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Influence of climate variability and length of rainy season on crop yields in semiarid Botswana

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ABSTRACT

Climate variability and change is expected to affect agricultural productivity among other sectors. Studying the influence of this variability on crop production is one measure of generating climate change resilience strategies. In this study, the influence of climate variability on crop yield is investigated by determining the degree of association between climatic indices and crop yields of maize and sorghum using spearman's rank correlation. The climatic indices used in this study are aridity index (AI), standardised precipitation evapotranspiration index (SPEI) at timescales of 1, 3, 6 and 12 months and southern oscillation index (SOI) representing El Niño southern oscillation (ENSO) influence on local climate. Local rainfall characteristics are expressed through length of the rainy season (LRS). Results reveal that ENSO influence is the most dominant across Botswana accounting for 85% and 78% variations in maize and sorghum yields respectively. Whereas AI and SPEI accounts for 70% and 65% variations in maize and sorghum respectively, LRS accounts for only 50% and 62% respectively. To facilitate agricultural planning, crop yield projections have been made using artificial neural network (ANN) models. The ANN projections indicate a likelihood of maize and sorghum yields declining by 51% and 70% respectively in the next 5 years. The high association between ENSO and crop yields in Botswana could further facilitate yield projections. Information generated from this study is useful in agricultural planning and hence strengthens farmers' strategies in mitigating impacts of climate variability and change in semiarid areas.

1. Introduction

Increasing human population comes with an increase in demand for energy and food, leading to generation and eventual release of more greenhouse gases into the atmosphere to meet these demands (Some'e et al., 2013; Vörösmarty et al., 2000). Continued buildup of these greenhouse gases in the atmosphere has been closely associated with rising global temperature, reduced rainfall and increased climate variability in general exerting pressure on agricultural water resources and hence on crop yields (Hansen et al., 2010; Rockström et al., 2009). Attempts have been made globally to increase food production through technological and infrastructural improvements. Besides this, high variations are still reported mainly attributed to climate disasters that have ravaged the world in recent decades mainly in the form of frequent droughts (Alexandratos et al., 2012; Cabas et al., 2010; Li et al., 2009). Droughts have been identified as the single most important climatic hazard affecting agricultural production according to Helmer and Hilhorst (2006), Li et al. (2009) and Sivakumar (2011). In the advent of climate change and an increase in climate variability, drought frequency and severity are expected to worsen with far reaching impacts felt in semiarid and arid locations further exacerbating the already declining crop yields (Byakatonda et al., 2016; Khan et al., 2016; Modarres and da Silva, 2007; Omoyo et al., 2015). Semiarid locations could also propagate into arid and hyper arid climates as a result of climate change if no adaptation measures are put in place (Some'e et al., 2013; Zhang et al., 2009). Further still, in developing countries where absorption of improved technologies is still low and with existence of poor infrastructure, impacts of climate variability and change are expected to be more severe (Hatfield et al., 2011; Sivakumar, 2011). Climate variability and change have been found to shift the onset and cessation of rain hence affecting the length of the rainy season (Amekudzi et al., 2015; Mugalavai et al., 2008). This revelation brings uncertainty to regular and timely water supply necessary for replenishing soil moisture putting livelihoods depending on rainfed agriculture more at risk. Various attempts have been made to evaluate the effect of climate variability and change on crop yields. At a global scale, Li et al. (2009), investigated the risk of climate change on crop yields using parametric methods to establish correlations between

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Table 1
Agricultural regions with respective synoptic stations and locations where yields were collected.

Agricultural Region	Synoptic Stations	Locations for crop data
Southern	SSKA, Jwaneng and Tsabong	Barolong, Ngwaketse South, Ngwaketse North, Tlokweng, Kweneng South, Kweneng North and Kgatleng
Central	Mahalapye	Mahalapye, Palapye and Serowe
Eastern	Francistown, Letlhakane and Selibe-Phikwe	Bobonong, Letlhakane, Selebi-Phikwe, Tati, Tutume, Mmadinare
Northern	Shakawe, Maun and Kasane	Ngamiland West, Ngamiland East and Chobe
Western	Ghanzi, Tshane and Tsabong	Ghanzi, Hukuntsi and Tsabong

climate variables and crop yields. They also simulated future drought risks using outputs from 20 General Circulations Models (GCMs). Their findings revealed that, the African continent is more vulnerable to climate variability and change than any other region of the world. Studies in other semiarid areas of Asia such as Iran by Bannayan et al. (2011, 2010) revealed that variability in temperature and climatic indices substantially affected barley and wheat yields. They also used parametric techniques to quantify relationships between climatic variables and crop yields. In semiarid areas of Kenya, Omoyo et al. (2015) investigated the relationship between climate variability and yields of maize using regression analysis. Their findings revealed that maize yields were declining with decreasing trends in rainfall amidst warming trends. Rowhani et al. (2011) while studying impact of climate variability on yields of maize and sorghum in Tanzania used linear mixed models. Their findings indicated that by the middle of the century, a temperature rise of up to 2 °C may lead to reduction in yields of around 10% for these crops under investigation. Earlier studies as explained above have used parametric correlation methods hence assuming a normal distribution in crop yields and climatic variables. Due to climate dynamics and uncertainties under changing environment, with influences from external predictors such as El Niño southern oscillation (ENSO), a normal distribution may not necessarily hold. Hence this study proposes the use of non parametric rank based correlation method to study the degree of association between climatic indices and crop yields. The influences of ENSO on southern Africa's climate has been well articulated in studies by Nicholson et al. (2001), Usman and Reason (2004) and Edossa et al. (2014). Botswana located in the subtropics with more than 80% of its population engaged in rainfed agriculture and classified as semiarid (Batisani and Yarnal, 2010), is selected as a study area. Studies conducted by Parida and Moalafhi (2008), indicate that rainfall has decreased across Botswana since 1979/80. A study by Batisani (2012) revealed significant correlations between rainfall variability and cereal yields. The study however did not incorporate the influence of ENSO and temperature on crop yields. Further still, the study did not provide any insights on future crop production trends. With overwhelming evidence of global warming, temperature may not be ignored in any climate impact study. Hence this study proposes the investigation of the association of crop yields with climate variability expressed through climatic indices such as Aridity index (AI) and Standardised precipitation evapotranspiration index (SPEI) under the influence of ENSO. These two indices incorporate both rainfall and temperature in their computations. Due to the complexity of climate dynamics, this study proposes the use of Artificial Neural Network (ANN) which mimics neural biological signals similar to human reasoning abilities (Byakatonda et al., 2016; Masinde, 2014) to make projections of crop yields. Nonlinear Autoregressive with Exogenous input (NARX) a specialized neural network for time series prediction with feedback connections is proposed for this task. NARX is a class of Dynamic Recurrent Neural Networks (DRNN) which has been proven to perform well mainly due to the time delay and feedback loops that are absent in static neural networks (Gao and Meng Joo, 2005; Guo and Xue, 2014; Lahmiri, 2016; Menezes and Barreto, 2008). In summary, the current study aims at investigating the influence of climate variability in form of climatic indices and length of the rainy season on maize and sorghum yields and at the same time provide crop yield projections for the next 5 years. The study specifically intends to determine the association between crop yields and 1) monthly AI, AI moving averages at 3, 6 and 12 months; 2) SPEI at timescales of 1, 3, 6 and 12 months; 3) southern oscillation index (SOI); 4)length of the rainy season; and 5) provide 5 year projections of maize and sorghum yields.

2. Data and methods

2.1. Data

Data used in this study comprised of locally observed meteorological times series, records of southern oscillation index (SOI) and crop yields. Crop yield data spanned a period from 1978/79 to 2013/14 prompting the use of climatic data covering the same time period.

2.1.1. Climatic data

Meteorological data was provided by the Department of Meteorological Services (DMS) of Botswana from 12 synoptic stations situated in the 5 agricultural zones as shown in Table 1. Total rainfall for the crop growing season (November- May) for the study area ranges from 600 mm in the northeast at Kasane to 250 mm in the southwest at Tsabong as shown on Fig. 1(a). Rainfall is highly variable with coefficients of variability (CVs) ranging from 48% at Tsabong to 27% at Kasane (Fig. 1(b)) bringing more uncertainties to rainfed agriculture, especially in the southwest. Mean seasonal maximum and minimum temperature of 32 °C and 18 °C respectively are experienced across Botswana.

The influence of ENSO on crop yields is studied using SOI which quantifies the magnitude of ENSO based on atmospheric pressure. Strongly negative values of SOI are associated with strong El Niño responsible for droughts in the southern hemisphere (Hoell et al., 2015; Rojas et al., 2014; Zaroug et al., 2014). Strongly positive SOI values, on the other hand, are associated with strong La Niña responsible for negative temperature anomalies that accounts for rain periods in Botswana. Data on SOI was obtained from the National Climate Data Center of National Oceanic and Atmospheric Administration (NOAA-NCDC, 2016). For analysis, the SOI data is arranged at monthly and seasonal scales based on the crop growing season.

2.1.2. Crop yield data

Yields of two main food crops in Botswana viz; maize and sorghum were obtained from the Ministry of Agriculture. The locations from which the data were collected in the respective agricultural zones are shown in Table 1 and Fig. 1(b). These locations are mainly situated in the Limpopo river basin in the east and southeast as well as Okavango basin in the north. The central and western areas of Botswana are predominantly dry bordering the Kalahari Desert hence the sparse distribution of agricultural locations. Crop yield data was aggregated according to agricultural zones as indicated in Table 1. The length of the growing season is deduced from the onset and cessation of rain dates. Rain onset across the study area occurs during November-December period and cedes between April and May. Areas in the north have earlier onset compared to southern drier locations. Both maize and sorghum are rainfed with yields in most cases closely following rainfall