and from west to east, with early onset for stations to the north and western side of the region. This relationship is more longitudinal than latitudinal. For example, there is a time lag of 2 weeks between the mean start of the season over Kigoma (14th November) and Tabora (1st December), and the season starts at least one month later in other areas.

These results differ from what Kowal and Knabe (1972) observed over northern Nigeria, where there was a good correlation ($r = 0.88$) between latitude and mean start of the rains. These results however, show the importance of the westerly wind regime (Congo airmass), which makes the ITCZ over the East Africa more active during the rainy season. It was observed by Brown and Cocheme (1973) that the ITCZ over East Africa suffers considerable displacement and distortion due the meridional pattern of East African coastline and highlands, which cause winds, to be more meridional than elsewhere in equatorial areas.

Conclusions

In most of the areas of unimodal rainfall regime, dry spell frequency is higher during the period close to onset and towards the end of the season. The mean start of the growing season is the first week of the month of December for all stations except Kigoma where the growing season starts a bit earlier in the second week of November. The growing season ends in April in most of the years. The decrease in rainfall during intermediate season (February and March) when the crop is at reproductive and maturation phenological phases, usually lead to reduced yields. The variation in the mean start of the growing season is from north to south and from west to east, with early onset for stations to the north and western side of the region, though the relationship is more longitudinal than latitudinal.

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