Agricultural Systems 160 (2018) 21–30

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Improving drought management in the Brazilian semiarid through crop forecasting

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ARTICLE INFO

Keywords:
Maize
Crop forecast
AquaCrop
Eta RCM

ABSTRACT

In this paper, we evaluated the performance of the model AquaCrop for crop yield forecasting in the Brazilian semiarid (BSA) using meteorological observation and Eta model seasonal climate forecasts as input data. The study area is characterized by low rainfall that is poorly distributed throughout the rainy season; thus, the region's agricultural productivity is vulnerable to climate conditions. AquaCrop was first calibrated using field experiments and subsequently applied to simulate an operational crop yield forecast system for maize under rainfed conditions. Simulations were performed with daily data for 37 growing seasons for the period 2001–2010. The seasonal climate forecast was used in combination with observed meteorological data to anticipate the crop forecast. Soil characteristics were derived from pedotransfer functions (PTFs). We were able to demonstrate the ability of the seasonal crop yield forecast system to provide timely and accurate information about maize yield at least 30 days in advance of the harvest. The development of improved crop yield forecasting system is crucial for implementing drought-preparedness measures in the BSA region.

1. Introduction

Crop models assist to improve management by allowing analyses of scenarios and management strategies, such as planting dates and densities, harvesting monitoring and crop growth forecasting. The crop production is affected by internal factors, genetic and heredity, and external factors such as management practices and environmental conditions. Among environmental factors, the effect of climate explained about one third of the crop yield variability (Leng et al., 2016; Ray et al., 2015). Therefore, many studies in the last few decades used field experiments and numerical modeling to understand the interactions between climate and agriculture (Greatrex, 2012).

Climate information is crucial not only to predict crop yields but also to determine optimum planting dates, to determine the economic feasibility of different crop management practices and to guide decisions to maximize the expected crop yield. Brazilian agriculture is well-known for its important role in the country's economy representing almost 15% of the Gross National Product (GNP) (CEPEA/USP-CNA, 2015) as well as its importance in global markets. Although most regions of the country have high crop yields, this is not the case in large areas of the semiarid northeastern part of the country. The Brazilian Semiarid – BSA has a population of 22.6 million inhabitants and a density of 23 hab.km^{-2} (Instituto Brasileiro de Geografia e Estatística-[Brazilian Institute of Geography and Statistics] (IBGE), 2014). Farming system in the region traditionally involves slash-and-burning and shifting cultivation, which has resulted in the increase deforestation of the shrublands (known as Caatinga). In addition, livestock became the main economic activity since the 19th century. Those management practices represent a serious threat to plant biodiversity conservation in the Caatinga biome (Mamede and Araújo, 2008) and have increased the risk of desertification (Vieira et al., 2015). Only recently, and because of the extended overgrazing and increasingly shorter fallow period, concerns about the sustainability of human activities in the Brazilian semiarid have arisen. Therefore, NGOs, state extension agencies, the federal government and international aid agencies have been promoted several actions to improve the quality of life of local population and to contribute to the preservation, conservation, and sustainable management of the Caatinga (World Bank, 2015). In spite of several initiatives, traditional management practices still persist in many areas of the semiarid (Nasuti et al., 2013) due to cultural reasons and difficulties

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https://doi.org/10.1016/j.agsy.2017.11.002
Received 28 November 2016; Received in revised form 8 November 2017; Accepted 8 November 2017

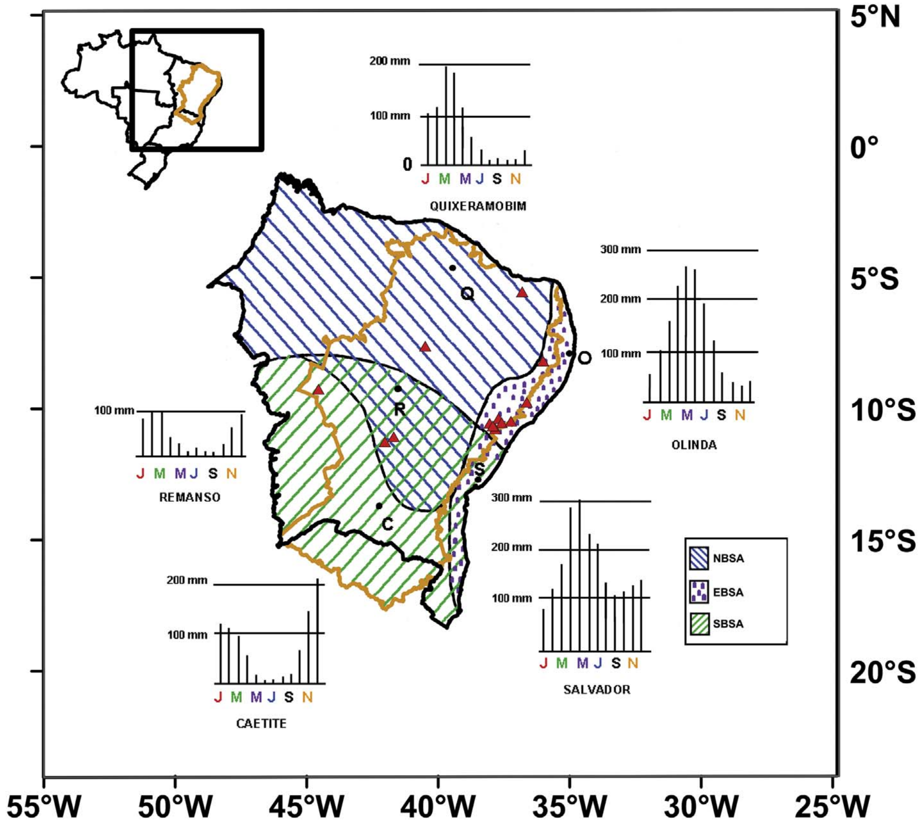

Fig. 1. Map of the study area delimiting the Northeast of Brazil in black and the semiarid region in orange. Shaded areas indicate the rainfall regimes: Northern Brazilian Semiarid – NBSA, Eastern Brazilian Semiarid -EBSA and Southern Brazilian Semiarid – SBSA. The black dots correspond to the location of five representative stations of the different rainfall regimes: Caetité - C, Salvador - S, Olinda - O, Quixeramobim – Q and Remanso - R, which annual rainfall cycle are shown in the bar graphs. The red triangles indicate the location of the experimental sites used in this study. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Redrawn from Kousky (1979)

related to market access for non-traditional agricultural products. Combined with the inadequate farming techniques, low-income farmers of the region usually grow crops under rainfed conditions and have low technological resources, such as low productivity varieties, with no resistant to pest and water deficits. In addition, their access to capital is limited. Under these conditions, productivity is extremely vulnerable to the high intraseasonal and interannual variability of rainfall that characterizes the Brazilian semiarid Northeast.

The most important subsistence crop in the semiarid region is maize (*Zea mays L.*). Maize is the main staple food for the population and is also used as silage to feed animals. Maize has the highest yield of the cereals and can be grown in the tropics and subtropics and even in semiarid regions under conditions with adequate water and soil fertility (De Figueredo, 2004). Although maize is tolerant of a wide range of temperatures, it is sensitive to soil water stress. Consequently, crop yield in the semiarid region varies up to 48% from one year to another; in the 2012 drought, yield loss was approximately 80% (CONAB, 2012). Severe drought triggers huge societal impacts that extend beyond the semiarid geographical domain. They also cause food shortages and environmental impacts related to biodiversity loss and desertification due to overexploitation of natural resources (Medeiros et al., 2013). To minimize the negative effects of droughts, costly governmental mitigation actions are put in place during droughts. The severe drought that affected the region during the period 2001–2016, for instance, which was the most intense of the past decades (Brito et al., 2017), caused significant impacts for population, as well as economical activities, with estimated losses of approximately $US 6 billion, mainly due to drought impacts on agricultural sector (Gutiérrez et al., 2014). Governmental actions require advance preparation to fulfill legal requirements. In this context, the sooner a drought is predicted, the more efficient and effective the use of public funds for mitigation actions are likely to be. Considering that food insecurity in the Brazilian semiarid is heavily dependent on rain-fed agriculture, the ability to predict and monitor crop yields throughout the growing season is crucial to decision makers for the preparation of necessary mitigation actions.

Drought monitoring in the Brazilian Northeast is currently based on a combination of a network of real-time rain gauges, three-month seasonal forecasts (Souza et al., 2001), indices based on remote sensing (Cunha et al., 2015) and maps of droughts (Martins et al., 2015). In general, the areas with rainfall deficits are identified based on maps of observed rainfall anomalies, and drought reports are produced using qualitative assessments of seasonal forecasts. Limitations of the existing monitoring are related to the lack of quantitative assessment of the impacts of a specific drought, such as, for instance, what the expected drop in productivity will be if a certain drought scenario should occur.

Discussions about the importance of early warning information on crop yield for farmers and decision makers have been presented in many studies (Cardoso et al., 2010). In addition, previous studies (Cantelaube and Terres, 2005) indicated that the accuracy of yield forecast models increases when meteorological forecast information is used. Cardoso et al. (2010) also suggested that the use of meteorological forecasts generates more reliable productivity estimates during the growth period than those generated using only climatological information.

Many studies have investigated the use of seasonal atmospheric models in crop models (Cardoso et al., 2010). In general, the efficiency of a crop yield forecasting system is related to the ability of atmospheric models to predict rainfall, temperature and other variables used as input by crop models. Despite the fact that studies have demonstrated that the ability of crop models to predict crop yield improves when climate forecasts are used as input, they concluded that it is necessary to address the uncertainties in climate forecasts and correct the systematic errors which affect the forecasted climate variables.

In this context, this paper demonstrates the feasibility of using operational seasonal forecasts for the northeast region of Brazil as input to the FAO's AquaCrop model to predict maize crop yield with sufficient lead-time to improve the planning of governmental mitigation actions during the episodic droughts.