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Effect of rainfall variability on the length of the crop growing period over the past three decades in central Malawi

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ABSTRACT: The present study investigates the trends of onset, cessation and length of growing period in central Malawi, critical for crop management decisions. These factors are especially important for the smallholder agricultural systems that predominantly depend on rainfall as in most parts of semi-arid southern African countries, such as the central region of Malawi. Onset identification was based on rainfall accumulation, while cessation was based on daily analysis of the ratio of actual to reference crop evapotranspiration. The length of the growing period for a particular season was obtained from the difference between the onset and cessation of that particular season. Series of 30 yr of historical daily climatic data (1980 to 2009) from 5 meteorological stations within the central region of Malawi were considered. Results indicated changes in the onset, cessation and consequently length of the growing period over the past 3 decades. A delayed onset and early cessation of the growing period, resulting in a shorter growing period, were observed. Seasonal rainfall amounts have changed little, but the number of rainfall events has changed remarkably. January has become wetter recently, including higher rainfall amounts and higher rainfall intensity. The results suggest the need for designing appropriate agronomic, soil and water management strategies to offset the negative effects of rainfall variability, especially for smallholder rainfed agriculture.

KEY WORDS: Rainfall · Onset · Cessation · Malawi · Length of growing period

1. INTRODUCTION

Agricultural production in southern Africa is mainly rainfed (Wiyo et al. 2000), as irrigation infrastructure is largely underdeveloped or not fully exploited (Wiyo et al. 1999). Since the amount and distribution of rainfall greatly affect crop production, food security and economic growth of countries in southern Africa (Wiyo et al. 1999), rainfall has been described as the primary limiting factor for crop production in most parts of the tropics (Stern & Coe 1984, Perera et al. 2002).

Malawi (9 to 18° S, 32 to 36° E) is a southern African country bordered by Tanzania, Mozambique and Zambia (Fig. 1). Maize is the main staple cereal that is usually grown by smallholder farmers, who own small farms (<3 ha) and use low levels of inputs for production (Wiyo et al. 1999, Cairns et al. 2013). Maize production is largely rainfed across the country; the central region with fertile soils is the main growing area, and is thus highly sensitive to water availability. Because of the marked seasonal nature of rainfall, crop selection and planning of farm activities for a successful season are difficult, and production is vulnerable (Raes et al. 2004).

Malawi has a sub-tropical climate which is relatively dry and strongly seasonal (Jury & Mwafulirwa 2002). The winter is very dry, and nocturnal temper-

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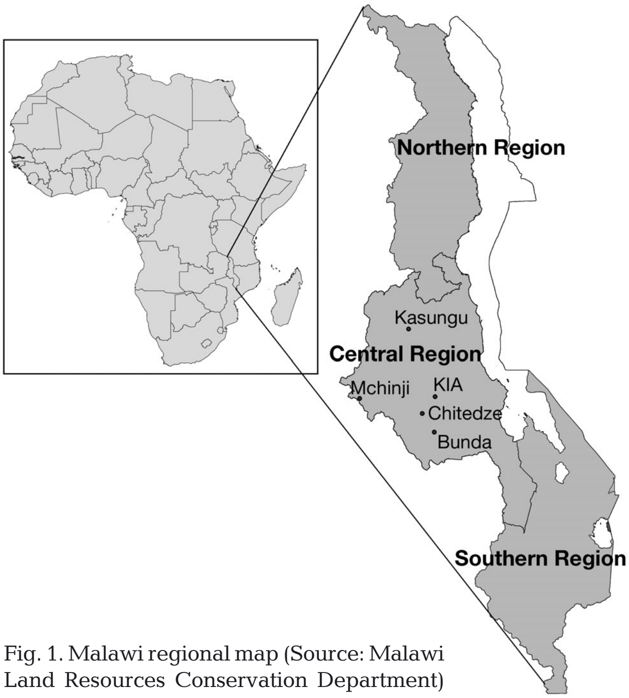

Fig. 1. Malawi regional map (Source: Malawi Land Resources Conservation Department)

atures decline to near 5°C from May to September. The climate of Malawi is strongly influenced by its position within the sub-continent in relation to the pressure and wind systems of the south eastern part of the African continent (Government of Malawi 1998). It is dominated by the north–south migration of the inter-tropical convergence zone (ITCZ) (Ngongondo et al. 2011). The ITCZ marks the convergence of the north-easterly monsoon and south-easterly trade winds, and during the rainy season, it oscillates over the country, often connecting with troughs in the Mozambique Channel. The other main rain-bearing system for Malawi is the northwest monsoon, composed of recurved tropical Atlantic air that reaches Malawi through the Congo basin (Jury & Mwafulirwa 2002). This system in conjunction with the ITCZ brings well-distributed rainfall over the country, and floods may be experienced. There are times when the country is affected by tropical cyclones originating from the West Indian Ocean (Frenken 2005). Depending on their position, cyclones may result in either dry or wet spells over Malawi. Easterly waves originating near Madagascar often penetrate up the Zambezi Valley during summer. Extra-tropical westerly waves are thought to be most active at the beginning and end of the rainy season (Jury & Mwafulirwa 2002). Some areas, especially the highlands to the south of the country, experience sporadic winter rains locally called chiperone between May and August. These rains originate from an influx of cool moist southeast winds during the period (Ngongondo et al. 2011).

Studies that have focused on rainfall trends in relation to onset, cessation and length of growing period (LGP) are few and for selected areas within southern Africa only. Tadross et al. (2005) looked at interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. The study used long-term rainfall to calculate trends of onset for the period from 1979 to 1997 over South Africa and found that onset during this period tended to occur later in the season, particularly over the coastal regions and Limpopo valley. Hachigonta et al. (2008) found no trends but substantial interannual variability in onset and cessation dates with a strong gradient between south and north of Zambia. Similarly, Mupangwa et al. (2011) reported no significant trends in the start and end times or changes in the LGP but a stronger relationship between the start and end of the growing season as aridity increases. More recently, Simelton et al. (2013) looked at whether rainfall is changing in Southern Malawi and Botswana, using farmer perceptions in conjunction with meteorological data to assess the perceived and actual rainfall in regard to trends of onset, duration and cessation of the season. In southern Malawi, they found that most of the farmers perceived a shift in the onset as rains used to start earlier and end later, while meteorological data proved otherwise. They also noted higher interannual variability in the timing of the onset, with increasing dry days and declining amounts of rainfall at the onset and cessation of precipitation.

These findings prompt us to conduct in-depth research on the rainfall characteristics in Malawi, especially the central region. Johnston et al. (2004) recommended attention to seasonal variations, such as onset, cessation and mid-season dry spells, when more accurate and useable seasonal information is to be used in agriculture. The key characteristics of rainfall include the amount, intensity, distribution, onset, cessation and LGP (Ezenekwe et al. 2013). LGP determines the growing season and selection of cultivars of various crops, and is critical for planning farming activities before and during the growing season (Mugalavai et al. 2008), providing more relevant information than seasonal rainfall totals (Hachigonta et al. 2008). Assessing long-term trends of growing season onset and cessation and LGP can help to formulate farming strategies to efficiently use the available water.

Various authors have reported several approaches for assessing trends of rainfall characteristics and their application to agriculture. Examples include determination of the start, end and dry spells of the growing season in semi-arid areas of southern Zimbabwe (Mupangwa et al. 2011) and in Zambia (Hachigonta et al. 2008) using rainfall data; analysis of the onset, cessation and LGP for western Kenya using rainfall and soil water balance (Mugalavai et al. 2008); and determination of growing-season onset and cessation date using rainfall and soil water balance respectively, to analyse trends and variability of rainfall in the Tigray region, Northern Ethiopia (Hadgu et al. 2013). Based on all these studies, it is imperative to use an approach that will be relevant for the end users, in this case, the smallholder farmers. Given that there are several ways of defining the onset of a growing period in the literature (AGRHYMET 1996, Camberlin & Diop 2003, Stern et al. 2003, Raes et al. 2004, Tadross et al. 2009, Ezenekwe et al. 2013), selecting the best method is difficult because these definitions exist at different scales and estimation is always subjective. The choice of criteria used in our study was guided by the prevailing major cereal crop grown and the agroclimatic conditions of the study area. A rainfall-based criterion used by the Famine Early Warning System given by AGRHYMET (1996) is used to determine the onset dates. The cessation dates of the rainy season were determined by criteria given by Mhizha et al. (2012), who used a combination of crop characteristics, soil water conditions, soil type, rainfall and evaporative power of the atmosphere.

To a smallholder subsistence farmer, having prior knowledge about onset dates of the rainy season is very useful for planning the timely preparation of fields. This knowledge also helps farmers to decide to use a less risky planting date or planting method or to sow less risky types/cultivars of crops. Furthermore, it minimises the risks involved in planting too early or too late (Omotosho et al. 2000). Knowledge of the early phases of previous rainy seasons can be applied to advise farmers on the use, type, rates and timing of fertilizer additions, on adapting sowing densities/patterns and, later in the season, on plant densities by thinning (Ezenekwe et al. 2013). Knowledge of the cessation dates during a particular season is important as it helps farmers to assess the possible LGP. It also provides information for the optimal harvesting and subsequent storage of crops, since unexpected late rains can cause these to spoil (Hachigonta et al. 2008). This information can also help with the year-to-year selection of crop cultivars adapted to the variability in the length of the rainy season (Hachigonta et al. 2008).

The presence of a relationship between onset, cessation dates and LGP is relevant for planning agronomic activities in the season (Mugalavai et al. 2008). Thus, reliable estimations of onset and cessation of the rain could help optimize rainwater use in semi-arid areas (Raes et al. 2004, Mugalavai et al. 2008). Therefore, assessing trends in rainfall characteristics based on past records is essential for developing suitable farming strategies (Hadgu et al. 2013) in different areas. The aim of this study is to investigate the characteristics and trends of rainfall in central Malawi, the main region for maize production in the country. The focus of the study was on the onset, cessation and LGP, which are crucial for effective rainfed crop production.

2. MATERIALS AND METHODS

2.1. Study site

The study was conducted in the central region of Malawi, between latitudes 12.5° and 14.5° S and longitudes 33° and 34.7° E (Fig. 1), where 90% of the economic activities are agro-based.

The area has a favourable climate for crop production. Its temperature ranges from 16 to 26°C, with annual average rainfall between 900 and 1200 mm, mainly concentrated in the period from November to April. The monthly reference evapotranspiration (ET_o) ranges from 90 mm in winter (May, June and July) to a peak of 180 mm in October (see Fig. 2)

The area has predominantly red soils (ferric luvisols) (Wiyo et al. 1999) with a sandy clay loam texture (Saka et al. 2003). These soils are generally well structured, deep and well drained. Ferric luvisols are highly productive; hence, the central region produces most of the maize in Malawi.

2.2. Meteorological data

Long series of daily rainfall from 5 meteorological stations in the central region of Malawi were collected from the Malawi Department of Climate Change and Meteorological Services (Table 1). Additional climatic data (minimum and maximum temperature, relative air humidity, solar radiation and wind speed) for computing reference evapotranspiration (ET_o) with the Penman Monteith equation (Allen et al. 1998) used by the FAO (Food and Agricultural Organisation of the United Nations) were obtained from the FAO New_LocClim climate estimator (FAO 2005).

Table 1. Geographical description of meteorological stations used in the study (30 yr period, 1980–2009). KIA: Kamuzu International Airport; m a.s.l.: meters above sea level

Station	Latitude (°S)	Longitude (°E)	Altitude (m a.s.l)
Bunda	14.18	33.77	1118
Chitedze	13.97	33.63	1149
Kasungu	13.02	33.47	1058
KIA	13.78	33.78	1229
Mchinji	13.80	32.90	1181

2.3. Onset, cessation and length of growing period (LGP)

The onset of the rainy season was determined for each station as the first day in the first 10 d period of the rainy season with a total rainfall of 25 mm, on the condition that it is followed by two 10 d periods with at least cumulative rainfall of 20 mm (AGRHYMET 1996, Hachigonta et al. 2008, Harrison et al. 2011). With these conditions, the initial moisture requirements for seed germination and crop establishment are considered. It also ensures that the soil moisture levels are high enough in the topsoil to sustain initial crop development. This criterion is adopted from the Famine Early Warning System, which was developed at the Agriculture-Hydrology-Meteorology (AGRHYMET) Regional Center in Niger. To avoid false starts of the rainy season, the search period was set from 1 October.

The cessation date of the rainy season was determined for each station based on the method used by Mhizha et al. (2012). It tailors cessation to crop and soil type by considering the ratio of actual evapotranspiration (ET_a) to ET_o, against the crop coefficient (K_c) at maturity. The cessation date was picked as the first day after 15 February when the ratio of ET_a to ET_o dropped below 0.35, which is the K_c value of maize at maturity (Allen et al. 1998). The initial search day of 15 February was selected to exclude and minimise the influence of mid-season dry periods (Mhizha et al. 2012), which usually occur in this area especially during the rainy season (Usman & Reason 2004, Nyakudya & Stroosnijder 2011). Another assumption is that the crop will have by this time surpassed the critical stage in its early development. In contrast to methods based on rainfall only (Tadross et al. 2009, Mupangwa et al. 2011, Hadgu et al. 2013), this method considers cessation of the growing period as a function of crop characteristics, soil water conditions and soil type in addition to the evaporating power of the atmosphere and rainfall of the location (Mhizha et al. 2012).

The soil water balance model BUDGET (Raes et al. 2006) was used to simulate ET_a on a daily time step. ET_a dropped below crop evapotranspiration ($ET_c = K_c \times ET_o$) when 55% of total available water was depleted. The crop was allowed to transpire beyond the normal crop cycle length as long as the available soil water allowed it. This was done by extending the normal period and keeping constant the crop characteristics ($K_{c,mid}$) of the mid-season stage (the mid-season until the end of the season was extended from 75 d to 200 d). The daily ratio of ET_a to ET_o was observed. The date when the ratio was below 0.35 was selected as the cessation date. Table 2 shows the maize crop characteristics that were taken from Doorenbos & Kassam (1979) and Allen et al. (1998).

The soil type used in all the simulations was sandy clay loam, which is commonly found in the central region of Malawi (Saka et al. 2003). Characteristics of the soil used in the simulations (Table 3) were obtained by means of a pedotransfer function (Saxton et al. 1986, Saxton 2003) based on soil texture analysis.

The LGP was calculated for each station as the period between the onset and cessation date, expressed in calendar days.

Table 2. Crop parameters for maize. Source: Doorenbos & Kassam (1979), Allen et al. (1998)

Growth stage	Length of growth stages (d)	Rooting depth (m)	K_c (crop coefficient)
Initial	20	0.3	0.17 (dry), 1.1 (wet top soil)
Crop development	40	0.3–1.2	(0.17–1.1) to 1.17
Mid-season until the end of season	75	1.2	1.17 to 0.35

Table 3. Soil characteristics of the study area used in the simulations. PWP: permanent wilting point; FC: field capacity; SAT: saturation point; TAW: total available water; K_{sat}: saturated hydraulic conductivity

Soil type	PWP (vol%)	FC (vol%)	SAT (vol%)	TAW (mm m^{-1})	K_{sat} (mm d^{-1})
Sandy clay loam	14.9	25.8	44.1	110	360

2.4. Trend analysis

2.4.1. Test of randomness and persistence

Trend detection in time series requires data that are random and persistence-free (Ngongondo et al. 2011) to solve the confounding effect of serial dependence when interpreting the results. Kulkarni & Von Storch (1995) argue that if the data series contain positive correlations, the non-parametric test could indicate a significant trend due to random effects of the data series. Therefore, in our study, the rainfall time series for each station was tested for randomness and independence using an autocorrelation function as described by Von Storch (1995) as follows:

$$r_k = \frac{\sum_{i=1}^{N-k}(x_i - \bar{x})(x_{i+k} - \bar{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (1)$$

where r_k is the lag–k autocorrelation coefficient, $\bar{x}$ is the mean value of a time series x_i, N is the number of observations, and k is the time lag. Random series have autocorrelations near zero for all time lag separations, except the zero lag coefficient which is always 1. In that case, statistical tests are directly applied to the series. Non-random series have ≥1 significantly non-zero autocorrelation values, and statistical tests in this case are applied to a pre-whitened series to account for the non-randomness.

2.4.2. Mann-Kendall test

There are numerous tests for detecting and estimating trends in meteorological data. The World Meteorological Organisation (WMO) recommends the non-parametric Mann-Kendall (MK) test statistic (Mann 1945, Kendall 1975) for the assessment of trends in meteorological data (WMO 1988). The MK test is simple, robust and less sensitive to outliers and missing data (Ngongondo et al. 2011, Tabari et al. 2014). The test is also recommended for non-normally distributed data series such as rainfall (Lettenmaier et al. 1994). The MK test has been widely applied in various trend-detection studies (Batisani & Yarnal 2010, Ngongondo et al. 2011, Hadgu et al. 2013, Tabari et al. 2014). In our study, the MK test was applied at a significance level of 5% to detect temporal trends in onset, cessation and LGP time series. The test statistic is computed as follows:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (2)$$

in which

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \quad (3)$$

The variance of S, for the situation where there may be ties (that is, equal values) in the x values, is given as follows:

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)\right] \quad (4)$$

where the x_j and x_i are the sequential data values, m is the number of tied groups (a tied group is a set of sample data having the same value), t_i is the number of data points in the ith group, n is the length of the data set, S is the MK test statistic, Z_{MK} is the normalized MK test statistic and $\mathrm{sgn}(x_j - x_i)$ is equal to 1, 0, −1 if $(x_j - x_i)$ is greater than, equal to, or less than zero, respectively (Tabari et al. 2014). The presence of a statistically significant trend is evaluated using the Z_{MK} value. The positive (negative) values of Z_{MK} indicate increasing (decreasing) trends, and the value $Z_{1-\alpha/2}$ denotes a quantile of the standard normal cumulative distribution. The null hypothesis H_0 should be accepted if $-Z_{1-\alpha/2} \le Z_{MK} \le Z_{1-\alpha/2}$ at a given level of significance (where α is a chosen level of significance).

2.4.3. Cumulative sum test

To find out in which year (or years) an abrupt change occurred in the time series, the cumulative sum (Cumsum) technique (Tabari et al. 2014) was used to identify the change point. The 'Cumsum' is calculated as follows (Kiely 1999):

$$S_k = \sum_{t=1}^{k}(x_t - \bar{x}), \qquad k = 1, 2, \ldots, n \quad (5)$$

where $\bar{x}$ is the average value of the time series. The possible change occurs when S_k is at its maximum. The Cumsum test was applied to the time series with significant trends.

The coefficient of variation (CV) was calculated to evaluate the variability of onset, cessation and LGP by dividing the standard deviation of the event by its mean.

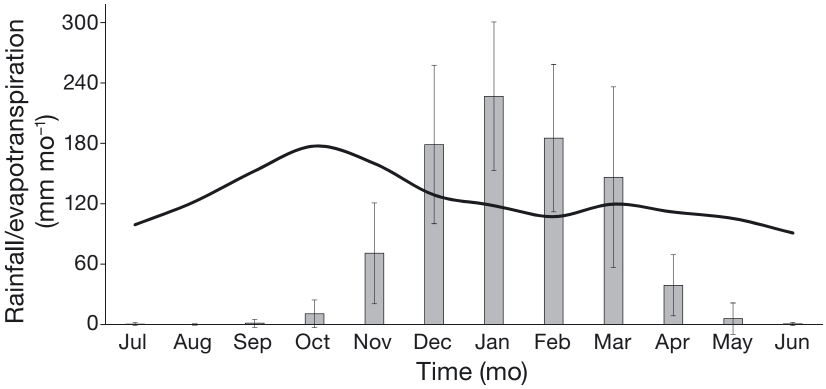

Fig. 2. Average (1970–2012) monthly rainfall (bars; error bars: standard deviation) and reference evapotranspiration (bold line) of the central region of Malawi (Source: Malawi Department of Climate Change and Meteorological Services)

2.5. Changes in rainfall amount and number of rainfall events

To assess the long-term changes of rainfall in terms of total amounts and number of rainfall events in the region, two 15 yr periods were compared. The data were divided into 2 groups owing to the results from the Cumsum technique, which was applied to time series that showed statistically significant trends. Our assumption is that the behaviour of rainfall changed after the 1995/96 season (based on the Cumsum results). The data were divided into an earlier period (1980 to 1994) and a later period of 1995 to 2009. Simelton et al. (2013) also reported similar changes in rainfall for central Malawi from the 1996/97 season onward, which indicates the notion of abrupt changes as indicated by the Cumsum results. Both the total rainfall amount and the number of rainfall events were calculated for each month. The threshold used for defining a significant rainfall event was 5 mm. This value is suitable for regions experiencing pan evaporation of ~5 mm d^{-1} (Fig. 2) and as an amount that can have significant influence on crop growth (Stern et al. 2003, Woltering 2005).

Table 4. Cross-correlation coefficients among the stations

	Bunda	Chitedze	KIA	Kasungu	Mchinji
Bunda	1	0.33	0.28	0.11	0.25
Chitedze		1	0.42	0.13	0.36
KIA			1	0.13	0.31
Kasungu				1	0.11
Mchinji					1

3. RESULTS

3.1. Serial correlation

The daily rainfall time series for each station did not reveal any significant serial correlations at all lags. The stations are not correlated to each other, as presented in Table 4. These time series were therefore random, meeting the independence distribution criteria. Therefore, the analysis of the trends of the rainfall characteristics did not require any further data manipulation, and the MK test was applied directly.

3.2. Onset of growing season

Fig. 3 shows the time series of onset dates of different stations in central Malawi. There is year-to-year variation, with all stations showing a tendency of the onset date being delayed from the last 10 d period of November in the beginning of the time series to the second 10 d period of December toward the end of the time series. The mean onset date is similar in all stations but Chitedze (Table 5). The pattern displayed by Chitedze is more closely linked to early start of the rains than the rest of the stations that fulfill the criteria used to define the onset. These dates are characterized with high standard deviation (>10 d), which indicates that the onset date in the last 30 yr has been changing significantly in most stations. The MK test revealed a statistically increasing trend at 95% level of confidence in all stations but KIA. The increasing trend means that the onset dates tends to start later in the season at all stations. There is high variability (CV > 20%) in the onset dates (Table 5), which creates difficulties in decision making for crop management especially regarding planting dates in the region. The 1995/96 season marks the time when an abrupt change in the onset dates was observed for Bunda, Chitedze, Kasungu and KIA, whereas for Mchinji, this change occurred in the 1996/97 season.

3.3. Cessation of growing season

Fig. 4 shows the time series of cessation dates for different stations in central Malawi. Mean cessation dates in all the stations are similar (around the last

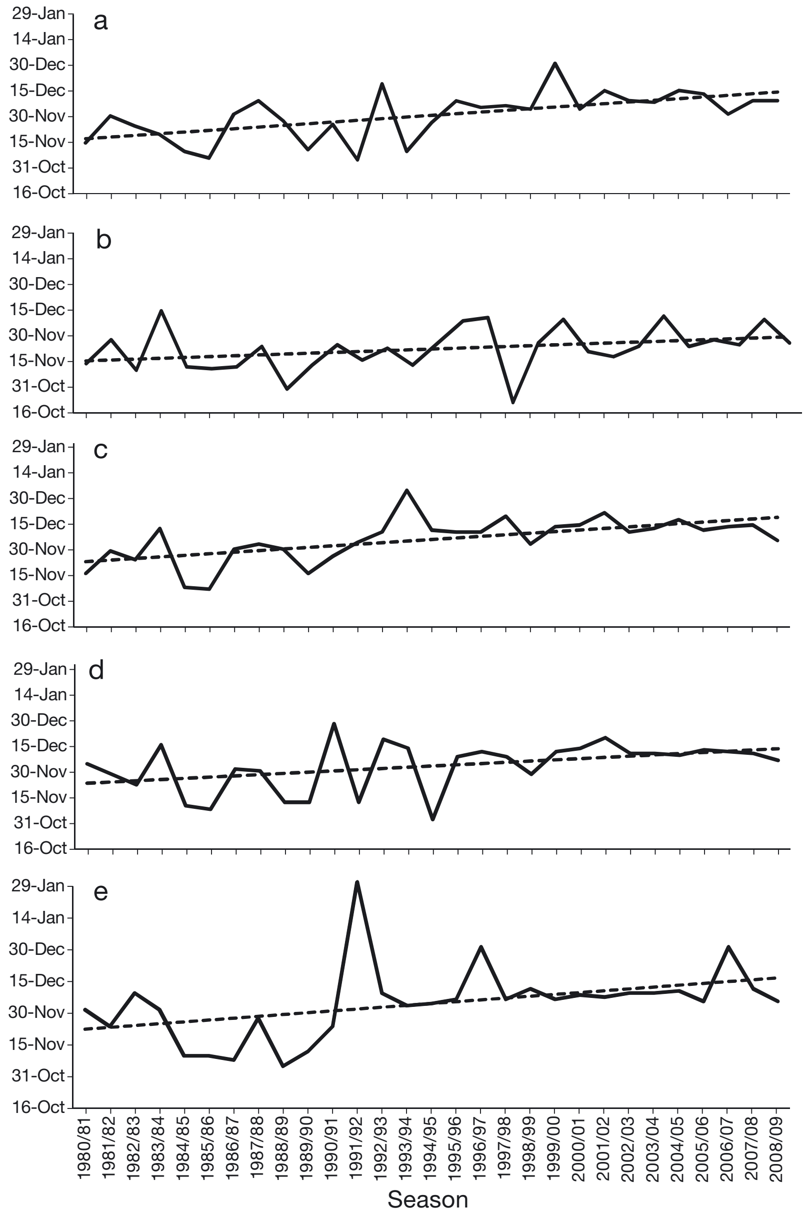

Fig. 3. Time series of onset dates for the central region of Malawi from the seasons 1980/81 to 2008/09 (a: Bunda; b: Chitedze; c: Kasungu; d: KIA; e: Mchinji). The dotted line shows the linear trend of the data points

but still unpredictable. A stable cessation date is advantageous to farmers in planning for off-season farming activities. These activities include searching for markets, processing farm produce and winter farming.

3.4. Length of growing period (LGP)

Fig. 5 shows the time series of the LGP for different stations in central Malawi. There is a general decreasing trend, following the general delay in onset and the advancement of the cessation date. The average LGP in the study region varied from 135 to 149 d depending on the location of the station (Table 5). Kasungu and KIA had 137 d, Mchinji had 135 d, while Bunda and Chitedze had 140 and 149 d respectively. However, all stations displayed high standard deviations (>20 d), which indicates how the LGP varies in time among the stations. The coefficient of variation in all stations but Kasungu (12%) showed high (>20%) year to year variability of LGP. This indicates how risky it is to rely on one type of crop in areas where LGP is constantly varying. Knowledge of the LGP is very useful in planning the type of cultivars to be grown based on their maturity period. All the stations revealed that the LGP has decreased in the last 3 decades. The MK test revealed a statistically significant decreasing trend in LGP at Chitedze and Kasungu. The 1995/96 season was when an abrupt change occurred.

10 d period of April) with high standard deviations (>20 d) as presented in Table 5. There is on average an earlier cessation of 15 d between 1980/81 and 2008/09 in these stations, approximately 5 d per decade. The MK test indicates a general decreasing trend at 95% confidence level in the cessation dates for all the sites except Kasungu. Contrary to the standard deviation, coefficients of variation are generally low in all stations, indicating low variability and possibly relatively stable cessation dates in the region

3.5. Changes in rainfall amount and number of rainfall events

Figs. 6 & 7 show the number of rainfall events per month and the total monthly rainfall amount in the rainy season for the 2 periods, i.e. 1980–1994 and 1995–2009. The earlier period (1980 to 1994) has a longer rainy season with the rainfall events spread over the 6 mo of the wet season for Bunda, Chitedze, Kasungu and KIA. However, in the later period (1995

Table 5. Statistical summary of onset, cessation dates and length of growing period (LGP) of central Malawi over the period 1980 to 2009. Z_{MK}: Mann-Kendall trend test; *statistically significant trend (α = 0.05); SD: standard deviation; CV: coefficient of variation; Cumsum: cumulative sum test showing the season where an abrupt change occurred in statistically significant trend results

Statistic	Station				
	Bunda	Chitedze	Kasungu	KIA	Mchinji
Onset date					
Mean	2 Dec	22 Nov	6 Dec	3 Dec	2 Dec
SD (d)	14	13	13	14	22
Z_{MK}	3.11*	2.36*	3.71*	1.74	2.29*
CV (%)	21	22	13	34	19
Cumsum	1995/96	1995/96	1995/96	–	1995/96
Cessation date					
Mean	21 Apr	21 Apr	22 Apr	19 Apr	16 Apr
SD (d)	21	21	11	21	27
Z_{MK}	–0.51	–1.82	0.56	–0.49	–0.53
CV (%)	10	10	12	13	05
LGP (d)					
Mean	140	149	137	137	135
SD	28	28	16	31	36
Z_{MK}	–1.651	–2.05*	–2.27*	–1.63	–1.73
CV (%)	20	19	12	22	27
Cumsum	–	1995/96	1995/96	–	–

to 2009), both the total seasonal rainfall and the number of rainfall events during the first and last months of the rainy season were lower, whilst there is a high peak of rainfall in January. More rain fell in the month of January in the later period (1995 to 2009). There was high variability in the rainfall amounts in all the stations as indicated by the large error bars in the graphs (Fig. 7). Mchinji station had a decline in both the monthly rainfall amounts and the number of rainfall events in a month during the rainy season.

Table 6 summarises the onset, cessation dates and LGP of the 5 stations in central Malawi in the 2 periods 1980–1994 (earlier) and 1994–2009 (later). The data-set was split into 2 time periods of equal length to evaluate if the increased total and intensity (amount of rainfall per rainy day) of rainfall in January has an effect on the rainfall characteristics. The results show that on average, onset dates have shifted from the last 10 d period of November to the first 10 d period of December between the earlier and later period. There is higher variability in the earlier period than in the latest period as shown by the high (>10 d) standard deviation and coefficient of variation (>20%). The MK test shows that there is an increasing trend in both the earlier and later periods, with Kasungu and Mchinji showing statistically significant increasing trends in the earlier and later period respectively. The cessation dates for all stations start from the second 10 d period of April for both of the periods considered. Unlike the onset dates, the standard deviation and coefficients of variation are not consistent in displaying higher and lower values. Almost all stations have low CV values (<15%), which indicates low variability in terms of cessation of the growing period. On average, the MK test shows a general decreasing trend in both of the periods in almost all stations. The LGP has decreased in all stations from an average of 145 d to ~130 d because of the delay in the onset of the seasons, although this change is not significant at the 95% confidence level in Bunda, KIA and Mchinji. There is also high interannual variability in the LGP that is reflected by high standard deviations and coefficients of variation in all the stations.

4. DISCUSSION

The objective of this study was to assess the trends of the onset and cessation of the growing period and the LGP in central Malawi for the cultivation of maize. The results indicate that the LGP has been getting shorter in the last 3 decades. This change follows a delaying trend in suitable onset dates and an advancing (early) cessation trend of the growing period in some areas. These characteristics are important as they influence crop production. The results support the notion that the rainfall patterns, which are important for maize production in central Malawi, have shifted. The seasonal amount of rainfall in the region is still the same, but the monthly rainfall and its variation are changing. An implication of this phenomenon is that farmers will have to adopt husbandry practices that can fit in this shortened growing season. However, our study has limitations as it only considered rainfall. Possible trends and shifts in other climatic variables like temperature and other environmental parameters were not considered. The interaction of these factors with rainfall might have an influence on the results presented here. Nonetheless, our assumption was based on the major limiting factor for crop production in the tropics, in this case rainfall.

These results compare well with previous findings of Hachigonta et al. (2008), who reported the seasonal decline between 1979 and 2002 in Zambia, while Hadgu et al. (2013) reported a similar trend of decreasing LGP from 1980 to 2009 in Tigray, north of Ethiopia, from both farmers' perception and meteo-

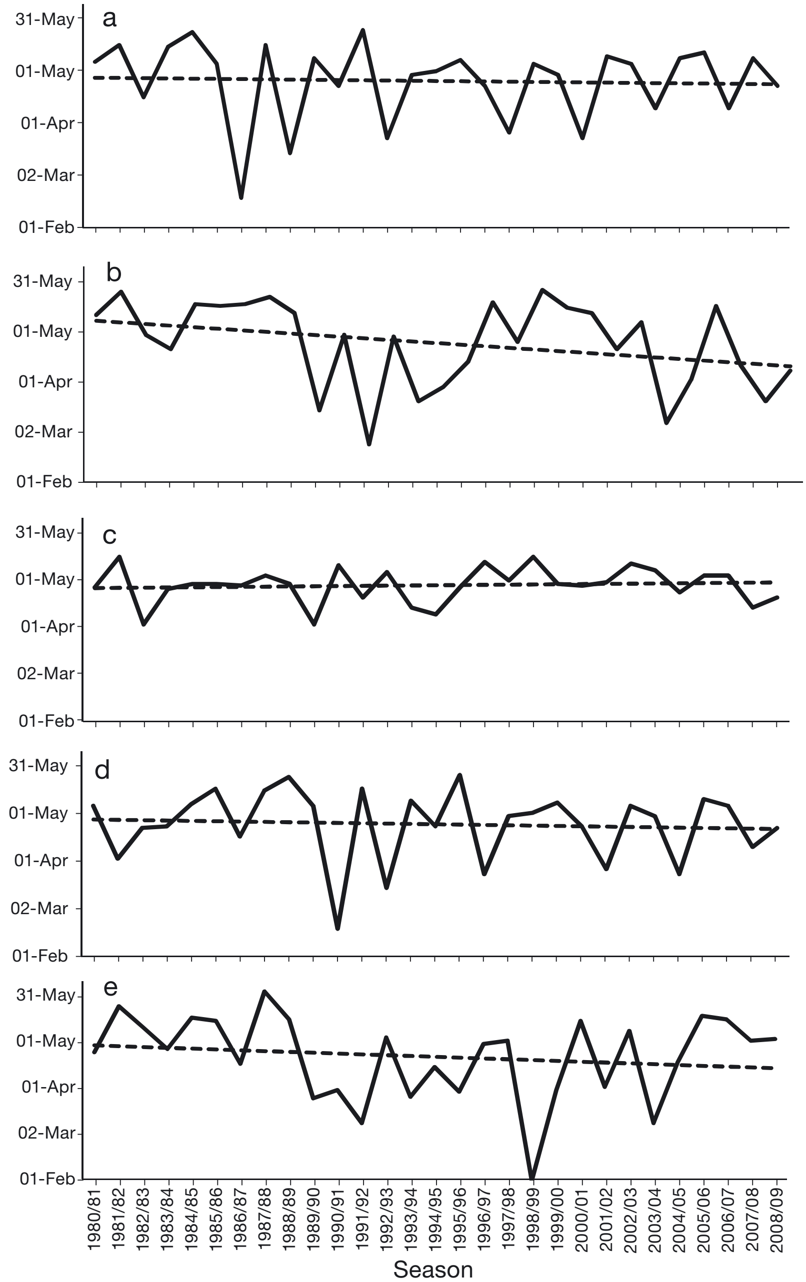

Fig. 4. Time series of cessation dates for the central region of Malawi from the seasons 1980/81 to 2008/09 (a: Bunda; b: Chitedze; c: Kasungu; d: KIA; e: Mchinji). The dotted line shows the linear trend of the data points

rological data. Ooms (2012) and Simelton et al. (2013) reported that Malawian farmers' perception in the central region of Malawi was that the start of the rainfall season is shifting from November toward mid-December while cessation is receding toward early April in recent seasons. It is evident from the current analysis that the season is indeed getting shorter, and this has great consequences for food security as problems can arise due to these agro-climatic shifts (Harrison et al. 2011). Farmers have to adjust their cropping calendars and possibly change their cultivars to suit the shorter LGP. This has a negative effect, as these short-season cultivars tend to produce less biomass; hence, total production is lower.

The results of the current study are in contrast with those of Mupangwa et al. (2011) in Zimbabwe and Mugalavai et al. (2008) in Kenya, who found no significant changes in the start, end and LGP. In Malawi, Vrieling et al. (2013) found no significant trends in LGP estimated from NDVI for the 1981–2011 period. This is partly comparable to KIA, Mchinji and Bunda, while Chitedze and Kasungu have significant trends. The source of this discrepancy might be the different approaches or criteria used in identifying the onset of the growing season and the data sets. In this research, we used observed data from stations, while Vrieling et al. (2013) used NDVI, which is spatial and pixel-based. With spatial data, there might be some overestimation of the values. Nevertheless, the authors advocated continuous monitoring of the seasons to detect any shifts if they arise in future.

Malawi's rainfall depends on the position of the ITCZ, which can vary in its timing and intensity from year to year (McSweeney et al. 2010a). The country experiences peak rainfall during the month of January, which is associated with the activities of the ITCZ and Congo air mass (McSweeney et al. 2010b). Malawi is usually under the active Congo air mass and ITCZ in January, resulting in unstable moist conditions over the country (Government of Malawi 2014). It is the activity of these 2 air masses that results in heavy rainfall in January in most parts of Malawi (Government of Malawi 2014). In recent years (1995 to 2009), there have been more rainfall events in the month of January than in the rest of the months of the rainy season. This means that there is more readily available water for the crop in the month of January than in the rest of the rainy season in this area. The results compare well with those of

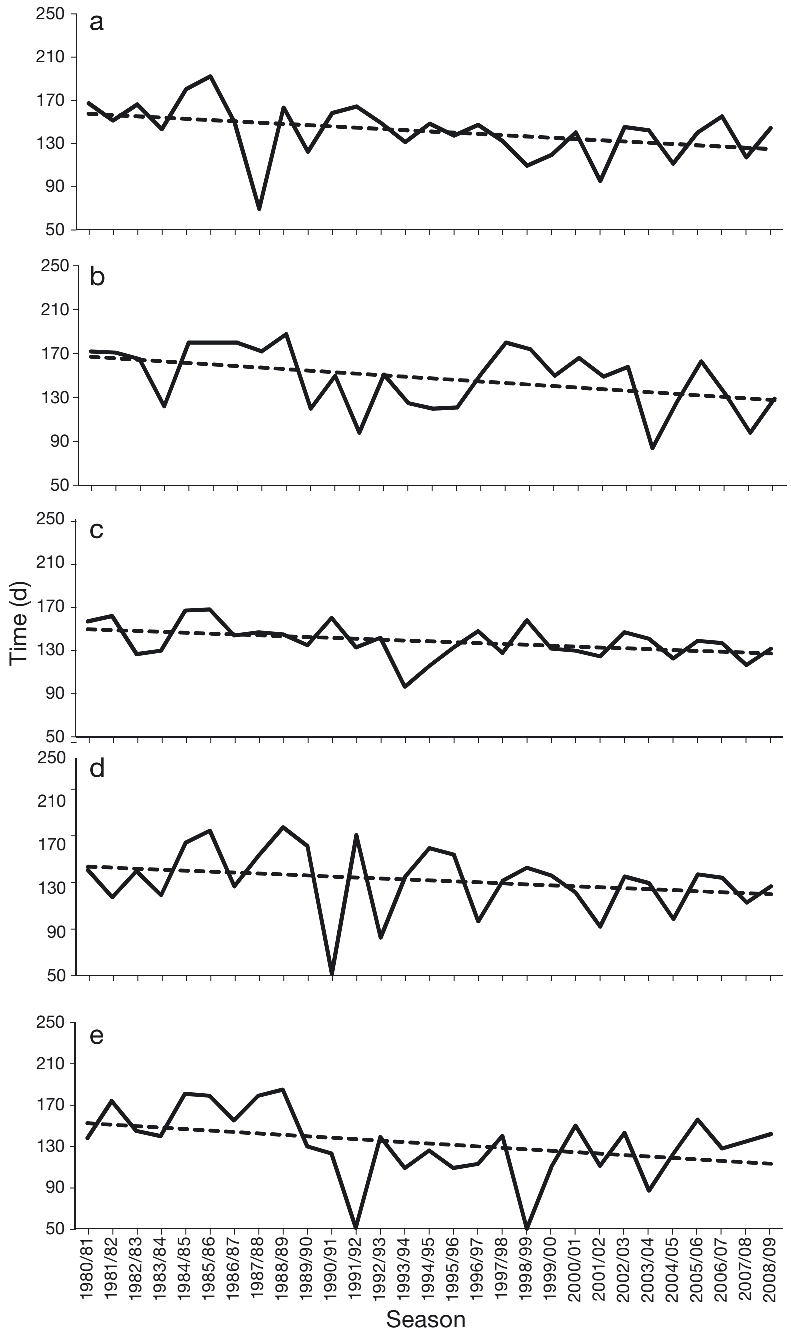

Fig. 5. Time series of length of growing period for the central region of Malawi from the seasons 1980/81 to 2008/09 (a: Bunda; b: Chitedze; c: Kasungu; d: KIA; e: Mchinji). The dotted line shows the linear trend of the data points

Simelton et al. (2013), who reported increased monthly rainfall totals for the month of January and significant decreases in monthly rainfall in December, February and April in the same region. The report further states that rainfall intensity became more variable from 1996/97 and significantly increased intensity in January by >80 mm. This result is in line with observations made by Twomlow et al. (2006) that characteristics of growing seasons are influenced by other factors such as rainfall distribution in additional to total rainfall and onset of the rains. Adiku et al. (1997) also stated a stronger influence of the distribution and reliability of rainfall during the growing season on the characteristics of the growing period than of total rainfall.

The large amounts of rainfall in January pose a threat to crop production. There is danger of waterlogging in the fields, which can lead to yield reduction through anaerobic stress in the roots. The extra water can also lead to soil erosion through surface runoff in the absence of soil conservation structures. The water will be lost through runoff, which takes away plant nutrients and loosens topsoil. The use of small ponds deliberately constructed within or adjacent to the field to harvest this extra water is suggested as a control measure. This construction might also in the long term control incidences of soil erosion as more water will be contained in these ponds, and hence, there will be less runoff. The use of field ponds has been a success in northern Ethiopia (Wondumagegnehu et al. 2007) where the growing season is too short and the collected water in the ponds is used for irrigation after cessation of the rains to meet the crop water requirements at the end of the season. However, this proposition comes with a price in that farmers have to be prepared to lose part of the fields to have the ponds constructed, and also that it requires additional costs in labour.

This study showed that ET_o is higher than the rainfall amounts in the months of March, April and May, which means that there is water stress during these months. The most critical month is March, as the maize crop is usually still at the grain-filling stage. There is a danger of yield reduction if there is a prolonged water stress during this sensitive growth stage. If the water stored in ponds is used to cover for this period, yield losses will be minimised.

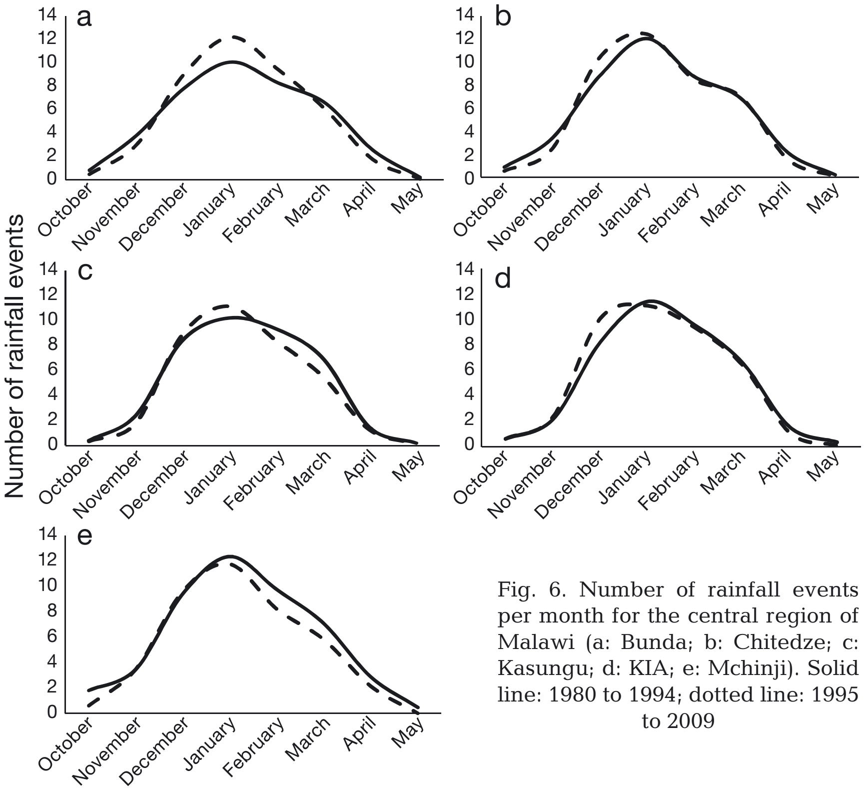

Fig. 6. Number of rainfall events per month for the central region of Malawi (a: Bunda; b: Chitedze; c: Kasungu; d: KIA; e: Mchinji). Solid line: 1980 to 1994; dotted line: 1995 to 2009

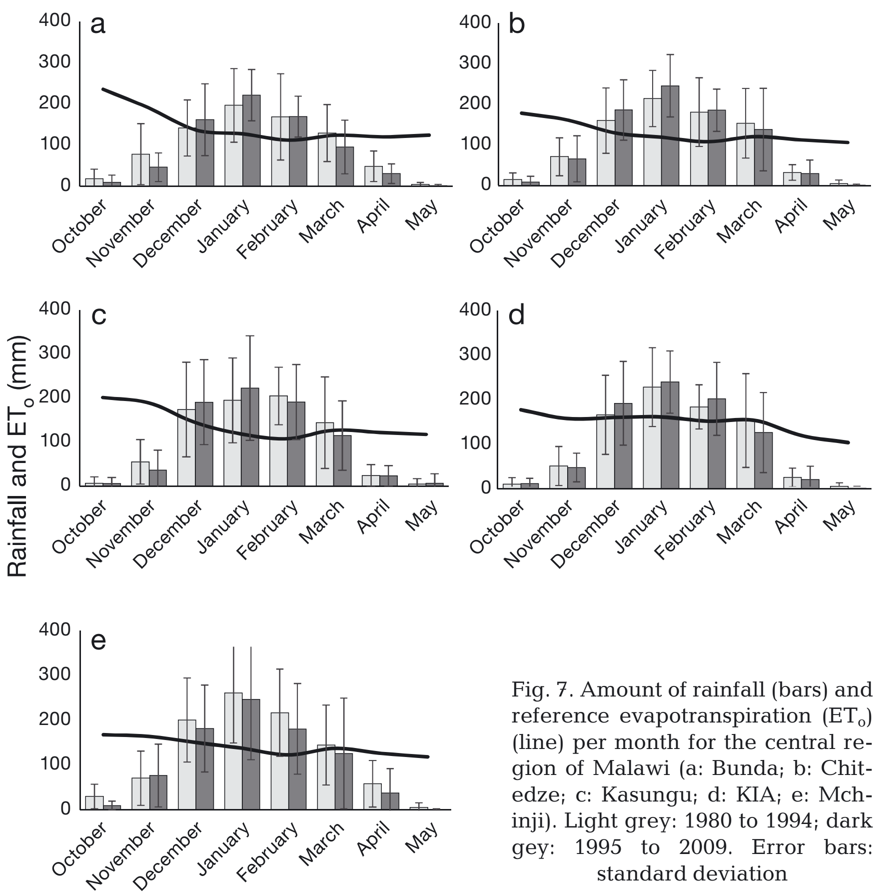

Fig. 7. Amount of rainfall (bars) and reference evapotranspiration (ET_o) (line) per month for the central region of Malawi (a: Bunda; b: Chitedze; c: Kasungu; d: KIA; e: Mchinji). Light grey: 1980 to 1994; dark gey: 1995 to 2009. Error bars: standard deviation

The variability in the onset and cessation of the growing period and consequently the LGP was expected because the rainfall in this region is usually considered variable (Vincent et al. 2013). These variations in the rainfall characteristics were expected as southern Africa is characterised by seasonal and within season rainfall variability. Substantial decadal to multi-decadal summer rainfall variability in southern Africa was reported by Tadross et al. (2005). The inter-seasonal variability of the rainfall in southern Africa was also reported by Tadross et al. (2009) and Hachigonta et al. (2008), which confirms these findings for Malawi's central region. The inter-annual variability of Malawi rainfall is strongly influenced by the position of the ITCZ and Indian Ocean sea surface temperatures, which can vary from one year to another due to variations in patterns of atmospheric and oceanic circulation, with El Niño Southern Oscillation as the main cause (Hoerling et al. 2006, Lyon & Mason 2007, 2009, McSweeney et al. 2010a). McSweeney et al. (2010a) emphasised the difficulty in predicting the influences of El Niño Southern Oscillation on the climate of Malawi by observing that Malawi sits between 2 regions of opposing climatic response to El Niño. Eastern equatorial Africa tends to receive above-average rainfall in El Niño conditions, whilst south-eastern Africa often experiences below-average rainfall. The opposite response pattern occurs in La Niña episodes. The response of climate in each of these 2 regions, and the extent of the area affected, varies with each El Niño or La Niña event, causing mixed responses in Malawi. Therefore, conflicting results regarding the onset, cessation and consequently LGP were expected due to these atmospheric activities. The average onset dates are similar among stations in the 2 periods but with high standard deviations, which suggests the complexity of effective decision

Table 6. Summary of statistics of onset, cessation dates and length of growing period (LGP) at 5 stations over the period 1980 to 2009 in the central region of Malawi. Earlier: 1980 to 1994; Later: 1995 to 2009. Z_{MK}: Mann-Kendall trend test; *statistically significant trend (α = 0.05); SD: standard deviation; CV: coefficient of variation

Statistic	Bunda		Chitedze		Kasungu		KIA		Mchinji	
	Earlier	Later	Earlier	Later	Earlier	Later	Earlier	Later	Earlier	Later
Onset date										
Mean	22-Nov	10-Dec	18-Nov	28-Nov	29-Nov	12-Dec	26-Nov	10-Dec	30-Nov	12-Dec
SD	13	7	11	13	15	5	17	5	27	9
Z_{MK}	–0.16	0.3	0.11	0.25	1.86*	0.4	0.38	0.74	–0.11	1.53*
CV (%)	25	10	23	22	25	6	27	16	47	22
Cessation date										
Mean	22-Apr	21-Apr	20-Apr	18-Apr	19-Apr	25-Apr	20-Apr	19-Apr	20-Apr	19-Apr
SD (d)	26	16	26	22	12	8	24	18	24	18
Z_{MK}	–0.33	0.89	–1.86	–1.19	0	–0.445	0.22	–0.3	–1.64	1.73
CV (%)	13	7	13	11	6	5	12	9	12	15
LGP (d)										
Mean	150	131	153	142	141	134	144	130	144	130
SD	29	38	29	28	20	11	38	20	38	20
Z_{MK}	–0.22	0.4	–1.2	–0.89	–1.2	–0.45	0.11	–1.49	–1.26	0.69
CV (%)	19	13	19	20	14	8	26	15	26	15

making related to planting dates and crop management. There is no stable planting date or window in this area, hence the need for further research to estimate the probabilities of planting windows with predictive models. The high coefficient of variation in LGP follows the pattern of the onset and cessation dates, hence decision making regarding the cropping calendar, cropping pattern and all crop-husbandry practices should be taken cautiously.

The results of this study provide insight into changes in the growing season with reference to the staple food in Malawi, maize. Since most of the smallholder farmers have limited access to agricultural technologies such as fertilizer, pesticides and improved seed, the yields have remained stable at <1 t ha^{-1} (Wiyo et al. 1999). Swift changes are needed to the local farmer practices to deal with the identified shortening of the LGP. Farmers need to adjust their current practices. One of the most widespread strategies for dealing with the increasing variability of the onset of rains is to change planting dates and to use staggered planting. These can take care of the false starts that occur at the start of the rainy season. This would also lessen the exposure of the young plants to early dry spells that occur during the early part of the growing season. Planting maize cultivars (hybrids) that have a shorter growth cycle than the cultivars traditionally used can be another potential adaptation strategy. Although local varieties are favoured due to their pest-resistance and grain texture, the use of early maturing drought-tolerant varieties can be beneficial as they grow quickly and can use the available moisture in a short time. These strategies give a relatively safe approach to food production.

5. CONCLUSION

Analysis of the characteristics of the growing season in central Malawi has shown significant changes in the onset, cessation and LGP. There is a clear delayed onset and advanced cessation in some stations and shorter LGP with time within the period considered (1980 to 2009). This pattern requires introduction of crop cultivars with a shorter growing cycle in this region so that the crops can reach maturity without suffering water stress. It also calls for timely preparation of any related crop-husbandry activities before and even during the growing period to realise good harvests.

Although the seasonal rainfall amount in Malawi showed no particular trends, there was greater rainfall in January recently (1995 to 2009) compared to earlier periods (1980 to 1994). It is also noted that the last months in the growing period showed a decline in the total rainfall and high evapotranspiration, which can often lead to crop water stress. These findings are essential for the smallholder farmers in central Malawi as the farmers can use the proposed strategies to identify the best maize cultivars that can do well in the short growing periods. With the changes in climate in this region, there is a need to invest in soil and water management technologies suitable for smallholder cropping systems to address the obvious and possible impacts of climate change in southern Africa.

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