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Research paper

Influence of El Niño-Southern oscillation (ENSO) on agroclimatic zoning for tomato in Mozambique

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ABSTRACT

Mozambique is a country dependent on agriculture as 70% of the country's population lives in rural areas, and approximately 80% of the nation economically active population works on agricultural jobs. Using climate/weather information in agriculture helps to reduce risks and benefit from favorable conditions for crop development. Agroclimatic zoning is one of the most useful tools to define suitable regions and spatial, temporal and environmental bounds for crop production. These bounds, however, are not static and can vary with sources of climatic variability such as the El Niño-Southern Oscillation (ENSO) phenomenon. Incorporating information about primary drivers of interannual climate variability, like ENSO, allows for better management adaptation. Tomato has a high economic impact in Mozambique's economy and its cropping success is highly dependent on weather conditions. The objectives of this study were to create an agroclimatic zoning for tomato production in Mozambique identifying regions and planting dates with optimal crop development for each phase of ENSO and to understand how ENSO phenomenon impacts the zoning. A third objective was to create an online tool (http://mz.agroclimate.org/plantio/) to assist farmers, extension agents and researchers to plan the crop season. Gridded data of daily air temperature and rainfall were collected between 1984 and 2014 from the Climate Forecast System Reanalysis (CFSR) and Famine Early Warning System Network (FEWS-Net) datasets provided by the US National Oceanic and Atmospheric Administration (NOAA). A generic tomato variety with growing cycle of 90 days was evaluated considering 24 planting dates throughout the year. Each growing cycle and planting date was classified as ideal, marginal, or unsuitable according to the conditions for tomato development. During summer months, the air temperatures were excessively high for tomato production except at high elevations. During fall and winter, most of the country is suitable for tomato production. Both El Niño and La Niña impacted the zoning, especially from November to May. During La Niña, suitable conditions were more frequent than during El Niño extending the planting window. High air temperatures during El Niño reduce crop suitability. Disseminating this information in a timely and accessible way will reduce climate risk for tomato production in Mozambique through the definition of location and planting dates with lower risk associated with climate variability.

1. Introduction

The use of weather and climatic information increases resilience in agricultural production systems (Fraisse et al., 2006), since several agricultural practices are influenced by weather conditions. African agricultural systems are more vulnerable to climate variability due to

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low input of resources, poor soil conditions (Unganai, 2000), and limited extension services (Smart et al., 2015). Mozambique's economy is dependent on agricultural production. One quarter of Mozambique's Gross Domestic Product (GDP) comes from agriculture, 70% of the country's population lives in rural areas, and approximately 80% of the nation's economically active population works in agricultural jobs (Instituto Nacional de Estatística, 2011).

Tomato (*Solanum lycopersicum)* is a crop adapted to a wide range of climate conditions, being preferable for Mozambique growers due to its high market value and commercialization as both fresh and processed produce. However, extreme weather conditions may damage the plants and reduce yield. High air temperatures can reduce pollen production and cause flowers to fall off. In addition, excess water may increase the incidence of diseases (Naika et al., 2005; Sonnemberg, 1985; Villareal, 1980).

One of the biggest challenges faced by growers in Mozambique is defining optimal timing to grow tomato across years. In most parts of Mozambique, tomato is grown during the dry season (April to September) as the crop has less pest and disease pressure and less physiological disorders caused by temperature stress (Ribeiro and Rulkens, 1999 cited by Cuane, 2008). As tomato price declines as a result of excess of production in the dry season (Johane, 2007), growers tend to plant tomato earlier in the year to take advantage of higher market prices. However, earlier planting coincides with high incidence of unfavorable weather conditions for crop development due to increased temperatures and excess of rainfall. Access to information for better defining crop timing based on intra- and interannual climate variability could greatly benefit growers. They could take advantage of higher market prices while knowing crop growth needs and risks by choosing an optimal growing window.

Better understanding of interannual climate variability allows decision makers to benefit from favorable conditions and reduce production risks (Fraisse et al., 2006). The main source of interannual climate variability around the world, including Mozambique, is the El Niño-Southern Oscillation (ENSO) (Fraisse et al., 2006; Ropelewski and Halpert, 1996), which is a coupled ocean-atmosphere phenomenon occurring in the western Pacific Ocean. This phenomenon has been reported as affecting climate and modifying agricultural management in the USA (Fraisse et al., 2006; Gelcer et al., 2013; Woli et al., 2015), South America (Berlato and Fontana, 2003; Gelcer et al., 2013; Ramirez-Rodrigues et al., 2014), Africa (Gaughan et al., 2015; Lobo, 1999; Mavie, 1999; Stige et al., 2006), Asia (Jagtap and Chan, 2000; Plisnier et al., 2000) and Europe (Ropelewski and Halpert, 1987). In Mozambique, the warm phase of ENSO (El Niño) has been linked with higher air temperatures and lower rainfall causing drought problems. For the cold phase of ENSO (La Niña), the opposite effect has been reported with predominantly lower air temperatures, higher rainfall and floods around the country (Meque and Abiodun, 2014; Ropelewski and Halpert, 1987).

Agroclimatic zoning is used to define suitable areas for crop production based on intra- and interannual climate variability, and is one of the most useful tools to reduce risks associated with climate variations. Zoning provides information to identify optimal planting dates for each region, helping to define crop suitability and periods when environmental conditions meet crop needs, reducing climate variability risk (Araya et al., 2010; Cunha et al., 2001; Maluf et al., 2001; Yamada, 2011). Thomé et al. (1999) created an agroclimatic zoning for tomato in southern Brazil, which used mean and minimum air temperatures, together with excess of rainfall to define suitable regions for production. Bagli et al. (2003) combined mean and minimum air temperatures and soil characteristics to create a tomato agro-pedo-climatological zoning defining ideal locations in Italy for tomato production. For Doorenbos and Kassam (1979), daily mean air temperatures between 18 and 25 °C are ideal for tomato development, while the tolerable range is 15–28 °C with water requirements varying from 400 to 600 mm per crop cycle.

Recent studies developed agroecologic zoning in Mozambique for soybean, maize, cassava, rice, peanut and cotton (Bolfe et al., 2011), showing the importance of defining proper regions for production of different crops in the country. The authors defined suitable, marginal and unsuitable areas for these crops. The zoning for horticultural crops is slightly different from row crops. Row crops have only one crop season per year due to longer growing cycle and rainfall dependency, while horticultural crops have shorter growing cycle and are typically irrigated or hand watered in Mozambique (Ribeiro, 2008).

The objectives of this study were i) to create an agroclimatic zoning for tomato production determining regions and planting dates with optimal growing conditions for Mozambique; ii) to determine the impact of ENSO phenomenon on tomato crop zoning and management practices; and iii) to create an online decision support tool to assist farmers, extension agents, researchers and policy makers to determine tomato planting dates with higher probability of success based on weather variability for ENSO phases. In this study, tomato was the selected crop because of its high economic importance in the region and its cropping success being highly dependent on weather conditions. The present study shows the combination of regions, planting dates and the ENSO phase that result in higher chances of tomato crop success in Mozambique.

2. Material and methods

2.1. Study area

Mozambique is located in southeastern Africa, in the southern hemisphere, between the latitudes 10° 28′ S and 26° 52′ S, with elevation varying from 0 to 2400 m (Fig. 1a)[2]. The country is under maritime influence, since the coast extends for more than 2400 km (Saetre and Silva, 1979). Several climate types are reported within the country due to the large latitudinal and elevational range. Using the Köppen-Geiger classification (Fig. 1b), the climate in most parts of Mozambique is equatorial savannah with dry winters (Aw), with some areas of hot semi-arid climate (BSh), and higher-elevation regions (above 1000 m) in Niassa, Tete and Zambezia and mid-elevations (from 500 to 1000 m) such as Manica province, with warm temperate climates with dry winters and hot summers (Cwa) (Kottek et al., 2006). The average annual rainfall ranges from 200 mm, in the western part of Gaza province, to 1200 mm in the Zambezia province (Hoguane, 2007). In most part of the country, the dry season extends from April to October, and the wet season extends from November to March when more than 90% of the total rainfall occurs. The highest air temperatures are observed in November, when the mean maximum temperatures in lower elevation regions in the central part of the country are as high as 40 °C. The lowest air temperatures occur in June and July in mid and high elevations at Manica, Tete and Niassa provinces. In these regions, the mean minimum temperature may be as low as 6 °C during winter. The yearly mean air temperature throughout the country ranges from 20 to 26 °C (AgroClimate Mozambique, 2016).

2.2. Data

Due to limited weather data availability from weather stations, daily grid-based information from 1983 to 2014 from the Famine Early Warning System NET (FEWS Net)[3] and Climate Forecast System Reanalysis (CFSR)[4] (Saha et al., 2010) from NOAA, were used for this study. Maximum and minimum air temperature information was obtained from the CFSR, with 0.25° of spatial resolution. Precipitation

[2] http://www.mapmart.com/.

[3] http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.FEWS/.Africa/.DAILY/.ARC2/.daily/.

[4] //ftp.cpc.ncep.noaa.gov/wd53rl/cfsr/.