Evaluation of CANEGRO Sugarcane model in East Uttar Pradesh, India

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ABSTRACT

The sugarcane crop growth simulation model was calibrated and validated in Eastern Uttar Pradesh (UP) region of Indo-Gangetic Plains of India using 12 years field experiment data conducted in several places. The results reveal that the CANEGRO Sugarcane model satisfactorily simulated the potential growth and yield of sugarcane crop. The model simulates the stalk height, stalk fresh mass and sucrose yield within ±15 % of range in comparison to the observed values. Therefore the validated CANEGRO Sugarcane model can be further used for applications such as prediction of crop growth, phenology, water management, potential and actual yields, performance of sugarcane under climate variability and change scenarios etc. The model may also be used to improve and evaluate the current practices of sugarcane growth management to achieve enhanced cane production and sugar recovery.

*Keywords***:** CANEGRO model, Sugarcane, Genetic Coefficients, Simulation, Climate.

Sugarcane (*Saccharum officinarum L.*) is one of the most important commercial crops in India. There are 35 millions farmers growing sugarcane and another 50 millions depend on employment generated by the 571 sugar factories and related industries. In Uttar Pradesh, Maharashtra and Tamil Nadu, sugarcane plays a major role in the state economy. Area under sugarcane cultivation and production has been highly fluctuating in India. Highest area cultivated under sugarcane in recent decade was 5.15 m ha in 2007 and lowest with 3.66 m ha in 2005 (FAO, 2010). Singandhupe *et al.* 2010 reports about 84% of the cultivated area irrigated in India. It occupies 51% of the total cultivated area of Uttar Pradesh, with a large number of supporting sugar factories. Despite total production of sugarcane in the state, average productivity (58.2 t ha^{-1}) is lower than the national average of 66.9 t ha^{-1} (Indian Sugar, 2008). The productivity of the crop is low mainly due to its late planting after wheat harvest during April to May (Singh *et al* 2008). Besides climatic variability, non climatic factors such as crop diversification, minimum support price, sugarcane mills condition also influence sugarcane production fluctuation in India. Therefore, it is essential to understand the impact of climate variability and crop management (water and nutrients) on sugarcane and sugar yields.

In recent times, the crop simulation models have been used extensively to study the impact of climate on agricultural production and food security. The output provided by the simulation models can be used to make appropriate crop management decisions and to provide farmers and other stakeholders with alternative options for their farming system options. In India, substantial work has been done in recent decades aimed at understanding the nature and magnitude of change in yield of different crops using the crop simulation model and remote sensing technique (Mall *et al*., 2006; Aggarwal *et al.,* 2008; Patel *et. al.,* 2010; Singh *et al.* 2010; Kumar *et al.,* 2010). The comprehensive crop simulation models for sugarcane have been developed and used for in depth study in South Africa, Australia and USA etc. (Keating *et al.,* 1999; O'Leary, 2000; Cheeroo-Nayamuth *et al.,* 2000; Inman-Bamber *et al.,* 2001 and 2002).

The quantitative establishment of relationship between climate variability and crop yields is vital because of the economic importance of crops and interest in the future of agriculture under possible climate change in the twenty-first century. The state of U. P. has highly variable weather from year to year. Despite such interest, a literature search has found hardly any attempts to quantify the climate signal in sugarcane yield. Therefore, calibration and validation of the sugarcane crop growth model in East Uttar Pradesh Region is the focus of this work for future studies.

MATERIALS AND METHODS

Climate of study area

East Uttar Pradesh extends geographically between latitudes 23.0 – 28.00N, longitudes 79.5 – 84.50E, and altitudes

70.0 – 147.0 meters and climatically comes under sub-tropical and dry sub-humid region of India. Long-term mean annual rainfall (period: 1970-2005) over the region is 1012 mm with coefficient of variation of 17%. Table 1 shows the description of the study sites in detail. Regarding spatial variability, annual rainfall varies between 800 mm in the western part (Kanpur and Farrukhabad district) to more than 1200 mm in the Northeast region of study area (some parts of Deoria, Gorakhpur, Basti and Gonda districts). Sonebhadra and adjoining parts of Mirzapur district located in the Southeast receives annual rainfall of more than 1100 mm. Number of rainy days are around 39 in Farrukhabad and 56 in Gorakhpur. Central region of East UP comprising Lucknow and Faizabad districts receive rainfall of 950 to 1050 mm and distributed over 46 to 47 rainy days. Coefficient of variation of annual rainfall over East UP meteorological sub-division ranged between 21 and 35%. Drought and floods are not unusual and some district of East UP always suffers either due to drought or floods occurring in some or other parts of the East UP subdivision.

CANEGRO Sugarcane model description

The DSSAT, developed by International Benchmark Sites Network for Agrotechnology Transfer (Tsuji, *et al.*, 1994), contains crop simulation models; databases for weather, soil and crops; and strategy evaluation programs integrated with a user friendly interface on microcomputers. For simulating cane development, growth, yield and other crop management needs, the CANEGRO model evaluated is one of 16 crop models embedded within the DSSAT software (Jones *et al.*, 2003). The CANEGRO Sugarcane model was originally developed by the South African Sugar Association Experiment Station (SASEX) to determine optimal harvest age because of risks from the stalk borer *Eldana sacchararina* (Inman Bamber, 1995). It has since been embedded into DSSAT and used in Africa (Inman-Bamber and Kiker, 1997), Asia (Jintrawet, 1995) and America. The model contains carbon simulation, crop development, energy and water simulation components.

The CANEGRO Sugarcane model employs a source–sink concept for mass growth, but includes the volume of stalks as a state variable to define the sink size. It also simulates canopy development, which is used to drive the energy balance of the crop by intercepting radiation for photosynthesis. Base temperature for canopy development is taken to be 16°C in the present study. Biomass is dynamically distributed among different components of the plant, including stalk sucrose, based on the crop's age, level of water stress and temperature. In this model, daily partitioning of assimilate between roots and aerial parts is simulated as a non-linear function of total biomass. A constant fraction of aerial dry mass is partitioned to stalk when thermal time since emergence exceeds a stipulated value. The rate of dry matter partitioning to stalk is regarded as the source strength. Partitioning of stalk dry matter is regulated by sink capacity and the source to sink ratio. Sink capacity is governed by current growing conditions, current stalk mass and varietal characteristics. The sucrose accumulation component of the model is based on a framework of sucrose distribution within stalks as it is affected by temperature and water stress. For sucrose partitioning parameter, the maximum sucrose contents in the base of stalk (t/t) is kept as 0.58.

Data used

The model requires a set of minimum data pertaining to daily weather, soil, genotype characteristics and crop management details. These data are provided to the model through different data files. A large number of field experiments have been conducted in East Uttar Pradesh region of Indo-Gangetic Plain, where the effect of different agro-ecological factors such as season, weather and climate, soil, planting dates, variety and water management has been studied on growth and cane yield of sugarcane crop at various locations. This database included all relevant information (including the different management practices adopted, location specific soil and weather conditions) obtained from field experiments conducted during 1992 to 2008 in major sugarcane producing regions of East U.P. and had representations ranging from Seorahi and Gorakhpur in tarai region of UP to Lucknow in Central UP and Varanasi in East UP

RESULT AND DISCUSSION

Calibration and derivation of genetic coefficients for sugarcane variety

To simulate a sugarcane variety, the model requires a set of genetic coefficients pertaining to phenology and growth. The genetic coefficients required in the CANEGRO Sugarcane model version 4.5 for seven varieties of sugarcane crop were estimated by repeated iterations in the model calculations until a close match between simulated and observed phenology, growth and yield was obtained. All calibration data required to derive genetic coefficients were obtained from field experiment conducted at Indian Institute of Sugarcane Research Institute (IISR), Lucknow; Genda Singh Sugarcane Breeding and Research Institute (GSSBRI), Seorahi (Kushinagar) and Sugarcane Research Centre, Gorakhpur and Banaras Hindu University, Varanasi during 1992 - 2008. In these field experiments, the sugarcane planting was done at row spacing of 75 cm and 90 cm, and the planting depth was maintained at 15 cm. A net 60 kg of urea per hectare

Table 1: Climatic and other geographical description of the study sites in Eastern Uttar Pradesh

Sl.	Lat.	Long.	Location	Altitude	Variety	Duration to maturity (days)	Cane yield (t ha^{-1})	Maximum temperature (^{0}C) range	Minimum temperature (^{0}C) range	Annual rainfall (mm)
1	25^{0}18'N	83^{0}03'E	Varanasi	78.0	CoS767, CoP94211	300-360	58-93	42.6 - 48.6	1.8 - 8.2	1051.3
2	26^{0}56'N	80^{0}52'E	Lucknow	113.0	CoJ64, Colk8102	295-350	56-85	42.2 – 46.6	0.2 – 3.7	964.7
3	27^{0}12'N	84^{0}12'E	Seorahi (Kushinagar)	99.8	CoSe95422, CoSe1421	305-370	58-93	36.9 – 42.8	3.8 – 5.8	1641.9
4	26^{0}45'N	83^{0}24'E	Gorakhpur	79.0	CoSe3234	305-370	60-90	41.0 - 45.5	0.0 – 7.3	1192.0

Table 2: Genetic coefficients of sugarcane cultivars used in the CANEGRO Sugarcane version 4.5 model

Definitions of genetic coefficients of cultivar	CoJ-64	CoLk-8102	CoS-767	CoSe-95422	CoSe-1421	CoSe-03234	CoP 94211
Maximum (no stress) radiation conversion efficiency expressed as assimilate produced before respiration, per unit PAR. (g MJ^{-1}). (PARCEmax)	8.50	8.95	8.85	9.5	9.9	9.5	9.5
Maximum fraction of dry mass increments that can be allocated to aerial dry mass (t t^{-1}) (APFMX)	0.86 .	0.88 .	0.88	0.88	0.88	0.88	0.88
Fraction of daily aerial dry mass increments partitioned to stalk at high temperatures in a mature crop (t t^{-1} on a dry mass basis) (STKPFMAX)	0.60	0.65	0.65	0.65	0.65	0.65	0.60
Sucrose partitioning: Temperature at which partitioning of unstressed stalk mass increments to sucrose is 50% of the maximum value (TBFT)	25.	25.	25.	25.	25.	25.	26.5
Thermal time to half canopy (^{0}Cd) (Tthalfo)	250.	250.	250.	250.	250.	250.	250
Base temperature for canopy development (^{0}Cd) (Tbase)	16.	16.	16.	16.	16.	16.	16
Maximum number of green leaves a healthy, adequately-watered plant will have after it is old enough to lose some leaves (LFMAX).	11	12	12	12	12	12	11
Max leaf area assigned to all leaves above leaf number MXLFARNO (cm^2)	355	360	360	370	360	365	355
Leaf number above which leaf area is limited to MXLFAREA	14	15	15	16	17	16	14
Phyllocron interval 1 (for leaf numbers below Pswitch, ^{0}Cd (base TTBASELFEX))	95	92	89	110	110	110	95
Phyllocron interval 2 (for leaf numbers above Pswitch, ^{0}Cd (base TTBASELFEX)) (PI2)	180	175	176	200	200	195	180
Leaf number at which the phyllocron changes. (PSWITCH)	15.	16.	16	15	14	13	15
|Maximum tiller population (stalks m^{-2}) MAX_POP	25.	26.5	26	24	24	23.4	30
Stalk population at/after 1600 degree days (m^{-2}) (POPTT16)	10.3	11.5	11.5	10	10.5	10.2	14
Thermal time to emergence for a plant crop (degree C days, base TTBASEEM) (TTPLNTEM)	340	350	340	360	360	360	340
Thermal time (baseTTBASEEM) from emergence to start of stalk growth (CHUPIBASE)	1850	1710	1740	1580	1600	1510	1710
Thermal time to peak tiller population (deg C days, TTBASEPOP) (TT_POPGROWTH)	670	620	610	580	600	570	670

was applied as basal dose at the time of planting. Plant population was kept as 13.3 plants m^{-2} for row spacing of 75 cm and 11.1 plants m^{-2} for row spacing of 90 cm.

The genetic coefficients determined in the CANEGRO Sugarcane model using the identical management and other conditions as in the field experiment for four varieties of sugarcane are presented in Table 2. These coefficients were used in the subsequent validation and application.

Validation of CANEGRO sugarcane model

Simulations using independent data set for validation were carried out for estimating stalk height, fresh stalk mass and sucrose yield. Overestimation/ underestimation of different growth parameters, regression between observed and simulated data and coefficient of determination have been discussed.

Stalk height

The simulated results for stalk height are presented against the measured stalk height in Fig. 1. Observed stalk height varied from 2.04 to 2.95 m whereas simulated stalk height ranged from 2.15 to 3.21 m. On an average, the model values were 6% higher than measured values. The result showed that model is able to simulate stalk height reasonably
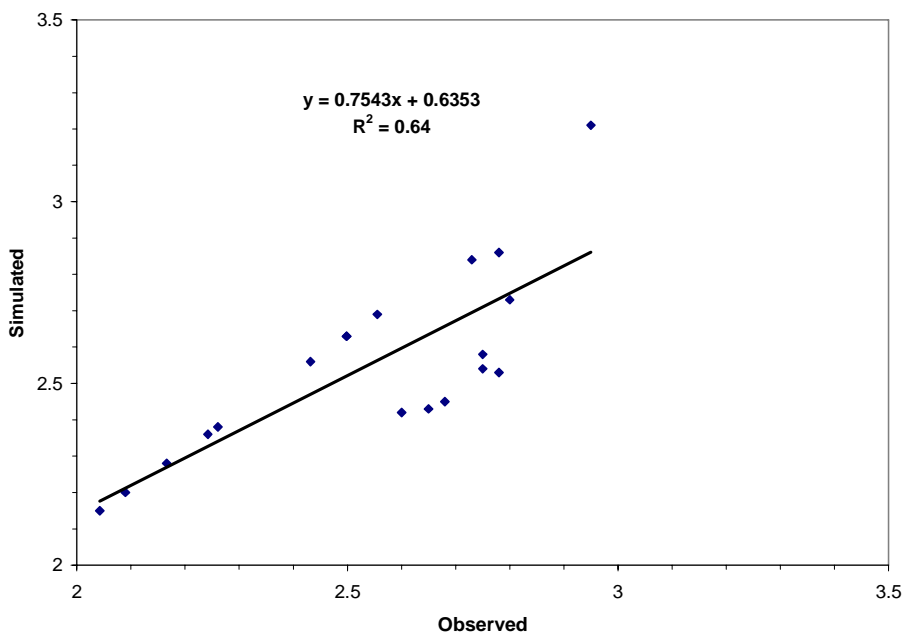
Fig 1: Observed Vs. simulated sugarcane stalk height (m) at harvest in Eastern UP
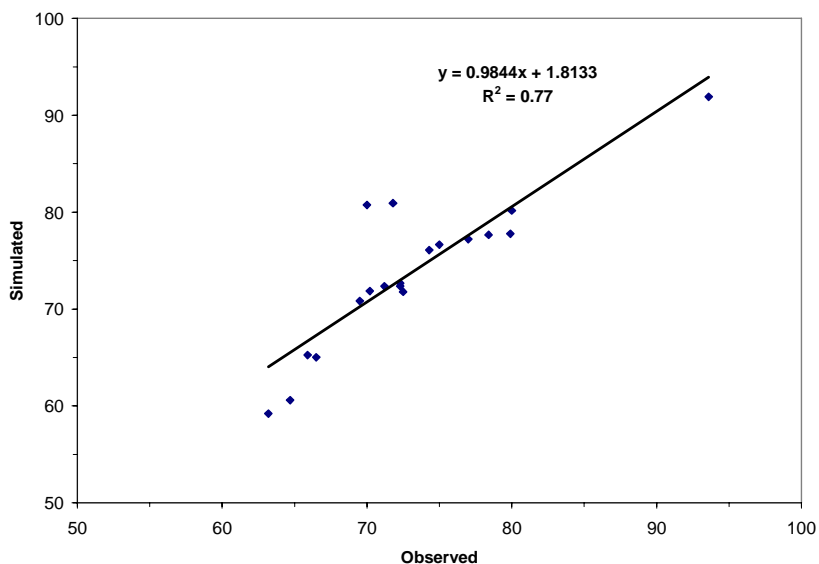
Fig 2: Observed Vs. simulated sugarcane fresh stalk yield (t ha^{-1}) at harvest in Eastern UP

well for most of treatments. In general, there was a good agreement between the observed and simulated values except some peak values.

Fresh stalk yield (Millable Cane)

Fresh stalk mass (FSM) or millable cane yield (t ha^{-1}) estimated by the model compared well within 3% of measured values of fresh stalk mass as shown in Fig. 2. Observed fresh

stalk yield varied from 63.2 to 93.6 t/ha whereas simulated fresh stalk yield ranged from 59.2 to 91.9 t ha^{-1}. The result showed that model is able to simulate fresh stalk yield reasonably well for most of treatments.

Sucrose mass

The simulated results for sucrose yield are presented
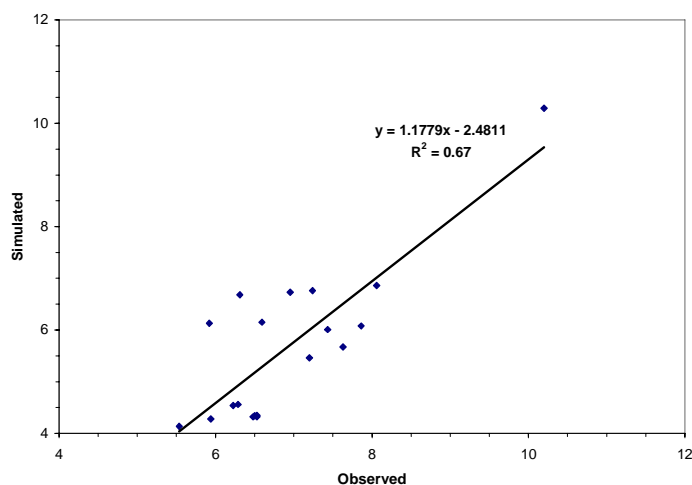
Fig. 3: Observed Vs. simulated sugarcane sucrose mass (t ha^{-1}) at harvest in Eastern UP

against the measured sucrose yield (t ha^{-1}) in Fig. 3. Observed sucrose mass ranged from 5.54 to 10.2 t ha^{-1} whereas simulated sucrose mass varied from 4.14 to 10.29 t ha^{-1} depending on locations. It is evident from Fig. 3 that model predicted sucrose mass within 15% of the observed sucrose mass except where the measured values were higher than ~7.0 t ha^{-1}.

The present discrepancy between simulated and observed results might be attributed partly to some error introduced in deriving the genetic coefficient of different cultivars of sugarcane. These agronomic experiments carried out in the past do not provide full range of crop and soil data needed for crop model evaluation and a few of them lack precision leading to generalization in deriving the genetic coefficients of sugarcane cultivar. The precision with which field measurement data used in the simulation studies as stressed by Mall and Aggarwal (2002) were not known but usually lies between ±10 to ±15 %.

CONCLUSION

The calibrated and validated CANEGRO Sugarcane model will be useful for further applications and decision making in Eastern Uttar Pradesh region. The CANEGRO Sugarcane model can be adopted for prediction of crop growth, phenology, water management, potential and actual yields, performance of sugarcane under various climate variability and change scenarios for further use in weather based farm advisories.

ACKNOWLEDGEMENTS

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