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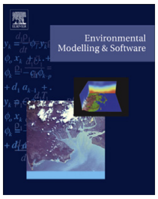

Sugarcane model intercomparison: Structural differences and uncertainties under current and potential future climates[☆]

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ABSTRACT

Sugarcane is one of the world's main carbohydrates sources. We analysed the APSIM-Sugar (AS) and DSSAT/CANEGRO (DC) models to determine their structural differences, and how these differences affect their predictions of crop growth and production. The AS model under predicted yield at the hotter sites, because the algorithm for computing the degree-days is based in only one upper cardinal temperature. The models did not accurately predict canopy and stalk development through time using growth parameters values developed from observed data, in combination with previously determined RUE for the cultivars. In response to elevated CO_2, both predicted higher yields, although AS showed higher sensitivity to CO_2 concentration, rainfall and temperature than DC. The Mean of simulations from both models produced better estimations than predictions from either model individually. Thus, applying the two models (in their current form) is likely to give the more accurate predictions than focusing on one model alone.

1. Introduction

Decision making and planning in agriculture increasingly utilizes crop models for a variety of tasks, such as yield forecasting in response to either variable climate conditions and/or the impacts of management changes. Most of the crop-growth simulation models used for these tasks are mechanistic and attempt to explain the relationship between parameters and simulated variables and mechanisms of the described processes (Palosuo et al., 2011). Crop models can also be used for generalizing experimental results for broader scales and conditions, compare management strategies, and predict plant growth and production. Such generalizations require robust models that can be evaluated under different environmental conditions to prove their robustness and allow for algorithm improvements when necessary.

Mechanistic crop models are only approximations of reality; therefore, uncertainty is inherent in their model parameters, model structure, and input data, which leads to uncertainty in their predictions (Wallach et al., 2012). One potential approach for reducing uncertainty that was recently proposed by the Agricultural Modeling Improvement and Intercomparison Project (AgMIP) (Rosenzweig et al., 2013) is to apply multiple models and use the mean or median of the ensemble as the predictors (Asseng et al., 2013). A more traditional approach is to ensure that models are thoroughly tested in the region in which they are being applied.

Brazil is one of the major sugarcane (*Saccharum* spp.) producers in the world. Sugarcane is an important crop for mitigating climate change as a major source for energy and food supplies (Goldemberg, 2007; Brumbley et al., 2008). Therefore, it is valuable to have accurate models for simulating growth, development, and climate change impacts for such crop.

Worldwide, there have been several models developed for sugarcane crop simulations: AUSCANE (Jones et al., 1989), DSSAT/CANEGRO (Jones et al., 2003; Inman-Bamber, 1991; Singels et al., 2008), QCANE (Liu and Kingston, 1995), APSIM-Sugar (Holzworth, et al., 2014; Keating et al., 1999, 2003), MOSICAS (Martiné, 2003), and CASUPRO (Villegas et al., 2005); however, only two of these models (APSIM-Sugar and DSSAT/CANEGRO) are widely available and supported. The number of sugarcane models is small in comparison to other important crops (e.g., Asseng et al., 2013, who compared 28 wheat models), so further testing and development of these models is clearly important.

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In this paper, we analyzed the APSIM-Sugar (AS) and DSSAT/CANEGRO (DC) models to determine their structural differences and how these differences affect their predictions of crop growth and production. Following the analysis of their structural differences, we 1) assessed the relative skill of the two models in simulating sugarcane production in Brazil; 2) verified if the average of the predictions from the two models gave more accurate predictions of sugarcane production in Brazil than predictions from each model separately; and 3) compared the predictions of sugarcane production under the primary changing climatic variables through a sensitivity analysis.

2. Materials and methods

2.1. Experiment description

Crop models were parameterized for cultivar RB867515, which accounts for nearly 27% (or 1.7 Mha) of the area of sugarcane cultivation in Brazil in 2012 (PMGCA, 2012), using field data from seven locations throughout Brazil (Fig. 1). Two of these experiments had two water-limitation treatments (rainfed and full irrigated), whereas the five remaining experiments were grown under rainfed treatments. All data were collected on plant crops. These datasets represented five distinct soil types and climates of Brazil (Table 1). All of the experiments received adequate N, P, and K fertilization and regular weed control and were planted using healthy cuttings with 13–15 buds/m^2. Row spacing varied from 1.4 m to 1.5 m. Sites 1 and 2 had two treatments (irrigated and rainfed), and all of the remaining datasets were from rainfed areas. Except Piracicaba, the irrigated treatments received water by drip or sprinkler irrigation that was scheduled following tensiometer monitoring to maintain the soil layers close to the field capacity down to a depth of at least 0.6 m, which ensured full water supply to the crop. In the Piracicaba Site, the soil water balance was used to manage the irrigation and ensure that crops were not exposed to water stress throughout the growing cycle. Irrigation was triggered every time the soil moisture reached 80% of the available soil water.

For Sites 1 and 2, detailed crop growth variables, including the green leaf area index (LAI), stalk population, stalk and aerial dry mass and number of green leaves, were measured at 4–5 week intervals over the cycle. At Site 3, the LAI, stalk population, sucrose concentration, and stalk mass were collected three to seven times at different intervals. For Site 4, the stalk population, stalk mass and stalk height were measured three times during the crop cycle, whereas the sucrose dry mass was measured 9 times from the mid-season through to harvest. For Sites 5 and 6, the stalk population, stalk mass and stalk height were measured once during the cycle, whereas the sucrose concentration was measured 13 times from the mid-season through harvest. For Site 7, five samples of the LAI, stalk population, sucrose concentration, and stalk mass were measured at regular intervals.

2.2. Model setup and input variables

The soil water dynamics in both of the models were configured in this study with a simple tipping bucket approach and algorithms for the redistribution of water derived from CERES (Jones and Kiniry, 1986). The water characteristics of the soil were specified in terms of the lower limit, drained upper limit and saturated volumetric water contents, and water movement was described using separate algorithms for saturated or unsaturated flow. Because the soil water parameters were not measured in some of the experiments (Olimpia, Colina, and Aparecida do Taboado), the values of water content at −10 kPa (drained upper water limit, DUL), at −1500 kPa (lower water limit, LL) and saturation (saturation water limit, SWL) were estimated using pedotransfer functions (PTF; Tomasella et al., 2000). The input data for the PTF were obtained from Ronaldo Rezende (pers. comm.), Tasso (2007), Andrade et al. (2012), Silva (2007), and Santos (2008). A retention curve was measured for the Piracicaba experiment in which undisturbed soil samples were saturated with distilled water and then the water contents were measured at matric potentials of −0.98, −1.96, −3.92, −9.80, −29.42, −49.03, −98.07, −490.33 and −1471 kPa.

The AS model has the capability to address the redistribution of solutes, such as nitrate and urea; however, this feature was not evaluated in this study because nitrogen stress was avoided in the experiments through adequate N fertilization, as nitrogen stress factor for photosynthesis showed no limitations in the simulations. Surface residue and crop cover reduces soil evaporation in the AS model, but not the DC model. Hence, we set AS model for simulating the crop growth in bare soil, which matches with DC and is a reasonable representation of the soil management for sugarcane plant crops.

The DC model required the input of a root exploration factor for each soil layer, which was a relative variable ranging from 1 (a soil most favorable for root growth) to near 0 (soil unfavorable for roots). Because the distribution of sugarcane root length was similar to an exponential pattern (Ball-Coelho et al., 1992; Laclau and Laclau, 2009), the values were estimated based on the approach proposed by Jones and Ritchie (1991) using the exponential geotropism constant, which is equal to 2.

The AS soil module used an “xf” parameter to govern the relative speed of the root front through a soil layer. This parameter was set at 1 at all sites except those in

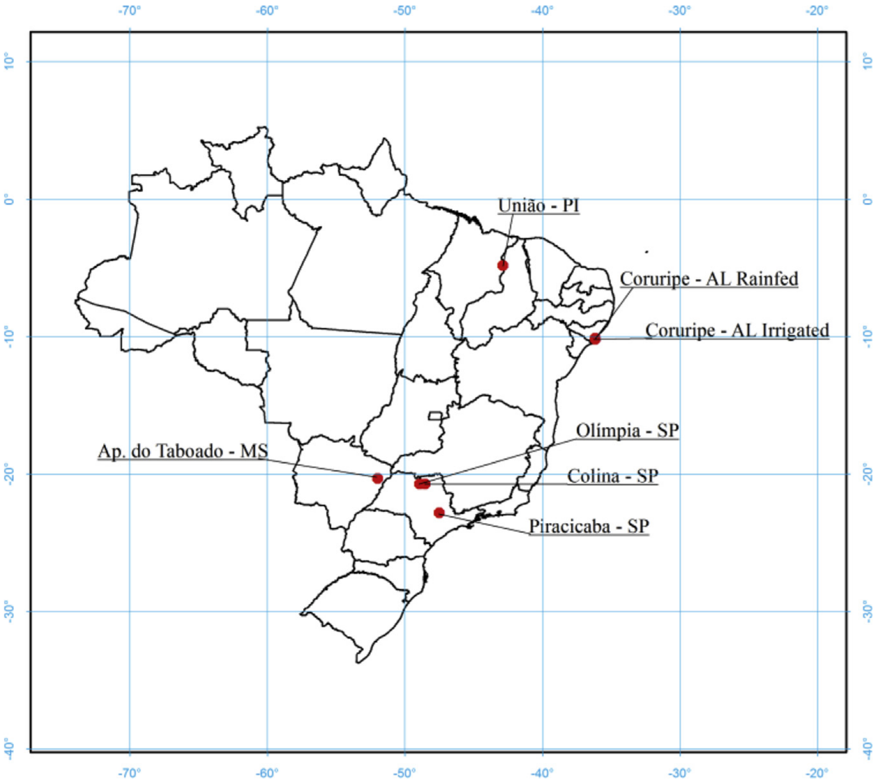

Fig. 1. Location in Brazil of field experiments using cultivar RB867515.