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Assessing Growing Season Changes in Southern Botswana

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ABSTRACT

Perfect timing of planting date is not only one of the key factors which strongly affect crop production in rain-fed agriculture but it is also a valuable leading indicator for food security monitoring in semi-arid environments like Botswana. This is especially true when, as in many parts of semi-arid regions, the rainy season starts with some light showers followed by dry spells, which can cause poor crop emergence or even desiccate a young crop and lead to poor yields and greater food insecurity and hunger. Unfortunately, such information on appropriate planting dates is rarely available from ground sources in a timely manner. However, operational remote sensing products such as vegetation index can be used to complement ground sources and hence fill missing gaps in planting date forecasting and monitoring. The aim of this study therefore was firstly to derive the growing season metrics for the southern district of Botswana using standard methods of deriving growing season from climatic indices and from satellite imagery and secondly to study the trend of the growing season metrics in the study area. The results from the two approaches showed that the onset and cessation of growing season had shifted backwards in both cases. Onset dates had shifted from the initial mid-September in the early 1960s to early November as of 2009 while cessation dates had shifted from early April to late January. Consequently, the growing season had contracted in length by an average of 14 decadal from the initial value of 22 decadal in the early 1960s. The study also showed no statistically significant difference between the growing season metrics derived from the two approaches (climatic and NDVI) hence any of the two approaches can be used to determine growing season metrics in the study area.

Keywords: growing season metrics, climatic indices, NDVI, decadal, agricultural decadal

INTRODUCTION

Growing season is defined as the period during which plant growth takes place (Carter 1998). The climatological growing "season" can be viewed as the entire period in which growth can theoretically take place, and should be distinguished from the growing "period" which is the period of actual growth (Carter 1998). Growing season variations are a useful climatic indicator and have several important climatological applications (Robeson 2002). A decrease in growing season due to variation in climatic elements such as rainfall, temperature or evapo-transpiration could result, for example, in alteration of planting dates leading to lower yields of traditional crops, which may not fully mature. Increasing growing season due to the same reasons, however, may provide opportunities for earlier planting, ensuring maturation and even possibilities for multiple cropping (depending on water availability). The effect of a shorter growing season is often the most significant negative impact of climate change on crops. Moreover, it has been observed that changes in growing season may be one of the indicators that may be used to detect climate change in an area (Chen *et al*. 2000).

In temperate climates the growing season is limited by seasonal changes in temperature and is defined as the period between the last killing frost of spring and the first killing frost of autumn, at which time annual plants die and biennials and perennials cease active growth and become dormant for the cold winter months (Rabenhorst 2005). In tropical climates, where there is less seasonal temperature variation, the amount of available moisture often determines the periods of plant growth; in the rainy season growth is luxuriant and in the dry season many plants become dormant. In desert areas, growth is almost wholly dependent on moisture (Spano *et al.* 1999). The growing season usually becomes shorter as distance from the equator increases. In equatorial and tropical regions the growing season ordinarily lasts all year. The length of the growing season often determines which crops can be grown in a region; some require long growing seasons while others mature rapidly.

There are two different methods conventionally used to estimate the period in which plant growth is restricted because of insufficient soil moisture: a) the probability of receiving effective rainfall; and b) the number of months in which rainfall is less than potential evapo-transpiration. Effective rainfall is defined as the minimum amount of rain necessary to start and maintain plant growth just above wilting point, and it corresponds to the amount of rainfall in excess of that lost through evapo-transpiration (Lunt 1995). The number of months in which rainfall is less than the potential evapo-transpiration identifies a period when plant growth is restricted by a lack of moisture and can be done simply by plotting the average evapo-transpiration and rainfall figures for each month for each recording station. Also in semi-arid areas these factors might lead to mildew, grain mold, poor growth due to poor aeration and nutrient leaching.

In recent years, determining the growing season of vegetation over large territories has become an important aspect of global climate change research (Chen *et al.* 2000). Hence the importance attached to satellite remote sensing in studying growing season. Because of the synoptic coverage and repeated temporal sampling satellites offer, remotely sensed data have a great potential for monitoring vegetation dynamics at regional to global scales (Myneni *et al*. 1997; Zhang *et al*. 2003). To quantify the spatial and temporal variation in vegetation growth and activity, vegetation indices can be calculated from satellite images. One such vegetation index is the normalized difference vegetation index (NDVI). A combination of both climatic and remotely sensed data based indices would enhance the study of grow-

Received: 2 December, 2010. Accepted: 3 March, 2011.

ing season changes particularly in the vast territorial expanses of semi-arid to arid regions such as Botswana.

In Botswana, the growing season generally occurs between October (onset) and March (cessation), but different factors determine the actual length of the growing season in the country. The first is the harsh and variable climatic conditions that characterize most parts of the country being semi-arid in nature. The rainfall pattern is generally unreliable with a coefficient of variation of annual mean rainfall of between 20 and 80% (Tsheko 2003). Also during the growing season, the country experiences very high temperatures of up to 40°C which lead to very high evapo-transpiration rates and hence soil moisture deficiency that varies from district to district. Secondly, about two thirds of the country is covered by sandy soils (Arenosols) which have low water retentive capacities and are infertile and easily eroded. Even in areas with relatively good soils, such soil characteristics as the water-holding capacity, deep water percolation and lateral seepage, all have a significant impact in determining the availability of water for cultivation and hence the growing season. Another important factor that determines the length of the growing season especially in the southern part of Botswana is the directive given by the village head. Usually the head of the village is the authority that instructs the farmers when to stop other village activities and go to the 'lands' and start ploughing. The importance of this factor is that no traditional farmer would plant without the instruction of the head of the village who gives the direction only when he is fully convinced that the amount of rainfall that has occurred is enough for cultivation. Given the vagaries of weather and its unpredictability, the village head's decisions may sometimes be faulty. Other factors such as shortage of ploughs or draught power for hire cannot also be neglected because they also influence the village head's decisions about the onset and cessation of the growing season. Agricultural Extension Officers also often advise farmers and village heads on when to start planting and they too need to have an objective way of reaching their decisions. The local people and agricultural extension workers both agree that the onset and cessation of the growing season have changed over the years and especially in more recent years. Unfortunately, there has been little done to analyze the trends in the growing season metrics over time. It is important to document the onset, the cessation and the length of the growing season in order to aid agricultural planning and agricultural extension services in the country. This is vital to efforts to achieve and maintain food security in Botswana as inscribed in the vision 2016 plan (Osei-Hwedie 2004).

Therefore, the aim of this study was to analyze and assess the changes that may have occurred in the onset, cessation and length of the growing season in the southern district of Botswana using both observed climatic data for the period 1961-2009, and NDVI data from Advanced Very High Resolution Radiometer (AVHRR) for the period 1985-2006. Although studies had been carried out on the relationship between crop yield and vegetation cover in Botswana using climatic, phenological and satellite data (Nicholson and Farrar 1994; Ringrose *et al.* 2002; Chipanshi *et al.* 2003), none have really assessed the growing season changes using observed climatic, phenological or satellite data.

Study area

This study was carried out in the Southern District of Botswana using Barolong Farms as case study (**Fig. 1**). The Southern District of Botswana is bounded by the North West province of South Africa in the south and locally by the South East, Kweneng and Kgalagadi Districts to the east, north and west, respectively. Barolong farms have been chosen as home for the National Master Plan for Arable Agriculture and Diary Development (NAMPADD) programme (a Botswana Government pilot agricultural programme). Barolong farms are one of the four main agricultural blocks with high potential arable land in the country. The area, according to Chipanshi *et al.* (2003), was one of the most important grain-producing areas in the nation with an average yield of 5000 metric tons/year and because of this it earned itself the name "bread basket" of Botswana. On aggregate, the Barolong people have been known to be successful arable farmers despite the fact that they have one of the smallest land areas compared to other districts in the country. But, over the past few years there has been a marked decline in agricultural yields in the area. Generally there has been a reduction in the importance of the area for crop production. Although the quantitative dimensions of the reduction in crop yield in Barolong remain unclear, the impact of changes in growing season to the decline cannot be ruled out; recently published agricultural statistics for 2008/2009 by the Central Statistics Office in Botswana indicates that the Barolong area is currently producing below its potential capacity.

Barolong Farms is a small tribal area extending for about 108,647 ha in the south-eastern corner of the Southern district and shares boundaries with South Africa. It is located between latitudes 25°27′ - 25°45′ S and longitudes 25°00′ - 25°45′ E (**Fig. 1**). The rainfall pattern in Barolong is highly variable both spatially and temporally and largely mirrors the prevailing climatic conditions of the sub district. On average, the district currently receives about 450 mm of rainfall annually (Tsheko 2003) with the highest amount of rain received between January and February (**Fig. 2**). Evaporation exceeds precipitation in the region, a typical feature of semi-arid regions. The sub-district is also characterized by great seasonal and daily variations in temperature, being very hot in summer (average daily high temperatures of 32°°C in January) and mild to cold in winter (average daily minimum temperature in July is 0.9°C). Seasonal fluctuations in mean temperatures between the warmest and the coldest months exceed 15°C (Tsheko 2003). Relative humidity is also typically low throughout the sub district, 28% in July. In February, relative humidity, the relative humidity ranges between 64 and 68%.

The soils in Barolong are predominantly *Luvisols* which cover more than 60% of the district while the rest of the area is covered by rocky outcrops and other soil types including *Lixisols*, and *Arenosols* (Soil Classification Working Group 1991). According to the Department of Surveys and Mapping in Botswana, most of the Barolong sub-district falls within the savannah biome with its associated bushveld vegetation. The remainder falls within the grassland biome comprising a wide variety of grasses typical of arid areas.

DATA AND METHOD

Data sets employed

In recent years, determining the growing season of vegetation over large territories has become an important aspect of agricultural monitoring (Chen *et al.* 2000). Hence the use of different methods to determine it. The use of agro-climatic models to assess the growing season has been observed to be of limited practical value because of spatial differences in soil characteristics and crop growth determining factors such as nutrition levels, plant disease, herbicide and insecticide use, crop type, and crop variety, which would make informational and analytical costs excessive (Kastens *et al.* 2005). Additionally, Kastens *et al.* (2005) indicated that agro-meteorological models are unable to completely simulate the different crop-growing conditions that result from differences in climate, local weather conditions, and land management practices. By contrast, a satellite-based method could provide estimated data for large areas at relatively low cost because there is no need to collect information on planting dates, varieties planted or daily rainfall or temperatures. Information from a satellite based method can also help in solving problems in areas where climatic data may not be easily available. However, remotely sensed data are not adequate to describe fully biophysical functions of plant growth, because such data only reflect the reflectance properties of the canopy and contain incomplete information on the biophysical

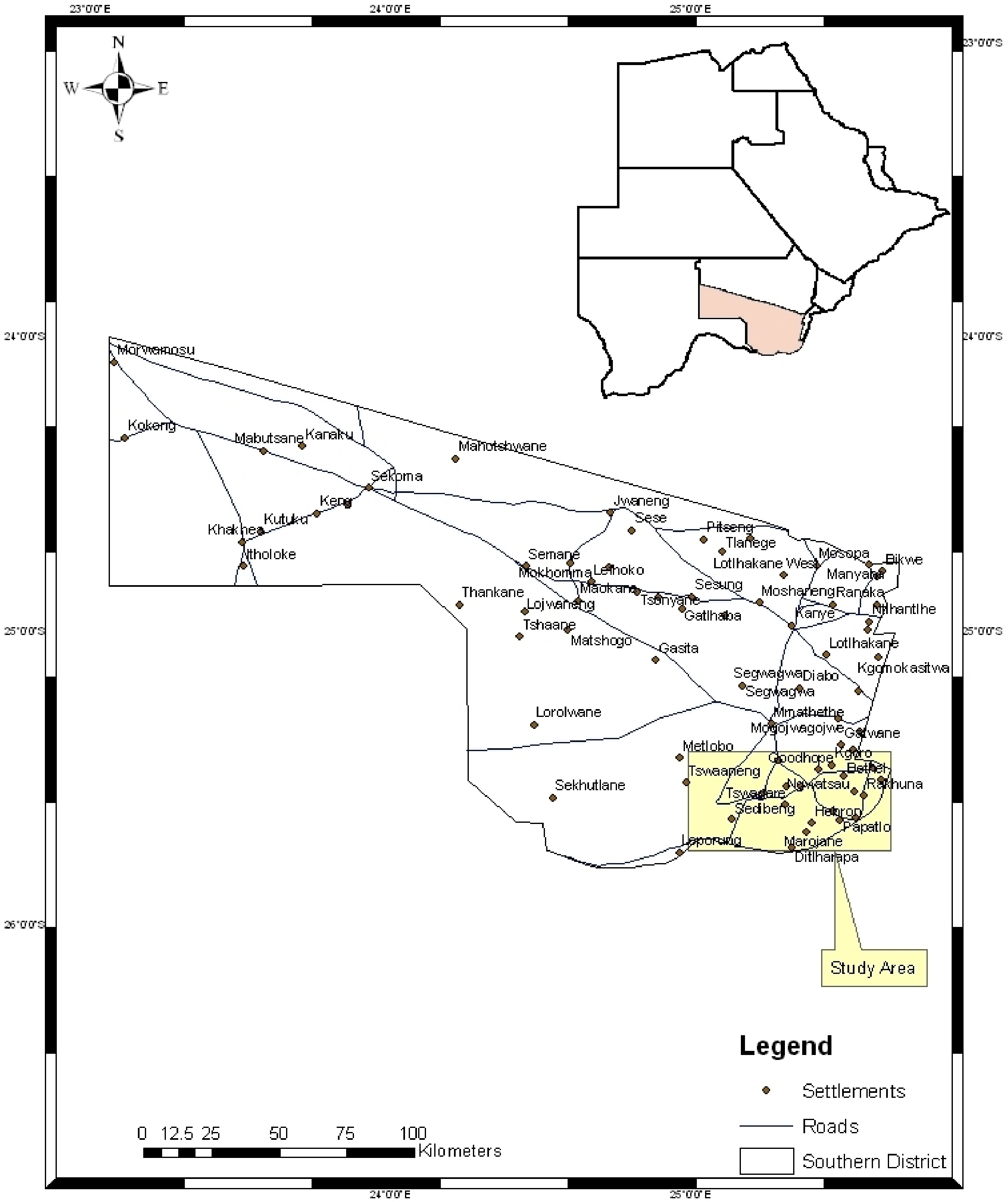

Fig. 1 The study area. Insert: Map of Botswana showing the study area.

processes of vegetation (Chen *et al.* 2000). Moreover, many factors unrelated to ecosystem variability, but associated with obtaining remotely sensed data (e.g. satellite drift, calibration uncertainties, inter-satellite sensor differences, bidirectional and atmospheric effects and volcanic eruptions), may cause unrelated variability in the data (Zhou *et al.* 2001). Therefore, to obtain a more comprehensive assessment of the growing season changes and for the purpose of this study, the two methods (satellite and climate approaches) were complemented.

Unit of measurement for determining onset and cessation dates

In this study, the onset the cessation and length of growing season are dates expressed in units of temporal composites of 10-day periods (decadal) from the start of the year. The decadal rainfall and temperature data (average of 10 days' recordings) were used to derive both onset and cessation of growing season in decadal form to complement the composite NDVI data from AVHRR which are usually received every 10 days. Thus, one unit equals 10 days for the AVHRR dataset.

For easy interpretation of the trend, the dates of onset and cessation have been presented in an agricultural decadal date format (ADD) such that the agricultural years are divided into decadal dates. For instance 1st decadal in September is represented as Decadal date 1 while 3rd Decadal in April is represented as Decadal date 24. The length of the growing season was determined as the difference between the composite dates of cessation and onset of the growing season in both cases.

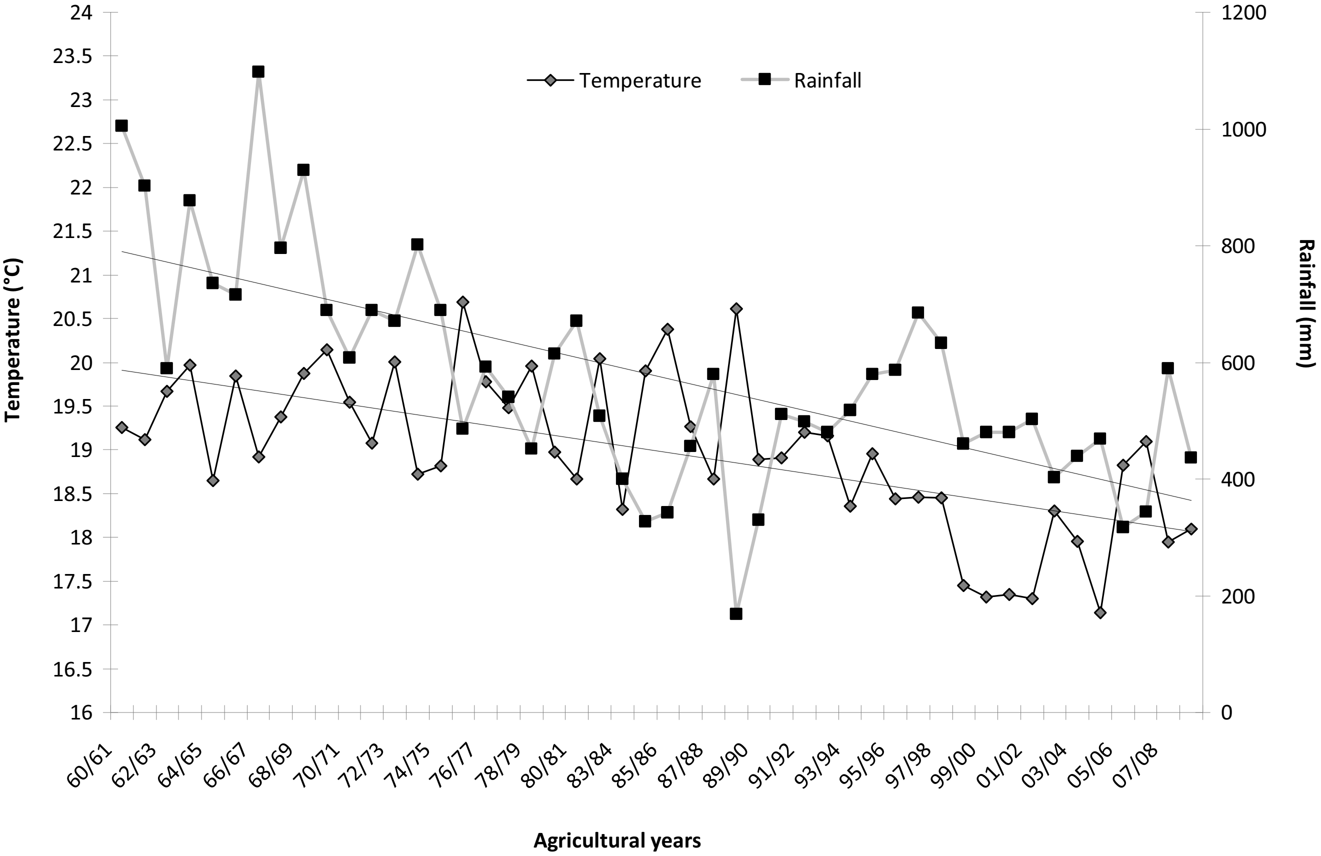

Fig. 2 Rainfall and temperature trend in Barolong. Top straight line = decreasing trend of rainfall; Bottom straight line = decreasing trend of temperature.

Deriving the Climatic Index

The onset and cessation criterion derived from climatic variables in this study was proposed by Vossen Paul (1990) in conjunction with the Botswana Department of Meteorological Services (DMS) and Ministry of Agriculture (MOA). The method is based on a specific amount of rainfall and the temperature that need to be observed over an arbitrary period of several days. This criterion is referred to as the Climatic Index in this study.

Having studied the climatic conditions of the country and the crops that are suitable for planting, Vossen concluded that starting from the early nineties, the growing season starts at the decadal (10 days average) when a total of 30 mm rainfall occurs for a minimum of two days after November 1st of every year. November 1st is considered because it has been observed that there is always a subsequent high frequency of dry spells when rain first occurs in September or October although onset may occur if there is evidence to show that enough rain has occurred in the month(s) preceding. The 30 mm rainfall was considered as the minimum required for the soils in Barolong to reach the minimum soil moisture requirement for cultivation. The cessation of growing season is said to occur 120 days (12 decadal) before the minimum temperature is ≤ 3°C for at least two consecutive decadal. This is done to prevent cultivation beyond the time when frost can possibly occur leading to plants senescence i.e. when plants are forced to stop growing. The length of the growing season was derived from the difference between the onset and the cessation. The growing season metrics were derived for the period of 1960/61-2005/06 agricultural seasons and then correlated with the satellite data which were also used to determine the onset, cessation and length of the growing season.

Derivation of the Vegetation Index, NDVI

To quantify the spatial and temporal variation in vegetation growth and activity, vegetation indices can be calculated from satellite images (Beck *et al*. 2005). One such vegetation index is the normalized difference vegetation index (NDVI). NDVI data capture the contrast between red and near-infrared reflectance of vegetation, which indicates the abundance and energy absorption by leaf pigments such as chlorophyll (Zhou *et al*. 2001). NDVI is a general biophysical parameter and it provides an indication of the photosynthetic activities of vegetation. Previously, in Botswana, NDVI data were obtained from AVHRR (Advanced Very High-Resolution Radiometer) instruments carried by meteorological satellites in the NOAA/NASA Earth Observing System or the Global Inventory Monitoring and Modeling Studies (GIMMS). But recently, due to cessation of the AVHRR receiving instruments, the Department of Meteorological Services (DMS) shifted to SPOT NDVI data which offer improved calibration and atmospheric corrections, as well as higher spatial resolution when compared to AVHRR (Zhang *et al*. 2003). However, because SPOT NDVI data are only available for a limited number of years (1998-2009) they have not been used in this study preference being given to the longer term AVHRR NDVI data. Usually, NDVI are of global extent, and the data have a spatial resolution of 1.1-8 km and a 10-15 day temporal frequency (Beck *et al*. 2005). These data (images) have been processed by DMS hence they are free from noise, cloud contamination, atmospheric perturbations, and variable illumination and viewing geometry which may reduce the quality of the data.

The NDVI pixel values of four different geographical locations in Barolong Sub district representing farms that had existed from at least 1982 till date were extracted from the images for each decadal (ten days passing of satellite) period from 1985 to 2006 using the spatial analyst tools in Arc Map. The average of the NDVI values was used as a representative value of the NDVI for the area. Thereafter, the difference between the annual maximum and minimum NDVI values of the study area was used to determine the seasonal mid points NDVI. The seasonal mid-point NDVI methodology that was used in this study employs techniques originally developed by White *et al*. (1997) and subsequently modified (White *et al*. 1999, 2002) to derive growing season metrics from satellite images. The average mid-points NDVI across all the years (1985-2006) were then used as the threshold to identify the onset and cessation of the growing season for each

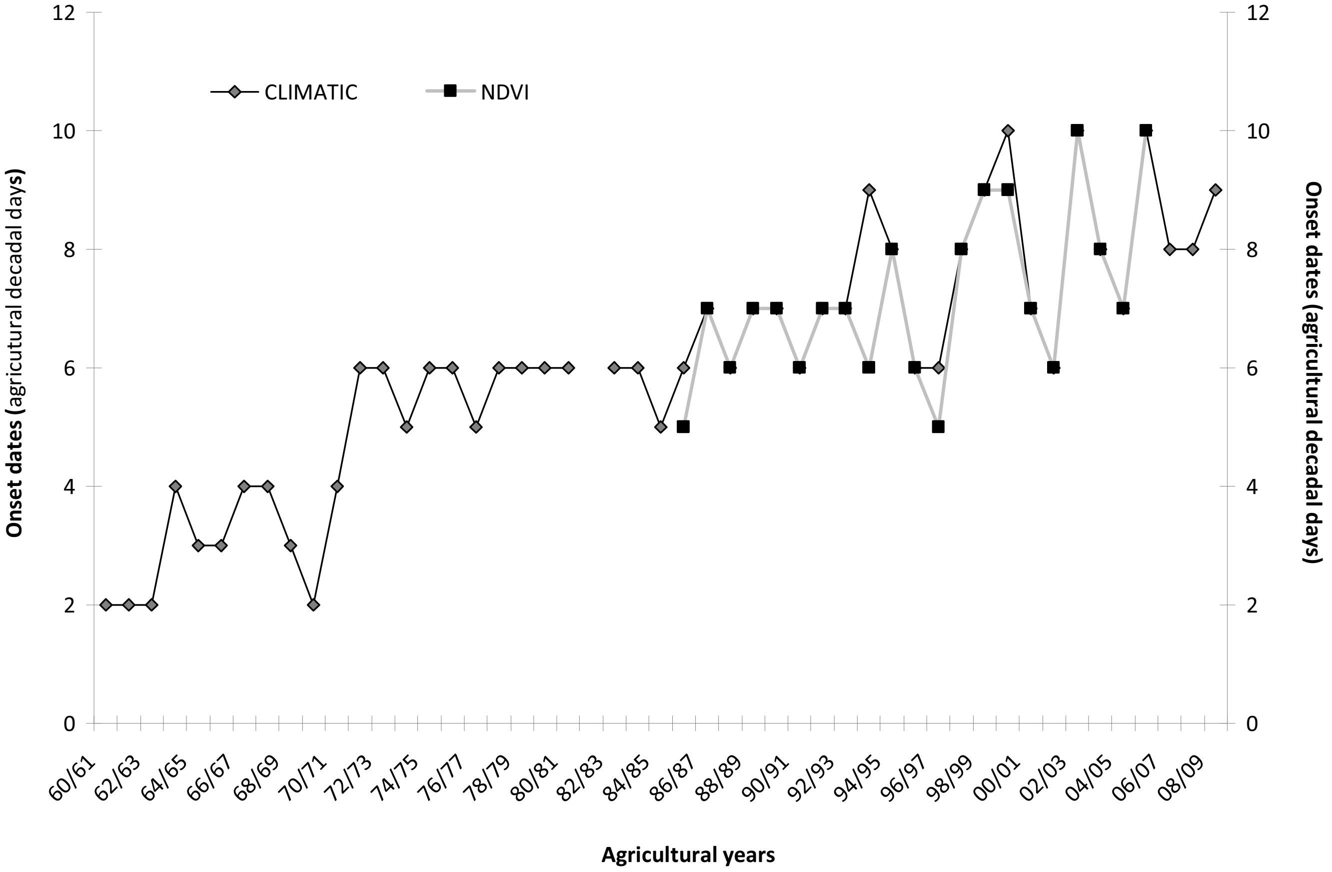

Fig. 3 Trends of onset in agricultural decadal days.

year. This ensured consistency across all the years in the definition of the dates of the onset and cessation of the growing season thereby allowing detection of changes between the years.

Trend Analysis of Growing Season Metrics

After the determination of the growing season parameters from the various datasets, the derived data were analyzed using analytical methods noted. The annual trends of the length of growing season derived from both climatic indices (1961-2009) and satellite (1985-2006) were presented in both tabular and graphic forms. The *t*-test was used to find out if there were any statistically significant differences between the data sets derived using the two different approaches based respectively on climatic and satellite derived indices. Furthermore, the coefficient of variation (CV) of the length of growing season derived from both the climatic indices and satellite was calculated. The outcome showed whether the growing season had been expanding, shrinking or shifting based on the initial length of growing season for the two approaches.

RESULTS AND DISCUSSION

Changes in onset dates

Observation of the trend of onset of growing season derived from climatic indices shows that in the early 1960s (1961/62, 1962/63, 1963/64) agricultural seasons, farmers usually planted in mid September (2^{nd} decadal). This further suggests that earlier than this the onset of growing season may probably have been earlier. Between 1964 and 1985, the onset of growing season fluctuated between 3^{rd} decadal in September (3 ADD) and 3^{rd} decadal in October (6 ADD) indicating a 3-decadal shift from the initial 2^{nd} decadal in September in the early 1960s. From 1985 till 2005, the onset of growing season fluctuated between 3^{rd} decadal in October (6 ADD) and 1^{st} decadal in December (10 ADD) with a tendency of shifting towards the 1^{st} decadal in December rather than the 3^{rd} decadal in October, either because the rains come late or because early rains are followed by a dry spell.

Also, the trend of onset of growing season derived from NDVI as observed from **Fig. 3** shows that there have been changes through time. For instance, the first year of available NDVI data (1985) indicated that the onset was in the 2^{nd} decadal in October (5 ADD) whereas by 2003-2004 the onset had shifted to 3^{rd} decadal in November (9 ADD) on average. This shows that there has been at least a 4-decadal (40 days) shift in the onset dates from the initial 2^{nd} decadal in October in the mid-1980s. This may also be attributed to changes in the timing and amount of rainfall as vegetation response and hence NDVI is a function of rainfall. The period of occurrence of NDVI maximum and minimum which determines the onset of growing season from NDVI has also shifted over the past years in the study area (**Table 1**).

The onset of growing season derived from both methods (satellite and climatic indices) was consistent except for the years 1985/86, 1996/97 and1999/00 agricultural seasons. In these cases, it was observed that the onset of growing season occurred a decadal earlier on the NDVI trend line than on the climatic index trend line. This may be due to good rains observed in those years since NDVI is a measure of vegetation response to rainfall amounts received. In all, it was observed that the onset of growing season derived from both climatic indices and NDVI showed a shift of at least 4-decadal (40 days) from the baseline 1960/61 onset dates.

Changes in cessation dates

As with the onset of growing season in the study area, the cessation of growing season was also observed to have changed over the years using both indices (**Table 2**). For instance, observation of the cessation of growing season derived from climatic indices shows that, between 1960 and 2009, there was a shift of at least 7 decadal in the cessation of growing season from 2^{nd} decadal in April (23 ADD) to 3^{rd} decadal in January (15 ADD) in the study area (**Fig. 4**). This

Table 1 Derived onset dates.

Year	Onset Dates (Climatic)	Onset Dates (NDVI)
60/61	SEPT 2nd decadal	
61/62	SEPT 2nd decadal	
62/63	SEPT 2nd decadal	
63/64	OCT 1ST decadal	
64/65	SEPT 3RD decadal	
65/66	SEPT 3RD decadal	
66/67	OCT 1ST decadal	
67/68	OCT 1ST decadal	
68/69	SEPT 3RD decadal	
69/70	SEPT 2nd decadal	
70/71	OCT 1ST decadal	
71/72	OCT 3rd decadal	
72/73	OCT 3rd decadal	
73/74	OCT 2ND decadal	
74/75	OCT 3rd decadal	
75/76	OCT 3rd decadal	
76/77	OCT 2ND decadal	
77/78	OCT 3rd decadal	
78/79	OCT 3rd decadal	
79/80	OCT 3RD DECDAL	
80/81	OCT 3RD decadal	
81/82	NO DISTINCT ONSET	
82/83	OCT 3rd decadal	
83/84	OCT 3rd decadal	
84/85	OCT 2ND decadal	
85/86	OCT 3rd decadal	OCT 2ND decadal
86/87	NOV 1st decadal	NOV 1ST decadal
87/88	OCT 3rd decadal	OCT 3RD decadal
88/89	NOV 1st decadal	NOV 1ST decadal
89/90	NOV 1st decadal	NOV 1ST decadal
90/91	OCT 3rd decadal	OCT 3RD decadal
91/92	NOV 1st decadal	NOV 1ST decadal
92/93	NOV 1st decadal	NOV 1ST decadal
93/94	NOV 3rd decadal	OCT 3RD decadal
94/95	NOV 2ND decadal	NOV 2ND decadal
95/96	OCT 3rd decadal	OCT 3RD decadal
96/97	OCT 3rd decadal	OCT 2ND decadal
97/98	NOV 2ND decadal	NOV 2ND decadal
98/99	NOV 3rd decadal	NOV 3RD decadal
99/00	DEC 1st decadal	NOV 3RD decadal
00/01	NOV 1st decadal	NOV 1ST decadal
01/02	OCT 3rd decadal	OCT 3RD decadal
02/03	DEC 1st decadal	DEC 1ST decadal
03/04	NOV 2ND decadal	NOV 2ND decadal
04/05	NOV 1st decadal	NOV 1ST decadal
05/06	DEC 1st decadal	DEC 1ST decadal
06/07	NOV 2ND decadal	
07/08	NOV 2ND decadal	
08/09	NOV 3rd decadal	

Table 2 Derived cessation dates.

Year	Cessation Dates (Climatic)	Cessation Dates (NDVI)
60/61	APR 2nd decadal	
61/62	MAR 2ND decadal	
62/63	MAR 3RD decadal	
63/64	APR 2nd decadal	
64/65	APR 1ST decadal	
65/66	MAR 3RD decadal	
66/67	MAR 3RD decadal	
67/68	MAR 3RD decadal	
68/69	APR 1ST decadal	
69/70	APR 1ST decadal	
70/71	MAR 2ND decadal	
71/72	MAR 1ST decadal	
72/73	MAR 2ND decadal	
73/74	MAR 1ST decadal	
74/75	FEB 3rd decadal	
75/76	MAR 2ND decadal	
76/77	MAR 1ST decadal	
77/78	FEB 3rd decadal	
78/79	FEB 2nd decadal	
79/80	FEB 1st decadal	
80/81	FEB 1st decadal	
81/82	No Distinct Cessation	
82/83	FEB 3rd decadal	
83/84	FEB 2nd decadal	
84/85	FEB 2nd decadal	
85/86	FEB 1st decadal	FEB 2ND decadal
86/87	FEB 3rd decadal	FEB 2ND decadal
87/88	FEB 1st decadal	FEB 2ND decadal
88/89	FEB 2nd decadal	FEB 2ND decadal
89/90	FEB 2nd decadal	FEB 2ND decadal
90/91	FEB 1st decadal	FEB 2ND decadal
91/92	FEB 1st decadal	FEB 3RD decadal
92/93	FEB 2nd decadal	FEB 2ND decadal
93/94	FEB 1st decadal	FEB 2ND decadal
94/95	FEB 1st decadal	FEB 1ST decadal
95/96	JAN 3rd decadal	FEB 1ST decadal
96/97	JAN 3rd decadal	FEB 1ST decadal
97/98	JAN 3rd decadal	FEB 1ST decadal
98/99	FEB 1st decadal	FEB 2ND decadal
99/00	JAN 3rd decadal	JAN 3RD decadal
00/01	JAN 2nd decadal	JAN 3RD decadal
01/02	FEB 1st decadal	JAN 3RD decadal
02/03	JAN 3rd decadal	JAN 3RD decadal
03/04	FEB 1st decadal	JAN 3RD decadal
04/05	JAN 3rd decadal	JAN 2ND decadal
05/06	JAN 3rd decadal	JAN 3RD decadal
06/07	JAN 3rd decadal	
07/08	FEB 1st decadal	
08/09	FEB 1st decadal	

was quite large in comparison with the shift in the onset of growing season and can be attributed to the occurrence of frost coming earlier now than in the 1960s. It was observed that frost (minimum air temperature of 3°C) occurred mostly in late July in the early 1960s and was responsible for the cessation dates being extended to mid April. By contrast, over the 13 years, 1996-2009, frost occurred in early to mid May, forcing farmers to plant earlier than or before 120 days before frost so as not to be affected by frost at any growth stage of crops. Moreover, cessation date derived from satellite in 1985 was determined to be in the 2nd decadal in February (17ADD) whereas in 2006, the cessation date had shifted backwards two decadal to 3rd decadal in January (15 ADD). This may be attributed to the fact that the period in which maximum and minimum NDVI occurred had shifted over the years. The cessation dates derived from satellite also showed a shift although to a limited extent when compared with the cessation derived from climatic indices obviously because of the much more limited time span of the NDVI data.

Changes in length of growing season

Analysis of the trend derived from climatic indices shows that the length of the growing season shrank by at least 15 decadal (150 days) over the last 46-year period. For instance, in the early sixties farmers could plant for a period of 7 months i.e. between September and May but between 2000 and 2009 the length of growing season had apparently shrunk to 2.5 months on average. Similarly, the length of growing season derived from NDVI showed a shortening from an initial 13 decadal days in 1985 to 6 in 2006 (**Fig. 5**). This represented a reduction of at least 7 decadal in length of growing season between the years. Furthermore, with coefficients of variation of 33.49 and 20.95% at the 95% significance level, it can be concluded that the length of growing season derived from both methods has reduced considerably. This generally is attributed not only to the changes in the timing and amount of rainfall but also to the higher temperatures which are responsible for fluctuations in the greenness values of vegetation and in the occurrence of frost experienced in the study area over the years.

Finally, comparison of the two datasets (onset, cessation

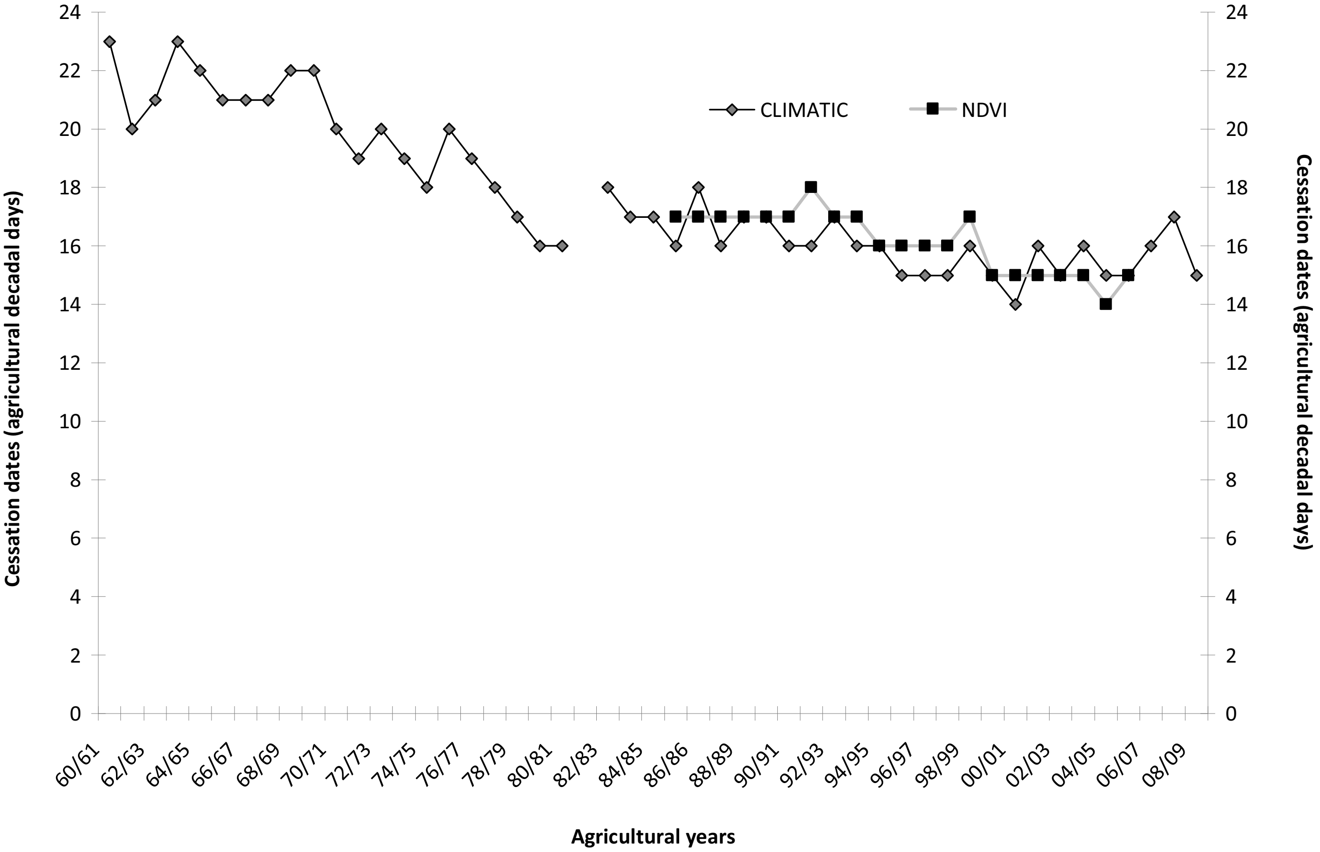

Fig. 4 Trends of cessation in agricultural decadal days.

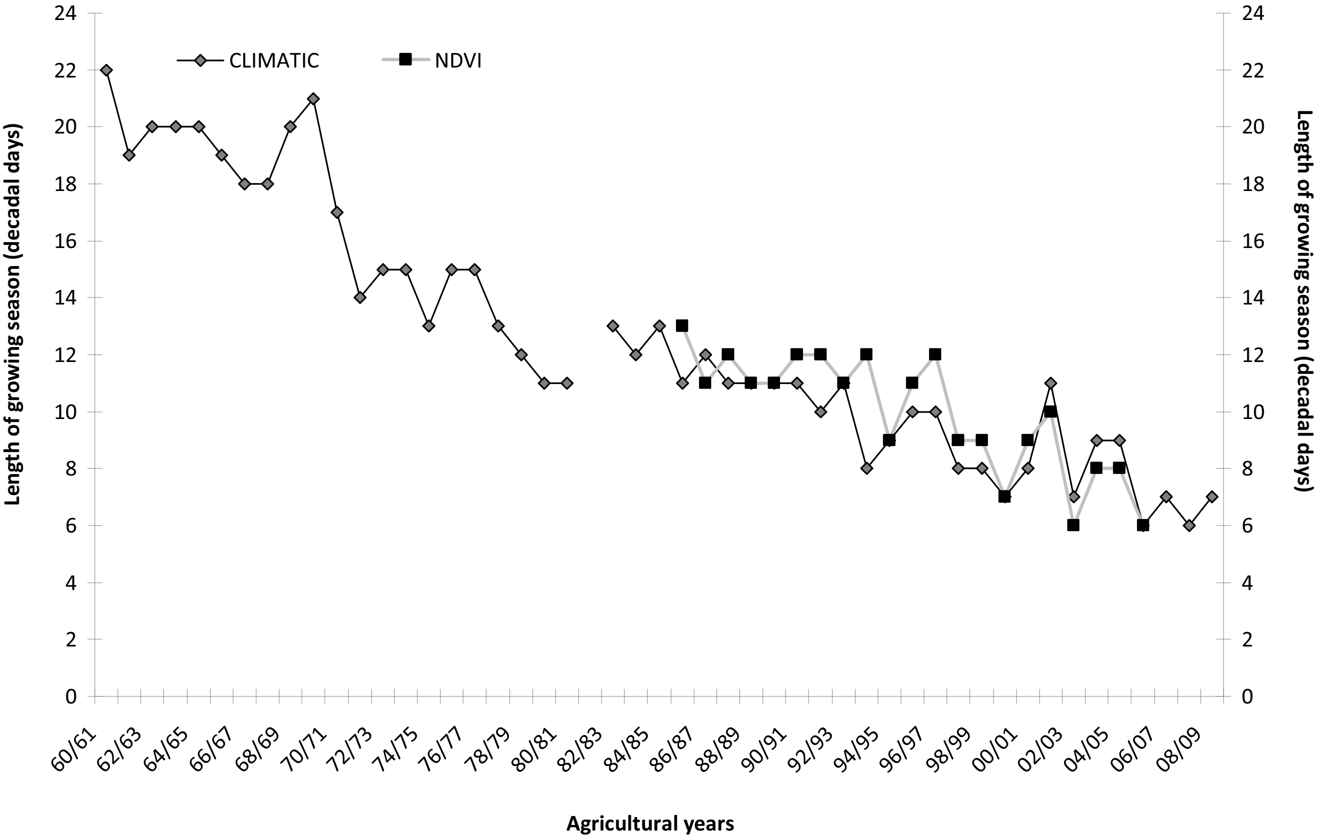

Fig. 5 Trends of length of growing season in agricultural decadal days.

and length of growing season derived from satellite and climatic indices) using two-tailed *t*-test further indicates that there is no statistically significant difference in the results obtained from the two approaches. Therefore, we can conclude that any one of the two approaches can be used to derive the growing season metrics in the study area.

CONCLUDING REMARKS

Although there have been various studies carried out on changes in the length of growing season, most of these have been in the north of the equator where lengthening of growing season has been reported. But this study south of the Equator shows differently that the length of growing season has been reducing and may continue to do so in future if present climatic trends continue. The application of satellite data especially in the form of NDVI in studying the growing season in a semi-arid environment like Botswana has proved quite useful. Although they are not the best remotely sensed data that could have been used the NDVI derived from AVHRR nevertheless produced results that are comparable and complementary to those obtained using climatic indices.

Given the increasing threat of global warming and climate change, it is clear that there would be further changes in the growing season metrics in Botswana. Therefore, there is urgent need to develop and implement appropriate mitigation measures in order to eliminate or reduce the impact these changes could have on food production within the country.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help rendered by the Agricultural Research Council, Institute for Soil, Climate and Water in Pretoria, South Africa in providing the climatic data for the years for which they are not available in Botswana. We, also, thank the Department of Meteorological Services, Botswana for providing the climatic and satellite imageries for the study area.

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