Original Research Article

CALIBRATION AND VALIDATION OF DSSAT (CROPGRO) MODEL FOR WINTER IRRIGATED COTTON IN TAMIL NADU

Abstract

Crop simulation model is used for predicting the crop productivity under various crop management practices and find out the yield gap of cotton crop,that require determination of genetic coefficient of a crop cultivar. Successful use of a crop model depends on the accuracy of calibration and validation of different parameters. This paper aimed to evaluate the DSSAT model using experimental data on the different nutrient managementpractices for cotton and calibrated and validated the data by usingDSSAT (CROPGRO) model. The field experiment was conducted at Cotton Breeding Station, TNAU, Coimbatore during 2018 to 2020 in winter irrigated season (August-January).The GNECAL tool from DSSAT was used to calibrate the CO17 variety of cotton. The yield and yield attributes, phonological stags, harvest index and biomass as simulated by model were compared with the observed data. The results for model predictions showed that the simulated growth and development of cotton was in good agreement with their corresponding observed values. The CROPGRO model can be successfully used for simulating the growth and yield of crop for major cotton growing region in Tamil Nadu.

Keywords: DSSAT, calibration, validation, crop simulation model, CROPGRO and cotton.

Introduction

Cotton is one of the most important cash crops and accounts for around 25% of the total global fiber production. It is also called as a white gold. The primary product of the cotton plant has been the lint, that covers the seeds within the boll. Lint is the most important economical product of cotton plant, provides a source of high-quality fiber for the textile industry. The cotton seeds, the primary by product of lint production, are an important source of oil for human consumption, and a high protein meal used as a livestock feed. The cotton waste after ginning is used for fertilizer and the cellulose from the stalk may be used for products such as paper and cardboard.

Cotton is an important commercial crop of India. The city of Coimbatore is known as the Manchester of South India, of the two thousand five hundred textile Mills in India, eight hundred

UNDER PEER REVIEW

textile mills exist in Tamil Nadu of which 300 are in Coimbatore District itself.To analysis the Growth of Cotton Cultivation in Tamil Nadu. The Co-efficient of Variation show that the production of the cotton has maximum variability of the 16.79 %. Whereas, it is 13.69% for productivity and 12.39% of the area. The productions of the cotton in Tamil Nadu 0.50 per cent are declining. Hence, it is suggested that the government of the Tamil Nadu should initiate the provision of the cotton seeds, fertilizers and pesticides at a subsidized rate through Cooperations societies. If government has considered this suggestion seriously, it is hope that a greater number of the cotton growers will come forward to cultivate the cotton in more area and this will increase the cotton economy of the nation (Mayilsami and Selvaraj, 2016).

The DSSAT is a suite of crop models integrated into a single software package in order to facilitate the application of crop simulation in research and decision-making. Crop models provide simulation of crop growth and development through numeric integration of the underlying physiological processes with the aid of computers (Wery and Lecoeur, 2000). The CROPGRO model is one of the crop simulation models that encompass the DSSAT (Jones *et al*., 2001).

DSSAT is a popular crop model used over 100 countries for more than 20 years. It is a microcomputer software package, that provides a shell program for the interface of crop-soil simulation models, data for soil and weather, and programs for evaluating management strategies. DSSAT includes more than 40 crop growth model. Among them, CROPGRO- Cotton is most widely used crop simulation model. Crop modelling study especially DSSAT on yield gap analysis. Cultivar coefficients of cotton variety of Tamil Nadu are not included in the cultivar database of DSSAT. Therefore, this study was undertaken: i) To generate genetic co-efficient of cotton CO17 cultivar required forrunning of DSSAT model in Tamil Nadu condition and ii) To calibrate and validate DSSAT crop model for simulation of growth and yield of cotton.

UNDER PEER REVIEW

Materials and Method

The experiment was carried out during winter irrigated season(August to January) in the year of 2018-2019 and 2019-2020. The climatic conditions at that season were favourable for satisfactory growth of the Cotton crop.CO17 variety from Tamil Nadu Agricultural University (TNAU) was chosen for the research study. The experiment was laid out in a Random Block Design (RBD) design with three replications. The experiment comprised of eighteen treatment combinations, containing one variety and six nutrient management treatments. The treatments were allotted randomly at each replication to reduce the experimental error.

Table 1. Experimental and Treatment Details

Crop	Cotton
Variety	CO 17
Experimental design	RBD
Treatment combinations	Main plot – Three, Sub plot -6
No. of replications	Three
No. of plots	18
Season	Winter irrigated (August to January)
Spacing	100 x 10cm
Season	Winter irrigated
Treatment details (Nutrient levels):	F1=120:60:60 (150%) R.D.F, F2=100:50:50 (125%) R.D.F, F3= 80:40:40 (100%) R.D.F, F4=60:30:30 (75%) R.D.F, F5=40:20:20(50%) R.D.F, F6=No Application (Control)

*R.D.F – Recommend Dose of Fertilizer

DSSAT (Decision Support System for Agro Technology Transfer), CROPGRO model were used to evaluate the yield gap of cotton crop. DSSAT model requires many inputs like weather, soil, experimental and genotype as data files to be incorporated into the CROPGRO model.

Input data for CROPGRO-Cotton model

‘CROPGRO-Cotton’ is a physiological based dynamic crop growth simulation model which is responsive to daily weather inputs. The minimum data required for running CROPGRO-Cotton are given below.

General Information:

List 1 : The general information.

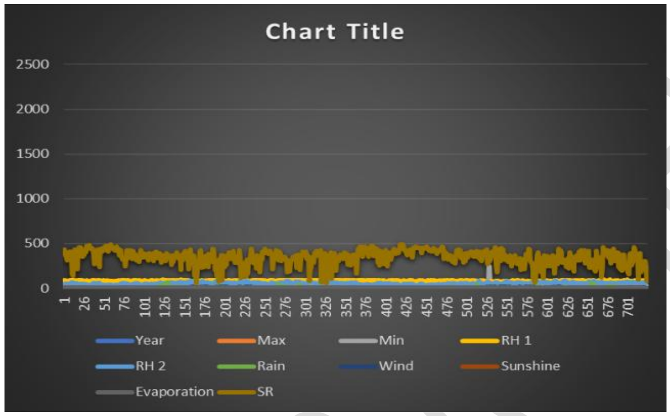
Country	India		
Latitude	11.01^0N	Longitude: 76.95^0 E	Altitude:427 MSL
Site Name	TNAU, Coimbatore		
Soil Data Source	NBSS		

Weather data

UNDER PEER REVIEW

The minimum data set of weather parameters that is mandatory for DSSAT crop simulation model includes maximum temperature, minimum temperature, relative humidity, rainfall and solar radiation on daily time step basis. Data were used after the quality check process. Weatherman tool from DSSAT model was used to convert the daily weather data on maximum temperature (°C), minimum temperature (°C), solar radiation (MJ m-^{2}day-^{1}) and rainfall (mm) for the crop period of the experimental fields into DSSAT weatherman file format.

Fig 1: Weather data chart of the Experiment site both the year of (2018-2020)



Soil data

The collection of soil database consists the properties of soil profile, soil water, soil nitrogen and root growth characteristics, soil taxonomic classification, soil texture and other descriptive data which were integrated into S Build tool in DSSAT to construct soil file for the experimental field.

Experimental file

The practices of crop management viz., cultural operations followed during the crop growth period were recorded at an interval of 20 days. The field characteristics and experimental conditions like weather station name, soil, field description details, initial soil and inorganic nitrogen conditions, planting geometries, irrigation and water management, fertilizer management details, organic residue application, chemical applications, tillage operations, environmental modifications, harvest management, simulation controls (specification of simulation options e.g. starting dates, on/off options for water and nitrogen balances, symbiosis) and output options are fed into the X Build tool in DSSAT.

Genotype data file

GENCAL tool available in DSSAT v4.7 model was used to adjust the genetic coefficient parameter from CROPGRO module to attain maximum desirable match between the observed and simulated data.

Calibration of the model

Calibration of model involves computing and adjusting certain model parameters or relationships to make the model work for any desired location. When using a crop model, one has to estimate the

UNDER PEER REVIEW

cultivar characteristics if they have not been previously determined. The model requires twenty cultivar specific genetic coefficients. The details of these coefficients are given below:

Parameters	**Description of parameters**
EXPON	Number of experiment used to estimate cultivar parameters
ECO#	Code for the ecotype to which this cultivar belongs
CSDL	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour)
PPSEN	Slope of the relative response of development to photoperiod with time (Positive for short day plants) (1/hour)
EM-FL	Time between plant emergence and flower appearance (R1) (photothrmal days)
FL-SH	Time between first flower and first pod (R3) (photothermal days)
FL-SD	Time between first flower and first seed (R5) (photothermal days)
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photohermal days)
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)
LFMAX	Maximum leaf photosynthesis rate at 30^0 C, 350 vpm CO^2 and high light (mg CO^2/m^2-s) ---from Reddy Adv. Agron. 1997?
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)
SIZLE	Maximum size of full leaf (three leaflets) (cm^2)
XFRT	Maximum fraction of daily growth that is partitioned to seed+shell
WTPSD	Maximum weight per seed (g)
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)
SDPDV	Average seed per pod under standard growing conditions (#/pod)
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)
THRSH	Threshing percentage. The maximum ratio of seed (seed/(seed+shell))
SDPRO	Fraction protein in seeds (g(protein)/g(seed))
SDLIP	Fraction oil in seed (g(oil)/g(seed))

Calibration is a step to train the model for a specific cultivar, whereas validation is to check its ability to simulate the yield. The genetic coefficients of respective cultivars act as the reference for the yield simulations in DSSAT framework. Even though, the ruling cultivars of the respective study regions did not find a place in DSSAT, the multilocation data from field trials were in turn used to develop Cultivar Specific Parameter. The GENCAL tool used these experimental data to develop suitable genetic coefficients for the selected cultivar, which was then used in yield simulation of cotton crop for Tamil Nadu.

Evaluation of derived CSP:

Statistical analysis methodologies viz., normalized root mean square error (RMSE), Index of agreement (*d*), coefficient of determination (r^2), modelling efficiency (EF) and mean error (E) between the observed and simulated value were used to evaluate the Cultivar Specific Parameter.

Root Mean Square Error (RMSE):

The normalized root mean square error (RMSE), was calculated with the help of following Equation (Loague and Green, 1991):

UNDER PEER REVIEW

$$\text{RMSE} = \frac{\sqrt{\sum_{i=1}^{n}(P_i - O_i)^2}}{\sqrt{N}}$$

Where n is the number of observations

P_i and O_i are predicted and observed values, respectively

N is the observed mean value.

RMSE is a good measure to understand the model accuracy to predict response. The value of the RMSE should be minimum or in other word should approach to zero (Timsina *et al.*, 2004).

Wilmott index of agreement

The Index of agreement (*d*) was estimated as shown in the following equation (Willmott *et al.*, 2012)

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| - |O_i - \bar{O}|)^2}\right]$$

Where n is the number of observations,

P_i the predicted variable,

O_i is a measured variable,

$\bar{O}$ is the mean of the observed variable.

A value of 1 for the index of agreement (*d*) indicates a good agreement between the simulated and observed data while values closer to 1 indicate better prediction. A *d* value of zero indicates no predictability.

Coefficient of determination (r^2)

The coefficient of determination (r^2) between observed and predicted data was calculated to obtain the trend in observed and predicted data.

Easy Grapher's mean error

Easy Grapher (EG) is a software package for graphical and statistical evaluation of DSSAT outputs (Yang and Huffman, 2004). EG calculates several statistics, such as Root Mean Square Error (RMSE), Mean Error (E or ME), Modeling Efficiency (Nash–Sutcliffe model efficiency coefficient) (EF) and index of agreement (*d*) to evaluate the simulated results with observed values that are provided in T file (Time series observations).

$$E = \sqrt{\sum (P_i - O_i)^2 / n}$$

Where P_i the predicted observation,

UNDER PEER REVIEW

O_i is a measured observation,

Validation

The model was run and validated by comparing the predicted output with observed parameters. Deviation of predicted value from observed were calculated and accuracy of the model to predict different crop parameters was quantified.

RESULTS AND DISCUSSION

The Genetic coefficients were evaluated and model was validated for different nitrogen level with different date of sowing the CO17 cultivar. DSSAT model was calibrated by different data sets on phenology, Leaf area index, bolls weight/plant, Biomass and seed cotton yield for evaluation of genetic coefficients.

Genetic Coefficients:

Genetic coefficients were evaluated for DSSAT model. The value of CSDL, PP-SEN, LFMAX and WTPSD used as default. The value of EM-FL, FL-SH, SD-PM, FL-LF, SLAVR, SIZLF, XFRT, SDPRO, SDLIP, SFDUR, SDPDV and PO-DUR was evaluated. Ortiz et.al, (2009) reported the values for most of the vegetative and reproductive cultivar coefficients were higher than those from the other commercial cotton cultivars that are part of the DSSAT data-base, suggesting that the cultivar that was grown in this experiment required more days to the beginning of the reproductive phase. The Evaluation table for the calibrated Cotton cultivar CO 17 presented in Table 2.

Table 2. Genetic coefficient of cotton cultivar evaluated under different Nitrogen level treatments

VARITIES	CSDL	PP-SEN	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF	LF MAX	SLAVR	SIZLF
CO 17	23	0.01	42	13	18	55	70	1.3	390	390

VARITIES	XFRT	WTPSD	SFDUR	SDPDV	PO- DUR	THRSH	SD PRO	SDLIP
CO 17	0.75	0.18	35	27	10	79	0.141	0.12

Calibration of Model:

Phenology

These results showed that model performance was found good for cotton cultivars for simulation of days to flowering. The simulation performance of the model in respect of days

UNDER PEER REVIEW

taken to maturity was found within an accepted level of error percent. Ortiz et.al., (2009) also showed the difference between observed and simulated values for the flowering and physiological maturity dates over the control treatment was two days. Also, the results of phenological stages of maize simulated by InfoCrop model are supported by Singh et.al., (1994), Akula (2003), Soler et.al., (2007). The Evaluation table for the calibrated and validated Cotton cultivar CO 17 presented in Table 3 and Table 4.

Table.3 The test and deviation statistics for the calibrated cotton cultivar CO 17 (2017-2018):

Variables	Observed	Simulated	Error (PE%)	RMSE	d-stat	E	r^2
Anthesis Day	36	45	1.27	10.05	0.36	0.83	-
Emergence Day	4	5	1.10	1.29	0.44	0.88	-
Days of Maturity	133	135	1.01	2.61	0.41	0.70	-
LAI Maximum	0.44	0.66	1.93	0.23	0.60	0.94	0.88
BWAM(Kg(dm)/ha)	2688	2715	1.04	60	0.94	0.91	0.83
HWAM(Kg(dm)/ha)	2320	2380	0.83	263.09	0.61	0.92	0.76
Canopy height(m)	0.68	0.78	1.19	0.11	0.93	0.90	0.90
Days of flowering	70	70	0.0	0.0	0.0	-	0.0

Where:O- Observed, S- Simulated, E(%)- Error %, RMSE- Root mean square error,MBE- mean bias error.

Growth and yield parameter

DSSAT model was validated for leaf area index (LAI), biomass and seed cotton yield of cotton measured at different crop growth stages. The simulation performance of the model in respect of LAI was good within an accepted level of error percent. Ortiz et.al., (2009) reported thatmodel underpredicted maximum LAI for all fumigated treatments. The evaluation of the model on an overall performance of simulation was good. Ortiz et.al., (2009) also reported the changes in boll weight accumulation throughout the season and the final boll weight at harvest were fairly well predicted by the CSM-CROPGRO-Cotton model. The biomass and seed cotton yield simulation were found good for all cultivars and 2nd and 3rd week of May sown crop. Ortiz et.al., (2009) also reported that calibrated coefficients improved the total biomass and boll weight predictions by 14.3% and 6.1%, respectively, when compared to the original default values. Also, these results are supported by finding of Soler et al., (2007) for maize and Singh et al., (1994) for groundnut yield and yield attributes simulated by PNUTGROW model.

UNDER PEER REVIEW

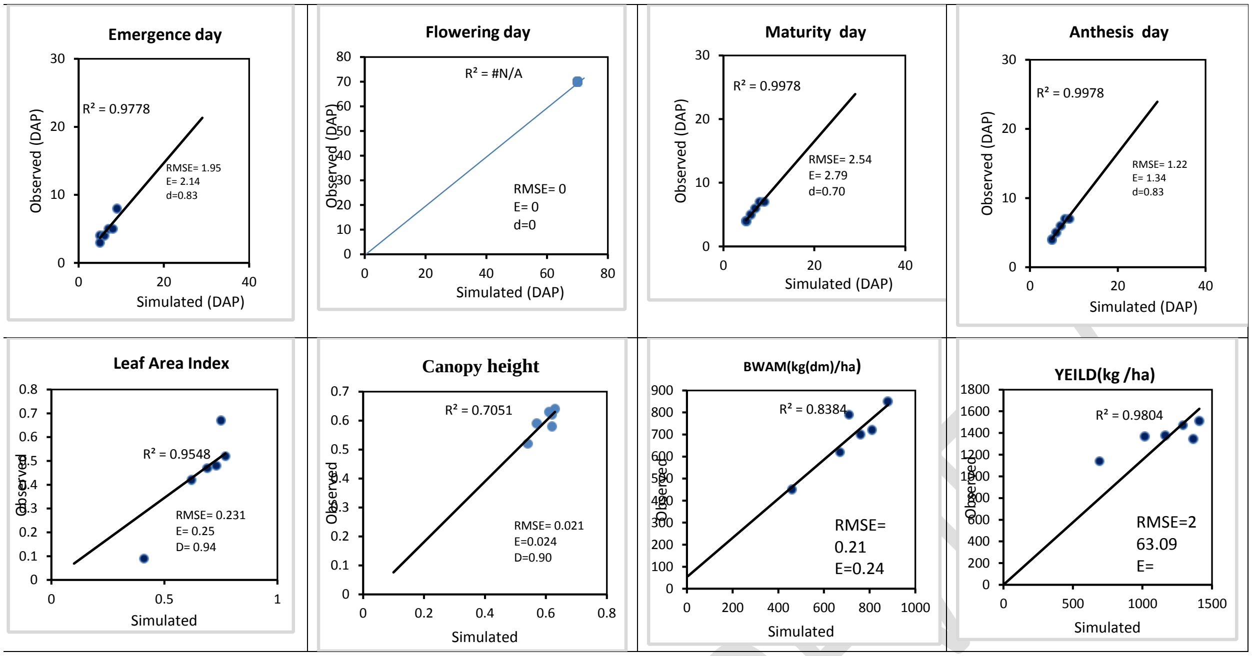


Fig 2: Observed and simulated data of growth and yield parameters of cotton (CO17) during the calibration process.

Validation of Model

Test criteria of cotton phenology simulated by DSSAT model are presented in Table 4

Days to flowering

The observed mean values of days to flowering for cotton cultivar CO 17 was 70 days, whereas the model simulated 70 days (Table 4).The percent error was observed (0.0).This clearly showed the model performance was found good. For simulation of days to flowering as percent error was <± 5.

Days to physiological maturity

CO 17 cotton cultivar is matured in 135 days. Which model Simulated 134 days as shown in table over (Table 4). Cotton cultivar performed better and the model overestimated the days to maturity. The percent error was over estimated by the model or error was negligible. The simulation performance of the model in respect of days taken to maturity was found best as error was < 1.0%.

Growth and yield parameters

Test criteria of growth and yield of cotton varieties using DSSAT model are presented in Table 4.

Maximum LAI

LAI of CO 17 Cultivar was 0.55, while model simulated LAI was 0.66 respectively. The percent error was 1.03%.The performance of model was in acceptable range. The evaluation of the model on an overall basis revealed that the simulation performance of the model in respect of LAI was found good with an accepted level (±10.0%).

UNDER PEER REVIEW

Biomass

The biomass yield of CO 17 cultivar was underestimated by the model. The average percent error for biomass yield was found 0.5 (CO 17). The biomass yield simulation was found good (±10.0%) for cotton cultivar. DSSAT model was evaluated for biomass (kg/ha) and seed cotton yield (kg/ha) of cotton presented in table 4.

Seed cotton yield

The seed cotton yieldobserved in field experiment for cv.CO 17 Was 2360 kg/ha while model simulated yield was2340 kg/ha, respectively. The average percent error was within acceptable error limit This shows that the evaluation of the model on an overall basis revealed that the simulated yield was good. The evaluation of the model on an overall performance of simulation was good.

Table 4: The test and deviation statistics for the Validation of cotton cultivar CO 17 (2019-2020):

Variables	Observed	Simulated	Error (PE%)	RMSE	d-stat	E	r^2
Anthesis Day	36	45	1.27	10.05	0.36	0.83	-
Emergence Day	5	5	0.0	0.0	0.0	0.0	0.31
Days of Maturity	134	135	0.2	0.6	0.40	-0.3	-
LAI Maximum	0.55	0.66	1.03	0.20	0.60	0.94	0.88
BWAM(Kg(dm)/ha)	2860	2840	0.53	70	0.91	0.1	0.07
HWAM(Kg(dm)/ha)	2340	2360	3.2	261.05	0.67	0.91	0.83
Canopy height(m)	0.65	0.75	1.19	0.11	0.93	0.90	0.89
Days of flowering	69	70	0.1	0.0	0.0	-	0.0

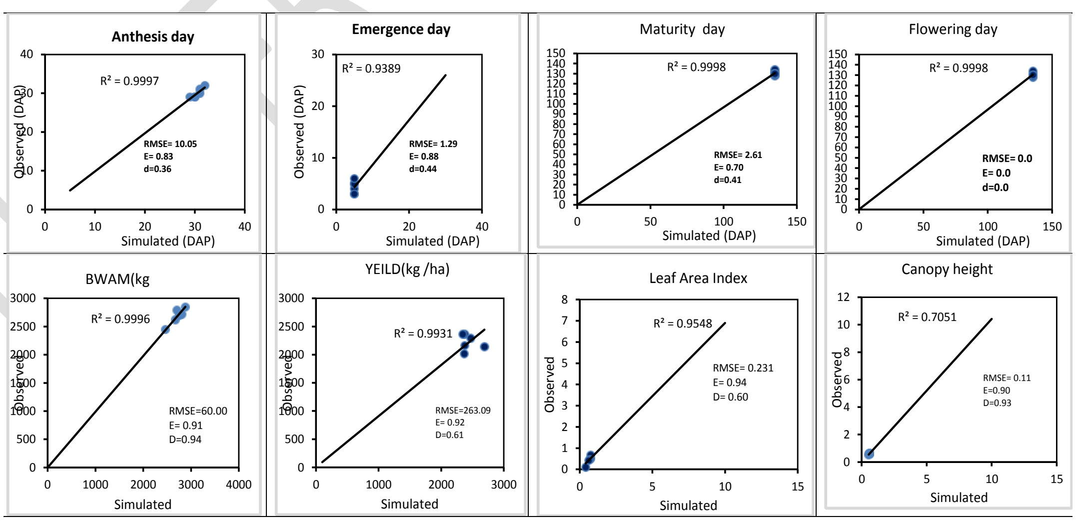


Fig:3Observed and simulated data of growth and yield parameters ofcotton (CO17) during the Validation process.

UNDER PEER REVIEW

CONCLUSION

Genetic coefficients were evaluated and DSSAT model was Calibrated and validated for CO17 cotton cultivarin different nitrogen treatments. The resultsshowed that the simulated growth and development of cotton was in good agreement with their corresponding observed values. The model performance in result to phenology was found to be good for CO17 cotton cultivar with all the nitrogen levels treatment.The CROPGRO cotton model can be successfully used for simulating the growth and yield of crop for major cotton growing region in Tamil Nadu.

REFERENCES

Guerra, L.C., Garcia Y Garcia, A., Hook, J.E., Harrison, K.A., Thomas, D.L., Stoocksbury, D.E. and Hoogenboom, G. 2007. Irrigation water use estimates based on crop simulation model and kriging. Agricultural water management, 89: 199-207.

Jones, J.,Keating, B., and Porter, C. (2001). Approaches to modular model development. Agricultural Systems, 70(2-3), 421-443.

Singh, P., Boote, K.J., Rao, A.Y., Iruthayaraj, Sabani, M.B., Shakh, A.M., Hundal, S.S., Natraj, R.S. and Singh, P. 1994. Evaluation of the groundnut model PNUTGRO for crop response to water availability, sowing dates and seasons. Field Crops Res., 39: 147-162.

Soler, C.M.T., Sentelhas, P.C. and Hoogenboom, G. 2007. Application of the CSM-CERES-Maize model for planting date evaluation and yield Int.J.Curr.Microbiol.App.Sci (2017) 6(4): 1031-1041 1041 forecasting for maize grown off-season in a subtropical environment. Eur. J. Agron., doi:10.1016/ j.eja.2007.03.002

Ortiz, B.V., Hoogenboom, G., Vellidis, G., Boote, K.,Davis, R.F. and Perry, C. 2009. Adapting the CROPGRO- cotton model to simulate cotton biomass and yield under southern root knot nametodes parasitism. Ameri. Soc. Agril. Bio. Engi., ISSN 2151-0032. 52(6): 2129-2140.