European Journal of Agronomy 96 (2018) 108–119

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Future climate change projects positive impacts on sugarcane productivity in southern China

Hongyan Ruan[a,b,c], Puyu Feng[b,d], Bin Wang[b], Hongtao Xing[b], Garry J. O'Leary[e], Zhigang Huang[a,c,*], Hao Guo[a,c], De Li Liu[b,f,**]

[a] *State Key Laboratory for Conservation and Utilization of Subtropical Agro-Bioresources, Agricultural College, Guangxi University, Nanning 530000, Guangxi, China*
[b] *NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, Wagga Wagga, NSW 2650, Australia*
[c] *Cultivation Base of Guangxi Key Laboratory for Agro-Environment and Agro-Product Safety, China*
[d] *School of Life Sciences, Faculty of Science, University of Technology Sydney, PO Box 123, Broadway, Ultimo, NSW 2007, Australia*
[e] *Agriculture Victoria Research, Department of Economic Development, Jobs, Transport and Resources, PB 260, Horsham, Vic 3400, Australia*
[f] *Climate Change Research Centre and ARC Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, NSW, Australia*

ARTICLE INFO

Keywords:
APSIM-Sugarcane
Sugarcane yield
Elevated CO_2
Statistical downscaling
General circulation model
High temperature

ABSTRACT

Climate change is recognised to alter the distribution of rainfall and increase temperature and atmospheric CO_2 concentration [CO_2] and pose a formidable challenge to the sustainability of various cropping industries around the world. Additionally, in specific regions, like China, and for particular crops, like sugarcane, the likely effects of climate change are not straightforward. This is because of non-linearity of the interacting climatic factors on crop growth and yield. In our study, the APSIM-Sugarcane model was used to examine the likely response of sugarcane in future climate scenarios. Statistically downscaled climate data based on 28 global climate models (GCMs) under RCP4.5 and RCP8.5 scenarios were used to generate the change in climate in southern China. The results show that the model well reproduced observations for biomass dry matter (DM), biomass fresh matter (FM), sugar yields (S) and leaf area index (LAI), with values for the index of agreement of 0.65, 0.71, 0.84 and 0.70, respectively. The values of RMSE were relatively low with 7.10 t ha^{-1} for DM, 18.87 t ha^{-1} for FM, 0.84 t ha^{-1} for S and 1.03 $m^2\,m^{-2}$ for LAI. On average, the ensemble of downscaled GCM projections showed a small increase in radiation and rainfall in the future at the four locations considered, with significantly increased temperature. Sugarcane yields in southern China appeared to be positively affected under future climate and [CO_2] changes. Overall, DM was projected to increase by 5.6 and 6.4 and 6.6 t ha^{-1} for RCP4.5 in 2030s, 2060s and 2090s relative to 1961–2010, respectively. However, RCP8.5 had less promotion compared to RCP4.5 on DM. Similar increased trends for three future time periods could be found in FM and S. Our results showed that the largest percentage change in S occurred at high latitude locations (e.g., Hezhou), with mean values 28.1% and 39.4% for RCP4.5 and RCP8.5 in 2030s, 44.2% and 23.5% in 2060s, and 41.1% and 45.5% for in 2090s, respectively. In addition, our multiple linear regression analyses showed that the changes in radiation, rainfall and temperature together with elevated [CO_2] could explain more than 70% of sugarcane yields change across four locations. Across all locations, increases in sugarcane yields were strongly correlated ($P = .001$) with each degree (Celsius) increase in future temperature and per mm increase in future rainfall. For example, the DM, FM and S increased 7.8–14.2, 16.6–36.1 and 2.7–6.1 kg $ha^{-1}\,mm^{-1}$ responding to rainfall, respectively. Although uncertainties in our study on the impact of climate change on sugarcane might arise from the choice of crop model and GCMs, the results would be pivotal for developing high-yield adaptive strategies as well as informing policy makers to improve sugarcane productivity in China.

1. Introduction

Sugarcane is a perennial grass grown over a wide range of climates around the world from latitudes of 30°N to 30°S (Bull and Glasziou, 1979). The crop is usually cultivated in the tropical and sub-tropical regions with adequate solar radiation and rainfall. The Chinese sugar

---

[*] Corresponding author at: State Key Laboratory for Conservation and Utilization of Subtropical Agro-Bioresources, Agricultural College, Guangxi University, Nanning 530000, Guangxi, China.

[**] Corresponding author at: NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, Wagga Wagga, NSW 2650, Australia.

E-mail addresses: hzg@gxu.edu.cn (Z. Huang), de.li.liu@dpi.nsw.gov.au (D.L. Liu).

https://doi.org/10.1016/j.eja.2018.03.007
Received 21 September 2017; Received in revised form 9 February 2018; Accepted 24 March 2018

industry is mainly located in the southern part of China that comprise mainly C4 sugarcane crops (*Saccharum* ssp.) and is about 1.5 million ha in size (Li and Yang, 2015). In contrast, only 14% of Chinese sugar production comes from sugar beet (*Beta vugalis* L.) that is grown in the cooler elevated northern regions (Huang et al., 2006). Guangxi has the largest sugarcane area and is the largest producer of sugar in China, accounting for about 70% of national area producing 7.21 million tons sugar per annum, which contributes to about 7 billion US dollars to the Gross Domestic Product (Li and Yang, 2015). This makes sugar a vital industry in Guangxi and for China generally (Zhu et al., 2007).

Rainfall, temperature and radiation are the major climate factors that affect sugarcane growth and development. Compared to the production of other sugar producing regions of the world, the long duration of low temperature, frost occurrence, wet and cloudy days in winter and spring are the major environmental factors that lead to severe constraints for sugarcane growth, especially for ratoon sprouting and the maturing period of accumulating sucrose and juice purity (Li et al., 2015). In addition, drought occurs often in the major sugarcane areas, which is also a major constraint because more than 80% of sugarcane is planted in the upland areas where irrigation is not available (Li and Yang, 2015).

Clearly, developing strategies to cope with the negative or take advantage of positive impacts of climate change is essential to inform public debate, policy makers and farmers to maintain sugar production in China. Increasing greenhouse gas concentrations are expected to increase China's surface air temperature and alter the temporal and spatial patterns of rainfall. The annual mean air temperature is predicted to increase 2.3–3.3 °C by 2050 and 3.9–6.0 °C by 2100, and annual rainfall is projected to increase 10–12% in 2100 relative to the 30-year average of 1961–1990 in China (Ding et al., 2006). Inevitably, future climate change would have significant impacts for sugarcane productivity. Therefore, sufficiently accurate predictions of sugarcane response to climate change are necessary to inform successful adaptation.

However, the effect of the interaction between rising CO_2 concentration [CO_2], increased temperature and rainfall on sugarcane yield has not been documented in this region, though there are many studies in the major sugar production regions in the world, that has assessed the effect of climate change on sugarcane yield (Biggs et al., 2013; Marin et al., 2013; Singels et al., 2014). For example, Cheeroo-Nayamuth et al. (2001) used the APSIM-sugarcane model (Keating et al., 1999) to simulate the sugarcane yield in Mauritius and found that larger reductions in sugarcane yield and sucrose production under increased temperature because of the lower water use efficiencies and high respiration demands irrespective of the change in rainfall. They concluded that irrigation was the best adaption option over others such as a change in cultivar or harvest date, but their assessment was based on simulations without considering the effects of CO_2 fertilisation on the physiology of the crop. However, Knox et al. (2010) used the DSSAT-Canegro model to explore the climate change impacts on sugarcane production in Swaziland and showed that the impacts of climate change can be offset by higher crop yields due to the direct effect of CO_2 fertilisation. Further, Marin et al. (2013) also using the DSSAT-Canegro model has shown that sugarcane yields are expected to increase by 24% by 2050 in southern Brazil based on earlier CMIP3 A2 and B2 CSIRO general circulation model (GCM) scenarios. More recent work by Singels et al. (2014) has also shown potential yield increases from 4 to 20% at representative sites in Australia, Brazil and South Africa from three GCMs to 2090. However, the possibility of negative net effects should not be overlooked (Everingham et al., 2015). Despite different scenarios the consideration of elevated [CO_2] in these sugarcane models points to likely increases in sugar yield as the climate changes with rising atmospheric CO_2 levels and warmer temperatures in the present major sugarcane production regions of the world. In addition, most of the previous studies have generated climatic inputs to the crop models by scaling historical observed climate using delta change method (Biggs et al., 2013; Knox et al., 2010; Marin et al., 2013; Webster et al., 2009) which merely considered the changes of climate means employing historical variance. The main limitation of such methodology is that it implicitly assumes that future temporal and spatial precipitation patterns are identical to that observed in the historical data.

The objectives of this study are to: (1) evaluate the performance of the APSIM-Sugarcane model using two-year's field experiment data in Guangxi, (2) investigate the future climate change impacts on sugarcane productivity in this region, and (3) identify the relationship between climate variables and sugarcane yields and examine strategies to cope with the impacts of climate change on sugarcane productivity in southern China.

2. Materials and methods

2.1. Study sites, climate and soil data

Guangxi is located in mountainous terrain in the far south of China. This region has a typical sub-tropical monsoon climate with long summer days and short winter days, high solar radiation and rainfall. Four sites, representing different climatic features within the region, were selected for this study (Fig. 1). Among these sites, Qinzhou is the hottest (annual average temperature of 22.7 °C) with highest rainfall (2149 mm). In contrast, Nanning has the lowest rainfall (1302 mm) with the second warmest temperature (22.5 °C). The remaining two

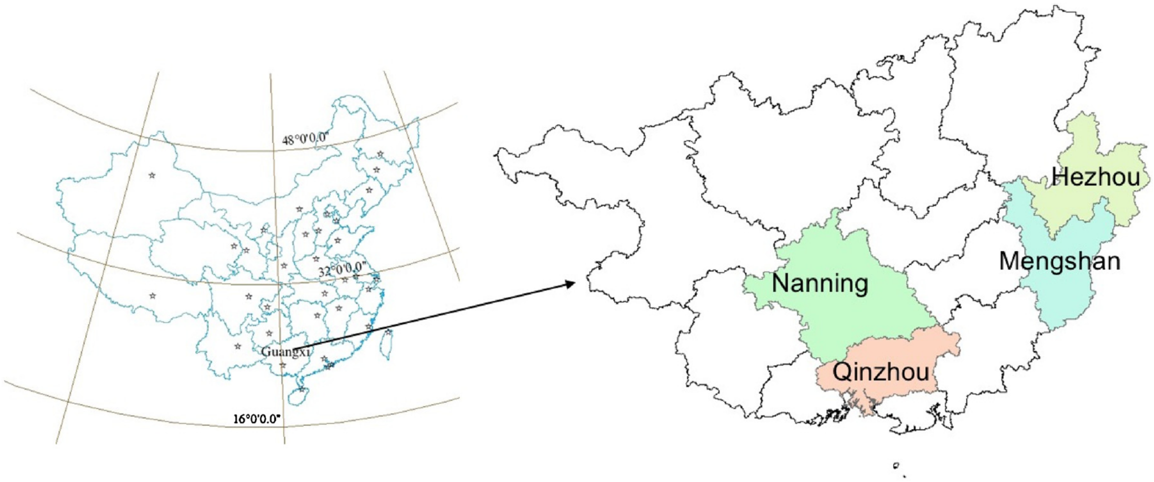

Fig. 1. The location of four study sites in Guangxi.