Renewable Energy 78 (2015) 26–34

Contents lists available at ScienceDirect

Renewable Energy

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

Impact of climate changes on potential sugarcane yield in Pernambuco, northeastern region of Brazil

André Luiz de Carvalho [a, *], Rômulo Simões Cezar Menezes [a, 1], Ranyére Silva Nóbrega [a, 1], Alexandre de Siqueira Pinto [b, 2], Jean Pierre Henry Balbaud Ometto [c, 3], Celso von Randow [c, 3], Angélica Giarolla [c, 3]

[a] Federal University of Pernambuco (UFPE), Av. Prof. Moraes Rego, 1235, Cidade Universitária, Recife, PE, CEP: 50670-901, Brazil
[b] Federal University of Sergipe (UFS), Av. Marechal Rondon, s/n Jardim Rosa Elze, São Cristóvão, SE, CEP: 49100-000, Brazil
[c] National Institute for Space Research (INPE), Av. dos astronautas, 1758, Jd Granja, CEP: 12227-010, São José dos Campos, SP, Brazil

ARTICLE INFO

Article history:
Received 25 July 2014
Accepted 8 December 2014
Available online

Keywords:
Global warming
Future climate scenarios
Century 4.5 model
Sugarcane

ABSTRACT

Sugarcane is a typical culture of hot and humid climate and therefore is well adapted to the climate in many regions of Brazil. However, there may be yield reductions in the Northeastern region of Brazil due to possible future reductions in rainfall levels. The aim of this study was to simulate, using the Century 4.5 model, the impact of climate changes on potential sugarcane yield in Goiana and Itambé, Zona da Mata of Pernambuco. The Century 4.5 model was booted with soil and climate data from 1950 to 2012. Data on total soil carbon, soil texture (sand, silt and clay contents), pH, soil density and soc stocks were obtained from previous studies. The climate scenario used was the average emissions SRES A1B, designed by Eta/CPTEC model for periods 2014–2040, 2041–2070 and 2071–2100, which is composed of LOW member (low emissions) and HIGH member (high emissions). According to the results obtained by A1B scenario, the potential yield can be reduced in the near future (2014–2040). The high temperatures in northeastern Brazil will increase the evapotranspiration rates, reducing the amount of water available in the soil, making the planting of sugarcane increasingly difficult, which tend to be strongly reduced in drier areas, such as cities located in the western portion of the Zona da Mata region, northern state of Pernambuco, Brazil.

1. Introduction

The global climate is undergoing constant changes in the last decades due to global warming that occurs due to human activities, notably deforestation, changes in land use and emissions of greenhouse gases from the burning of fossil fuels. Global warming is the increase in mean temperature due to the increased greenhouse effect [1], which occurs when part of the infrared radiation emitted by the earth is absorbed by gases contained in the atmosphere. These gases are known as greenhouse gases (GHGs), which main components are water vapor and CO_2. In the previous decade, there has been an average increase of 2% in the CO_2 concentration in the atmosphere, showing that the absorption of carbon by natural systems is not occurring at the same rate as it has been emitted [2,3]. According to future climate projections published by IPCC (Intergovernmental Panel on Climate Change), the average earth temperature will increase up to 5 °C by the end of the century [4].

It is likely that climate changes promote impacts on agriculture, impairing the distribution of global agricultural production [5] and aggravating the problem of hunger in the most vulnerable parts of the planet, such as poor countries of Africa, Asia and Latin America [6]. Large agricultural producers, such as Brazil, may be affected by changes in the global climate, since the temperature rise threatens the cultivation of various agricultural crops. Several studies have shown that the main agricultural crops aimed at feeding the world's population such as rice, wheat, soybeans, corn, beans and

* Corresponding author. Tel.: +55 (81) 2126 8000.
E-mail addresses: del.andre2@hotmail.com (A.L. Carvalho), rmenezes@ufpe.br (R.S.C. Menezes), ranyere.nobrega@yahoo.com.br (R.S. Nóbrega), alexandresp@ufs.br (A.S. Pinto), jean.ometto@inpe.br (J.P.H.B. Ometto), celso.vonrandow@inpe.br (C. von Randow), angelica.giarolla@inpe.br (A. Giarolla).
[1] Tel.: +55 (81) 2126 8000.
[2] Tel.: +55 (79) 2105 6600.
[3] Tel.: +55 (12) 3208 6000.

http://dx.doi.org/10.1016/j.renene.2014.12.023
0960-1481/

coffee will suffer productivity losses due to the increase in temperatures and changes in rainfall regime [7–11]. However, some crops that are more resistant to high temperatures, such as sugarcane, may benefit from climate changes until they reach their limit of tolerance to increased temperature and water stress [9].

Brazil is the world leading producer of sugarcane and harvested nearly 618 million tons in 2010. The perspectives for future increases in sugarcane production may be limited by possible reductions in water availability in some regions and increased expected demand of water for other uses. Moreover, in the future, these areas may be influenced by climate changes, becoming hotter and drier, and may be not suitable for cultivation of various crops currently produced [12]. In most regions of Brazil, sugarcane will show no loss of suitable areas, but in the Northeastern region, in addition to reduction of suitable areas, declining crop yield may also occur, being feasible only under irrigation [9].

Computational models such as APSIM, DSSAT, Century and others have been used to analyze the impacts of climate changes on the development of sugarcane. The Century model simulates the dynamics of carbon and nutrients (nitrogen, phosphorus and sulfur) in natural and cultivated biomes in temperate soils [13]. The Century is a mechanistic model that analyzes long-term dynamics of soil organic matter (SOM) and nutrients in the soil-plant system in several agroecosystems. This model was originally developed to simulate the dynamics of SOM in grasslands in North American plains [14], but has been used in various biomes, soil types and climates [14,15].

Recently, studies performed with the Century model in version 4.0 in the Zona da Mata of Pernambuco state, Brazil, evaluated the efficiency of the model to simulate the dynamics of soil carbon in sugarcane agrosystems under different management practices [16,17]. By combining models that simulate the dynamics of C and climate models, the effects of climate changes on sugarcane yield can be investigated using future climate scenarios, provided by the Eta/CPTEC regional climate model that represents projections of emissions of greenhouse gases for the future climate and thereby simulate the dynamics of carbon and nutrients under these climatic conditions.

Thus, the present study aimed to evaluate the impact of climate changes on the potential sugarcane yield using the Century 4.5 model for the A1B climate change scenario (IPCC-SRES).

2. Materials and methods

2.1. Locations

The potential sugarcane yield (ton ha^{-1}) in future years was simulated for two municipalities located in the Zona da Mata region, northern state of Pernambuco: Goiana and Itambé. This region presents optimum conditions for sugarcane cultivation, which ranges 25 °C–33 °C for air temperature and 1500 to 2000 mm for rainfall [18,19]. Goiana is located on the coast (7°55′S, 35°00′W, 13 m) and the climate was classified as tropical Atlantic (Aw) according to the Koppen classification, with high rainfall and low temperature variations during the year. The annual rainfall is high, with average of 1800 mm, and the annual average air temperature is 24.6 °C. Itambé is located on the western side of the Zona da Mata of Pernambuco (7°30′S, 35°10′W, 179 m). According to the Koppen climate classification, the climate type is tropical Atlantic (As), characterized by hot and dry with average annual air temperature is 24.2 °C. The average annual rainfall is 1200 mm.

Climate variables required for booting the Century 4.5 model were monthly accumulated rainfall (mm) and maximum and minimum temperature (°C). The historical series of monthly precipitation was obtained from the National Institute of Meteorology (INMET) and from the Agency for Water and Climate (APAC) at meteorological stations distributed in the state of Pernambuco. The data used cover the period from 1950 to 2012 [20]. The Inverse Distance Weighting (IDW) interpolation method was applied on the rainfall series to obtain the rainfall series of the study areas [21]. The monthly air temperature data (maximum and minimum) were estimated using the Estima T software developed by the Federal University of Campina Grande, to estimate air temperature in northeastern Brazil. It determines the coefficients of the quadratic function to average, maximum and minimum monthly temperatures as a function of local coordinates of longitude, latitude and altitude [22].

The soil data required to boot up the model came from the experimental fields of Itapirema in Goiana and IPA station in Itambé: total organic carbon (TOC), texture (sand, silt and clay contents), soil density, pH and soil organic carbon stocks (Table 1).

2.2. Climate scenarios from Eta/CPTEC regional model

2.2.1. SRES A1B climate scenario

Sugarcane yield was simulated using the SRES A1B climate scenario generated by the Eta/CPTEC regional model through dynamic downscaling of the HadCM3 global model [25]. The Eta/CPTEC regional model has high resolution (40 km lat-lon) with 20 vertical layers on South America. The climate scenario used was SRES A1B, i.e., a scenario of average Green House Gases emissions. In the present study, two subsets with different sensitivities to CO_2 emissions were considered: LOW (low emissions) and HIGH (high emissions), both belonging to the A1B scenario. Variables precipitation and maximum and minimum temperature for the present climate (1961–1990) and future climate (2014–2100) were considered by assessing this scenario.

2.2.2. Correction of systematic errors of data of the Eta/CPTEC regional model

2.2.2.1. Air temperature. The predictions of the numerical models have systematic errors that occur due to active physical processes and the initial and boundary conditions represented in the models. Therefore, it is necessary to make comparisons of analysis with data of the Eta/CPTEC model and with observed data to verify the magnitude of systematic errors.

For air temperature data, the correction of systematic errors (°C) occurred by subtracting the monthly averages from monthly average data generated by the Eta/CPTEC model [26].

$$\text{SYSTEMATIC ERROR} = \text{TEMP}_{\text{ETA/CPTEC}} - \text{TEMP}_{\text{OBS}} \quad (1)$$

where: $TEMP_{ETA/CPTEC}$ corresponds to air temperature (°C) simulated by the Eta/CPTEC model and $TEMP_{OBS}$ corresponds to measured air temperature (°C) both refer to the 1961–1990 period.

A series of thirty years of model and observed data for the period of the present climate (1961–1990) was divided into two other periods: a series for the correction of systematic errors (1961–1985) and the other to verify the correction efficiency (1986–1990). The first period was used to calculate the systematic error that was used to correct the model data for the second period and thus to verify the correction efficiency by comparison with observed data [27].

2.2.2.2. Rainfall. The approach used for the corrections of systematic errors in temperature data is not suitable for rainfall data. The correction of this variable was performed by multiplication factor c [28,26], Defined as: