PARAMETERIZATION AND EVALUATION OF PREDICTIONS OF DSSAT/CANEGRO FOR BRAZILIAN SUGARCANE

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ABSTRACT

The DSSAT/CANEGRO model was parameterized and its predictions evaluated using data from five sugarcane experiments conducted in Southern Brazil. Some parameters whose values were either directly measured or considered to be well-known were not adjusted. Ten of the 20 parameters were optimized using a Generalized Likelihood Uncertainty Estimation (GLUE) algorithm using the leave-one-out cross-validation technique. Model predictions were evaluated using measured data of LAI, stalk and aerial dry mass, sucrose content, and soil water content, using bias, root mean squared error (RMSE), modeling efficiency (Eff), correlation coefficient and agreement index. The DSSAT/CANEGRO model simulated the sugarcane crop in Southern Brazil well, using the parameterization reported here. The soil water content predictions were better for rainfed (mean RMSE=0.122mm) than for irrigated treatment (mean RMSE=0.214mm). Predictions were best for aerial dry mass (Eff=0.85), followed by stalk dry mass (Eff=0.765) and then sucrose mass (Eff=0.17). Number of green leaves showed the worst fit (Eff=-2.300).

Key-words: crop modeling; *Saccharum spp.;* leave-one-out cross-validation; GLUE

INTRODUCTION

Sugarcane (Saccharum spp.) is of major social and economic importance in Brazil. It is one of the most important commodities in Brazilian agribusiness, contributing to the energy and food security of the country, as sugar, ethanol and biomass for energy are produced from sugarcane (Goldemberg, 2007).

Crop simulation models may contribute to improved crop monitoring and yield forecasting, while enhancing our understanding of sugarcane growth and yield. CANEGRO model was shown to accurately simulate sugarcane yield when compared to South African sugar industry data by Bezuidenhout & Singels (2006a, b). A new version of CANEGRO (Singels et al., 2008) has been included with version 4.5 of the Decision Support System for Agrotechnology Transfer (DSSAT) environment (Jones et al., 2003, Hoogenboom et al., 2010).

These efforts to model the sugarcane crop reflect the fact that simulated processes often have to be modified in order to adapt models to specific environments, supporting the idea that there is no universal crop model (Sinclair & Seligman, 1996) even for a single crop such as sugarcane. These authors emphasized the benefit for a group of researchers to build their own model appropriate to their specific purpose, with the possible use of formalisms from existing models. However, there are also advantages to adapting an existing model compared to developing a new one in terms of cost and time. To utilize an existing model for a particular crop, nevertheless, the main physiological parameters controlling the growth and development of that crop must be known, the model must be parameterized, and its predictions evaluated.

This paper has two major goals: 1) parameterize the DSSAT/CANEGRO model for Southern Brazilian production systems using an objective and automatic procedure; and 2) evaluate the predictions of stalk mass and sucrose accumulation using a cross-validation computer experiment.

MATERIAL AND METHODS

CANEGRO was parameterized and evaluated using data from two Brazilian cultivars, collected in four locations in Brazil (Suguitani, 2005; Laclau and Laclau, 2009; Tasso Jr., 2007; Santos, 2008) (Table 1). All experiments received adequate N, P and K fertilization and regular weed control and were planted using healthy cuttings with 13 to 15 buds m^{-2}. Row spacing varied from 1.4 m to 1.5 m. One of the datasets had two treatments (irrigated and rainfed), and all the remaining data were for rainfed. The irrigated treatment received water by sprinkling and the irrigation schedule was determined by tensiometer monitoring to maintain the soil layers close to field capacity down to a depth of at least 1 m. Soil water potential was measured every 2–3 days (before 8 a.m.) over the study period (Laclau and Laclau, 2009). These data were used to evaluate the model's soil water balance algorithm.

Table 1. Sources of experimental data used and main soil and climate characteristics of each site.

Dataset	Site	Planting and Harvest Dates	Cultivars	Crop Cycle[1]	Climate[2]	Treatments
1	Piracicaba/SP, 22º52'S, 47º30'W, 560m asml	10/29/2004 and 9/26/2005	RB72-454 SP83-2847 NCo376	PC	21.6°C, 1230mm, CWa	1) Irrigated, 2) Rainfed
2	Aparecida do Taboado/MS, 20º05'19"S, 51º17'59"W, 335m asml	7/1/2006 and 9/8/2007	SP83-2847	R1	23,5 °C, 1560, Aw	3) Rainfed
3	Colina/SP, 20°25'S 48°19'W, 590m asml	2/10/2004 and 6/15/2005	RB72-454 SP83-2847	PC	22.8 °C, 1363mm, Aw	4) Rainfed
4	Olimpia/SP, 20°26'S, 48°32'W, 500m asml	2/10/2004 and 6/15/2005	RB72-454 SP83-2847	PC	23.3 °C, 1349mm, Aw	5) Rainfed

[1] PC - Plant cane crop; R - ratoon crop and following number is the ratoon rank.

[1] Respectively: mean annual temperature, annual total rainfall, Koeppen Classification

As soil water parameters were not measured, the values of UWL, LWL, and SWL were defined using the pedotransfer functions (PTF) provided by Tomasella et al. (2000). The input data for PTF were provided by Suguitani (2005); Laclau and Laclau, (2009); Tasso Jr. (2007) and Santos (2008). The hydraulic conductivity at saturation (KSat) was estimated based on (Poulsen et al., 1999).

Considering the cultivar of measurements taken and different measurement strategies in each dataset, the leave-one-out cross-validation method (Wallach et al., 2006) of data splitting was used to simultaneously include all the variability of conditions and measurements in the parameter estimation and evaluation of the model predictions.

Ten of the 20 CANEGRO model cultivar parameters were optimized, including those related to leaf and tiller phenology (Ttplntem, Ttratnem, Chupibase, Tt_Popgrowth, Max_Pop, and Poptt16), radiation conversion efficiency, sucrose accumulation and partitioning coefficients (Parcemax, Apfmx, Stkpfmax, and Suca). A DSSAT v4.5 built-in algorithm (Jones et al., 2010) of the Generalized Likelihood Uncertainty Estimation (GLUE) method (Mertens et al., 2004) was used for estimating the 10 CANEGRO cultivar parameters.

Model predictions were evaluated using the following outputs: LAI, stalk and aerial dry mass, sucrose content, and soil water content for datasets 1 and 2. The quality of predictions were computed using bias, root mean squared error, modeling efficiency, correlation coefficient (Wallach, 2006) and agreement index (Willmott, 1981) as agreement measures.

RESULTS AND DISCUSSION

Water content, as measured by tensiometers in soil layers centered at 10cm, 30cm, 50cm and 80cm, was reasonably accounted by the model. Since tensiometer measurements reflect the matric potential rather than water content, this comparison may not be strictly valid and does not warrant statistical treatment. Better agreement was achieved in the first half of the crop cycle for both treatments, while the rainfed simulations showed better overall agreement in part due the greater oscillations of matric potential during the crop cycle (Figure 1b).

From the 160^{th} DAP to 210^{th} DAP it is possible to observe a drought period in the rainfed treatment (Figure 1b) during which the model simulated the observed values well. At 211 DAP a heavy rain event was observed and soon after the model’s soil-water simulation deviate more from the observed value than in the previous period. Laclau and Laclau (2009) reported considerable root mortality in the 0-0.2 m soil layer from 179 DAP to 241 DAP in the rainfed crop. This was mostly due to water stress, and was followed by some recovery of root dry mass afterwards.

Those observation from Laclau and Laclau (2009) may explain the consistent underestimation trend after 250 DAP, since the model did not compute any root loss during the mentioned drought period, implying a root water uptake capacity greater than the observed one, and explaining the model’s lack of fit after 179 DAP (Figure 1b). The water content peak simulated near 211 DAP could be interpreted as an effect of the lower KSsat for this site, retaining water after rainfall and releasing it slowly.

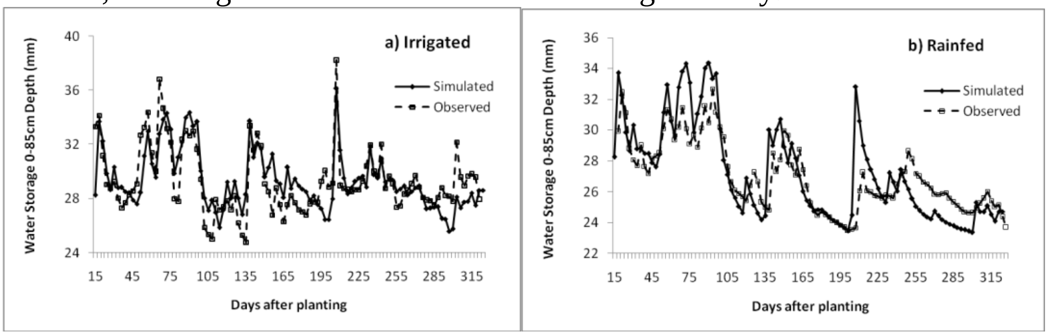

Figure 1. Simulated and measured soil water content to 90 cm soil depth.

Because DSSAT/CANEGRO is intended to simulate the partitioning among plant components, including stalk dry mass and sucrose, comparison of model predictions to these two frequently-available field measurements is particularly important. The RMSEP of 9.8 t/ha and 9.6 t/ha for RB72-454 and SP83-2847, respectively are higher than either the values obtained by Singels and Bezuidenhout (2002) (RMSE=5.48 t ha^{-1}) in CANEGRO simulations of the NCo376 cultivar in South Africa, or values from Cheeroo-Nayamuth et al. (2000) using APSIM model to simulate sugarcane growth in Mauritius (RMSEP = 6.0 t ha^{-1}). However, these RMSE are lower than those values obtained by O´Leary (2000) using an older version of CANEGRO, without the modifications of the photosynthesis algorithm proposed by Singels and Bezuidenhout (2002).

Agreement measures for sucrose content showed low predictive skills relative to the other variables (Figure 2), with model efficiency for sucrose content ranging from 0.23 to

0.11 for RB72-454 and SP83-2847, respectively. The values of r and d-index were slight lower than observed by Singels and Bezuidenhout (2002) and by Singels et al. (2008), with a tendency to underestimate sucrose content mainly very late in the crop cycle for both cultivars.

The simulated root dry mass values were always higher than observed throughout the crop cycle (Figure 2), despite the high partitioning coefficient (parameter APFMX) which drives synthesized biomass to above ground parts. The negative bias shown by simulated root length density may be also a consequence of the low specific root length used in the DSSAT/CANEGRO species file, as mentioned above.

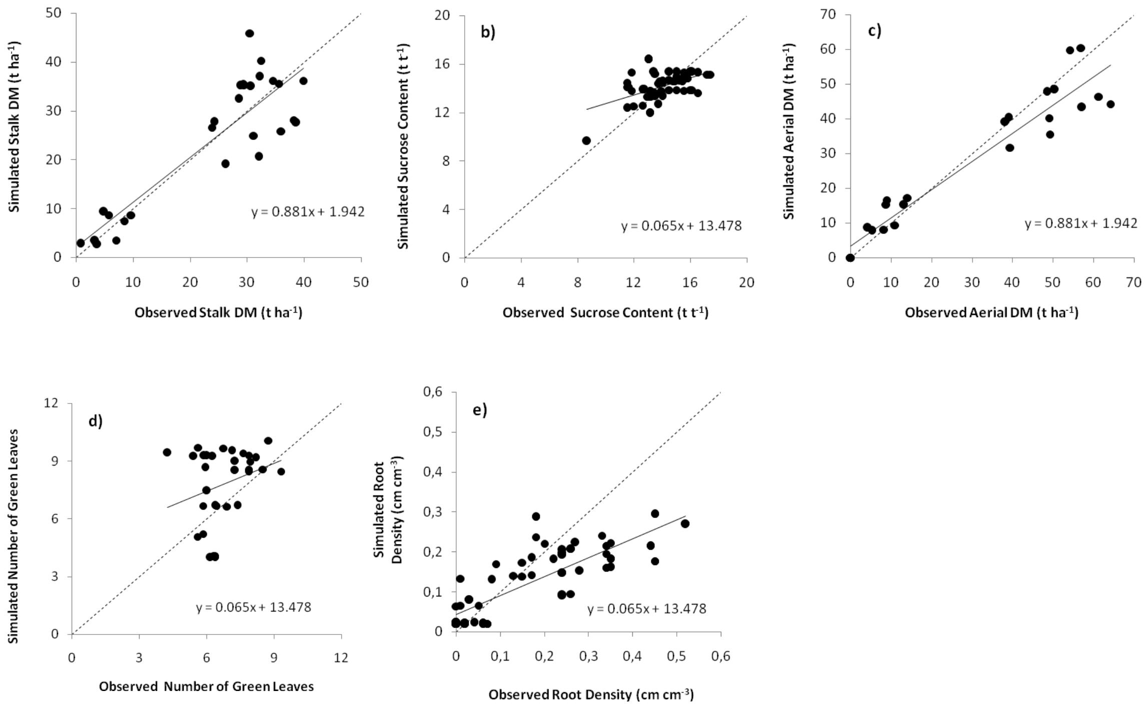

Figure 2. Simulated values (based on cross-validation) versus observed for (a) stalk dry mass, (b) sucrose content, (c) aerial dry mass, d) number of green leaves, and e) root length density for both cultivars in all treatments.

CONCLUSIONS

The DSSAT/CANEGRO model simulated the sugarcane crop in Southern Brazil well. The cross-validation technique permits the use of diverse datasets that would be difficult to use separately because of the heterogeneity of measurements and measurement strategies. This technique allowed the richness of this variability to contribute to parameterization. This provides the opportunity to use large amounts of existing data, which is typically under-used in modeling studies, and allows faster progress in countries like Brazil, where the crop has been studied with other objectives. The simulation errors were comparable with those found in other models, and reported in the literature.

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