Journal of Agrometeorology 18 (2) : 234-239 (December 2016)

Calibration and validation study of sugarcane (DSSAT- CANEGRO V4.6.1) model over North Indian region

A.H.BHENGRA, M.K. YADAV, CHANDRABHAN PATEL,P.K. SINGH[1], K.K. SINGH[1]and R.S.SINGH*[1]

Department of Geophysics, Banaras Hindu University, Varanasi – 221005

[1]Agromet Service Cell, India Meteorological Department, New Delhi 110003

Email: rsingh_61@yahoo.co.in

ABSTRACT

The DSSAT CANEGRO model was calibrated and validated using field experimental data (1997-2013) from four locations of north Indian region.The genetic coefficients for 10 cultivars of sugarcane were estimated.R^2 obtained between measured and simulated stalk yield was 0.69 with the nRMSE (7.50%) and D-index (0.91) and R^2 between measured and simulated sucrose mass was 0.57 with the nRMSE(11.75%) and D-index (0.85). The model underestimated both the stalk fresh mass as well as sucrose mass by 2 and 6 per cent only, respectively.Hence,the CANEGRO model can be used to simulate the phenology and yield attributes of sugarcane cultivars of north India particularly of Uttar Pradesh region. The model can also be used to evaluate and improve the present practices of sugarcane crop management to obtain increased cane production and sugar recovery.

Keywords: CANEGRO DSSAT (version 4.6.1)model, calibration & validation study,Sugarcane crop, North Indian region.

Sugarcane is long duration (8-10 months duration) and an important commercial crop in India. Since the crop is facing different season and environmental conditions during its life cycle and hence productivity as well as maturation is directly affected by all these conditions. The yields per hectare are comparatively low in Uttar Pradesh (59 t ha^{-1} in 2012-13) in comparison to national average yield (70 t ha^{-1}) (Anonymous, 2015).The low productivity of sugarcane is mainly caused by late planting (April- May) (Singh *et. al.*, 2008, Singh *et al.*, 2010). So it is very important to analyze the impact and effect of climatic variations and crop management (e.g. Irrigation, nutrients etc.) on yields (Singh *et al.*, 2010). Since sugarcane is long duration crop it is highly influenced by climatic variability such as high temperature during the summer and very low minimum temperatures in winter which ultimately highly influence the ultimate yield of crop (Samui *et al.*, 2003). Because of this variations along the crop life cycle, predicting the crop's responses to those different stimuli may allow improved planning (Inman-Bamber *et al.*, 2002;Scarpari and Beauclair, 2004; Scarpari and Beauclair, 2009), since they are aimed at characterizing management alternatives, creating more realistic scenarios for decision analysis simulations and optimizations, increasing the efficiency of management and strategic decisions along the cropping season (Boote *et al.*, 1996; O'Leary, 2000).

Crop models quantify yields based on weather (radiation, max temperature, min temperature, rainfall, etc.), soil factors (available water, physical properties and depth), crop physiological properties (variety and genotype constant), agronomic management (sowing date, plant population, amount and timing of irrigation and fertilizer applications) and other factors that reduce crop growth such as pests and diseases. Since crop growth model integrates the effects of different factors on productivity, they provide a unique opportunity to supplement results of field trails.

Very few studies have been reported using crop growth models for the sugarcane crop in India. The CANEGRO model has been used by Inman-Bamber*et al.* (1996) for the study of sugarcane yields in relation to light interaction within the green canopy. In a field experiment in 1994-95 at La Mercy, South Africa with sugarcane cv. NCo376, scheduling irrigation using the CANEGRO crop model produced the highest cane (118.2 t ha^{-1}) and sucrose (15.6 t ha^{-1}) yields, but this was not significantly different from using the conventional irrigation scheduling through the use of pan evaporation data (112.2 and 15.2 t ha^{-1}, respectively). Some fields experiment at research and farmer's field level have been conducted in India in piece meal and reported in literature and are available for testing of the model. Therefore, an effort has been made in the present study to evaluate the DSSAT-CANGRO model version 4.6.1 under the north Indian zone particularly for entire Uttar Pradesh region.

MATERIAL AND METHODS

DSSAT version 4.6.1 (Hoogenboom*et al*., 2015) is a software application program having crop simulation models for 42 crops including the sugarcane crop. It was initially developed by International Benchmark Sites Network for Agro-technology Transfer (IBSNAT) (Tsuji *et al*., 1994) as also described by Singh *et al*., 2010. The Canegro model in DSSAT makes use of genetic information defined in species, ecotype and cultivar files.

Data development

The crop growth model uses daily weather data together with a set of parameter describing crop, soil, and management factor to simulate sugarcane growth over the growing season. The daily weather data for 43 years (1971-2013) of maximum and minimum temperature, sunshine hours and rainfall at some stationsover north Indian region were collected for this study. The data on soil physical characteristics (soil albedo, soil water drainage constant, field capacity, wilting point, organic content, bulk density, N-content and critical soil water in different layers) was collected for the study area. For the determination of genotype coefficient for different varieties, the following minimum existing data sets were also collected: date of planting, flowering, and maturity, cane yield and cane sucrose percentage, biomass, cane number (m^{-2}) and nitrogen uptake by plants ($kgha^{-1}$ and %) etc. For the evaluation of the models the different experimental data, multi-year and location data of cane yield, sucrose yield and maturity dates were also collected.

To simulate a sugarcane crop cultivar or variety, the model requires many genetic coefficients. In cultivar module, there are more than 20 genetic coefficients parameters/ crop coefficients in which some used to simulate crop phenology, leaf phenology, tiller phenology, growth/ biomass partitioning and sucrose accumulation. The genetic coefficients, using CANEGRO Sugarcane model (DSSAT version 4.6.1), for ten cultivars of sugarcane out of which six early namely CoP 94211, CoJ 64, CoSe 03234, CoSe 01235, CoSe 98231 and CoSe 95422 andfour midlate maturing cultivars CoS 8436, CoS 767, CoLk 8102 and CoSe 92423 were estimated by repeated interaction in the model calculations until a close match between simulated and observed phenology, growth and yield was obtained. To generate genetic coefficients for above said cultivars of sugarcane all required data were collected from field experiment conducted at Genda Singh Sugarcane Breeding Research Institute (GSSBRI), Seorahi (Kushinagar), (27.20° N, 84.20° E), Sugarcane Research Centre, Gorakhpur, (27.75° N, 83.40° E), Institute of Agricultural Sciences (IAS), Varanasi, (25.30° N, 83.05° E) and GBPUA&T, Pantnagar (28.98° N, 79.68° E) during the period (1997-2013). The genetic coefficients computed by the CANEGRO model using the identical management and other conditions as in the field experiments for all variety is presented in Table 1.

RESULTS AND DISCUSSION

Calibration of the CANEGRO sugarcane model

To simulate the crop phenology, four parameters (TTPLNTEM, TTRATNEM, TT_POPGROWTH and CHUPIBASE) are used in model. TTRATNEM value has kept 203 for all 10 cultivars. For TTPLNTEM (i.e. Thermal time to emergence for a plant crop) value has given as per cultivar ranges from 340-360° Cd. The value for TT_POPGROWTH (i.e. Thermal time to peak population) ranges from 550-700° Cd and most important parameter which influence the crop phenology is CHUPIBASE which described as the thermal time between emergence to start of stalk growth. It is highly cultivar specific (Singels and Bezuidenhout, 2002). The range in our study has chosen 750-850° Cd for early maturing varieties and 950-1200° Cd for midlate maturing varieties of sugarcane. Singels and Bezuidenhout (2002) has taken the value 1050° Cd for cultivar NCo376 and from field experiments data of north Indian cultivars practices it can be concluded that early maturing varieties can have CHUPIBASE value lower than midlate maturing varieties.

The leaf phenology has been simulated using three parameters of genetic coefficients in the model (Inman-Bamber, 1991) are PI1, PI2 and PSWITCH and their values ranges 90-110^{0}Cd leaf^{-1}, 170-220^{0} Cdleaf^{-1}and 13-16 leaf number, respectively (Table 1).

Tthalfo and Tbase temperature simulates canopy cover of sugarcane crop and it is assumed to be cultivar specific (Singels and Donaldson, 2000) in our study we have taken Tthalfo ranged between 220-250 ° Cd and Tbase is 16°C which agree with the values published earlier.

For biomass partitioning three parameters (PARCEmax, APFMX and STKPFMAX) take highly

Table 1: Genetic coefficients of sugarcane cultivars used in the CANEGRO (DSSAT version 4.6.1) model.

Genetic coefficient	CoP 94211	CoS 8436	CoS 767	CoJ 64	CoSe 98231	CoLk 8102	CoSe 03234	CoSe 01235	CoSe 92423	CoSe 95422
PARCEmax	8.6	8.4	9.2	8.5	8.3	9	8.4	8.4	8.4	8.3
APFMX	0.85	0.83	0.89	0.84	0.88	0.88	0.82	0.82	0.88	0.82
STKPFMAX	0.58	0.55	0.59	0.58	0.6	0.65	0.54	0.54	0.6	0.53
SUCA	0.64	0.64	0.64	0.64	0.64	0.58	0.58	0.58	0.64	0.64
TBFT	27.5	28	27	27	27	27	27	28	26.8	26.5
Tthalfo	220	220	250	250	250	250	250	220	250	250
TBase	16	16	16	16	16	16	16	16	16	16
LFMAX	11	10	12	11	12	12	12	12	12	12
MXLFAREA	355	345	355	355	370	360	365	365	360	370
MXLFARNO	14	14	14	14	16	15	16	16	16	16
PI1	90	95	90	95	90	92	110	110	100	90
PI2	170	180	176	180	170	175	195	195	220	170
PSWITCH	15	15	15	15	13	16	13	13	15	15
TTPLNTEM	340	340	340	340	350	350	360	360	360	360
TTRATNEM	203	203	203	203	203	203	203	203	203	203
CHUPIBASE	750	950	1200	800	750	1100	800	800	950	850
TT_POPGROWTH	670	610	700	670	550	620	570	570	600	580
MAX_POP	26	22	26	25	23.5	26.5	23.4	23.4	23	24
POPTT16	11	11	11.5	10.3	10.2	11.5	10.2	10.2	9.5	10
LG_AMBASE	220	220	220	220	220	220	220	220	220	220
DELTTMAX	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07

Note: Brief descriptions of the above genetic coefficients are mentioned below:

PARCEmax Maximum = (no stress) radiation conversion efficiency expressed as assimilate produced before respiration, per unit PAR. (gMJ^{-1}); APFMX = Maximum fraction of dry mass increments that can be allocated to aerial dry mass (tt^{-1}); STKPFMAX = Fraction of daily aerial dry mass increments partitioned to stalk at high temperatures in a mature crop (tt^{-1} on a dry mass basis); SUCA = Sucrose partitioning parameter: Maximum sucrose contents in the base of stalk (tt^{-1}); TBFT = Sucrose partitioning: Temperature at which partitioning of unstressed stalk mass increments to sucrose is 50% of the maximum value (p C); Tthalfo = Thermal time to half canopy (p Cd); TBase = Base temperature for canopy development (p Cd); LFMAX = Maximum number of green leaves a healthy, adequately-watered plant will have after it is old enough to lose some leaves; MXLFAREA = Max leaf area assigned to all leaves above leaf number MXLFARNO (cm^2); MXLFARNO = Leaf number above which leaf area is limited to MXLFAREA; PI1= Phyllocron interval 1 (for leaf numbers below Pswitch,p Cd (base TTBASELFEX)); PI2 = Phyllocron interval 2 (for leaf numbers above Pswitch,p Cd (base TTBASELFEX)); PSWITCH Leaf number at which the phyllocron changes; TTPLNTEM = Thermal time to emergence for a plant crop (°Cd, base TTBASEEM); TTRATNEM = Thermal time to emergence for a ratoon crop (°Cd, base TTBASEEM); CHUPIBASE = Thermal time (baseTTBASEEM) from emergence to start of stalk growth (°Cd); TT_POPGROWTH = Thermal time to peak tiller population (°Cd, TTBASEPOP); MAX_POP = Maximum tiller population (stalks m^{-2}); POPTT16 = Stalk population at/after 1600 degree days (m^{-2}); LG_AMBASE = Aerial mass (fresh mass of stalks, leaves, and water attached to them) at which lodging starts ($t\ ha^{-1}$); DELTTMAX = Max change in sucrose content per unit change in stalk mass in the unripenened section of the stalk ($t\ ha^{-1}$);

Table 2: Regression equation fitted through origin (i.e. 1:1 line) to show underestimation or overestimation by the Canegro model w. r. t. different yield attributes (n=25) during validation of model.

Parameter	Regression line trend through origin	c.c.(r)
Stalk fresh mass (t ha^{-1})	SFM (Simulated) = 0.98SFM (observed)	0.820
Sucrose content (%)	SC (Simulated) = 0.97 SC (observed)	0.849
Sucrose mass (t ha^{-1})	SM (Simulated) = 0.94 SM (observed)	0.701

Table 3: Simulated fresh stalk mass and sucrose mass of a dominating earlymaturing cultivar (CoSe95422) in contrast to other dominating mid late maturing cultivars(CoS 767) under standard run using normal weather data based on the period (1971-2013).

Location	Early maturing (CoSe 95422)		Mid late maturing(CoS 767)	
	Stalk fresh mass(t ha^{-1})	Sucrose mass(t ha^{-1})	Stalk fresh mass (t ha^{-1})	Sucrose mass(t ha^{-1})
Pantnagar*	57.9	7.2	57.2	7.6
Gorakhpur	73.5	6.2	79.1	9.6
Meerut	64.1	5.1	75.9	9.4
Shahjahanpur	67.9	5.9	78.6	9.9
Varanasi	77.4	7.3	87.9	10.9
Seorahi**	72.1	7.1	80.3	10.1
Mean	68.8	6.5	76.5	9.6

* Normal weather based on the period from 1985- 2013; ** Normal weather based on the period from 1997- 2008.

importance in the model. PARCEmax i.e. the maximum radiation conversion efficiency expressed as assimilate produced before respiration, per unit PAR, ranges between 8.2 to 9.2 g MJ^{-1}. And parameter APFMX which is described as maximum fraction of dry mass increments that can be allocated to aerial dry mass (tt^{-1}) ranges from 0.82 to 0.89 tt^{-1}. According to Singels and Bezuidenhout(2002) these two parameters are not cultivar specific but in our study values for both parameters changing due to different weather conditions at different locations. The range used for PARCEmax in our study is lower than the value suggested by Singels and Bezuidenhout (2005) as they have given 9.9 g MJ^{-1} for their region and cultivar NCo376.They also suggested the value of 0.89 tt^{-1} for APFMX in their literature coincide with the higher value we have found in our study. Another parameter STKPFMAX which is the fraction of daily aerial dry mass increments partitioned to stalk at high temperatures in a mature crop (tt^{-1} on a dry mass basis) fall within the range (0.55 - 0.65) agree with Singelsand Donaldson (2000) as they have suggested the range 0.65 (0.65–0.8), our sugarcane cultivars range is lower from them.

For simulation of sucrose yield in model, only two parameters which were highly influential viz. TBFT and DELTTMAX. TBFT is the temperature at which partitioning of unstressed stalk mass increments to sucrose is 50% of the maximum value and it ranges from 26.8° C to 28.0° C in our study. It was found in well agreement with range (22.0° C to 28.0° C) reported bySingels and Bezuidenhout (2002). Similarly, DELTTMAX ie. maximum change in sucrose content per unit change in stalk mass in the unripenened section of the stalk (tha^{-1})ranges from 0.07 to 0.09 (t ha^{-1}) and in well agreement with the results (0.05 to 0.08) given by Singels and Bezuidenhout (2002). According to them, the value of DELTTMAX is high for high sucrose varieties under fully irrigated conditions.Though, across the cultivars there are variations in the genetic coefficient, which may be related to change in the crop growth, phenology and other output.

For calibration purpose we have selected 51 data point (i.e. different treatments with respect to cultivars, experimental fields, row spacing, sowing dates etc.). On average, the model simulate stalk fresh mass more or less equal to measured stalk fresh mass[Fig. 1(a)] with R^2(0.78), nRMSE (5.96%) and D-index (0.94). The model also simulate sucrose mass more or less equal to measured sucrose mass [Fig. 1(b)] with R^2(0.74), nRMSE (9.25%) and D-index (0.92). Finally the derived genetic coefficients using the above data point are presented in Table 1. Among the various crop characteristics listed, some are physiologically very important but don’t have impact on the productivity of

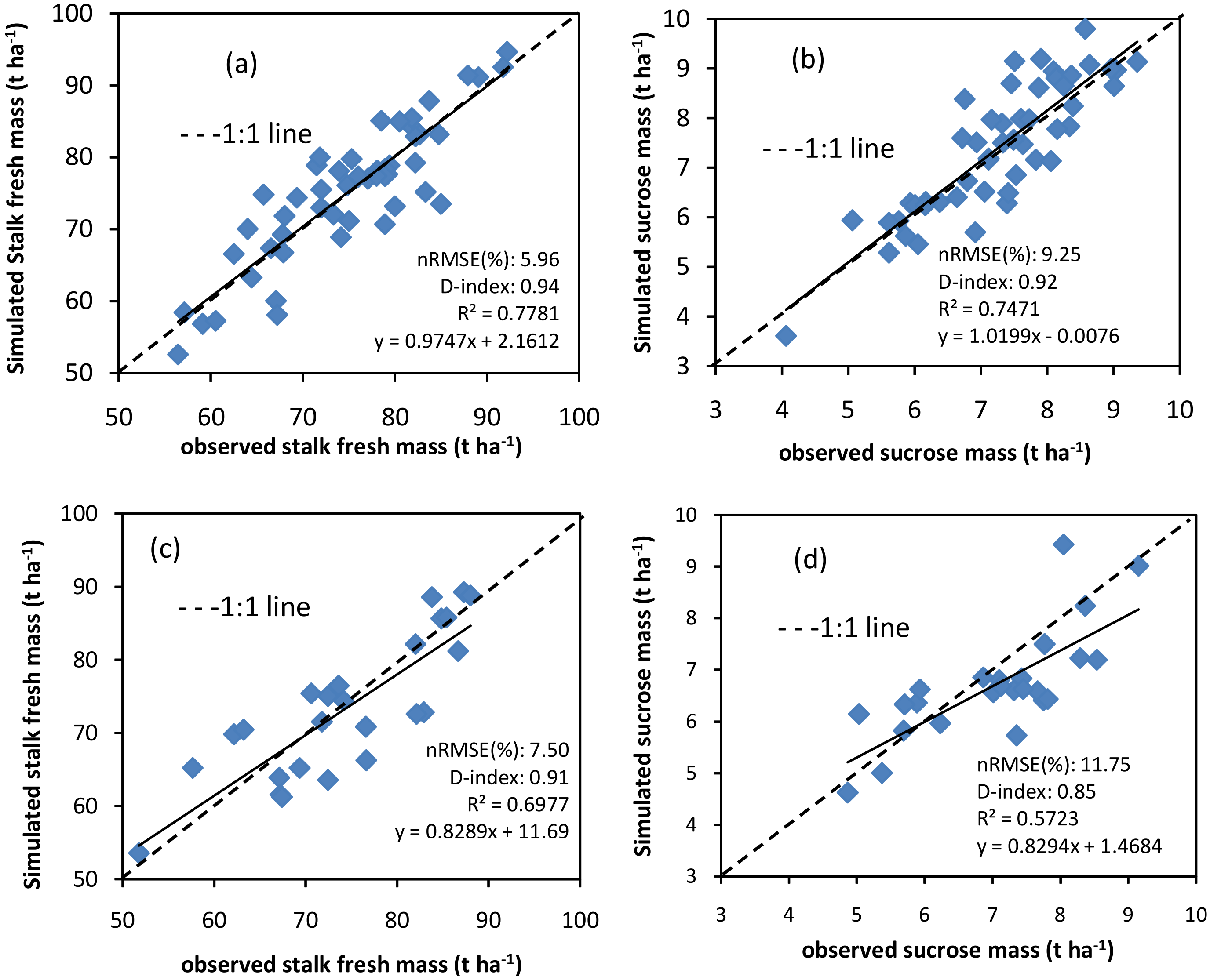

Fig 1: Measured v/s simulated data used in calibration: (a) stalk fresh mass (t ha^{-1}), (b) sucrose mass (t ha^{-1}) and validation: (c) stalk fresh mass (t ha^{-1}), (d) sucrose mass (t ha^{-1}).

sugarcane at harvest. However, some genetic coefficients (viz:PARCEmax, APFMX, STKPFMAX, TBFT and CHUPIBASE) have got much significant influence on the various yield attributesas well as on the maturity period of the sugarcane crop.

Validation study of DSSAT-CANEGRO sugarcane model

The first step into validating a model is to compare its computed value to a well established model or by field measurements. For most validation processes, very few influential variables can be measured directly and their accuracy is not always excellent or well known. The model results for stalk fresh mass (t ha^{-1}) and sucrose mass (t ha^{-1}) are plotted against measured stalk fresh mass (t ha^{-1}) and measured sucrose mass (t ha^{-1}), respectively. For both the yield parameters, the simulated values were found almost equal to the measured one. Then the above genetic coefficients as given in Table 1 are used for another 25 data set for validation purpose. And we have found that the simulated stalk fresh mass (SFM) is 2% underestimated than measured SFM with R^2(0.70), nRMSE (7.5%) and D-index(0.91)[(Table 2 and Fig. 1(c)] and simulated sucrose mass (t ha^{-1}) (SM) also underestimated by 6% than observed SMR^2(0.57), nRMSE (11.75%) and D-index(0.85) [(Table 2 and Fig. 1(d)].

Detailed output of the standard run (Table 3) with respect to dominating early maturing cultivar CoSe95422 were compared for stalk yield (57.9 t ha^{-1} at Pantnagar, 72.1 t ha^{-1} atSeorahi, 73.5 t ha^{-1} at Gorakhpur, 77.4 t ha^{-1} at Varanasi, 64.1 t ha^{-1} at Meerut and 67.9 t ha^{-1} at Shahjahanpur) and sucrose mass (7.2 t ha^{-1} at Pantnagar, 7.1 t ha^{-1} atSeorahi, 6.2

t ha^{-1} at Gorakhpur, 7.3 t ha^{-1} at Varanasi, 5.1 t ha^{-1} at Meerut and5.9 t ha^{-1} at Shahjahanpur). Similarly, the standard run with respect to dominating mid late maturing cultivar CoS767 (Table 3) were compared for stalk yield (57.2 t ha^{-1} at Pantnagar, 80.3 t ha^{-1} atSeorahi, 79.1 t ha^{-1} at Gorakhpur, 87.9 t ha^{-1} at Varanasi, 75.9 t ha^{-1} at Meerut and 78.7 t ha^{-1} at Shahjahanpur) and sucrose mass (7.6 t ha^{-1} at Pantnagar, 10.1 t ha^{-1} atSeorahi, 9.6 t ha^{-1} at Gorakhpur, 10.9 t ha^{-1} at Varanasi, 9.4 t ha^{-1} at Meerut and 9.9 t ha^{-1} at Shahjahanpur).This was performed to analyse the importance of crop genetic coefficients of two contrasting cultivars CoSe95422 (early maturing) and CoS767 (mid late maturing) for the behavior and verification of the model at six locations namely Pantnagar, Seorahi,Gorakhpur, Varanasi, Meerut and Shahjahanpur to account for genotype environment interaction. This output of the model has confirmed that the yield of the mid-late maturing cultivar (CoS 767) was considerably higher in comparison to early maturing cultivar (CoSe 95422) over all the six locations.

CONCLUSIONS

The validated outcomes of DSSAT-CANEGRO sugarcane model reveals that this model satisfactorily simulate the yield attributes of observed crop data and can be adopted for prediction of crop growth, phenology, water management, potential and actual yields for sugarcane crop over north Indian region and results can be used for farmers at regional level and agro-advisory programs. These results are comparable with those published in recent literature, confirming that model performance is satisfactory.

REFERENCES

Anonymous, (2015). Directorate of Economics and Statistics,Department of Agriculture and Cooperation, India.

Boote, K.J., Jones, J.W. and Pickering, N.B.(1996). Potential uses and limitations of crop models. *Agron.J.*, 88: 704-716.

Hoogenboom, G., J.W. Jones, P.W. Wilkens, C.H. Porter, K.J. Boote, L.A. Hunt, U. Singh, J.I. Lizaso, J.W. White, O. Uryasev, R. Ogoshi, J. Koo, V. Shelia and G.Y. Tsuji. (2015). Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.6.1 (www.DSSAT.net). DSSAT Foundation, Prosser, Washington.

Inman-Bamber, N. G. (1991). A growth model for sugar-cane based on a simple carbon balance and the CERES-Maize water balance. *South African J. Plant Soil*, 8(2): 93-99.

Inman-Bamber N. G., Muchow, R.C., and Robertson, M.J. (2002). Dry matter partitioning of sugarcane in Australia and South Africa.*Field Crops Res*., 76(1): 71-84.

Inman-Bamber N.G., Wilson, J.R., Hogarth, D.M., Campbell, J.A. and Garside,A.L. (1996). Opportunities for increased radiation utilisation by sugarcane in South Africa. Proceeding of the Annual Congress, South African Sugar Technologists Association, No. 70, pp. 162-165.

O'Leary,G. J.(2000). Review of three sugarcane simulation model with respect to their prediction of sucrose yield. *Field Crops Res*., 68: 97-111.

Samui, R., John, G. and Kulkarni, M. B.(2003). Impact of Weather on Yield of Sugarcane at Different Growth Stages.*J. Agric. Physics*, 3(1-2): 119-125.

Singels, A. andBezuidenhout, C. N. (2002). A new method of simulating dry matter partitioning in the Canegro sugarcane model. *Field Crops Res.*, 78(2): 151-164.

Singels, A., and Donaldson, R. A. (2000). A simple model of unstressed sugarcane canopy development. *Proc. S. Afr. Sugar Technol. Assoc*., 74: 151-154.

Singh, K.K., Mall, R. K.,Singh, R. S. and Srivastava A. K.(2010). Evaluation of CANEGRO-Sugarcane simulation model in East Uttar Pradesh, India. *J. Agrometeorol*., 12(2): 181-186

Singh, S.P., Gangwar, B. and Singh, M.P.(2008). Economics of Sugarcane-based Farming System in Western Uttar Pradesh.*Agri. Eco. Res. Review*, 21: 109-117.

Scarpari, M. S. andBeauclair, E. G. F.(2004). Sugarcane maturity estimation through edaphic-climatic parameters. *Sci. Agri.*, 61(5): 486-491.

Scarpari, M. S. and Beauclair, E. G. F., 2009. physiological model to estimate the maturity of sugarcane. *Sci. Agri.*,66(5): 622-628.

Tsuji, G.Y., Uehara, G. and Balas, S. (1994). DSSAT version 3 Volumes 1, 2, and 3. International Benchmark Sites Network for Agrotechnology Transfer. University of Hawaii, Honolulu, Hawaii(Eds).

Received : November 2015 ; Accepted : September 2016