Journal of Agrometeorology 21 (3) : 388-391 (September 2019)

Short communication

Calibration and validation of CANEGRO model for sugarcane in south Gujarat region

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Sugarcane (*Saccharum officinarum* L.) is main source of sugar in India. Sugar is an essential item of mass consumption and the cheapest source of energy, supplying around 10 % of the daily calorie intake. In India, sugarcane occupies about 4.73 million hectares area with a total production of 376.90 million tons at an average productivity 79.7 t ha^{-1} (Anon., 2018). Uttar Pradesh, Maharashtra and Karnataka contribute about 77 % of the total cane production and accounts for about 73 % of the total acreage under the crop of which Uttar Pradesh has 47 % of the area in the whole country (Anon., 2018). Sugarcane being a tropical plant its growth and yield are more sensitive to weather conditions (Kushwaha and Pal, 2000).

The CANEGRO model is a crop simulation model for sugarcane crop, developed at the South African Sugarcane Research Institute (SASRI) and incorporated in DSSAT environment (Inman-Bamber, 1991; Singels and Bezuidenhout, 2002). Simulation modeling is useful tool to study the effect of different climatic parameters as well a management practices on sugarcane production and quality of its produce. Such work on sugarcane crop has been done extensively in Brazil and South Africa, but isolated work in India. Hence, in this paper attempt has been made to calibrate and validate the CANEGRO (DSSAT v4.7) model for sugarcane in south Gujarat region.

The daily weather data were collected from agrometeorological observatory, N.A.U., Navsari. The field experimental data (2012-13 to 2016-17) collected at Main Sugarcane Research Station, N.A.U., Navsari (20° 57' N and 72° 54' E) under two varieties (Co 86032 and Co99004) during date of planting (D_1: November 15-25 and D_2: December 15-25) were used to derive genetic coefficients. The soil of the experimental field was clayey in texture and dark grayish brown type with flat topography. The recommended dose of fertilizer (250 kg N ha^{-1}, 125 kg P2O5 ha^{-1} and 125 kg K2O ha^{-1}) and all the recommended agronomic practices were adopted during the experimental period. The crop parameters such as days to emergence, plant height, LAI, dry matter accumulation, cane yield, commercial cane sugar were recorded for evaluation of the CANEGRO model. The genetic coefficients of sugarcane were estimated by using GLUE (Generalized Likelihood Uncertainty Estimation) program inbuilt within the package of the DSSAT software. The program randomly generates parameters that are being estimated (either phenology or growth attributes) from the prior distribution of parameter values and runs the model for calibration (He *et al*., 2010).

The performance of the model was tested using the test criteria as suggested by Willmott (1982). They are listed as mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE), percent error (PE), correlation coefficient (r) and refined index of agreement (d_r) (Willmott *et al*., 2012).

$$MAE = \sum_{i=1}^{n}]1P_i - O_i 1[/n$$

$$MBE = \sum_{i-1}^{n}]P_i - O_i[/n$$

$$RMSE = \left[\sum_{i=1}^{n})P_i - O_i(^2/n\right]^{1/2}$$

PE (%) = {(simulated – observed) / observed} * 100

Where, P = simulated O = observed

The refined index of agreement (d_r) is expressed as (Willmott *et al*., 2012)

$$d_r = 1 - \frac{\sum_{1=i}^{n}|P_iO-_i|}{c\sum_{1=i}^{n}|O_iO\bar{-}|}, \text{ When } \sum_{i=1}^{n}|P_i - O_i| \le c\sum_{i=1}^{n}|O_i - \bar{O}|$$

Or

$$d_r = \frac{c\sum_{1=i}^{n}|O_iO\bar{-}|}{\sum_{i=1}^{n}|P_i - O_i|} - 1, \text{ When } \sum_{i=1}^{n}|P_i - O_i| > c\sum_{i=1}^{n}|O_i - \bar{O}|$$

Where, c=2.

The CANEGRO-sugarcane model was calibrated using the field trial data of the 2012-13, 2013-14 and 2014-15 for two sugarcane cultivars (V_1 - Co 86032 and V_2 - Co 99004) planted on two dates (D_1: November 15-25 and D_2: December

Table 1: Calibrated genetic coefficients of two cultivars of sugarcane

Parameter	Description of parameter coefficients controlling development aspects	Co 86032	Co 99004
Max PARCE	Maximum (no stress) radiation conversion efficiency expressed as assimilate produced before respiration, per unit PAR. (g/MJ)	9.88	9.90
APFMX	Maximum fraction of dry mass increments that can be allocated to aerial dry mass (t/t)	0.93	0.87
STKPFMAX	Fraction of daily aerial dry mass increments partitioned to stalk at high temperatures in a mature crop (t/t on a dry mass basis)	0.78	0.78
SUCA	Sucrose partitioning parameter: Maximum sucrose contents in the base of stalk (t/t)	0.62	0.55
TBFT	Sucrose partitioning: Temperature at which partitioning of unstressed stalk mass increments to sucrose is 50% of the maximum value	26	27
Tthalfo	Thermal time to half canopy (^{o}Cd)	250	250
TBase	Base temperature for canopy development (^{o}Cd)	16	16
LFMAX	Maximum number of green leaves a healthy, adequately-watered plant will have after it is old enough to lose some leaves.	12	12
MXLFAREA	Max leaf area assigned to all leaves above leaf number MXLFARNO (cm^2)	629	369
MXLFARNO	Leaf number above which leaf area is limited to MXLFAREA	15	15
PI1	Phyllocron interval 1 (for leaf numbers below Pswitch, ^{o}C.d (base TTBASELFEX))	94	107
PI2	Phyllocron interval 2 (for leaf numbers above Pswitch, ^{o}C.d (base TTBASELFEX))	199	218
PSWITCH	Leaf number at which the phyllocron changes.	18	17
TTPLNTEM	Thermal time to emergence for a plant crop (degree C days, base TTBASEEM)	450	500
TTRATNEM	Thermal time to emergence for a ratoon crop (degree C days, base TTBASEEM)	203	203
CHUPIBASE	Thermal time (baseTTBASEEM) from emergence to start of stalk growth	1050	1050
TT_POPGROWTH	Thermal time to peak tiller population (deg C days, TTBASEPOP)	680	557
MAX_POP	Maximum tiller population (stalks/m^2)	38	38
POPTT16	Stalk population at/after 1600 degree days (/m^2)	11.3	11.3
LG_AMBASE	Aerial mass (fresh mass of stalks, leaves, and water attached to them) at which lodging starts; t/ha	220	220

15-25). The derived genetic coefficients of CANEGRO model for both varieties are presented in Table 1.

Validation is the process of assessing the performance of model for predicting the things such as days to emergence, plant height, dry matter accumulation, leaf area index, cane yield, commercial cane sugar yield (C.C.S.) compared with the observed data were used to validate the CANEGRO model with independent data set of 2015-16 and 2016-17. The performance of the model was evaluated with the test criteria *viz.* MAE, MBE, RMSE, PE, r, and d_r.

The simulated results for days to emergence are presented against the observed days to emergence in Fig. 1(a). Data pertaining to days to emergence revealed that the model simulated the days to emergence with reasonably good accuracy for both cultivars and dates of transplanting with average error percent was 0.57. The MAE, MBE and RMSE and r were 0.17, 0.50, 2.24 and 0.47 respectively, indicate reasonably good performance of the model with slightly underestimated. The index of agreement (d_r) was 0.70 which indicate that the validated CANEGRO model can be used for simulating days to emergence with reasonable accuracy.

Plant height (m)

It may be seen in Fig. 1(b) that the simulated results for plant height are presented against the observed plant height with reasonably good accuracy for both cultivars and dates of transplanting with average error percent was 3.25. The MAE, MBE, RMSE and d_r were 0.09, 0.09, 0.22 and 0.42 respectively, indicate reasonably good performance of the model with slightly overestimated. Further the correlation coefficient was 0.97 which was highly significantly indicate that the validated CANEGRO model can be used for simulating plant height with reasonable accuracy. These results are in good agreement with the findings of Singh *et al.* (2010) for validation of plant height using CANEGRO-sugarcane model in east Uttar Pradesh, India.

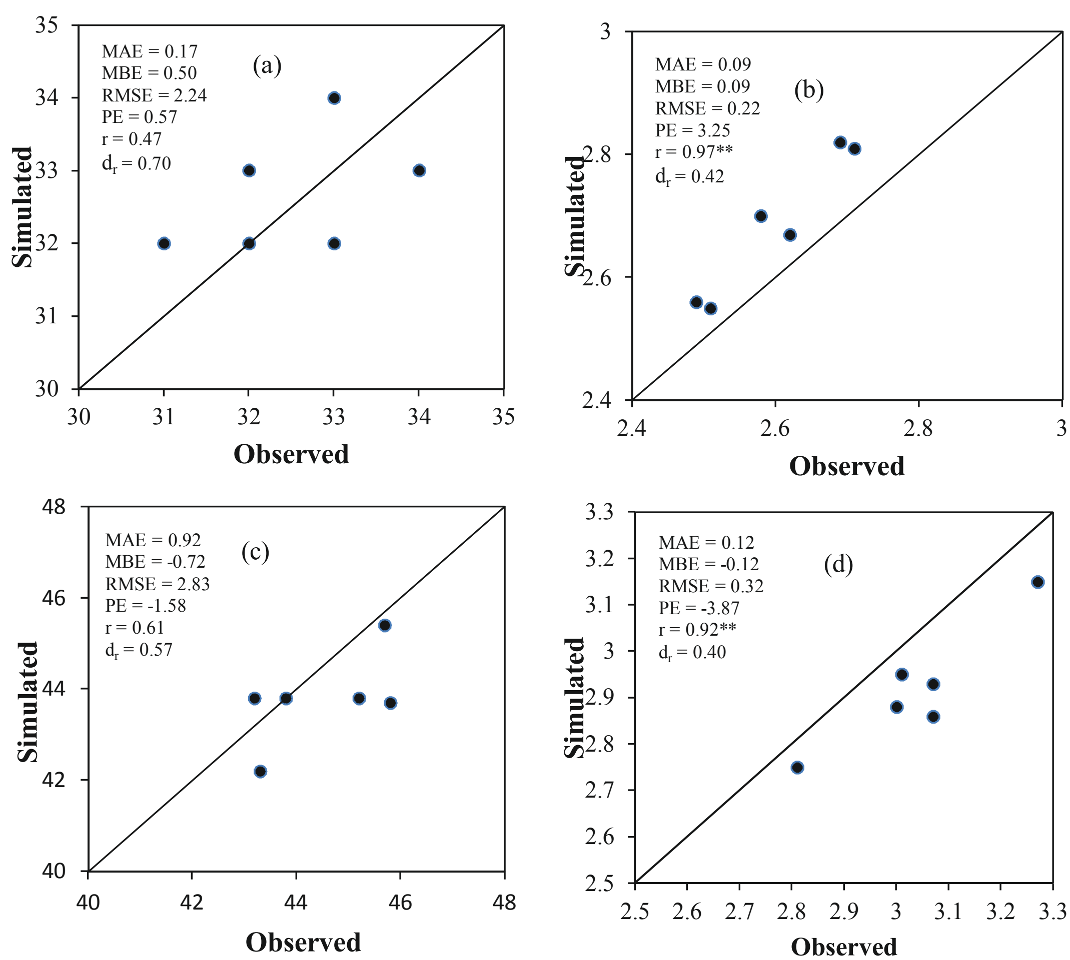

Fig. 1: Observed vs. simulated (a) days to emergence, (b) plant height, (c) dry matter accumulation, (d) LAI, (e) cane yield and (f) commercial cane sugar yield with test criteria for validation period (2015-16 and 2016-17)

Dry matter accumulation (t ha^{-1})

The simulated results for dry matter accumulation are presented against the observed dry matter accumulation in Fig. 1(c). The result revealed that the model simulated the dry matter accumulation with reasonably good accuracy for both cultivars and dates of transplanting with average error percent was -1.58. The MAE, MBE, RMSE, r and d_r were 0.92, -0.72, 2.83, 0.61 and 0.57 respectively, indicate reasonably good performance of the model with slightly underestimated, which indicate that the validated CANEGRO model can be used for simulating dry matter accumulation with the accepted level of accuracy.

Leaf area index (LAI)

Leaf area index was underestimated by the model for all cultivars in all dates of planting are presented in Fig. 1(d). It may be seen that MAE, MBE, RMSE, PE and d_r were 0.12, -0.12, 0.32 -3.87 and 0.40 respectively, indicate reasonably good performance of the model. The correlation coefficient was 0.92 highly significant which indicate that the validated CANEGRO model can be used for simulating leaf area index with the reasonable accuracy.

Cane yield (t ha^{-1})

The simulated results for cane yield are presented against the observed cane yield in Fig. 1(e). The result revealed that the model simulated the dry matter accumulation with reasonably good accuracy for both cultivars and dates of transplanting with average error percent was 0.70. The MAE, MBE and RMSE were 0.73, 0.73 and 1.98 respectively, indicate reasonably good performance of the model with slightly overestimated. Further the correlation coefficient was 0.96 which was highly significant and the index of agreement (d_r) was 0.69 which indicate that the validated CANEGRO model can be used for simulating cane yield with reasonable accuracy. These results are supported by the Singh *et al.* (2010) for cane yield of different cultivars of sugarcane.

Commercial cane sugar yield (C.C.S) (t ha^{-1})

CANEGRO model simulate the commercial cane sugar yield quite close with observed are presented in Fig. 1(f). Data pertaining to the model simulated the commercial cane sugar yield with reasonably good accuracy for both cultivars and dates of transplanting with average error percent was 1.90. The MAE, MBE and RMSE were 0.32, 0.30 and 0.89 respectively, indicate reasonably good performance of the model. Further the correlation was 0.75 and the index of agreement (d_r) was 0.59 which indicate that the validated CANEGRO model can be used for simulating C.C.S. yield with reasonable accuracy. The results showed that error percent less than ± 5.5 percent are quite acceptable for crop growth simulation studies. These findings are supported by Singh *et al.*, (2010) for C.C.S. yield of sugarcane who found that majority of simulation were within ± 5.5 percent of the observed

The validated CANEGRO sugarcane model can be used for identifying research gaps, yield forecasting, performance of sugarcane under climate variability and climate change study. The model may also to be used to improve and evaluate the current practices of sugarcane growth management to enhance sugarcane production.

ACKNOWLEDGMENTS

Authors gratefully acknowledge the field experimental data on sugarcane provided by Main Sugarcane Research Station, Navsari Agricultural University, Navsari (Gujarat).

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Received : November 2018 : Accepted : August 2019