CLIMATE CHANGES AND TECHNOLOGICAL ADVANCES - PROJECTED IMPACTS ON THE SUGARCANE CROP PRODUCTIVITY IN TROPICAL SOUTHERN BRAZIL

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ABSTRACT: In this study, an agrometeorological model was used to estimate sugarcane yield in tropical southern Brazil, based on future climatic scenarios presented in the fourth Intergovernmental Panel on Climate Changes (IPCC) report. The sugarcane yield was evaluated considering the possible impacts caused by changes in temperature, precipitation, sunshine hours and CO2 concentration in the atmosphere as well as technological advances in 2020, 2050, and 2080, for the A1B scenario. The results show that increasingly higher temperatures will cause an increase of the potential productivity (PP), since such variable affects positively the efficiency of the photosynthetic processes of C4 plants; however, the changes in solar radiation and rainfall will have less impact. PP will increase by 15% in relation to the present condition in 2020, by 33% in 2050 and by 47% in 2080. Regarding the actual productivities (AP), the increase observed in PP will compensate the negative effect of the increasingly water deficit. AP will increase by 12% in relation to the present condition in 2020, by 32% in 2050 and by 47% in 2080.
KEYWORDS: climate changes, water balance, agrometeorological model, sugarcane.

MUDANÇAS CLIMÁTICAS E AVANÇO TECNOLÓGICO - EXPECTATIVAS DE SEUS IMPACTOS NA PRODUTIVIDADE DA CULTURA DA CANA-DE-AÇÚCAR NA REGIÃO CENTRO-SUL DO BRASIL

RESUMO: Neste estudo, foi utilizado um modelo agrometeorológico para estimar a produtividade da cana-de-açúcar na região de Piracicaba, SP, Brasil, baseado nos cenários futuros do clima apresentados no quarto relatório do Painel Intergovernamental sobre Mudanças Climáticas (IPCC). A produtividade da cana-de-açúcar foi avaliada levando-se em consideração as possíveis alterações de temperatura, precipitação, insolação e concentração de CO2 na atmosfera, assim como os avanços tecnológicos nos anos de 2020, 2050 e 2080, para o cenário A1B. Os resultados mostram que o aumento da temperatura acarretará aumento da produtividade potencial (PP), já que essa variável afeta positivamente a eficiência do processo fotossintético das plantas C4; entretanto, as alterações na radiação solar e na chuva terão menores impactos na produtividade. A PP aumentará cerca de 15% em relação à condição atual em 2020, de 33% em 2050 e de 47% em 2080. Com relação à produtividade real (AP), o aumento da PP compensará o efeito negativo causado pelo aumento do déficit hídrico. A AP aumentará cerca de 12% em relação à condição atual em 2020, de 32% em 2050 e de 47% em 2080.
PALAVRAS-CHAVE: mudanças climáticas, balanço hídrico, modelo agrometeorológico, cana-de-açúcar.

INTRODUCTION: Agriculture is the economical activity that most depends upon the weather and climate conditions (Assad et al., 2004). The climate affects the growth and development of plants, as well as the pests that may harm the crops. Any change in the climate condition will impact crop growth and development, as well as the relationship of the plants with microorganisms. The best way to study the impact of climate change on agriculture, more specifically on crop yield, is by applying crop simulation models (Challinor et al, 2005). These models are tools that allow knowing the influence of the climatic conditions on the growth, development and productivity of crops. Its use enables to minimize environmental risks and production costs, what may be an important aid for the definition of public policies and decision making. This work aimed to determine the potential productivity and climatic risks associated to sugarcane production, by means of a crop simulation model. The climatic data related to a eighty-year period for the Piracicaba region, state of São Paulo, Brazil, were taken into consideration to quantify possible impacts of the global warming on sugarcane crop productivity, according to the prognosis of the fourth IPCC report, as well as technological advances.

MATERIAL AND METHODS: This study was conducted for the Piracicaba region, state of São Paulo, Brazil, chosen because it is one of the main regions of the State regarding sugarcane production, with a tropical climate (wet summer and dry winter). The weather data were taken from the database of a conventional agrometeorological station located at the following coordinates: $22^o42'$ S; $47^o38'$ W; and 546 masl, in Piracicaba, for the period from 1927 to 2006. The weather data, in a 10-day time interval, considered in this study were: air temperature (maximum, minimum and mean), sunshine hours and rainfall, which were used to estimate potential evapotranspiration, climatological water balance, crop water balance and sugarcane potential and actual productivity.

The crop potential productivity (Yp) was estimated by the Agro-Ecological Zones model (AZM) (Doorenbos and Kassam, 1994). This model estimates the maximum yield rate of a crop, obtained with a highly productive variety, very well adapted to the respective growth environment, with water, nutritional and phytosanitary requirements supplied, and with the productivity conditioned only by the genetic characteristics of the crop and the environmental conditions (solar radiation, photoperiod and air temperature). The actual productivity (Ya) for sugarcane in the context of this study refers only to water-limited yield, not accounting for fertilization levels and pests damage. The Ya for sugarcane was calculated by a model that estimates the yield rate due to the potential productivity (Yp) and relative water deficit, which occurs in each phase of development, according to the water deficit sensitivity index (Ky). Thus, by knowing the relation between actual and crop evapotranspiration (ETa/ETc), Yp and Ky, it is possible to determine (Ya) of a crop by the following equation:

$$Ya = Yp \prod_{i=1}^{m} \left[1 - Ky_i \left(1 - \frac{ETa_i}{ETc_i} \right) \right]$$

Kc and Ky values for the use of Ya equation were those obtained by Santos et al. (2006) and Gazzola (2007) for a commercial sugarcane crop in Piracicaba, SP. The data related to potential and actual sugarcane productivity, obtained by the Agro-Ecological Zones and water deficit penalization methods, were determined for an eighty-year historic series, considering the observed conditions of temperature, precipitation, sunshine hours and the current CO_2

concentration in the atmosphere. Such analysis was considered as the current scenario (C0). The climatic conditions of the scenario A1B (IPCC, 2007) were used in the simulations. This scenario was adopted for presenting the most rational use of energy sources, combining fossil and non-fossil fuels. The changes of temperature for A1B scenario range from 1.7 to 4.4°C. It also indicates that there may be -5 to +5% variations in rainfall during summertime, and -5 to -10% variations during wintertime for the Piracicaba region (IPCC, 2007).

A linear increase from 370 ppm (current concentration) to 721 ppm by 2080 was considered to evaluate the effect of the increasing CO_2 concentration in the atmosphere. The increment in sugarcane productivity caused by that increase was considered as 0.029% ppm^{-1}. Scenarios with combinations of increase in temperature, variation in precipitation and sunshine hours, and increment in productivity caused by an increase in CO_2 concentration in the atmosphere (440, 559 e 721 ppm) were used to analyze the sugarcane productivity variability, caused by climate changes for the Piracicaba region, in the years of 2020 (C1 to C7), 2050 (C8 to C14) and 2080 (C15 to C21). The importance of the technological advances was also highlighted in this study, since the genetic improvement of crops, associated with adequate management practices, is responsible for the increase in sugarcane productivity seen in the last decades. The sugarcane crop technological trend considered was established based on data from the IBGE's Automatic Recovery System – SIDRA.

The simulations of the sugarcane potential and actual productivities for Piracicaba region, for an eighty-year period, were done for each of the established scenarios to determine the sugarcane temporal yield variability under such conditions. This procedure was adopted to have the average productivity and its variability, expressed in terms of the standard deviation. Therefore, for each scenario the model was run 80 times, for each year of the 80-year period, considering the climate variability that has been observed in Piracicaba region. The productivities were analyzed by two ways: individually, for each type of sugarcane crop (plant crop and ratoon crop); and considering the general productivity, calculated as a function of the percentage of each type of sugarcane in the field in a commercial crop (15% of the area with plant crop, 25% with early ratoon crop, 39% with mid ratoon crop, and 21% with late ratoon crop).

RESULTS AND DISCUSSION: The potential productivity for each type of maturity cycle of sugarcane crop in the future scenarios may increase when compared to the current scenario. For C0, the potential productivity of the sugarcane plant crop reaches 148 TCH, whereas for the sugarcane ratoon crop the potential is 112 TCH for the early cycle, 97 TCH for the medium cycle and 116 TCH for the late cycle. The general average potential productivity for sugarcane in Piracicaba region is 112.5 TCH. Considering the future scenarios, the potential productivity of the sugarcane plant crop may range from 168.5 to 170.4 TCH in 2020 (C1 to C7), from 191 to 193 TCH in 2050 (C8 to C14) and from 209.6 to 212.1 TCH in 2080 (C15 to C21). For sugarcane ratoon crops, the potential productivity for scenarios C1 to C7 (2020) may range from 127.6 to 129.4 TCH for early cycle, from 111.5 to 113.1 TCH for mid cycle, and from 131.9 to 133.8 TCH for late cycle. For 2050, corresponding to scenarios C8 to C14, the potential productivity may increase, ranging from 147.5 to 149.5 TCH for early cycle, from 130.3 to 132.1 TCH for mid cycle, and from 152.1 to 154.2 TCH for late cycle. Finally in 2080, scenarios from C15 to C21, the ratoon crop potential productivity my reach the following ranges: from 162 to 164 TCH for early cycle; from 145 to 146.7 TCH for mid cycle; and from 167.1 to 169.2 TCH for late cycle. Considering the proportion of the areas of each type of sugarcane maturity cycle in the field, the general potential productivity will change from 112.5 TCH (C0) to the following ranges: from 128.4 to 130.2 TCH in 2020, from 148.3 to 150.1 TCH in 2050, and from 163.6 to 165.6 TCH in 2080, which correspond to increases of 15%, 33%, and 47%, respectively.

Table 1 – General sugarcane potential productivity (PP), considering the proportion of each type of maturity cycle in the field: 15% with plant crop; 25% with early ratoon crop; 39% with mid ratoon crop; and 21% with late ratoon crop.

Scenarios	General PP	Scenarios	General PP	Scenarios	General PP
2020	TCH	2050	TCH	2080	TCH
C1	130.0	C8	150.1	C15	165.3
C2	129.8	C9	149.8	C16	165.1
C3	128.4	C10	148.3	C17	163.6
C4	130.2	C11	150.1	C18	165.4
C5	129.9	C12	149.9	C19	165.6
C6	128.5	C13	148.4	C20	163.9
C7	129.5	C14	149.4	C21	164.6

In relation to the actual productivities, in which the effect of the water deficit is considered, a similar pattern is observed to the variation of the AP values in relation to the potential productivity in the future scenarios. Considering the current climate conditions (C0), the actual productivity is 110 TCH for sugarcane plant crop, 83 TCH for early ratoon crop, 74 TCH for mid ratoon crop, and 73 TCH for late ratoon crop. For the future scenarios, the actual productivity of the sugarcane plant crop may range from 122 to 123 TCH in 2020 (C1 to C7), from 139.4 to 140.6 TCH in 2050 (C8 to C14) and from 154.7 to 155.9 TCH in 2080 (C15 to C21). For ratoon crops, the actual productivity for scenarios C1 to C7 (2020) may range from 91.6 to 93 TCH for early cycle, from 83.5 to 84.4 TCH for mid cycle, and from 80.2 to 81.4 TCH for late cycle. For 2050, corresponding to scenarios C8 to C14, the actual productivity may increase, ranging from 108 to 109.4 TCH for early cycle, from 99.2 to 99.9 TCH for mid cycle, and from 95.4 to 96.7 TCH for late cycle. Finally in 2080, scenarios from C15 to C21, the ratoon crop actual productivity my reach the following ranges: from 121 to 122 TCH for early cycle; from 112 to 112.7 TCH for mid cycle; and 108.2 to 109.3 TCH for late cycle. Considering the proportion of the areas of each type of sugarcane maturity cycle in the field, the general actual productivity will change from the present 81 TCH to the following ranges: from 90.1 to 91.2 TCH in 2020, from 106.1 to 107.1 TCH in 2050, and from 119.2 to 120.1 TCH in 2080 (Table 2), which correspond to increases of 12%, 32%, and 47%, respectively.

Table 7 – General sugarcane actual productivity (AP), considering the proportion of each type of maturity cycle in the field: 15% of plant crop; 25% of early ratoon crop; 39% of mid ratoon crop; and 21% of late ratoon crop.

Scenarios	General AP	Scenarios	General AP	Scenarios	General AP
2020	TCH	2050	TCH	2080	TCH
C1	90.9	C8	107.0	C15	119.8
C2	91.1	C9	107.0	C16	120.1
C3	90.4	C10	106.3	C17	119.5
C4	90.7	C11	106.6	C18	119.6
C5	90.8	C12	106.7	C19	120.0
C6	90.1	C13	106.1	C20	119.2
C7	91.2	C14	107.1	C21	120.1

Although the results of this study indicate increases in the potential and actual productivities of sugarcane in every future scenario for Piracicaba region, including the effects of climate change and technological advances, in relation to the current condition, it is necessary to highlight that these data should be considered as an indication of what may happen in future situations, since the evaluation of the impacts of the climate changes on the productivity of crops is very uncertain.

CONCLUSIONS: The agrometeorological model used to estimate sugarcane productivity was a very useful tool to describe the effect of climate change and technological advance on sugarcane productivity. The results obtained led to the conclusion that there will be a beneficial effect of the climate changes on the sugarcane productivity, due to the increase in temperature and CO_2 concentration. The technological advances, which include development of new varieties and best management practices, will also contribute for incrementing productivity. Changes in solar radiation and rainfall, due to their very high uncertainty, will have less effect on sugarcane productivity. The PP will increase by 15% in relation to the present condition in 2020, by 33% in 2050 and by 47% in 2080. Regarding the AP, the increase observed in PP will compensate the negative effect of the increasingly water deficit. AP will increase by 12% in relation to the present condition in 2020, by 32% in 2050 and by 47% in 2080. Although the results obtained in this study show increases in the sugarcane potential and actual productivities in every future scenario, they have to be considered with caution, due to the high degree of uncertainty related to the limitations of the agrometeorological model used and to the large spatial resolutions of the climate change projections.

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