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Calibration and evaluation of the DSSAT/Canegro model for sugarcane cultivars under irrigation managements

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ABSTRACT: Model calibration is a fundamental factor to obtain high accuracy in the estimation of crop growth and yield. This study aimed to parameterize the genetic and ecotype coefficients of the DSSAT/Canegro model for five sugarcane cultivars kept under three water managements, besides evaluating the accuracy of the model in predicting sugarcane stalk yield, sugar yield and height. Experimental field data were obtained from two years (2016 and 2017) of cultivation at FCAV/Universidade Estadual Paulista, Jaboticabal, SP, Brazil. The cultivars were maintained under supplementary irrigation, deficit irrigation and no irrigation. Data of the supplementary irrigation treatment (without stress) were used for the parameterization of each cultivar. Model accuracy was assessed by Pearson correlation (r), root mean squared error (RMSE), mean bias error (MBE), index of agreement (d) and confidence coefficient (c). The DSSAT/Canegro model is highly accurate in predicting stalk and sugar yields of sugarcane grown under water regimes, presenting itself as a viable alternative in sugarcane yield simulation. For better performance of the DSSAT/Canegro model, it is necessary to parameterize the variables related to the ecotype of the cultivars, besides the specific coefficients of the cultivars.

Key words: *Sacharum* spp., crop model, parameterization, yield

Calibração e avaliação do modelo DSSAT/Canegro para cultivares de cana-de-açúcar sob manejos de irrigação

RESUMO: A calibração de modelos é fator fundamental para a obtenção de elevadas acurácias na estimativa do crescimento e rendimento das culturas. Este estudo teve como objetivo parametrizar os coeficientes genético e de ecotipo do modelo DSSAT/Canegro para cinco cultivares de cana-de-açúcar mantidas sob três manejos hídricos, além de avaliar a precisão do modelo na estimativa da produtividade de colmos, produtividade de açúcar e altura de colmos. Foram utilizados dados experimentais de campo obtidos em dois anos de cultivo (2016 e 2017) na FCAV/Universidade Estadual Paulista, Jaboticabal, SP. As cultivares foram mantidas sob irrigação suplementar, irrigação deficitária e não irrigadas. Foram utilizados os dados do tratamento de irrigação suplementar (sem estresse) para a parametrização de cada cultivar. A acurácia do modelo foi verificada pela correlação de Pearson (r), raiz do erro quadrático médio (RMSE), erro médio (MBE), índice de concordância (d) e coeficiente de confiança (c). O modelo DSSAT/Canegro apresenta elevada acurácia na predição da produtividade de colmos e de açúcar da cana-de-açúcar cultivada sob regimes hídricos, apresentando-se como alternativa viável na simulação do rendimento da cultura. Para melhor performance do modelo DSSAT/Canegro, é necessário a parametrização das variáveis relacionadas ao ecotipo das cultivares, além dos coeficientes específicos das cultivares.

Palavras-chave: *Sacharum* spp., modelo de cultura, parametrização, produtividade



INTRODUCTION

Sugarcane is one of the most planted crops in the world, and Brazil is the largest producer, with 22% of the world's production (USDA, 2017). The expansion of the area cultivated with sugarcane in the country implies the occupation of marginal areas, especially in relation to water availability. Management tactics such as irrigation and utilization of water deficit-tolerant cultivars are the best options to overcome this problem (Graça et al., 2010).

More than 60% of the variability in crop yield can be explained by the edaphoclimatic factors (Ray et al., 2015). Due to the complexity in understanding the factors of the soil-plant-atmosphere system, crop growth models are effective tools to evaluate the effect of agricultural management practices on the growth and yields of crops of interest (Singels et al., 2014; Vianna & Sentelhas, 2014; 2016).

Among the various models available in the literature, the Canegro model (Singels et al., 2008), included in the software DSSAT (Hoogenboom et al., 2015), can be applied to assist the interpretation of experimental results and also in long-term simulations, in order to estimate the interannual variability of yield and thus recommend management practices for sugarcane (Nassif et al., 2012; Hoffman et al., 2018). Since there are differences of growth among sugarcane cultivars, the accuracy of the model depends on its adequate parameterization, being performed according to each genotype.

This study aimed to parameterize the genetic and ecotype coefficients of the DSSAT/Canegro model for five sugarcane cultivars kept under three water managements, besides evaluating the accuracy of the model in predicting sugarcane stalk yield, sugar yield and height.

MATERIAL AND METHODS

The field experiment was carried out at Universidade Estadual Paulista, Câmpus of Jaboticabal, SP, Brazil (21° 14' 50" S, 48° 17' 05" W and altitude of 570 m). The climate of the region is Aw (Köppen), characterized by an average annual precipitation of 1416 mm (1975-2015), with a total average of 255 mm in the rainiest month (December) and 25 mm in the driest month (July) (Alvares et al., 2013). The soil of the experimental area is classified as Oxisol. Its physical and chemical characteristics, which were added to the experimental file of the DSSAT system, are presented in Table 1.

Sugarcane was planted in November 2014, using pre-sprouted seedlings. The first harvest occurred in May 2015. The experiment was evaluated in two seasons (2015-2016 and 2016-2017), referring to the second and third harvests, respectively. The first year of evaluation was from May 16, 2015 to May 16, 2016 and the second from May 16, 2016 to July 03, 2017.

The experiment consisted of treatments with two factors: irrigation, in the plots, and sugarcane cultivar, in the subplots.

The irrigation factor had three depths (supplemental irrigation - 100% ETc; deficit irrigation - 50% ETc and no irrigation) whereas the cultivar factor had five cultivars (CTC 4, IAC 93-3046, RB 86-7515, IAC 95-5000 and IAC 91-1099), with 12 blocks. The experimental design was partially balanced incomplete blocks (PBIB), with three cultivars per block. This design is considered a good option to evaluate a large number of treatments in small areas (Bose & Nair, 1939). The sketch of the experimental area, as well as further information on the design of the experiment are found in Coelho et al. (2019).

The experimental unit consisted of four 4.5-m-long sugarcane rows spaced by 1.5 m and with seedlings spaced by 0.5 m (13,333 seedlings ha⁻¹). The two lateral rows, as well as 1 m on each end of the central rows were considered borders, so the observation area corresponded to 2.5 m of each central row.

A subsurface drip system was used for irrigation, installed at 0.30 m depth in the soil before sugarcane planting. The drip tube had a nominal diameter of 16 mm, 500-micron-thick tube wall and emitters spaced by 0.30 m. Water, of underground origin, was filtered by a 125 micron disc filter. The pressure of the irrigation system was stabilized by a regulator and monitored by a manometer, being kept at 100 kPa. The nominal flow rate of the drip tube was 5 L h⁻¹ m⁻¹.

Irrigation management was carried out based on the water requirements of the crop, according to the FAO-56 method, using meteorological data obtained daily at the automated agrometeorological station of FCAV/UNESP. Reference evapotranspiration (ET_o) was daily estimated by the Penman-Monteith equation (Allen et al., 1998). Crop evapotranspiration (ET_c) was calculated as the product between crop coefficients (K_c) and ET_o (Allen et al., 1998). The K_c values were, respectively, 0.50, 0.80, 0.95, 1.10, 1.20, 0.90 and 0.65 corresponding to the phenological stages of sprouting (up to 25% ground cover), initial tillering (25 to 50% ground cover), tillering (50 to 75% ground cover), stem growth (75 to 100% ground cover), maximum stem growth, onset of senescence and maturation, respectively.

Irrigation consisted of supplying the water demand of sugarcane and was interrupted 45 days before the harvest of each year for the maturation of the crop. In the first year of evaluation, supplemental irrigation (100% ET_c) was applied when there was accumulated water deficit of 30 mm, i.e., the crop was irrigated when the sum of crop evapotranspiration minus precipitation was greater than or equal to 30 mm. For deficit irrigation, the management was the same, but only 15 mm of water were applied at each deficit of 30 mm. In the second year of evaluation, the same management was used, but a deficit of 20 mm was employed. The difference in irrigation management between the years was adopted to better evaluate the effect of irrigation on crop yield and the sensitivity of the DSSAT/Canegro model in the simulation. A water application efficiency of 90% was considered for irrigation.

Table 1. Physical and chemical characteristics of the soil of the experimental area

Layer (m)	pH CaCl ₂	P _{res} (mg dm ⁻³)	S	H + Al	Al	K	Ca	Mg	SB	CEC	V (%)	OM			Sand (g kg ⁻¹)	Silt
												OM	Ds	Clay		
												(g dm ⁻³)			(g kg ⁻¹)	
0-0.20	5.4	41	45	32	1	1.8	51	21	73.8	105.4	70	25	1.29	580	220	200
0.20-0.40	5.2	19	53	34	0	1.6	31	13	45.4	79.4	56	18	1.20	600	190	210

P_{res} - Phosphorus (resin); pH in calcium chloride; SB - sum of bases; CEC - Cation exchange capacity; V - Base saturation; OM - Organic matter; Ds - Soil bulk density

For both years, fertilization was performed with the application of 130 kg ha⁻¹ of K₂O and 180 kg ha⁻¹ of N, using potassium chloride and ammonium sulfate as sources, respectively. There was no need for phosphate fertilization due to the high phosphorus concentrations determined by the soil chemical analysis (Table 1). In irrigated plots, fertilization was performed by fertigation, splitting the dose into eight equal applications. In the non-irrigated management, fertilization was performed 30 days after the harvest.

The technological analyses were performed according to CONSECAN (2006). Stalk yield (TCH, Mg ha⁻¹) was determined by harvesting 5 m of row in each subplot. Sugar yield (TPH: Mg ha⁻¹ of ATR: total recoverable sugar) was calculated as the product between ATR (kg t⁻¹) and stalk yield (Mg ha⁻¹) divided by 1000.

After harvesting and weighing, ten stalks per subplot of sugarcane were sent to the laboratory for technological analysis. The sugarcane height used to verify the accuracy of the model was measured at 270 days after the previous harvest. Five stalks per subplot were measured to calculate the mean. Sugarcane height was standardized from the soil surface to the tip of the stalk.

For the simulation of stalk yield, sugar yield and height using the Canegro model (Singels et al., 2008), the meteorological and sugarcane management factors were added. Data of meteorological elements for Jaboticabal, SP, Brazil, were used in the DSSAT program. The daily variables inserted were maximum temperature, minimum temperature, wind velocity, air relative humidity, precipitation and global solar radiation. The FAO 56 method was used to estimate ETC within the DSSAT system. As the Canegro model is not sensitive to fertilization (Singels et al., 2008), this management practice was not inserted in the file of experimental conditions in the program.

A file was created for soil analysis for the experimental conditions. The data shown in Table 1 were entered in the system to simulate crop yield. The model used for soil organic matter dynamics was The Century (Singels et al., 2008). The cultivars CTC 4, IAC 93-3046, RB 86-7515, IAC 95-5000 and IAC 91-1099 were parametrized using sensitivity analysis. Parameterization can be performed using the generalized likelihood uncertainty estimation (GLUE) method. However, this technique can assume values for parameters different from those observed in the field, because it always aims at the lowest error of estimation. The studies conducted by Marin et al. (2011) and Nassif et al. (2012) were used as reference of values for Brazilian cultivars in the parameterization by sensitivity analysis.

The genetic coefficients of the cultivars and the ecotype coefficients (Table 2) were used for the proper parameterization. Table 2 presents only the genetic and ecotype coefficients modified in the calibration in relation to the coefficients already existing in the model. Usually, only the genetic coefficients of the cultivars are calibrated in models; however, it was necessary to calibrate the coefficients of the ecotypes of the cultivars, since some genotypes did not have an a yield increase response when irrigated, and the coefficients are associated with the sensitivity of the model to the water stress on the ecotype of the cultivars. The parameterization of each cultivar was performed for the treatments subjected to supplementary irrigation (without stress) in the first year (2016) of evaluation.

The quality of fit of the model was evaluated by the Pearson correlation coefficient (r), root mean squared error (RMSE) (Eq. 1), mean bias error (MBE) (Eq. 2), index of agreement (d) (Eq. 3) (Willmot, 1981) and confidence coefficient (c) (Eq. 4) (Camargo & Sentelhas, 1997). The predicted values of stalk yield, sugar yield and height were compared to the mean values observed in the field. The accuracy of the model was verified

Table 2. Parameters of the genetic coefficients of the cultivars and the ecotype coefficients in the DSSAT/Canegro model

Parameter	Unit	Genetic coefficients
Parce _{max}	g MJ ⁻¹	Maximum radiation conversion efficiency expressed in assimilates produced before respiration, per unit of photosynthetically active radiation (PAR)
APFMX	Mg Mg ⁻¹	Maximum fraction of dry mass increment that can be allocated to aboveground dry mass
STKPF _{max}	Mg Mg ⁻¹	Fraction of daily increment in aboveground dry mass partitioned to the stalk at high temperatures in mature crop
Suca	Mg Mg ⁻¹	Maximum sucrose concentration in the base of stalk
TBFT	°C	Temperature at which sucrose partitioning is 50% of the maximum stalk mass increment (without stress)
T _{thalf}	GD	Degree days for canopy development to reach half the spacing
T _{base}	°C	Base temperature for crop development
L _{fmax}	Leaves	Maximum number of healthy green leaves (plants adequately irrigated may loose leaves after this number)
MXLFArea	cm ²	Maximum leaf area
MSLFArno	Leaves	Leaf number above which the area is limited by MXLFArea
PI1	GD	Phyllochron 1 for leaves below Pswitch
PI2	GD	Phyllochron 1 for leaves above Pswitch
Pswitch	Leaves	Leaf number at which phyllochron change occurs
TTPLNTEM	GD	Degree days for plant cane emergence
TTRATNEM	GD	Degree days for ratoon cane emergence
ChupiBase	GD	Degree days for start of stalk growth
TT_PopGrowth	GD	Degree days for peak tillering to occur
Max_Pop	Stalks m ⁻²	Maximum tiller population
PopTT16	Stalks m ⁻²	Stalk population after 1600 degree days
Ecotype coefficients		
SWDF2AMP	%	Sucrose partition sensitivity to the water stress parameter
CS_CNreduc	%	Canopy reduction due to water stress
dPERdT	mm h ⁻¹	Change in plant extension rate per unit of temperature change
POPCF (2)	-	Stalk population coefficient, under ideal conditions (without stress), as a function of degree days
POPdecay	-	Tiller senescence rate

for each cultivar, using data from the 3 water managements, totaling 6 conditions (3 for each year).

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (Y_{obs_i} - Y_{est_i})^2}{N}} \tag{1}$$

$$MBE = \frac{\sum_{i=1}^N (Y_{obs_i} - Y_{est_i})}{N} \tag{2}$$

$$d = 1 - \frac{\sum_{i=1}^N (Y_{obs_i} - Y_{est_i})^2}{\sum_{i=1}^N (|Y_{est_i} - \bar{Y}| + |Y_{obs_i} - \bar{Y}|)^2} \tag{3}$$

$$c = r \times d \tag{4}$$

where:

- N - number of data;
- Y_{obs_i} - observed values of Y;
- Y_{est_i} - estimated values of Y; and,
- \bar{Y} - mean of observed values of Y.

RESULTS AND DISCUSSION

In general, the parameters related to growth ($Parce_{max}$, APFMX, MXLFArea, Max_Pop, PopTT16, ChupiBase, TTRATNEM and TT_PopGrowth) and sucrose accumulation ($STKPF_{max}$ and Suca) showed large alterations in comparison to the standard cultivar for the calibration of the DSSAT/Canegro model (Table 3). For the parameter $Parce_{max}$, related to dry mass conversion, the minimum and maximum changes in comparison to the standard cultivar were 26% and 49%, respectively. This indicates that the cultivars evaluated have higher conversion of radiation into dry mass than the standard

cultivar of the model. A similar result was reported by Nassif et al. (2012), who observed an increase of up to 37% in this parameter for the Brazilian sugarcane cultivars.

For the parameters APFMX and $STKPF_{max}$, related to the increment of dry mass, the adjusted values were different from those observed for the standard cultivar and by Marin et al. (2011) and Nassif et al. (2012). In the study conducted by these authors, the values of the two parameters were close to those observed for the standard cultivar. However, to estimate sucrose accumulation under different water conditions and sugarcane height with higher accuracy, it was necessary to change the values of these two coefficients, since values close to that of the standard cultivar underestimated these characteristics of sugarcane.

Regarding the parameter sucrose accumulation (Suca), it was observed that the mean values for the Brazilian cultivars were higher than that of the standard cultivar, indicating greater efficiency in sugar accumulation. Among cultivars, the value of RB 86-7515 (0.69) was higher than the average of the others evaluated. Another parameter that had a large discrepancy compared to the standard cultivar was MXLFArea, which is related to leaf area. The values adopted for the cultivars evaluated were, on average, 40% higher than the standard value. This is due to the fact that, if the standard value is adopted, leaf area index is underestimated (Marin et al., 2011), mainly because the number of tillers of the standard cultivar is higher than those found in the Brazilian cultivars, as evidenced by the parameters Max_Pop and POPTT16.

The other indices that have a high discrepancy when compared with the standard values were TTRATNEM, ChupiBase and TT_PopGrowth. These indices are related to the length of the crop cycle, for ratoon emergence, peak tillering and beginning of stalk development, all in the unit of degree days. The values were adjusted according to the ratoon cane emergence time observed in the field and the time, in days, at which peak tillering occurred. Thus, the evaluated cultivars are earlier compared to the standard cultivar.

According to Marin et al. (2011), Brazilian cultivars tend to have higher values of parameters related to growth and lower

Table 3. Parameters of the sugarcane cultivars, in the calibration phase, and of the standard cultivar

Parameter	Cultivar					
	CTC 4	IAC SP93-3046	RB 86-7515	IAC 95-5000	IAC 91-1099	Standard (NCo376)
$Parce_{max}$	13.5	14.8	13.9	12.5	13.47	9.9
APFMX	0.687	0.93	0.68	0.7	0.721	0.88
$STKPF_{max}$	0.85	0.72	0.82	0.87	0.86	0.65
Suca	0.635	0.62	0.69	0.645	0.626	0.58
TBFT	25	25	23	25	25	25
Tthalf	230.4	250	250.8	240.4	232.2	250
Tbase	14.49	16	15	15	15	16
Lf_{max}	9.924	12	9.96	10	10	12
MXLFArea	500.2	500	505.2	520.2	502.2	360
MSLFArno	14.99	12	15.19	15	15	15
PI1	89.3	69	89	70.3	74.3	69
PI2	120.1	169	130	130.1	128.1	169
Pswitch	15.9	14	16.14	15.9	15.9	18
TTPLNTEM	500.6	428	300.4	500.6	500.6	428
TTRATNEM	100	100	100	100	100	203
ChupiBase	550	550	565	560	560	1050
TT_PopGrowth	400	400	404	412	405	600
Max_Pop	25.4	23.85	18.93	19.22	23.89	30
PopTT16	11.44	10.9	7.29	9.76	11.59	13.3

values of parameters related to phenology, when compared to the standard cultivar, indicating greater earliness and efficiency of transformation into biomass. For stalk yield and sugar yield, the parameters with highest sensitivity in the response of the Canegro model were $Parce_{max}$ and $STKPF_{max}$ (Souza et al., 2017).

In the calibration of the genetic coefficients of sugarcane cultivars, it was observed that all genotypes showed similar response in stalk yield and sugar yield when subjected to irrigation depths, even when the parameters varied. However, in both years of evaluation (2016 and 2017), the cultivars CTC 4 and RB 86-7515 showed low response to irrigation, that is, increasing water depths did not increase the yield of these genotypes.

As sugarcane has great genetic variability and commercial cultivars come from the cross of several species of the genus *Saccharum* (Carr & Knox, 2011), the coefficients of the ecotypes of the cultivars were also altered from the standard established in the model. This was used to change the response of the cultivars to irrigation, reducing some parameters for cultivars with no response to water management and maintaining the values for those with increased yield under increasing irrigation depths.

According to Silva et al. (2014), some sugarcane cultivars are more adapted to irrigation than others. Water deficit-sensitive genotypes showed lower photosynthetic rate and a higher reduction of chlorophyll a concentration, chlorophyll b concentration and chlorophyll a/b ratio than tolerant cultivars (Graça et al., 2010; Zhang et al., 2015).

The ecotype parameters SWDF2AMP, CS_CNreduc, and POPCF(2) were responsible for the response of the ecotype of the cultivars to the water stress (Table 4). The highest sensitivity to water stress occurred for the parameter POPCF(2). For the cultivars CTC 4 and RB 86-7515, the values of all the above-mentioned parameters were altered in comparison to the standard ecotype defined by the model.

The cultivar with lowest response to irrigation was RB 86-7515, showing the highest value of POPCF(2). It is followed, respectively, by the cultivars CTC 4, IAC 95-5000 and IAC 91-1099. In addition, it can be observed that only the cultivars CTC 4 and RB 86-7515 showed the coefficients SWDF2AMP and CS_CNreduc altered in comparison to the standard, indicating genotypes that are not responsive to irrigation. Another modified coefficient of the ecotype of the cultivars was responsible for crop growth (dPERdT). This modification was necessary because the model underestimated the height of the cultivars when using the standard value (0.176).

For the first year of evaluation, it was observed that irrigation reduced the sugar concentration of some sugarcane cultivars (Table 5). As the harvest in this case (2016) occurred at the beginning of the season (May), there were conditions

for sugarcane growth, reducing the concentration of sugar in the stalks. For the second year of evaluation (2017), the harvest occurred in July, and there was no reduction in sucrose concentration for the cultivars maintained under irrigation. Irrigation can reduce the dry mass content of sugarcane, increasing the water concentration in the juice, a fact that is directly associated with the reduction of sugar concentration in the stalks (Nogueira et al., 2016).

There were no parameters in the model associating high water availability in the soil in periods of low temperature, interfering with the sucrose concentration in the stalks. Moreover, there are also no parameters associating a value of water deficit so that the sucrose concentration is not altered due to possible irrigations.

An obstacle is the absence of some parameter relating the loss of crop yield to the course of the seasons, since the vigor and uniformity of the clumps decrease over time (Vianna & Sentelhas, 2016). In this context, Dias & Sentelhas (2017) developed a coefficient (K_{dec}) that associates sugarcane yield drop with the course of the seasons. Using this coefficient, the error of prediction using the DSSAT/Canegro model was reduced by more than 50%.

The genetic and ecotype coefficients of each cultivar were calibrated according to the treatment without water restriction (SUPPL) in the first year of evaluation (2016). From the calibration, stalk yield (TCH), sugar yield (TPH) and height were simulated for the other water managements (DEF and RF) in the two years of evaluation (2016 and 2017). The simulated data of each cultivar were then compared with the data observed in the field. The DSSAT/Canegro model had high accuracy in the estimation of stalk yield and sugar yield for the sugarcane cultivars (Table 6).

According to the confidence index "c" (Camargo & Sentelhas, 1997), only the cultivar RB 86-7515 did not have a good classification for TCH. The RMSE for TCH ranged from 9 to 14.81 Mg ha⁻¹, while the Pearson correlation coefficient varied from 0.66 to 0.92. It is observed that the accuracy (r) for estimating the TCH of the cultivar RB 86-7515 was low, very different from the others. The accuracy of the model for the cultivars was virtually the same as those observed in the studies conducted by Marin et al. (2011) and Hoffman et al. (2018), since the authors observed correlation from 0.69 to 0.95 and RMSE from 5 to 15 Mg ha⁻¹. In addition, the index of agreement for TCH ranged from 0.93 to 0.98 and the model trend (MBE) varied from -6.44 to 10.31 Mg ha⁻¹.

For sugar yield (TPH), the cultivar RB 86-7515 also had the worst accuracy values among the cultivars evaluated. The correlation between the observed and model-simulated values for this genotype was 0.49, besides showing the highest RMSE (2.84 Mg ha⁻¹). In addition, the classification according to the

Table 4. Parameters of the ecotypes of the sugarcane cultivars evaluated and of the standard cultivar

Parameter	Cultivars					
	CTC 4	IAC SP93-3046	RB 86-7515	IAC 95-5000	IAC 91-1099	Standard (NCo376)
SWDF2AMP	0	0.5	0	0.5	0.5	0.5
CS_CNreduc	0	0.3	0	0.3	0.3	0.3
dPERdT	0.21	0.21	0.21	0.2	0.2	0.176
POPCF (2)	-0.07001	-0.00201	-0.11001	-0.00801	-0.00801	-0.00201
POPdecay	0.004	0.004	0.004	0.002	0.002	0.004

Table 5. Stalk yield (TCH), sugar yield (TPH) and height observed in the field and simulated by the DSSAT/Canegro model as a function of the treatments under water regimes

Cultivars/Year	Water regime	TCH (Mg ha ⁻¹)		TPH (Mg ha ⁻¹)		Height (m)	
		Observed	Simulated	Observed	Simulated	Observed	Simulated
CTC 4/2016	RF	126.41	115.35	19.37	18.08	2.72	2.80
	DEF	125.62	123.40	17.78	19.61	2.88	3.12
	SUPPL	127.17	126.65	20.24	20.24	3.03	3.50
CTC 4/2017	RF	106.22	90.32	17.10	13.30	2.64	2.25
	DEF	122.88	117.23	18.38	18.43	2.85	3.02
	SUPPL	124.55	133.17	19.37	21.47	3.06	3.60
IAC SP93-3046/2016	RF	101.85	108.99	15.85	16.50	2.36	2.13
	DEF	110.06	138.35	17.06	21.90	2.51	2.28
	SUPPL	157.64	152.06	23.69	24.50	2.65	2.44
IAC SP93-3046/2017	RF	101.13	89.04	15.26	12.82	2.18	1.55
	DEF	128.26	134.23	20.19	21.26	2.57	1.80
	SUPPL	152.97	167.88	24.62	27.50	2.81	2.14
RB 86-7515/2016	RF	113.94	109.20	17.15	18.80	2.71	2.95
	DEF	118.54	118.50	17.01	20.80	2.86	3.23
	SUPPL	119.65	121.70	17.32	21.50	3.01	3.51
RB 86-7515/2017	RF	107.01	85.00	16.81	13.60	2.84	2.46
	DEF	138.21	112.00	21.70	19.80	3.06	3.20
	SUPPL	138.90	128.00	22.63	22.80	3.09	3.76
IAC 95-5000/2016	RF	108.51	123.20	16.25	16.81	2.37	2.36
	DEF	139.02	140.00	19.55	19.82	2.67	2.60
	SUPPL	149.67	145.85	21.39	20.75	2.96	2.87
IAC 95-5000/2017	RF	98.37	87.86	16.06	12.58	2.50	1.90
	DEF	131.56	128.48	21.16	19.78	3.02	2.46
	SUPPL	136.18	159.91	22.34	25.10	3.01	3.05
IAC 91-1099/2016	RF	133.29	136.77	20.75	19.24	2.62	2.37
	DEF	146.92	153.23	21.20	22.52	2.77	2.61
	SUPPL	165.99	160.14	24.16	23.45	2.91	2.87
IAC 91-1099/2017	RF	118.86	98.86	18.35	14.70	2.63	1.90
	DEF	148.55	142.39	23.54	22.10	3.12	2.46
	SUPPL	160.94	175.97	26.30	27.70	3.11	3.05

2016 – Second harvest of sugarcane; 2017 – Third harvest of sugarcane; RF – rainfed treatment (without irrigation); DEF – treatment under deficit irrigation; SUPPL – treatment under supplementary irrigation

Table 6. Performance (validation) of the DSSAT/Canegro model in the predicting of stalk yield (TCH), sugar yield (TPH) and height of sugarcane

Cultivar	r	RMSE	MBE	d	c	Classification (c)
Stalk yield - TCH (Mg ha ⁻¹)						
CTC 4	0.89	9	4.45	0.94	0.84	Very good
IAC SP93-3046	0.86	14.64	-6.44	0.98	0.85	Very good
RB 86-7515	0.66	14.81	10.31	0.93	0.62	Median
IAC 95-5000	0.86	12.34	-3.67	0.98	0.84	Very good
IAC 91-1099	0.92	11.18	1.2	0.98	0.9	Excellent
Sugar yield - TPH (Mg ha ⁻¹)						
CTC 4	0.71	1.99	0.18	0.92	0.65	Median
IAC SP93-3046	0.9	2.58	-1.3	0.98	0.89	Excellent
RB 86-7515	0.49	2.84	-0.78	0.94	0.46	Poor
IAC 95-5000	0.9	1.93	0.32	0.98	0.88	Excellent
IAC 91-1099	0.94	1.91	0.77	0.98	0.9	Excellent
Sugarcane height (m)						
CTC 4	0.98	0.36	-0.19	0.93	0.9	Excellent
IAC SP93-3046	0.6	0.51	0.45	0.89	0.54	Passable
RB 86-7515	0.7	0.42	-0.26	0.9	0.63	Median
IAC 95-5000	0.7	0.34	0.21	0.95	0.67	Good
IAC 91-1099	0.67	0.42	0.32	0.91	0.61	Median

r – Pearson correlation coefficient; RMSE – Root mean squared error; MBE – Mean bias error; d – Index of agreement; c – confidence coefficient

confidence index was considered weak. For the other cultivars, the parameterization used was adequate to estimate the TPH, showing high accuracy. The statistical indices obtained for TPH estimation were adequate, being close to those obtained by Nassif et al. (2012).

For sugarcane height, the model had high predictive accuracy only for the cultivar CTC 4, with $r = 0.98$, $d = 0.93$, $RMSE = 0.36$ m and confidence coefficient (c) of 0.9. For the others, the values of correlation ranged between 0.6 and 0.7. Model parameterization often guarantees high accuracy for some variables while for others the result is less accurate (Nassif et al. 2012), a fact observed in the present study for sugarcane height.

The performance of the model, fundamentally, should be evaluated by the accuracy in predicting the variables related to agricultural and economic yields. The model showed high accuracy in predicting the stalk and sugar yields of the evaluated cultivars. Thus, by using local climate and soil data, in addition to the calibrated parameters of the cultivars, it is possible to use the Canegro model to define the best management for each genotype, such as irrigation management, harvest time and yields of stalks and sugar. Evaluating irrigation strategies for sugarcane cultivars in different phenological stages, regions and types of soil with the DSSAT/Canegro model, Vianna & Sentelhas (2016) observed that a water depth of up to 150 mm applied through irrigation is ideal for the crop. Moreover, the highest yield responses due to irrigation occur in sandy soils and semiarid regions.

In the present study, the irrigation depths applied for the treatment under supplemental irrigation were 360 and 640 mm in the years of 2016 and 2017, respectively. The values for the treatment under deficit irrigation were equivalent to half of the water depth applied in each year. Despite large differences in the amount of water applied between the years, the model

had high sensitivity and accuracy in the estimation of yield and growth attributes of the sugarcane cultivars, presenting itself as a viable alternative to be used in the water management of the sugarcane crop.

CONCLUSIONS

1. The DSSAT/Canegro model has high accuracy in predicting stalk yield and sugar yield of sugarcane cultivated under different water regimes, hence being a viable alternative in the simulation of sugarcane yield.

2. Only the cultivar RB 86-7515 did not have good parameterization of the model for estimating yield and growth attributes when cultivated under three water regimes.

3. For better performance of the DSSAT/Canegro model, it is necessary to parameterize the variables related to the ecotype of the cultivars, besides the genetic coefficients of the cultivars.

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