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Energy cane yield simulated by the DSSAT/CANEGRO model using climate scenarios in Teotônio Vilela, AL, Brazil

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ABSTRACT: Energy cane is a sugarcane variety obtained through genetic improvement and it has higher biomass production, essential for energy generation. Mathematical models for crop forecasts are excellent tools to support crops and can assist in the establishment of energy cane in different environments and in climate change scenarios. The objective of this work was to evaluate the impacts of climate change on energy cane yield simulated by the DSSAT/CANEGRO model in Alagoas, Northeast of Brazil. We used meteorological, crop and soil data from a field experiment conducted in Teotônio Vilela/AL in 2016 and 2017. The energy cane variety used was Vertix 2, cultivated in a plant cane cycle, with planting date on February 4, 2016, and harvesting date on January 31, 2017. Climate projections (2017-2060) were used based on RCPs (2.6, 4.5, 6.0 and 8.5). The model showed high precision and accuracy in simulations with values of 0.98 and 0.94 for fresh matter and 0.99 and 0.88 for dry matter, for d and r indices, respectively. In the RCP8.5 scenario, the yield reduction may be up to 15% (fresh matter) and 13.5% (dry matter) by 2060.

Key words: climate; modelling; sugarcane

Produtividade de cana energia simulada pelo modelo DSSAT/CANEGRO usando cenários climáticos em Teotônio Vilela, AL, Brasil

RESUMO: A cana energia é uma variedade de cana-de-açúcar obtida por meio de melhoramento genético e que apresenta maior produção de biomassa, sendo essencial para a geração de energia. Modelos matemáticos para previsões de safras são excelentes ferramentas de apoio às lavouras e podem auxiliar na implantação da cana energia em diferentes ambientes e em cenários de mudanças climáticas. O objetivo deste trabalho foi avaliar os impactos das mudanças climáticas na produção de cana energia simulada pelo modelo DSSAT/CANEGRO em Alagoas, Nordeste do Brasil. Foram utilizados dados meteorológicos, da cultura e de solo de um experimento de campo desenvolvido em Teotônio Vilela/AL em 2016 e 2017. A variedade de cana energia utilizada foi a Vertix 2 e seu cultivo foi no ciclo cana-planta, com plantio realizado em 4 de fevereiro de 2016 e colheita em 31 de janeiro de 2017. As projeções climáticas (2017-2060) foram utilizadas com base nos RCPs (2.6, 4.5, 6.0 e 8.5). O modelo apresentou alta precisão e exatidão nas simulações com valores de 0,98 e 0,94 para a matéria fresca e 0,99 e 0,88 para a matéria seca, para os índices d e r, respectivamente. No cenário RCP8.5, a redução na produtividade pode ser de até 15% (matéria fresca) e 13,5% (matéria seca) até 2060.

Palavras-chave: clima; modelagem; cana-de-açúcar

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Introduction

Energy cane is a sugarcane variety derived from genetic improvement of wild species (*Sarcharum spontaneum* and *Sarcharum robustum*) with commercial hybrids, whose main characteristics are high fiber content, tillering and biomass production (Caversan, 2017). Thus, energy cane is classified as an energy crop, being considered ideal for biofuel, electrical and thermal energy production from its biomass (Silva, 2016). Its rusticity and greater resistance to the attack of pests and diseases enable its cultivation in areas of low agricultural suitability, being combined with the recovery of degraded areas and soil erosion control, in addition to requiring less agricultural inputs (Matsuoka et al., 2014).

Climate change scenarios have promoted greater demand for crops with higher resistance to water deficit and edaphoclimatic adversities. Thus, it is essential to know the implications of climate variations on growth and development of energy cane, in order to improve its yield. For this reason, predictions about future climate, using agrometeorological models, are important to assess the impact of climate change on energy cane yield, in addition to assisting in decision making on production management strategies (Silva, 2012; Jones & Singels, 2018).

The use of mathematical models for crop forecasting is useful to generate information regarding energy cane cultivation in future climate scenarios. These crop models are used to study the effects and interactions of environmental conditions, in addition to allowing the simulation of scenarios under different soil and atmosphere conditions, and also to assist in the planning of irrigation and other agricultural practices (Singels et al., 2008).

Currently, the crop model most used for the cultivation of sugarcane varieties is DSSAT (Decision Support System for Agrotechnology Transfer) (Singels et al., 2008). DSSAT/CANEGRO has been used in several locations around the world, making production analyses for sugarcane cultivation more agile and effective (Marin et al., 2011). For this, the DSSAT/CANEGRO model calibration must be performed with experimental data in order to obtain better performance in the simulations. In Brazil, the DSSAT/CANEGRO model was used to simulate production and growth variables for sugarcane varieties in São Paulo (Jones et al., 2015) and to analyze the impacts of climate change on sugarcane yield (Silva, 2012; Marin et al., 2013).

According to the Global Climate Models (GCMs) projections, climate change may benefit sugarcane, with increased yield, due to its greater resistance to high temperatures, until its limit to water and thermal stress is reached (Carvalho et al., 2015). However, studies involving impacts of climate change and energy cane are still scarce. Future climate projections are based on reports released by the IPCC (Intergovernmental Panel on Climate Change), which indicate climate vulnerability according to the socioeconomic development for each location, using the RCPs (Representative Concentration Pathways) (Oliveira, 2015).

Therefore, the objective of this research was to evaluate the impacts of climate change on energy cane yield simulated by the DSSAT/CANEGRO model in the region of Coastal Tablelands in the Alagoas state, Northeast of Brazil.

Materials and Methods

Study location and obtaining of meteorological data

The research was conducted in an experimental area of GranBio company, with approximately 1.0 ha, located at Fazenda Rocheira, in Teotônio Vilela city, state of Alagoas (09°55’35” S; 36°17’03” W; 124 m), Northeast Brazil. The region’s climate, according to Thornthwaite climate classification, is megathermal (A’) dry sub-humid (C1), with little or no excess water (d), and a concentration of 41.5% of the reference evapotranspiration (ET_0) from December to March. The total annual rainfall is 1,076 mm, with a concentration of 58% in April to July and poor water distribution throughout the year. During this period, the lowest temperatures occur and, consequently, the lowest reference evapotranspiration, while in the other months the opposite occurs (Sarmento, 2019).

Meteorological data (global solar radiation, rainfall, air temperature (maximum and minimum), relative humidity and wind speed) were obtained from an automatic agrometeorological station (Micrologger CR10X, Campbell Sci., Logan, Utah) of the Laboratory of Agrometeorology and Solar Radiometry at the Federal University of Alagoas (LARAS - UFAL), located in the experimental area.

Field experiment

Experimental design and treatments

The experimental design was in randomized blocks with three replications, in which the treatments were twenty-three genotypes of energy cane and another genotype of sugarcane. However, only seven sugarcane genotypes and one commercial sugarcane genotype (RB92579) were evaluated in the experiment. The research gave priority to the sugarcane genotypes of Vertix, from GranBio´s genetic improvement program, and the RB92579 sugarcane variety, for showing excellent agronomic performance in the Northeast (Agrolink, 2019). The plots consisted of six 10-meter-long rows. To perform the modeling on the DSSAT/CANEGRO platform, genotype VX12-1744 was selected, registered as Vertix 2 variety (Boschiero et al., 2018) at the Ministry of Agriculture, Livestock and Food Supply.

The irrigation method used was sprinkling, according to the design water depth of the GranBio farm, using the mobile linear displacement irrigation system, which was 60 mm, in a 15-day interval, applying 120 mm monthly.

Planting and crop management

Planting was carried out on February 04, 2016, with pre-sprouted seedlings (MPB), which were propagated asexually by means of buds arranged in tubes with substrate. The transplant occurred when the seedlings were more than 45 days after planting (DAP). The spacing was 0.70 m between plants, alternating between 0.90 and 1.50 m between rows. Basal fertilization was carried out in the planting furrow with 50 kg ha^{-1} of nitrogen, plus 150 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O. For weed control, 1,440 g ha^{-1} of the active ingredient of Metribuzin plus 120 g ha^{-1} of the active ingredient of Mesotrione were applied. Harvest was carried out on January 31, 2017.

Plant growth and development analysis

Growth analyses were performed monthly from ten plants marked on the two central rows of each plot. The growth variables analyzed were: Plant height, leaf area index (LAI), stalk diameter, tillering and dry biomass. The assessments to determine dry biomass were destructive, based on the collection of three clumps per plot. The plant material was kept in a forced ventilation oven at 65 °C until the mass had a constant value (Sarmento, 2019; Silva, 2019).

Leaf area was measured using the device LAI-2000, and LAI was calculated using the ratio between leaf area and the area occupied by the plants (Sousa et al., 2015; Sarmento, 2019). The crop cycle was divided into four phenological stages (Table 1). The reference evapotranspiration (ET_0, mm) was calculated by the parameterized Penman-Monteith method for a hypothetical crop according to FAO bulletin no. 56 - Food and Agriculture Organization (Allen et al., 1998). The crop evapotranspiration (ETc, mm) was determined by the product between ET_0 and crop coefficient (Kc), in which the Kc was determined according to the single-Kc method proposed in the FAO 56 bulletin. The Kc values were adjusted according to the weather conditions of the place and crop (initial Kc: 0.40; intermediate Kc: 1.25; final Kc: 0.75) (Allen et al., 1998).

Production variables

The energy cane biomass production was evaluated bimonthly and at the final harvest of the experiment. Tons of green mass per hectare, tons of dry mass per hectare and agro-industrial variables such as °Brix, percentage of fiber, total reducing sugars and total recovered sugars were evaluated. These variables were determined from 300 grams of green biomass crushed in a forage chopper, according to the methodology described by Sarmento (2019).

DSSAT/CANEGRO model

Model parameterization

Energy cane growth and development variables were simulated using the CANEGRO model, which is included in the DSSAT system (Singels et al., 2008). For DSSAT/CANEGRO model parameterization, meteorological data were inserted in the climate file, such as: global solar radiation (W m^{-2}), maximum and minimum air temperature (°C), rainfall (mm), wind speed (m s^{-1}) and air humidity (%). The data used for the soil file were: texture (sand, silt and clay), density and pH of the study area. In addition, the model also requires data that regulate the physical-hydraulic soil properties, such as soil moisture at field capacity, permanent wilting point and saturation, in addition to the depth of the soil. Crop management data (variety, row spacing, plant population and information on the amount and date of irrigation and fertilization) were also used.

This model is based on sugarcane growth and development modeling processes, which include phenology, canopy growth, biomass and sucrose accumulation, partition, root growth, water stress and lodging (Singels et al., 2008; Nassif et al., 2012).

Calibration of the DSSAT/CANEGRO model for energy cane genetic parameters

The model was adjusted by changes in specific parameters related to sugarcane crop (Table 2), from a standard variety (NCo-376) previously calibrated in the DSSAT/CANEGRO model as suggested by Singels et al. (2008).

Genetic parameters for the standard cultivar of the DSSAT/CANEGRO model are relevant for both plant cane and ratoon cane. The adjustments were made manually, based on the characteristics expressed by the Vertix 2 sugarcane genotype in the field. First, the crop parameters related to the phenology and growth (TTHALFO, TBASE, LFMAX, MXLFAREA, MXEFARNO, PI1, PI2, PSWITCH, TTPLNTEM, CHUPIBASE, TT_POPGROWTH, MAX_POP, POPTTI6) were adjusted and, later, the parameters related to yield (PARCEMAX, APFMX, STKPFMAX, SUCA, TBFT, LG_AMBASE).

DSSAT/CANEGRO model evaluation

For statistical evaluation of the DSSAT/CANEGRO model performance, the Wilmott's Index of Agreement (d), the Root Mean Square Error (RMSE), the Coefficient of Determination of the linear regression (R^2) and Pearson's Correlation Coefficient (r) between observed and simulated variables were used. The variables evaluated were: fresh and dry matter, leaf area index, stalk height and tillering.

Climate scenarios

Climate projections that comprise the present climate (1961-1990) and future climate (2017-2060) were obtained using the Eta-MIROC5 Regional Climate Model (RCM) and the Marksim DSSAT Weather File Generator software (gismap.ciat.cgiar.org/Marksim). Climate projections in Eta-MIROC5 were carried out using four RCPs: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. In the Fifth Assessment Report - AR5 (2013), RCPs represent representative CO_2 concentration pathways

Table 1. Crop coefficient for energy cane according to DAT.

Stage/Period	I	II	III	IV	Total
Stage start	**02/04/2016**	**03/25/2016**	**06/03/2016**	**01/08/2017**	
Period (days)	50	70	220	26	366

Stage I – initial; Stage II – growth; Stage III – development and Stage IV – final.

Table 2. Input parameters of the DSSAT/CANEGRO model for energy cane.

Parameters	Descriptions	Units	NCo-376	Vertix 2
PARCEMAX	Maximum (no stress) radiation conversion efficiency expressed as assimilate produced before respiration, per unit of PAR.	g MJ^{-1}	9.90	30.90
APFMX	Maximum fraction of dry mass increments that can be allocated to aerial dry mass.	Mg Mg^{-1}	0.88	0.90
STKPFMAX	Fraction of daily aerial dry mass increments partitioned to stalk at high temperatures in a mature crop.	Mg Mg^{-1}	0.65	0.65
SUCA	Maximum sucrose contents in the base of stalk.	Mg Mg^{-1}	0.58	0.58
TBFT	Temperature at which partitioning of unstressed stalk mass increments to sucrose is 50% of the maximum value.	ºC	25	25
TTHALFO	Thermal time to half canopy.	ºC d	250	250
TBASE	Base temperature for canopy development.	ºC	16	16
LFMAX	Maximum number of green leaves a healthy, adequately-watered plant will have after it is old enough to lose some leaves.	Leaf	12	11
MXLFAREA	Maximum leaf area assigned to all leaves above leaf number MXLFArno.	cm^2	360	380
MXEFARNO	Leaf number above which leaf area is limited to MXLFArea.	Leaf	15	15
PI_1	Phyllocron interval 1 for leaf numbers below Pswitch.	ºC d	69	120
PI_2	Phyllocron interval 2 for leaf numbers above Pswitch.	ºC d	169	169
PSWITCH	Leaf number at which the phyllocron changes.	Leaf	18	18
TTPLNTEM	Thermal time to emergence for a plant crop.	ºC d	428	950
TTRATNEM	Thermal time to emergence for a ratoon crop.	ºC d	203	203
CHUPIBASE	Thermal time from emergence to start of stalk growth.	ºC d	1,050	1,050
TT_POPGROWTH	Thermal time to peak tiller population.	ºC d	600	900
MAX_POP	Maximum tiller population.	Stalks m^{-2}	30	27
POPTTI6	Stalk population at/after 1600°C d^{-1}.	Stalks m^{-2}	13.3	18.58
LG_AMBASE	Aerial mass (fresh mass of stalks, leaves, and moisture) at which lodging start.	Mg ha^{-1}	220	220

for the total radiative forcing until 2100: RCP2.6 = 2.6 W m^{-2}; RCP4.5 = 4.5 W m^{-2}; RCP6.0 = 6.0 W m^{-2}; and RCP8.5 = 8.5 W m^{-2}. RCPs are climate scenarios with projections for the future radiative forcing gas emission rates and mitigation efforts. RCP2.6 is the most optimistic scenario, which reaches its peak in the middle of the 21st century. RCP4.5 and RCP6.0 are a continuation of the current emissions pathway, which reaches a global radiative forcing until the year 2100. For RCP8.5, the heating is designed to extend beyond 2100 in all scenarios, with the exception of RCP2.6, with the radiative forcing of 8.5 W m^{-2} more than pre-industrial levels. Each RCP provides spatially distributed data sets on land use changes and sectoral emissions of air pollutants and specifies the annual concentrations of greenhouse gases up to the year 2100.

Results and Discussion

DSSAT/CANEGRO model calibration

Production variables

Measured and simulated biomass (fresh and dry matter) of energy cane are shown in Figure 1. It was observed that, in general, the model tended to overestimate and underestimate, respectively, the fresh and dry matter values during its cultivation cycle. Anyway, in both simulations satisfactory representations were obtained in the variation curve of these variables. The final values of fresh and dry matter simulated by the DSSAT/CANEGRO model were 165,000 and 46,500 kg ha^{-1}, which differed from the observed values by 18.7% and 3.3%, respectively. Fresh and dry matter simulations using the DSSAT/CANEGRO model obtained a high degree of fit to observed data in the field, indicating simulation precision, with R^2 equal to 0.94 and 0.88 for fresh and dry matter, respectively (Table 3).

Studies involving the simulation of energy cane are scarce or nonexistent. However, several studies address the simulations of sugarcane varieties by agrometeorological models. Nassif et al. (2012) obtained reasonable fits in simulations for fresh matter of the RB86-7515 sugarcane variety (d = 0.74, R^2 = 0.51 and RMSE = 30,300 kg ha^{-1}). Marin et al. (2011) obtained good results for dry matter of RB72454 (RMSE = 9,800 kg ha^{-1}) and SP83-2847 (RSME = 9,600 kg ha^{-1}) varieties.

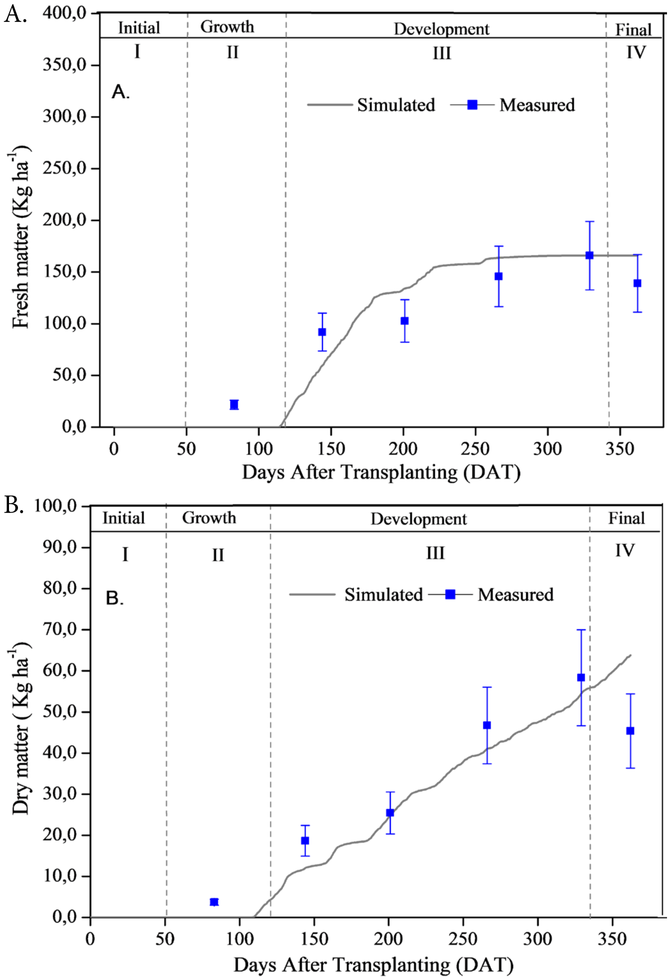

Figure 1. Measured and simulated fresh (A) and dry (B) matter throughout the crop cycle.

Table 3. Statistical indices: Coefficient of Determination (R^2), Willmott's Index of Agreement (d), Root Mean Square Error (RMSE) and Pearson's Correlation Coefficient (r) for production and growth variables of an energy cane variety.

	R^2	d	RMSE	r
Production variables				
Fresh matter	0.94	0.98	24.37	0.94
Dry matter	0.88	0.99	10.27	0.88
Growth variables				
Leaf Area Index	0.72	0.99	1.66	0.72
Stem height	0.98	0.99	0.94	0.98
Tillering	0.75	0.99	5.77	-0.75

Growth variables

Measured and simulated Leaf Area Index (LAI) of energy cane are shown in Figure 2. In general, the model tended to underestimate the LAI during almost its entire growing cycle. The final value of LAI simulated by the Century model was 2.95 m^2 m^{-2}, which represented errors of 2.4%. In general, it was observed that there was a good correlation between the observed and simulated data, with R^2 equal to 0.72 (Table 3).

Sugarcane LAI was analyzed by Silva (2012), who observed a limitation in the parameterization of this variable for RB92579 sugarcane variety. Marin et al. (2009) suggest that

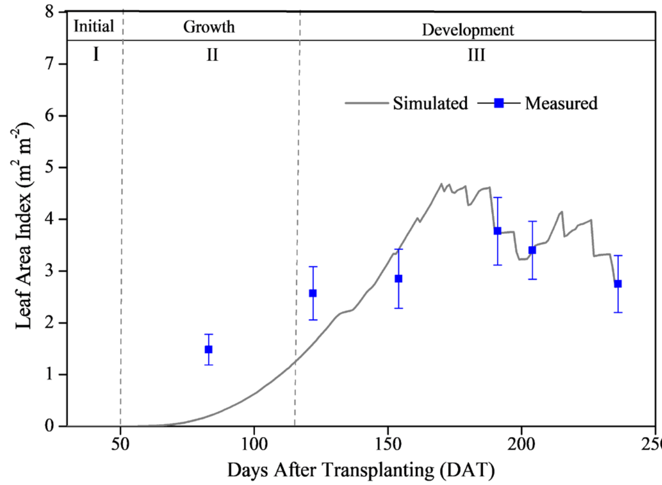

Figure 2. Measured and simulated Leaf Area Index (m^2 m^{-2}) throughout the crop cycle.

further studies are needed to better fit this variable in the DSSAT/CANEGRO model.

Measured and simulated stalk height for energy cane are shown in Figure 3. In general, the model underestimated the stalk growth throughout its cultivation cycle. Despite this, the model managed to represent the variation curve of stalk height, indicating a high degree of fit between the observed and simulated data in the statistical indices (Table 3), with R^2 equal to 0.98. The maximum stalk height simulated by the DSSAT/CANEGRO model was 2.65 m, with an error of -25.6%. This result may indicate systematic error and, therefore, the need to improve the representativeness of the parameters related to this variable.

Nassif et al. (2012) obtained stalk height results for CTC7 (d = 0.80; RMSE = 0.48; R2 = 0.94) and CTC20 (d = 0.81; RMSE = 0.63; R^2 = 0.92) sugarcane varieties, also indicating a good degree of fit of the model with these varieties in comparison to the observed data.

Measured and simulated tillering of energy cane are shown in Figure 4. The tillering did not show typical behavior of sugarcane varieties (it reaches its maximum peak, decreases

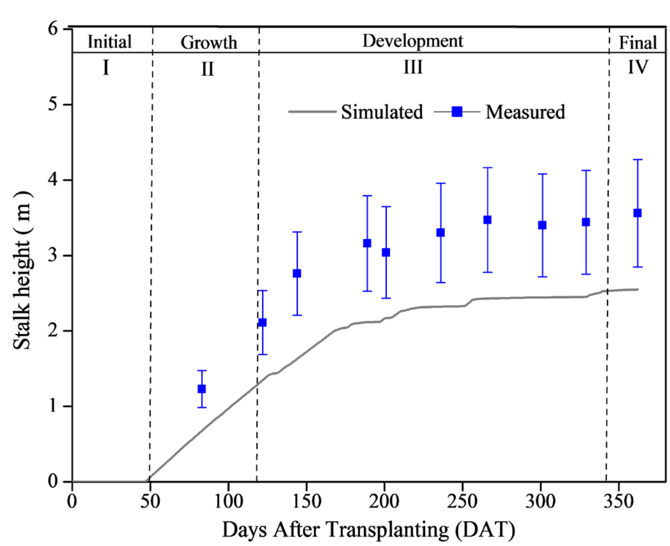

Figure 3. Measured and simulated stalk height throughout the crop cycle.

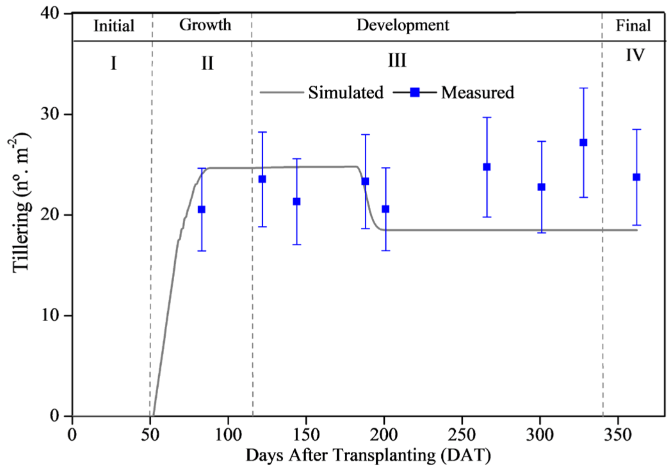

Figure 4. Measured and simulated tillering throughout the crop cycle.

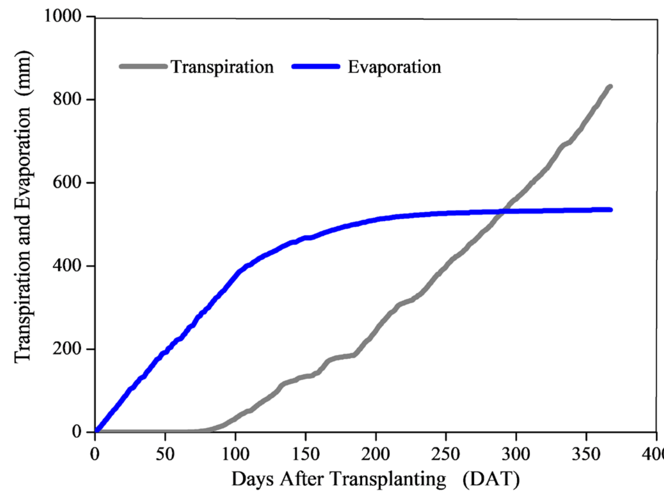

Figure 5. Accumulated transpiration (T; mm) and evaporation (E; mm) simulated by the DSSAT / CANEGRO model for energy cane, in the state of Alagoas.

and stabilizes). This atypical behavior for energy cane may be due to the fact that it has rhizomes, which implies plants that sprout faster, with denser tillering. Sugarcane in its early days had this characteristic (rhizomes), but in the last 100 years, breeding programs have concentrated only on varieties with a higher content of sucrose, and this rhizome characteristic has been reduced (Matsuoka et al., 2012). The final simulated value of tillering of the energy cane was 18.5 stalks m^{-2}, with an error of -21.3%. In general, the statistical indices showed similarity between the observed and simulated data (Table 3), with R^2 equal to 0.75. The DSSAT/CANEGRO model encountered some difficulties in the analysis of tillering, requiring more evaluations for energy cane genotypes.

Nassif et al. (2012), in a study on tillering with the RB867515 sugarcane variety, obtained satisfactory results (d = 0.873 and R^2 = 0.57).

Water balance analysis

The DSSAT/CANEGRO model was also used to simulate the transpiration and accumulated evaporation for energy cane (Figure 5). Initially, the evaporation was greater than the transpiration due to the slow growth of the leaf area of the energy cane, but the accumulated total of transpiration was greater. The model performed well in the crop evapotranspiration (ETc) simulations, with a simulated ETc of 1,367 mm and observed ETc of 1,080 mm, a difference of 26.6%, with the E/ETc ratio being 60.9% and T/ETc was 39.1%. These values were lower than those found by Carvalho et al. (2017) with RB93509 sugarcane variety in plant cane and ratoon, in an experiment conducted by Almeida et al. (2008) in Rio Largo, Alagoas, in which the E/ETr ratio was 44% in the plant cane and 32% in ratoon and the T/ETr ratio was 56% in the plant cane and 68% in the first ratoon cycle. The E/ETc ratio was 32% in the plant cane and 20% in the ratoon and T/ETc was 42% in the plant cane and 42% in ratoon.

Energy cane yield in climate change scenarios

Prediction correlation made in DSSAT/CANEGRO using meteorological data observed and meteorological data from MIROC5

The need to use meteorological data from the MIROC5 model is due to the greater precision in the analysis and representativeness in the DSSAT/CANEGRO model, making the simulations for the present and future scenarios more accurate (Guimarães et al., 2016). Thus, it was necessary to carry out an evaluation on obtained data based on the climate scenarios simulated by MIROC5. In Figure 6, the correlation of fresh and dry matter simulation data was observed using meteorological data measured and obtained in the climate scenarios simulated by the MIROC5 model for RCPs 2.6, 4.5, 6.0 and 8.5.

There was a high correlation for simulated fresh and dry matter with measured and simulated data by the MIROC5 model. The correlations for fresh matter showed a high R^2 value, ranging from 0.92 to 0.94 in all RCPs. The good results observed in the correlations between the yield of fresh and dry matter with measured and simulated data provided support for the simulations in the future period to be made.

Impacts of climate change on energy cane yield

The values of observed fresh and dry matter in the field were 138,000 and 45,000 kg ha^{-1}, respectively. Yield projections of fresh and dry matter of energy cane can be seen in Figure 7. The simulations carried out for the fresh and dry matter variables of the current scenario (2017) obtained values of 145,000 and 41,000 kg ha^{-1}, 135,000 and 38,000 kg ha^{-1}, 136,000 and 38,000 kg ha^{-1}, and 133,000 and 37,000 kg ha^{-1}, respectively for RCPs 2.6, 4.5, 6.0 and 8.5, with model errors below 20% (Figure 7).

In the projections, all RCPs showed an increase in yield (fresh and dry matter) up to the year 2060, with the exception of the RCP8.5 scenario in which yield started to decrease after 2037. Comparing the yield of energy cane for the current period (2017) with those projected for 2060, the increase in yield was greater in RCP6.0, with 160,000 and 45,000 kg ha^{-1}, increases of 24,000 kg ha^{-1} (17.7%) and 7,000 kg ha^{-1} (18.6%). In RCP8.5, increased energy cane yield in the first years of the projection was

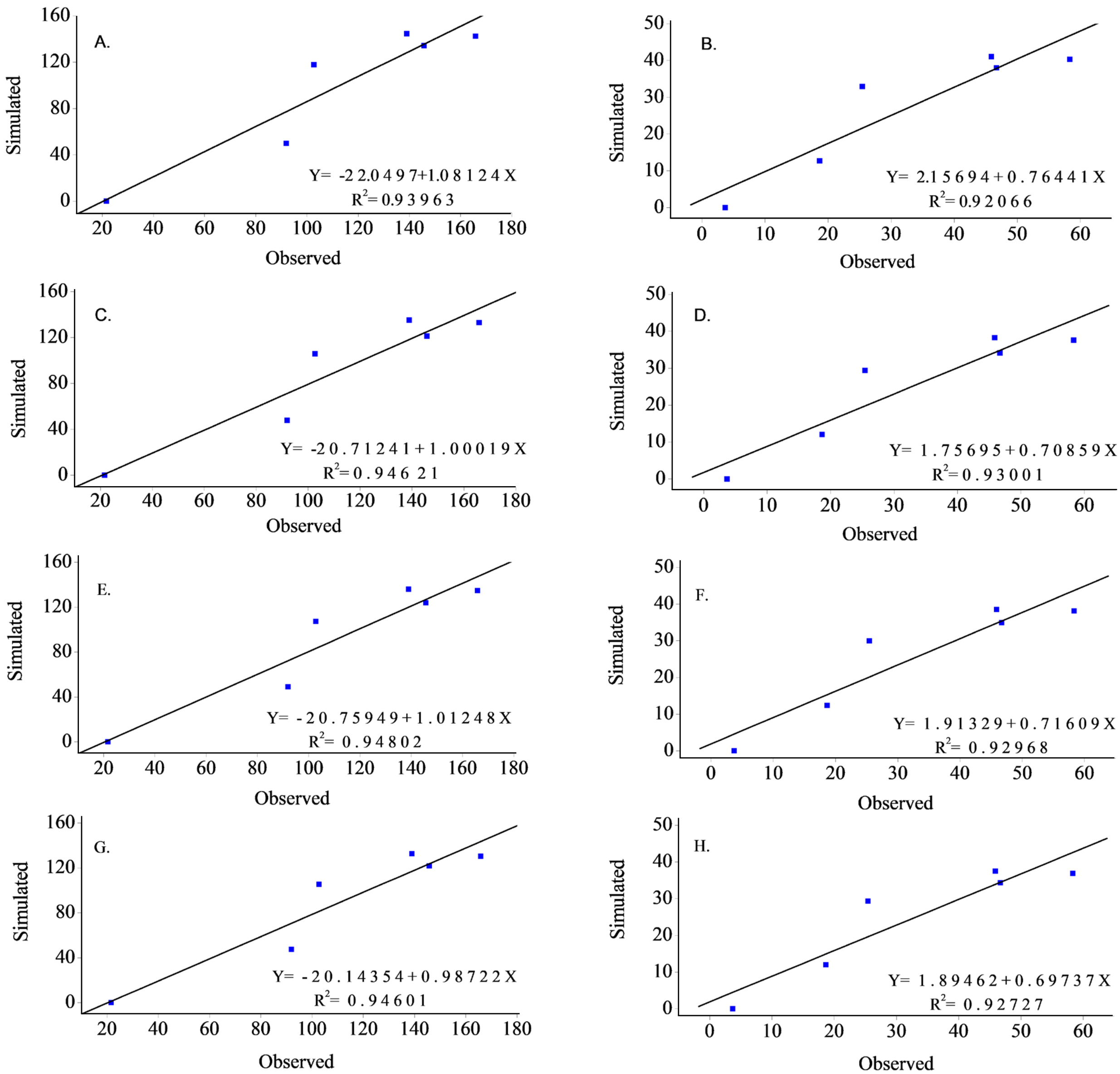

Figure 6. Correlation between fresh (LEFT) and dry matter (RIGHT) for meteorological data observed in the field (X AXIS) and those simulated by DSSAT/CANEGRO (Y AXIS) using climate scenarios of the MIROC5 model, for RCPs 2.6 (a, b), 4.5 (c, d), 6.0 (e, f) and 8.5 (g, h) for the present period (2016-2017).

observed, reaching values of 146,000 and 41,000 kg ha^{-1} in 2036, that is, increases of 9.8% and 10.7%. However, from that year on, the yield of sugarcane began to decrease, probably due to the high temperatures projected in RCP8.5, which reach a maximum increase of 4.0 °C (Guimarães et al., 2016), showing that the sugarcane was sensitive to the gradual increase in temperature. Thus, the yields of energy cane were 113,000 and 32,000 kg ha^{-1} in 2060, and thus reductions of 15% and 13.5%, respectively for fresh and dry matter, compared to 2017.

These results show that sugarcane can benefit from climate change due to the increase in air temperature. Thus, its cultivation may be expanded to areas where there are restrictions due to low temperatures, expanding its area suitable for planting to the southeastern and southern regions of the country. The increase in temperature and CO_2 emissions can promote an increase in sugarcane yield, due to the increase in efficiency in the photosynthesis process, a fact observed until the plant reaches its tolerance to climatic conditions and, with this, shows a reduction of yield (Carvalho et al., 2015). This is the explanation for yield reduction of energy cane in the scenario RCP8.5, in which the increase close to 4.0 °C in the air temperature may have reached the maximum tolerance of the plant, causing thermal stress. Pinto et al. (2018) stated that the projections used indicated an increase in yield (RB867515 sugarcane variety) in the state of São Paulo simulated based on climate scenarios RCPs by the APSIM-Sugar and DSSAT/CANEGRO models on three different harvest dates. Marin et al. (2015) stated that there was an increase in the growth of sugarcane (RB867515 sugarcane variety) under conditions of increased rainfall and simulated CO_2 concentration in several locations across the country

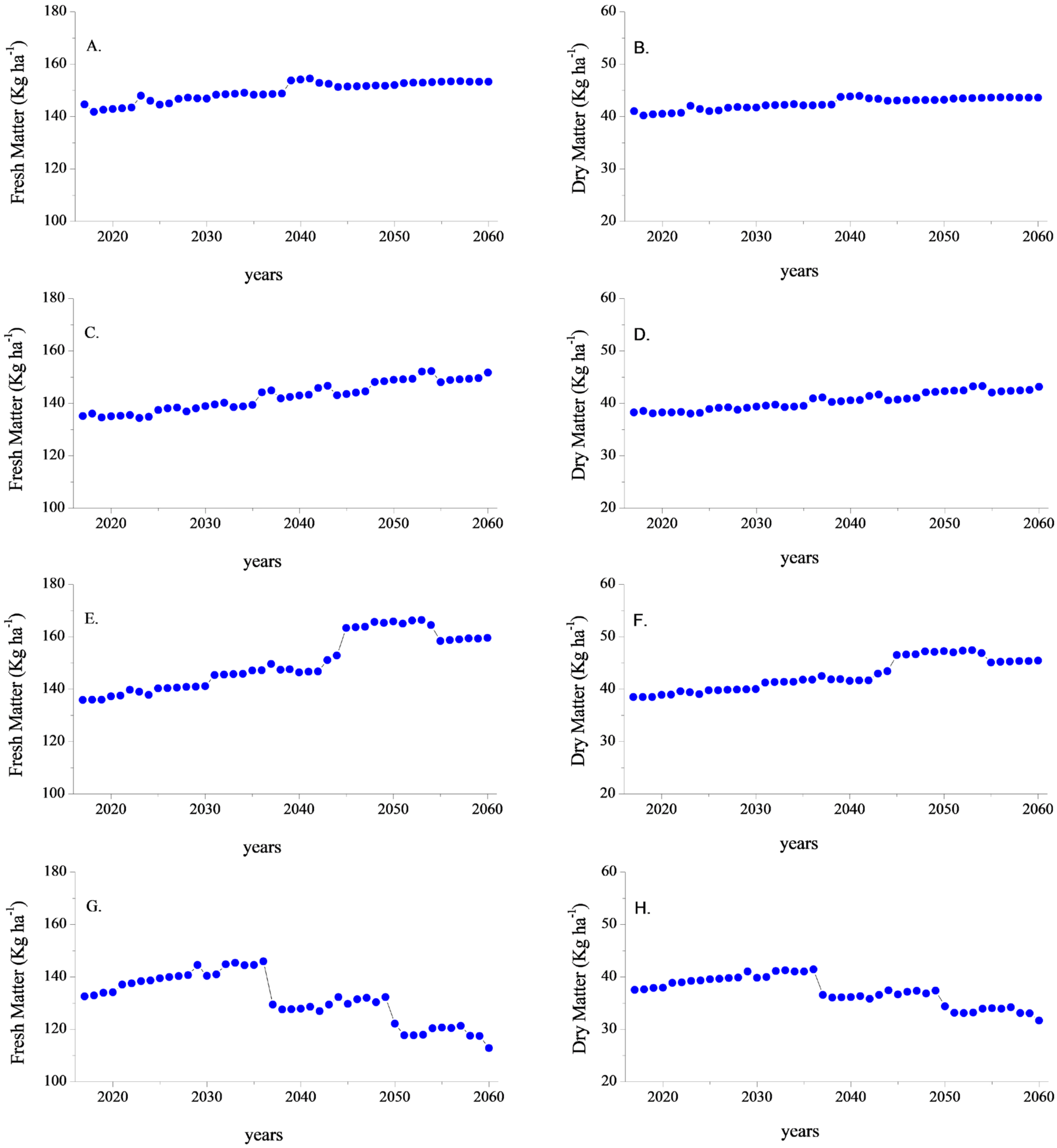

Figure 7. Projections of fresh (LEFT) and dry (RIGHT) matter of energy cane for RCPs 2.6 (a, b), 4.5 (c, d), 6.0 (e, f) and 8.5 (g, h), for the period of 2017-2060, in the region of Teotônio Vilela-AL, Brazil.

using the DSSAT/CANEGRO and APSIM models, but its growth was limited by the increase temperature (+6.0 °C), impacting its yield.

Conclusions

The DSSAT/CANEGRO model satisfactorily simulates growth and development parameters of energy cane, from a variety of sugarcane inserted in the model. The yield of fresh and dry matter is satisfactorily reproduced by the model with errors of less than 20%, which shows that the model is capable of carrying out simulations and projections for the future climate.

Energy cane may have an increase in yield due to climate changes, in the RCPs scenarios (2.6, 4.5 and 6.0), due to the increase in air temperature until 2060. In the RCP6.0 scenario, the maximum increase in yield may be up to 17.7% and 18.6% by 2060, for fresh and dry matter, respectively. However, increasing the air temperature by up to 4.0 °C (scenario RCP8.5) may result in a reduction in yield of up to 15% and 13.5% by 2060 for fresh and dry matter, respectively.

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Compliance with Ethical Standards

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