

Effects of Climate Change On the Sugarcane Productivity

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Abstract

The progressive increase in global temperature causes concern worldwide, which is constantly looking for ways to minimize the impacts caused to the environment as a result of human activities in the last decades. As a result, "clean energy" has been the solution to control pollution and global warming, as they cause low environmental impacts. Today, biofuels and mainly bioethanol derived essentially from sugarcane replaces fossil fuels very efficiently. Due to the high influence and relevance that sugarcane exerts nationally, in relation to the economic and environmental issue, it is vitally important to think about how its production system will be in scenarios that consider climate change. In order to analyze this system is necessary to obtain data, not always easily obtained in field research, for this reason, the agricultural modeling through the simulation of scenarios can contribute by predicting situations and helping to make future decisions. Therefore, an APSIM® simulation model was proposed, validating it with local data and later the effects of climate change on sugarcane productivity were studied through agricultural modeling simulating three (3) scenarios with change in average air temperature and CO₂ concentration: S1 without climate change (current), S2 (year 2020) with change of + 0.24°C and increase of +26 ppm of CO₂, S3 (year 2040) with change of +0.84°C and increase of +114 ppm of CO₂ and S4 (year of 2080) with change of + 1.14°C and increase of +201 ppm of CO₂. The studied climatic change scenarios may lead to higher stalks and sugar productivity per hectare due to higher rates of CO₂ fixation and temperature increase.

Keywords: agricultural modeling, bioenergy, saccharum officinarum, scenario simulation.

1. Introduction

The atmosphere of Earth consists basically of nitrogen (N₂, 78.1% of the volume), oxygen (O₂, 20.9% of the volume) and argon (Ar, 0.93% of volume), but these gases interact in a restricted way with the solar radiation and do not interact with the infrared radiation. However, the atmosphere is also composed of other gases, such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), known as greenhouse gases, which cover less than 0.1% of the atmosphere volume, and they have an important role in the energy and climate balance of the planet by absorbing and emitting infrared radiation. If there was no process described previously, the temperature of the Earth would be 33°C colder on its surface, but due to the natural greenhouse effect, an increase in temperature occurs, resulting in a global average temperature of 14°C, providing the existence and maintenance of life on the planet (Machado, 2005).

The emission of pollutant gases from human activities has been one of the possible causes of climate changes in recent years (Berlato et al., 1995). From the end of the last century, there was an increase of

0.3 to 0.6°C in the average temperature of the Earth (Houghton et al., 1996). And in the 21st century, this increase is likely to reach 6.4°C (IPCC, 2007).

The agricultural production is a very affected area, as climate change interferes in the amount of energy (solar radiation), temperature and water consumption (evapotranspiration), among others. The increase of the terrestrial temperature directly affects the constancy and ordering of the rains, increasing the existence of floods and droughts (Karl et al., 1996).

With the problem of global temperature change, humanity has been seeking ways to minimize the impacts caused to the environment. A possible alternative is the generation of renewable energy, since it releases less harmful gases to the atmosphere, such as those derived from hydrocarbons, besides being an energy from inexhaustible natural resources. An example of these energies is the bioethanol produced from sugarcane or energy cane, used not only as energy, but also to produce biodegradable plastics and sugar.

According to the mechanism of photosynthesis, sugarcane is a C4 plant, showing a high rate of photosynthesis, with a higher capacity for the production of bioenergy (ethanol), high water absorption by its leaves, higher efficiency under low concentrations of CO₂ and eminent adaptation to high temperatures (BNDES, 2008 and Gouvêa et al., 2009). The CO₂ is essential for the photosynthesis, so if its high concentration did not lead to a rise in temperature, it would contribute to higher plant productivity. However, with the climate change, this productivity can be altered and it can eliminate the advantageous consequences of the large amount of CO₂ (Streck, 2005).

Analyzing at first, apparently the sugarcane would not have many difficulties in adapting to the higher temperatures, coming from the possible global warming, but surpassing 38°C, the growth of the plant practically does not occur, as well as in temperatures below 25°C, where it grows slowly (Gouvêa et al., 2009).

Due to the high influence and relevance that sugarcane exerts nationally, in relation to the economic and environmental issue, it is vitally important to think about how its production system will be in a few years from now if climate change continues at this same pace. In order to analyze this system is necessary to obtain data, not always easily obtained in field research, for this reason, the agricultural modeling through the simulation of scenarios can contribute by predicting situations and helping to make future decisions.

Simulation systems are advanced computer programs that provide its users, mostly researchers, with useful modules for predicting future situations, enabling a prior determination of what actions to take, often resulting in greater efficiency and lower cost (McCown et al., 1996).

The APSIM® (Agricultural Production Systems Simulator) is a software that allows simulations of agricultural production models. The main innovation is the change from a central concept that a crop responds to the sources of resources for the concept that a soil as the basis of the process responds to the climate, management and crops (McCown et al., 1999).

So, the aim of this work was to validate the APSIM® simulation model with local data and, after validation, to study the effects of climate change on sugarcane productivity through agricultural modeling, simulating scenarios with change in the average air temperature and CO₂ concentration.

2. Materials and Methods

2.1 Simulation Validation

For the simulations, the APSIM® program was used, supplying it with climatological and edaphology data of sugarcane management and fertilization. These data were obtained from the Institute of Meteorological Research of UNESP (IPMET), of previous data of the edaphology conditions (chemical and physical) (Table 1 and 2), and of the productive system (crop management and fertilization) from the Experimental Farm of the University of *Sagrado Coração*, located in Brazil, in the municipality of Agudos in the State of São Paulo, respectively.

The climatological data were obtained from the automatic meteorological station (EMA) composed of 288 readings per day (one reading every 5 minutes) for each of the parameters (solar radiation, maximum and minimum temperature and precipitation). Therefore, the values were integrated, converting them into daily data. The range of sample consisted of 1892160 data (288 readings/day * 365 days * 18 years), which after integration became 6570 data of each climatological parameter.

The validation of the simulation model was carried out through the contrasting of the output variables: tonnes of sugarcane per hectare (TCH) and tonnes of sugar content per hectare (TSH), with real data from the planting of SP80-3280 variety. It was planted with 1.5m spacing with simultaneously fertilization of 40, 150 and 150 kg.ha⁻¹ of N, K₂O and P₂O₅, respectively. It was conducted in the field for 380 days and then harvested, determining the TCH and TSH.

Table 1. Chemical characteristics of the experimental area soil.

| Layers | pH | M. O. | P | S-SO4 | K | Ca | Mg | Al | H+Al | V |
|--------|-------------------|--------------------|------------------------------|-------|---|------|------|----|------|----|
| cm | CaCl ₂ | g dm ⁻³ | ----mg dm ⁻³ ---- | | -----mmol _c dm ⁻³ ----- | | | | | % |
| 0-20 | 5.2 | 19.0 | 19.0 | 3.0 | 0.9 | 27.0 | 14.0 | 0 | 22.0 | 66 |
| 20-40 | 5.3 | 14.0 | 11.0 | 2.0 | 0.4 | 21.0 | 12.0 | 0 | 20.0 | 64 |
| 40-80 | 5.5 | 7.0 | 3.0 | 6.0 | 0.2 | 21.0 | 7.0 | 0 | 16.0 | 66 |

Table 2. Physical characterization of the experimental area soil

| Layers | Sand | Silt | Clay |
|--------|-------------------------------|------|------|
| cm | -----g kg ⁻¹ ----- | | |
| 0-20 | 660 | 70 | 270 |
| 20-40 | 600 | 60 | 340 |
| 40-80 | 530 | 70 | 400 |

Granulometric analysis – hydrometer method (BOUYOUCOS, 1927)

To determine the TCH, the final harvest was carried out in 1m of the sugarcane line and the proportional relation with the area of each plot was made, considering 5.556 linear meters ha⁻¹. The determination of the sugar content (CCS) (percentage in mass of apparent sucrose) was carried out through grinding and homogenizing sugarcane samples. The extraction of the juice was done by pressing, at 250 kgf cm⁻² for 1 minute, 500 g of shredded and homogenized sample. From the extracted juice, the CCS was analyzed

(CONSECANA, 2003). The product between TCH and CCS obtained the TSH.

Sigmoid regressions of the actual data of tons of stalk per hectare (TCH) and sugar (TSH) were carried out over time, comparing them with the regressions of the simulated values according to the function: $Y = Y_{max} / (1 + \exp(-(DAC-A) / B))$, in that: Y: accumulation of the simulated variable in $Mg\ ha^{-1}$, Y_{max} : maximum value of the simulated variable (horizontal asymptote), A and B are the constants of the function and DAC: days after cutting.

Statistical indicators were applied to the data from the simulations in order to compare them with the actual data of the crop and to accept as valid or not this simulation. These indicators were: the Pearson correlation coefficient (r), the Willmott concordance index (Id) and the regression coefficient (R^2), which evaluate the variation and precision of the simulated values in relation to the actual values of each process (Morettin & Bussab, 2003 and Willmott, 1981). Keating et al. (1999) defined as satisfactory values above 0.75 for simulations made using Apsim®.

2.1 Simulation of scenarios

Four (4) simulation scenarios were generated: 1 (S1) without climate change (current), 2 (S2) (year 2020) with change of + 0.24°C and increase of +26 ppm of CO₂, 3 (S3) (year 2040) with change of +0.84°C and increase of +114 ppm of CO₂ and 4 (S4) (year of 2080) with change of + 1.14°C (Figure 1) and increase of +201 ppm of CO₂ (Berlato et al. 1995 and Gouvêa et al., 2009), obtaining tonnes of sugarcane per hectare (TCH) and sugar (TSH).

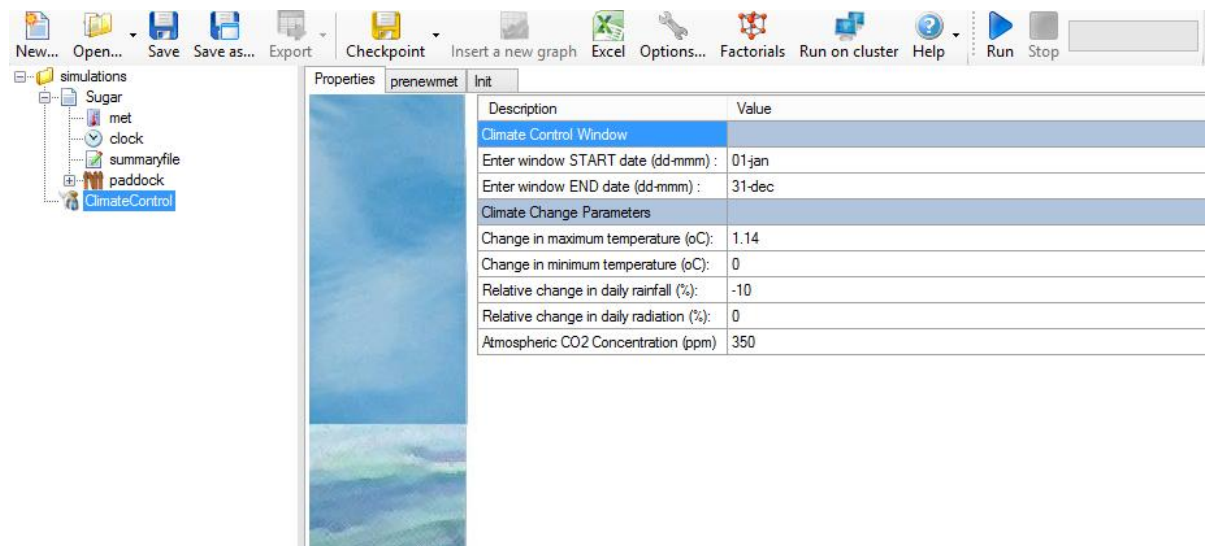


Figure 1. Parameters of climate change

3. Results and Discussion

The TCH and TSH values obtained satisfactory validation indexes (Table 3). Keating et al. (1999) reported coefficients of determination (R^2) for the Apsim® model predictions when compared to observed values of 0.93 for crop biomass (TCH) and 0.83 for stalk sucrose (TSH). These results emphasize the possibility of using Apsim® software as a tool to simulate future scenarios and validate the subsequent results of climate change.

Table 3. Validation of the model for the variables:tonnes of sugarcane per hectare (TCH) and tonnes of sugar content per hectare (TSH).

| Variables | Average (Mg.ha ⁻¹) | | R ² | Id | r |
|-----------|--------------------------------|-----------|----------------|------|------|
| | Real | Simulated | | | |
| TCH | 89.02 (±3,6*) | 92.56 | 0.75 | 0.88 | 0.85 |
| TSH | 14.40 (±1,5) | 14.15 | 0.81 | 0.92 | 0.89 |

R² coefficient of determination, Id Willmott agreement index, r Pearson correlation coefficient, * standard deviation of the average.

The table 4 shows the sigmoid regression equations for the TCH and TSH variables. The Ymax values for the equations are consistent with the productivity maximums reported in the literature (Thorburn et al., 2003; Ng Kee Kwong & Deville, 1994) with the current weather conditions.

There is a trend of increase in the stalk productivity and sugar per hectare related to the change of scenario (greater supply of radiation (temperature) and higher concentration of CO₂).

Gouvêa et al., 2009 and Melo et al. (2007) also studied increases in sugarcane productivity with climatic changes. In both studies, and with different simulation models, the positive response of the crop to the increase in temperature (increase in photosynthetic efficiency) and CO₂ concentration (understood as increased fertilization) was evidenced. The results obtained in this study are relevant because they separate only two components of a group that is always studied together when talking about climate change and that is formed by: temperature, concentration of greenhouse gases, ocean temperature, sea level rise, amount and distribution of precipitation, among others.

Although, the negative effect of climate change on crop productivity is known (Field et al., 2014), sugarcane crop has adaptive physiological mechanisms, which would result in increases in productivity (TCH and TSH), it can be inferred from the analysis of the two parameters (CO₂ concentration and air temperature). One of these mechanisms is the concentration of CO₂ in the cells of the mesophyll that allows the subsequent transport and decarboxylation in the vascular sheath (Allen et al., 1985). With higher CO₂ gradients in the atmosphere, higher photosynthetic rates are expected and thus higher accumulation of biomass and photoassimilates.

However, an important factor (not considered in this scenario simulation) is the availability of water to the crop. According to Field et al. (2014), changes in the quantity and distribution of water through precipitation are expected, generating times with large deficits and times with large surpluses, some of them not available to the plant. The sugarcane has physiological mechanisms that can increase the efficiency of water use, avoiding this deficit (Vu et al., 2006; Vu & Allen, 2009), and those are related to the increase in the concentration of CO₂ and the consequent increase in the diffusion gradient from the atmosphere to the chloroplast. With this, higher photosynthetic rates are obtained with the same stomatal

conductance, improving the plant water status (Owensby et al., 1997).

Table 4. Sigmoid regression equations of the variables: stalk productivity per hectare (TCH) and tons of sugar per hectare (TSH) in Mg ha⁻¹, in the studied scenarios (S).

| C | TCH | R ² | TSH | R ² |
|---|---------------------------------------|----------------|-------------------------------------|----------------|
| 1 | Y= 89.02/(1+exp(-(**x-208.36)/42.24)) | 0.99* | Y= 12.03/(1+exp(-(x-205.19)/54.49)) | 0.99* |
| 2 | Y= 93.84/(1+exp(-(x-189.11)/37.88)) | 0.99* | Y= 14.83/(1+exp(-(x-216.99)/58.01)) | 0.97* |
| 3 | Y= 98.48/(1+exp(-(x-226.96)/51.06)) | 0.99* | Y= 16.31/(1+exp(-(x-174.69)/56.89)) | 0.99* |
| 4 | Y= 104.56/(1+exp(-(x-220.45)/52.66)) | 0.99* | Y= 18.41/(1+exp(-(x-177.95)/56.43)) | 0.99* |

*Significant with (p <0.05). ** X=DAP (days after planting).R²= coefficient of determination.

4. Conclusion

The Apsim® program can simulate future scenarios of the sugarcane crop with high degree of confidence.

The studied climatic change scenarios may lead to higher productivity of stalks and sugar per hectare due to higher rates of CO₂ fixation and temperature increase in the center-west region of São Paulo.

5. References

Allen, L.H.; Jones, P.H.; Jones, J.W. Rising atmospheric CO₂ and evapotranspiration. In: Advances in evapotranspiration. St. Joseph: ASAE, 1985.p.13-27

Berlato, M. A.; Fontana, D. C.; Bono, L. Tendência temporal da precipitação pluvial anual no Estado do Rio Grande do Sul. Revista Brasileira de Agrometeorologia, Santa Maria, 1995, v. 3, p. 111-113.

BNDES, Banco Nacional de Desenvolvimento Econômico e Social e CGEE, Centro de Gestão e Estudos Estratégicos (Org.). Bioetanol de canca-de-açucar: energia para o desenvolvimento sustentável. Rio de Janeiro: BNDES, 2008.

C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, L.L. White IPCC, 2014: climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the Fifth Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, p. 1132

Gouvêa, J. R. F.; Sentelhas, P. C.; Gazzola, S. T.and Santos, M C. Climate changes and technological advances:impacts on sugarcane productivity in tropical southern brazil. Sci. agric. (Piracicaba, Braz.). 2009, vol.66, n.5, pp.593-605.

Houghton, J. T.; MeiraFilho, L. C.; Callander, B. A.; Harris, N.; Katternberg, A.; Maskell, K. Climate change 1995: the science of climate change: contribution of working group I to the second assessment report of the Intergovernmental Panel on Climate Change. P. 584 .Cambridge (England): Cambridge University Press. 1996.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE.Climate change 2007: the physical Science Basis -Contribution of Working Group I to the Fourth assessment report of the Intergovernmental

Panel on Climate Change. Cambridge: University Press, 2007.

Karl, T. R.; Knight, R. W.; Easterling, D. R.; Quayle, R. G. Indices of climate change for the United States. *American Meteorological Society Bulletin*, Boston, 1996, v. 77, n. 2, p. 279-292.

Keating, B. A.; Robertson, R. C.; Muchow, N. I. Huth modelling sugarcane production systems development and performance of the sugarcane module. *Field Crops Research*, 1999, v. 61, p. 253 – 271.

Machado, P.L.O. DE A. Carbono do solo e a mitigação da mudança climática global. *Revista Química nova*, Rio de Janeiro, 2005, v. 28, n. 2, p. 329-334.

Mccown. R. L.; Hammer, G. L.; Hargreaves, J. N. G.; Holzworth, D. P. and Freebairn, D. M. APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. *Agricultural Systems*, 1996, v. 50, p. 255-271.

Melo, S. B.; Galon, L.; Souza, E. F. M.; Rezende, M. L.; Renato, N. S. Aquecimento global e um estudo da produtividade potencial da cana-de-açúcar para a região de São Paulo. *Caatinga*, Mossoró, 2007, v. 20, n. 4, p. 10-17.

Morettin, P.A.; Bussab, W.O. *Estatística básica*, Saraiva, 5.ed., São Paulo, 2003, p.526.

Ng Kee Kwong K. F. & Deville J. Application of 5N-labelled urea to sugar cane through a drip-irrigation system in Mauritius. *Fertilizer Research*, 1994, v. 39, p. 223.

Owensby, C. E.; Ham, J. M.; Knap, A. K.; Bremer, D.; Auen, L. M. Water vapor fluxes and their impact under elevated CO₂ in a C₄-tallgrass prairie. *Global Change Biology*, 1997, v.3, p.189-195.

Streck, N.A. Climate change and agroecosystems: the effect of elevated atmospheric CO₂ and temperature on crop growth, development, and yield. *Ciência Rural*, 2005, v.35, n.3, p.730-740.

Thorburn. P. J.; Dart, I. K.; Biggs, I. M.; Baillie, C. P.; Smith, M. A.; Keating, B. A. The fate of nitrogen applied to sugarcane by trickle irrigation. *Irrigation Science*, 2003, v. 22, p. 201-209.

Vu, J. C. V.; Allen Jr., L. H.; Gesch, R. W. Up-regulation of photosynthesis and sucrose metabolism enzymes in young expanding leaves of sugarcane under elevated growth CO₂. *Plant Science*, 2006, v.171, p.123-131.

Vu, J. C. V.; Allen Jr., L.H. Stem juice production of the C₄ sugarcane (*Saccharum officinarum*) is enhanced by growth at double-ambient CO₂ and high temperature. *Journal of Plant Physiology*, 2009, v.166, p.1141-1151.

Willmott, C. J. On the validation of models. *Physical Geography*, 1981, v. 2, p. 184-194.

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