Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.5631

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (4):** 1738-1754 (2017)

International Journal of Pure & Applied Bioscience

Research Article

OPEN ACCESS

Evaluation of CSM-CROPGRO-Cotton Model under Varied Plant Densities and Nitrogen Levels for Simulating Crop Growth, Development and Seed Cotton Yield

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Received: 30.07.2017 | Revised: 11.08.2017 | Accepted: 12.08.2017

ABSTRACT

CSM-CROPGRO-Cotton Model under DSSAT v4.6 has been extensively tested and validated in many studies, mainly in United States. The objective of this study was to test and validate this model in Telangana state of India for dynamic simulation of development, growth and seed cotton yield of two cotton cultivars (MRC 7201 and WGCV 48) under varied plant densities and nitrogen levels. The model was first calibrated with data (phenology, biomass and yield components) collected during 2015 and 2016at Rajendranagar, Hyderabad location against the best performing treatments P_2N_1 and P_2N_2 ($P_{2:}$ 55,555 plants ha^{-1}, N1:120 kg N ha^{-1} and N1:150 kg N ha^{-1}) in field trials. The model was then validated with data recorded against remaining seven treatmentsof 2015. Calibration of CROPGRO-Cotton model with genetic coefficients of Bt and non Bt cultivars MRC 7201 and WGCV-48 for seed cotton yield (kg ha^{-1}) with the values of R^2 were 0.96 and 0.83, RMSE were 49.7 kg ha^{-1} and 169.4 kg ha^{-1} and d-Stat were 0.98 and 0.92, respectively. Simulation of days to flowering, days from planting to physiological maturity, LAI and seed cotton yield with normalized RMSE (NRMSE) values of less than 10% across all the plant densities and nitrogen were considered excellent.Hence, there is a dire need to assess impact of climate variation on seed cotton yield under various climatic regions of Telangana state to ensure fibre quality and yield in future.

Key words: *Gossypium hirsutum L., CSM-CROPGRO-Cotton, simulation, crop growth, phenology, DSSAT, Cotton cultivars.*

Cite this article: Nagender, T., Reddy, D.R., Sreenivas, G., Rani, P.L., Surekha, K., Gupta, A. and Sreekanth, P.D., Evaluation of CSM-CROPGRO-Cotton Model under Varied Plant Densities and Nitrogen Levels for Simulating Crop Growth, Development and Seed Cotton Yield, *Int. J. Pure App. Biosci.* **5(4):** 1738-1754 (2017). doi: http://dx.doi.org/10.18782/2320-7051.5631

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the major cash crops of India, popularly known as 'white gold' and 'King of fibres' for its role in the national economy in terms of foreign exchange earnings and employment generation. It is the world's leading source of natural textile fibre and fifth largest oilseeds crop which covers 40% of the global textile need[2] . and 3.3 % of edible oil[6] .respectively. This crop provides livelihood to 60 million people in India by way of support of agriculture, processing and textiles and it contributes to 29 % of the national GDP[12]. India has the credit of the largest area under cotton (126.55 lakh ha) and ranks second in cotton production (400 lakh bales) during 2014-15. However, the productivity of seed cotton in India is 537 kg ha^{-1} which is below the world average of 790 kg ha^{-1}. In Telangana, the cotton crop is being grown in an area of 16.51 lakh ha with the productivity of 515 kg ha^{-1}. This crop is mostly grown in Alfisols of Southern Telangana agro-climatic zone. The high density planting system (HDPS) is now being conceived as an alternate production system having a potential for improving productivity and profitability, increasing efficiency, reducing input costs and minimizing risks associated with India's cotton production system. In many countries, narrow row plantings have been adopted after showing improvement in cotton productivity[1]. Monsanto has reported a 13-65 per cent rise in yields in Gujarat, while the yields were up 44 per cent in Maharashtra. In Andhra, the yields were up by about 48 per cent. The adoption of HDP, along with good fertilizer management and better genotypes, is a viable approach to break the current trend of stagnating yield sunder primarily rainfed hirsutum (upland) cotton growing areas. So, a proper space between plants and row spacing is a key agronomic factor to optimize the crop profit[30]. The fertilizer use has played a crucial role in boosting the agricultural productivity.

Nitrogen (N) is a key management component in cotton production which regulates photosynthesis and cotton development by stimulating the production of dry matter energy rich compounds but its management can reduce final yield and N use efficiency[21]. Nitrogen influenced both vegetative and reproductive growth[23] as its deficiency decreased yield by accelerating premature leaf senescence[5] and early cut-out[19], while, N in excess can delay crop maturity and promote boll shedding, diseases and insect damages[11,16]. Diagnosing and correction of nitrogen deficiency is not difficult while excess of N is more difficult to detect and rectify, which necessitates applying N in appropriated doses to get maximum economical potential yield. Crop success depends on economically optimum levels of N fertilizers[7]. The cotton cultivars evolved in different agro climatic regions behave differentially to application of mineral fertilizers[18]. Hence there is a continuous need to find out the optimum nitrogen levels for local cotton cultivars in ever changing environment. The traditional best management practices development methods based on field experiments are usually effective but expensive, time-consuming, and have limited ability to explore the many management options related to plant densities and fertilization. Furthermore, the results obtained are inherently temporally and spatially specific, *i.e.*, the conclusions drawn on some given field conditions and time might not be valid any more for other situations. Alternatively, crop models have fallen into the scope of developing potential crop management strategies.

The CSM-CROPGRO-Cotton model is a member of the CROPGRO group of models[10] in DSSAT. Crop models have been described as a "quantitative schemes for predicting the growth, development and yield of a crop, given a set of genetic coefficients and relevant environmental variables"[15]. Models can be used to predict crop growth, development and yield as a function of soil, climate, weather, and crop management conditions. Crop simulation models predict crop performance in relation to individual land qualities like moisture supply, nutrient supply and radiation balance that contribute to crop growth and yield[20]. They are employed in land evaluation to quantify production under potential and growth limiting situations[3]. Models are also used to quantify the effects of moisture stress, nutrient stress, soil erosion, and genotypic response and greenhouse gas (GHG) emissions under different land use and management regimes. The simulation models are the most reliable tools for estimating potential and water-limited yields because they accurately account for variations in weather across years and locations, consider interactions among the crop. In India, studies on the use of CSM-CROPGRO-Cotton model for evaluation and validation have not been reported. Keeping the above points in view, an experiment was formulated with the objective to evaluate CSM-CROPGRO-Cotton model under varied plant densities and nitrogen levels for simulating crop growth, development and seed cotton yield.

MATERIALS AND METHODS

The investigation was carried out during *Kharif* 2015-16 and 2016-17 at Agricultural Research Institute, Rajendranagar, Hyderabad situated at an altitude of 542.3 m above mean sea level at 17°19' N latitude and 78°23' E longitude. It is in the Southern Telangana agro-climatic zone of Telangana. According to Troll's climatic classification, it falls under semi-arid tropics (SAT).The experiment was laid out in randomized block design with factorial concept and replicated thrice. There were two cultivars *viz.*, V_1: MRC 7201 Bt and V_2: WGCV 48 non Bt three plant densities*viz.*, P_1:90 cm X 60 cm (18,518 plants ha^{-1}), P_2:60 cm X 30 cm (55,555 plants ha^{-1}) and P_3: 45 cm X 15 cm (1, 48,148 plants ha^{-1}) and three nitrogen levels (N_1: 120 kg ha^{-1}, N_2: 150 kg ha^{-1} and N_3: 180 kg ha^{-1}). Cotton crop was sown on July 8, 2015 and July 7, 2016 by dibbling seeds in opened holes with a hand hoe at depth of 4 to 5 cm. Thinning was completed after crop emergence to maintain uniform plant population according to the treatments.Nitrogen was applied as per the treatments (wherever it was required) in the form of urea (46 % N) in four equal splits (20, 40, 60 and 80 days after sowing) to Bt cotton cultivar (MRC 7201).Whereas, for non Bt cotton cultivar (WGCV 48), nitrogen was applied in three equal splits (30, 60 and 90 days after sowing).All other agronomic practices such as irrigation, weeding,plant protection measures and earthling up etc. were kept normal and uniform for all the treatments.

Crop growth modeling: Field data collected from the experiments during 2016 and 2016 growing seasons was used for calibration and validation of CROPGRO–Cotton model.The daily weather data including site specific information was collected and used for creating weather file (RJNR.WTH) and running CROPGRO–Cotton model. The soil samples were collected from opened-up soil profile and soil physical and chemical characteristics described layer wise. The same data was used for creating soil file (RJNR.SOL) for running CROPGRO–Cotton model.Plant characteristic and crop management data were obtained for experiment site and used as input data for the model. Calibration was focused on those cultivar parameters most likely to be affected under different treatments. Calibration is a process of adjusting some model parameters to our own conditions. It is also necessary for getting genetic co-efficient for new cultivars used in modeling study. So, the model was calibrated with data (that included phenology, biomass and yield components) collected during 2015-16 and 2016-17 at ACRC, Rajendranagar, Hyderabad during year 2015 and 2016. The genetic coefficients required by the model for these cultivar parameters were estimated (from our data) as follows: 1) candidate coefficient-parameters were selected; 2) the values of the coefficient-parameters were changed by running CROPGRO in an optimization shell until the error sum of squares (simulated minus observed) was minimized; and 3) the set of coefficients that produced the lowest RMSE (root mean square error) and higher d-statistics value were adopted. Lower RMSE is desirable.

Calibration was done by iteratively running the crop model within an appropriate value of the coefficient concerned that was observed or measured in our field study. Cultivar coefficient values were then changed until the simulated and measured values matched or were within predefined error limits through evaluation of the RMSE and d-statistics values until most suitable sets of coefficients were obtained. The calibration process is an iterative, trial-and-error process described by Hanson and Hanson *et al*. Genetic coefficients for two cotton cultivars were calibrated. Once the genetic coefficients were calibrated, it should be validated to check the accuracy of the model simulations it was run with data recorded against remaining treatments of planting densities, nitrogen levels of two cultivars. The data on phenology, development, growth and yield for year 2015-16 and 2016-17 was used for validation of CROPGRO-Cotton model. During all this process available observed data on crop phenology (flowering and physiological maturity date), crop growth (leaf area index and total dry matter production), total boll weight and seed cotton yield were compared with simulated values using same genetic coefficients.

Simulation performance was evaluated by calculating different test statistics like root mean square error (RMSE)[27]. The computed values of RMSE determine the degree of agreement between the simulated values with their respective observed values, and a low RMSE value that approaches zero was desirable. The RMSE was calculated according to equation.

$$\textbf{RMSE (root mean square error)} = \left[\sum_{i=1}^{n}(p_i - o_i)^2 / n\right]^{0.5}$$

D-value represents Willmott index of agreement (Willmott, 1982) ranging from 0 to 1, and being 1is the perfect agreement.

$$\mathbf{d} = 1 - \left[\frac{\sum_{i=1}^{n}(p_i - o_i)^2}{\sum_{i=1}^{n}\left(\left|p_i^{'}\right| + \left|o_i^{'}\right|\right)^2}\right]$$

Where,

n = is the number of observations,

p*i*= is the predicted observation,

o*i*= is a measured observation,

P!*i*= P*i* - M and O!*i*= O*i*- M (M is the mean of the observed variable).

Overall model performance indicated with normalized RMSE values. Normalized RMSE (NRMSE) gives a measure (%) of the relative difference of simulated verses observed data. The simulation is considered excellent with a normalized RMSE less than 10 per cent, good if the normalized RMSE is greater than 10 and less than 20 per cent, fair if the normalized RMSE is greater than 20 per cent and less than 30 per cent, and poor if the normalized RMSE is greater than 30 per cent[14]. The NRMSE was calculated following equation.

$$\textbf{Normalized root mean square error} = \left[\frac{RMSE}{\bar{O}}\right] x100$$

The Coefficient of Residual Mass (CRM) was used to measure the tendency of the model to overestimate or underestimate the measured values. The CRM is defined by

$$\textbf{CRM} = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i}$$

Where, O_i and P_i are the observed and predicted values respectively for the i^{th} data point of n observations. A negative CRM indicates a tendency of the model towards over estimation[29].

RESULT AND DISCUSSION

The genetic coefficients determined through model calibration using the identical conditions as in the field experiments for cotton cultivars MRC 7201 BGII and WGCV-48 are presented in Table 1. These coefficients were used in the subsequent validation and application.

The critical short day length below which reproductive development progresses with no day length effect (for short day plants) was 23 hrs. for both cultivars, slope of the relative response of development to photoperiod with time (positive for short day plants) was 0.01 hrs^{-1} for both cultivars, time between plant emergence and flower appearance for MRC 7201 BGII (40 PTD) and WGCV-48 (44 PTD), time between first flower and first pod for MRC 7201 BGII (12.7 PTD) and WGCV-48 (12.0 PTD), time between first seed and physiological maturity 25.06 PTD for both cultivars, time between first flower and end of leaf expansion for MRC 7201 BGII (78.02 PTD) and WGCV-48 (60.02 PTD) and maximum leaf photosynthesis rate at 30^0C, 350 ppm CO_2, and high light for MRC 7201 BGII (3.98 mg CO_2 m^{-2} s^{-1}) and WGCV-48 (3.25 mg CO_2 m^{-2} s^{-1}).

Specific leaf area of cultivar under standard growth conditions for MRC 7201 BGII (206 cm^2 g^{-1}) and WGCV-48 (185 cm^2 g^{-1}), maximum size of full leaf for MRC 7201 BGII (305 cm^2) and WGCV-48 (290 cm^2), maximum fraction of daily growth that is partitioned to seed + shell for MRC 7201 BGII (0.64 %) and WGCV-48 (0.50 %), maximum weight per seed for MRC 7201 BGII (0.18 g) and WGCV-48 (0.17 g), seed filling duration for pod cohort at standard growth conditions for MRC 7201 BGII (39 PTD) and WGCV-48 (22 PTD), average seed per pod under standard growing conditions for MRC 7201 BGII (27 no. pod^{-1}) and WGCV-48 (20 no. pod^{-1}), Time required for cultivar to reach final pod load under optimal conditions for MRC 7201 BGII (12.5 PTD) and WGCV-48 (15.9 PTD), threshing percentage for MRC 7201 BGII (68 %) and WGCV-48 (67.5 %), fraction protein in seeds and fraction oil in seeds was 0.153 g (protein) g $(seed)^{-1}$ and 0.12 g (oil) g $(seed)^{-1}$ for both cultivars respectively.

The model performed well in simulation of growth, phenology, seed yield and biomass (Table 2) during calibration process across all plant densities and nitrogen levels for two cultivars *viz.*,MRC 7201 BGII and WGCV-48.

Calibration results showed that model predicted only one day difference between observed and simulated days to flowering for MRC 7201 BGII cultivar with RMSE of 0.5 day while, for WGCV-48 cultivar observed and simulated days to flowering with RMSE 0.5 day between simulated and observed values across different plant densities and nitrogen levels. CROPGRO-Cotton simulated same number of days from planting to physiological maturity with RMSE of 0.9 day for both the cultivars.

Calibration of CROPGRO-Cotton model with genetic coefficients of Bt and non Bt cultivars MRC 7201 and WGCV-48 for total biomass (kg ha^{-1}) with the values of R^2 were 0.96 and 0.85, RMSE were 635.5 kg ha^{-1} and 307.2 kg ha^{-1} and d-Stat were 0.86 and 0.85, respectively. While, boll weight at maturity (kg ha^{-1}) with the values of R^2 was 0.81 and 0.89, RMSE were 208.2 kg ha^{-1} and 129.6 kg ha^{-1} and d-Stat were 0.92 and 0.96, respectively for the Bt and non Bt cultivars.

The results of calibration of CROPGRO-Cotton model with genetic coefficients of Bt and non Bt cultivars MRC 7201 and WGCV-48 cultivar for seed cotton yield were presented in Table 4.11. The values of R^2 were 0.96 and 0.83 respectively for two cultivars, indicating a high degree of colinearity between observed and simulated values. A model with R^2 value of 0.5 and above is acceptable[22]. The RMSE for seed cotton yield was 50 and 169 kg ha^{-1}, which was 0.6 and 3.3 % of the less mean observed yields compared to simulated yields. Considering the variability in the growing conditions for two years, the low values of RMSE obtained also reinforce the fact that the model results were acceptable. There was a good agreement between observed and simulated seed cotton yield with RMSE of 50 and 169 kg ha^{-1} for MRC 7201 BGII and WGCV-48 cultivars respectively.

Model validation

CROPGRO- Cotton model was validated using independent data set collected during the year of 2015 and 2016 against plant densities and nitrogen level treatments under variable weather conditions. The corresponding simulation results were depicted in figures wherever necessary.

Days to flowering

Simulated values of days to flowering of CROPGRO-Cotton model for MRC-7201 cultivar (Figure 1)was very closer to the observed data, with RMSE value of 1.0 days, CRM value of -1 and NRMSE value of 1 %. This clearly explained that, CROPGRO-Cotton model overestimated the days to flowering to the extent of 1 %. However, under present study simulation of days to flowering was considered excellent as the NRMSE value was less than 10 %.Simulated values of days to flowering for WGCV-48 cultivar (Figure 2)was very closer to the observed data, with RMSE value of 0.5 days, CRM value of -1 and NRMSE value of 1 %. This clearly explained that, CROPGRO-Cotton model overestimated the days to flowering to the extent of 1 %. However, under present study simulation of days to flowering was considered excellent as the NRMSE value for WGCV-48 cultivarwhich was less than 10 %.At three cotton growing regions of Pakistan (Faisalabad, Multan and Sahiwal) the simulated values of crop phenology (days to flowering) by the CROPGRO-Cotton model were reliable with the recorded data, with root mean square error (RMSE) less than 2 days during both years 2009 and 2010[26].

Days to physiological maturity

A perfect match for MRC-7201 cultivar (Figure 1)was noticed between the observed and simulated values for days to physiological maturity with RMSE, NRMSE and the CRM values of 1 day, 1 and 1 respectively, showed the tendency of model to underestimate the days to physiological maturity by 1 %. However, the simulation was considered as excellent with NRMSE value was being less than 10 %. For WGCV-48 (Figure 2) cultivar simulated values of days to physiological maturity of was very closer to the observed data, with RMSE value of 2 days, CRM value of 2 and NRMSE value of 2 %. This clearly explained that, CROPGRO-Cotton model underestimated the days to physiological maturity to the extent of 2 %. However, under present study simulation of days to physiological maturity was considered excellent as the NRMSE value for WGCV-48 cultivarwhich was less than 10 %. Simulated and observed maturity dates were very close to 1:1 line for both the years 2009 and 2010 having higher values of R^2 (0.99) showed the goodness of the CROPGRO-Cotton model during evaluation and validation[26].

Leaf area index (LAI)

Maximum leaf area index under different plant densities and nitrogen levels for MRC-7201 cultivar (Figure 3)was considered excellent as the NRMSE value was 9.4 per cent with RMSE value of 0.50 and CRM value of 1.1. Positive CRM value indicated the tendency of model to underpredict the LAI by 1.1 %. CROPGRO-Cotton model for WGCV-48 cultivar (Figure 4)predicted maximum LAI values were closely related to the observed values of maximum LAI with RMSE 0.4, NRMSE with 9.2 per cent whereas the CRM value was 3.4, showing the tendency of model to underpredict the LAI by 3.4 % with different levels of nitrogen and plant densities. LAI measurements were estimated from canopy height and width, which could be a contributing factor. In addition, the CROPGRO-Cotton model may have underestimated the effects of competition among plants when the planting density was higher than normal. The simulated LAI for the typical planting density was approximately midway between that for the dense and sparse treatments[25].

Boll weight (kg ha^{-1})

Validation of CROPGRO-Cotton model showed the tendency of model to over predict the boll weight (kg ha^{-1})by 2 % with RMSE and NRMSE value of 301 kg ha^{-1} and 6 % respectively. Here, the simulation was considered as excellent with NRMSE value in below 10 % for MRC-7201 cultivar(Figure 5).CROPGRO-Cotton model for WGCV-48 cultivar(Figure 6)**,** simulated boll weight (kg ha^{-1}) reasonably well with RMSE 350 kg ha^{-1} across different plant densities and nitrogen levels. CRM value 4 %, which showed the tendency of model to overpredict the boll weight (kg ha^{-1}) by 4 % with increase in plant densities and nitrogen levels. The simulation was considered good with a NRMSE of 9 %, resulted in excellent simulation.Kumar *et al*. (2008) revealed that the pod yield was predicted accurately by the model. The results indicated that under biotic stress-free simulations, the CROPGRO-Soybean model can be used to predict soybean yield in different environments as determined by season, optimum sowing date, inter and intra spacing, management practices, prevailing weather parameters and moisture regimes.

Seed cotton yield (kg ha^{-1})

There was a good agreement between observed and simulated seed cotton yield across plant densities and nitrogen levels with RMSE value 300 kg ha^{-1}. While, the positive CRM value indicated the tendency of the model to underpredict the seed cotton yield by 5 %. With respect to NRMSE values the simulation was excellent with 9 % for MRC-7201 cultivar (Figure 7).Observed seed cotton yield was in good agreement with simulated seed cotton yield of CROPGRO-Cotton with highest RMSE value of 350 kg ha^{-1} while, the CRM value of 4 showed the tendency of model to simulate 4 % less yield with increased plant densities and nitrogen levels for WGCV-48 cultivar(Figure 8). Here, NRMSE value 9 % indicating simulation was considered as excellent with NRMSE value was being less than 10 %. Further, the values were scattered on either side of the zero reference line, indicating that it was devoid of any systemic errors. Thus, the values of seed cotton yield (kg ha^{-1}) used for validating the CROPGRO-Cotton are within the acceptable range.The results from this study showed an acceptable agreement between simulated and observed values for seed cotton yield of MRC-7201 and WGCV-48 cultivars for model evaluation in Telangana state.

Wajid*et al*. (2014) found that the model simulated seed cotton yield reasonably well with error percentage of 3.17 to 7.06 during 2009 having RMSE values 134.67 to 227.00 kg ha^{-1} in all the treatments of sowing date, nitrogen levels and cultivars. Similarly during 2010, error percentage in the prediction of seed cotton yield was in the range of 1.64 to 6.43 with RMSE of 122 to 179 kg ha^{-1}. The MPD was 5.30 and 4.38 during 2009 and 2010, respectively. Cammarano*et al.* (2011) recorded that lint yield was well simulated for all the treatments (Root Mean Square Error 100 kg ha^{-1} for the 2008 growing season and 254 kg ha^{-1} for the 2009 growing season). When the model was run in different locations between south east Queensland and northern New South Wales it accurately simulated cotton yield (y= 0.75x +218.2; r^2= 0.79; RMSE= 395.3 kg ha^{-1}). Similarly Ortiz *et al.* (2009) reported that prediction by CROPGRO-Cotton for seed cotton fell within a range of -11.2 % to 2.7 %. It is also evident from the yield data for individual seasons that observed and simulated values of sowing done in May gave the higher seed cotton yield than late sowing; these results are in accordance with Ali *et al*.

Total biomass

Total observed biomass production for MRC-7201 cultivar (Figure 9) showed highest RMSE value of 2450 kg ha^{-1} to the model simulated values. The CRM value was -1 %. The CROPGRO-Cotton model overpredicted the total biomass by 1 %. The simulation is considered to be fair as NRMSE between 20 to 30 % as observed NRMSE was 26 %.At increased plant densities and nitrogen levels showed maximum difference between simulated and observed values with highest RMSE value of 1832 kg ha^{-1} of biomass. The CRM value was 11 % showing the tendency of model to under predict the total biomass with increasing plant densities. The simulation was considered fair for the total biomass for

WGCV-48 cultivar (Figure 10) with a NRMSE of 22 %. Therefore, it may be expected that these models, as currently parameterized, will not perform well when simulating cotton biomass production under increased plant densities and nitrogen levels. Thorp *et al.* (2014b) found that the CROPGRO-Cotton model simulation of canopy weight was overly unresponsive to planting density, as it generally underestimated canopy weight for the dense treatment and overestimated canopy weight for the sparse treatment.

Nitrogen uptake by biomass

Nitrogen uptake by biomass was simulated with highest RMSE value of 33 kg ha^{-1}. The CRM value was -15 % showing the tendency of model to overpredict the nitrogen uptake with increase in nitrogen levels from 120 kg ha^{-1} to 180 kg ha^{-1} and increased plant densities from 1.8 plants m^{-2} to 14.8 plants m^{-2}. The simulation was fair with NRMSE value of 25 % for MRC-7201 cultivar (Figure 11).Observed nitrogen uptake was compared with simulated values by biomass for WGCV-48 (Figure 12)with RMSE value 28 kg ha^{-1}. The CRM value was -1 %, showing the tendency of model to overpredict the nitrogen content by 2 % with increased plant densities and nitrogen levels. However, the simulation was fair with NRMSE value of 25 %. The CROPGRO-Cotton model did not fully describe the effects of resource competition at the higher planting density. The CROPGRO-Cotton model simulations for 1.85 plants m^{-2} and 5.6 plants m^{-2} were in similar agreement with measured days to flowering, days to physiological maturity, LAI, seed cotton yield (kg ha^{-1}) and boll weight (kg ha^{-1}) Simulations for the 14.8 plants m^{-2} diverged more substantially from measurements.

Table 1: Genetic coefficients of MRC 7201 BGII and WGCV-48 used for CROPGRO-Cotton model

S.No.	Parameter	Description of coefficients	Value	
			MRC 7201 BGII	WGCV-48
1	**CSDL**	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants)	23	23
2	**PPSEN**	Slope of the relative response of development to photoperiod with time (positive for short day plants)	0.01	0.01
3	**EM-FL**	Time between plant emergence and flower appearance (R_1)	40	44
4	**FL-SH**	Time between first flower and first pod (R_3)	12.7	12.0
5	**FL-SD**	Time between first flower and first seed (R_5)	13.4	13.4
6	**SD-PM**	Time between first seed (R_5) and physiological maturity (R_7)	25.06	29.06
7	**FL-LF**	Time between first flower (R_1) and end of leaf expansion	78.02	60.02
8	**LFMAX**	Maximum leaf photosynthesis rate at 30^0 C, 350 ppm CO_2, and high light	3.98	3.25
9	**SLAVR**	Specific leaf area of cultivar under standard growth conditions	206	185
10	**SIZLF**	Maximum size of full leaf (three leaflets)	305	290
11	**XFRT**	Maximum fraction of daily growth that is partitioned to seed + shell	0.64	0.50
12	**WTPSD**	Maximum weight per seed	0.18	0.17
13	**SFDUR**	Seed filling duration for pod cohort at standard growth conditions	39	22
14	**SDPDV**	Average seed per pod under standard growing conditions	27	20
15	**PODUR**	Time required for cultivar to reach final pod load under optimal conditions	12.5	15.9
16	**THRSH**	Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity	68	67.5
17	**SDPRO**	Fraction protein in seeds (g(protein)/g(seed))	0.153	0.153
18	**SDLIP**	Fraction oil in seeds (g(oil)/g(seed))	0.12	0.12

Table 2: Observed and predicted phenology, yield attributes, seed yield, and total biomass after calibration of CROPGRO-Cotton model

Variable Name	Cultivars	Observed	Simulated	r^2	RMSE	d-Stat.
Flowering (days)	MRC 7201 BGII	51	52	0.82	0.5	0.86
	WGCV-48	56	56	0.82	0.5	0.86
Physiological maturity (days)	MRC 7201 BGII	104	104	0.96	0.87	0.96
	WGCV-48	114	114	0.97	0.86	0.97
Total biomass (kg ha^{-1})	MRC 7201 BGII	10001	9491	0.96	635.5	0.86
	WGCV-48	8635	8390	0.85	307.2	0.85
Seed cotton yield (kg ha^{-1})	MRC 7201 BGII	3428	3449	0.96	49.7	0.98
	WGCV-48	2495	2581	0.83	169.4	0.92
Boll weight at maturity (kg ha^{-1})	MRC 7201 BGII	5587	5683	0.81	208.2	0.92
	WGCV-48	3920	3876	0.89	129.6	0.96

Note: Data of 2015 and 2016 was used for calibration of model.

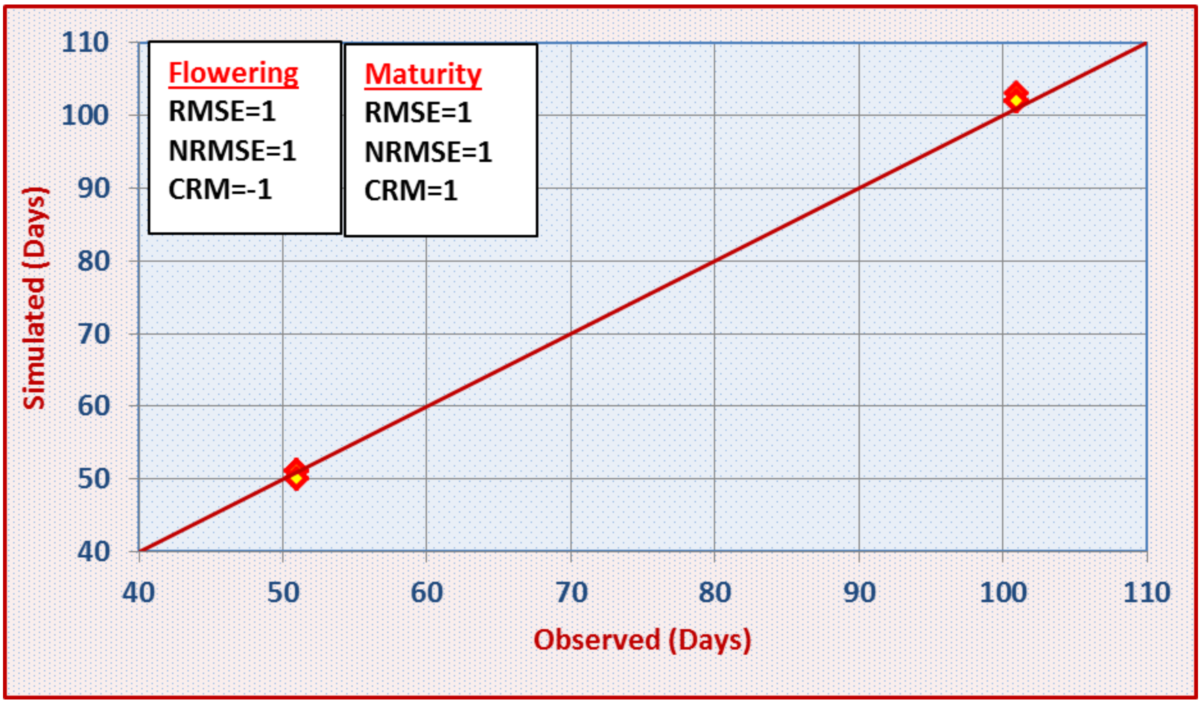

Fig. 1: Observed and simulated days to flowering and physiological maturity of MRC-7201 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

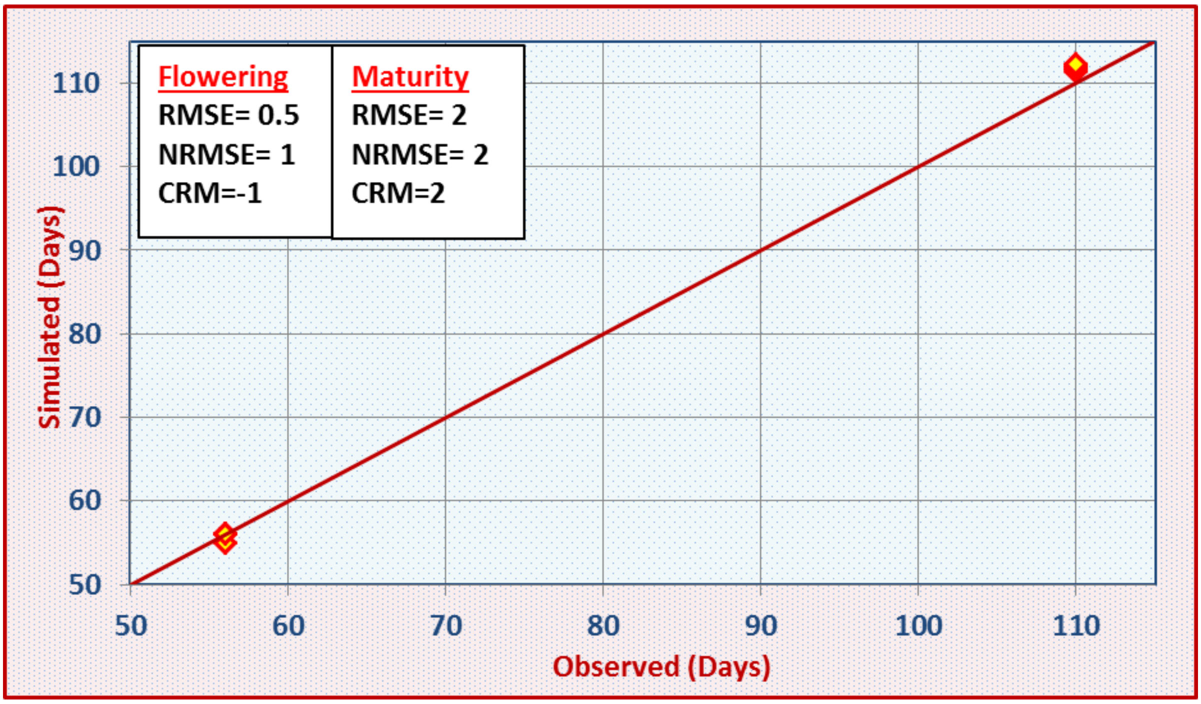

Fig. 2: Observed and simulated days to flowering and physiological maturity of WGCV-48 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

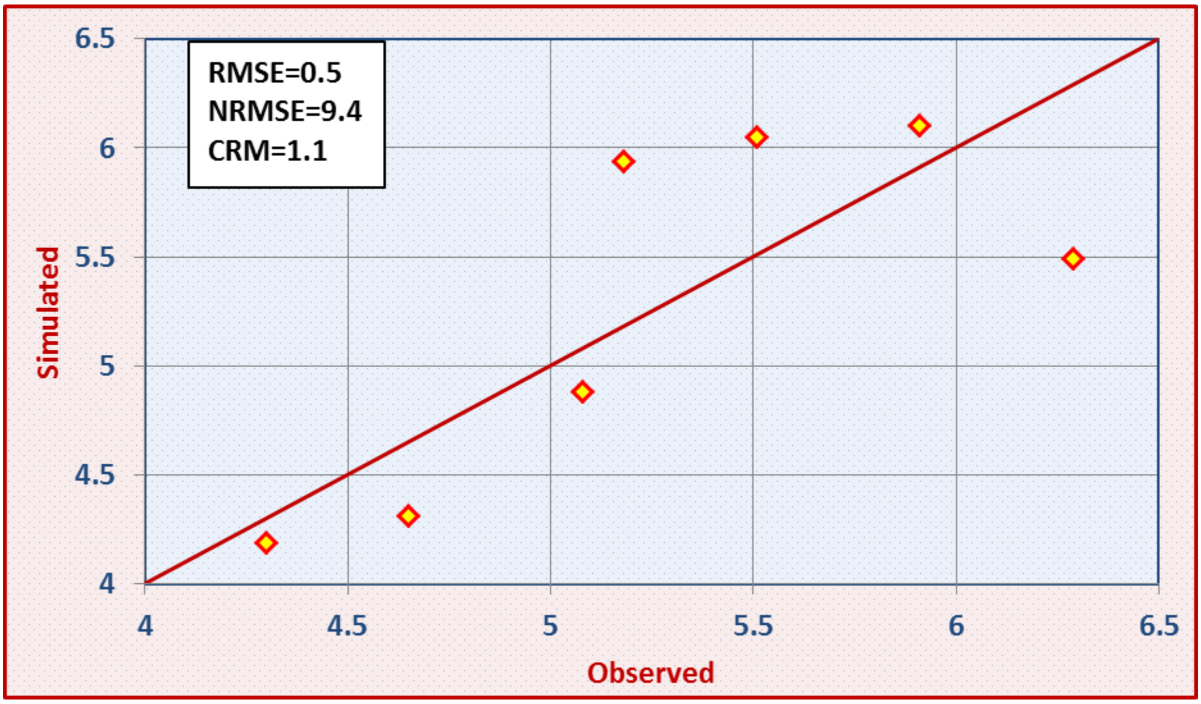

Fig. 3: Observed and simulated maximum LAI of MRC-7201 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

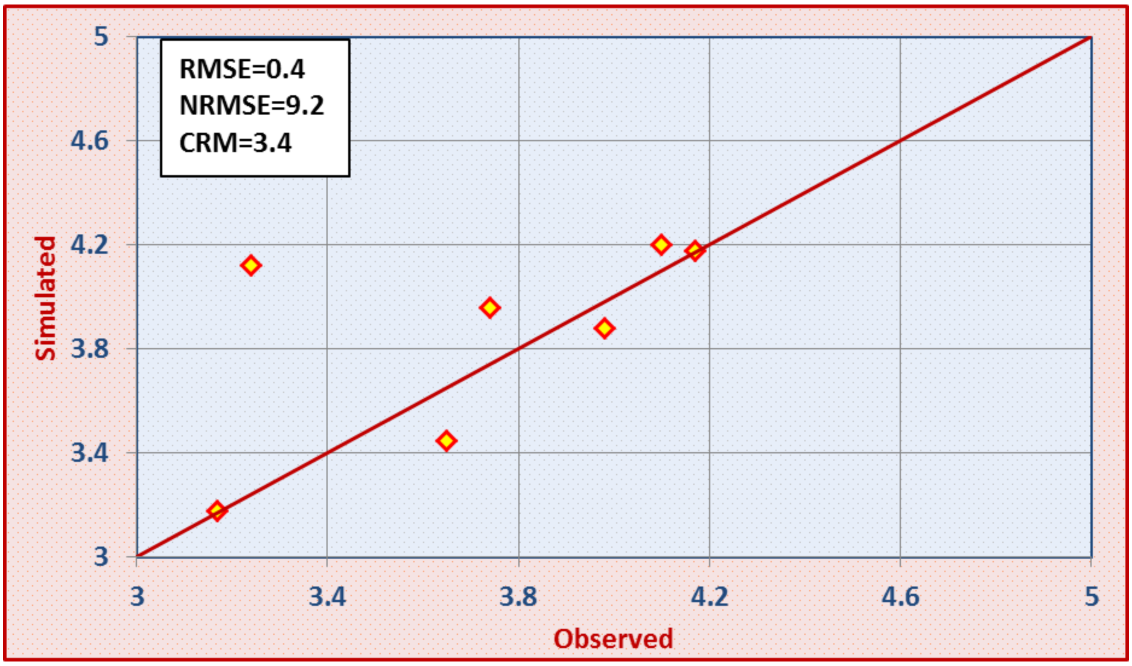

Fig. 4: Observed and simulated maximum LAI of WGCV-48 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

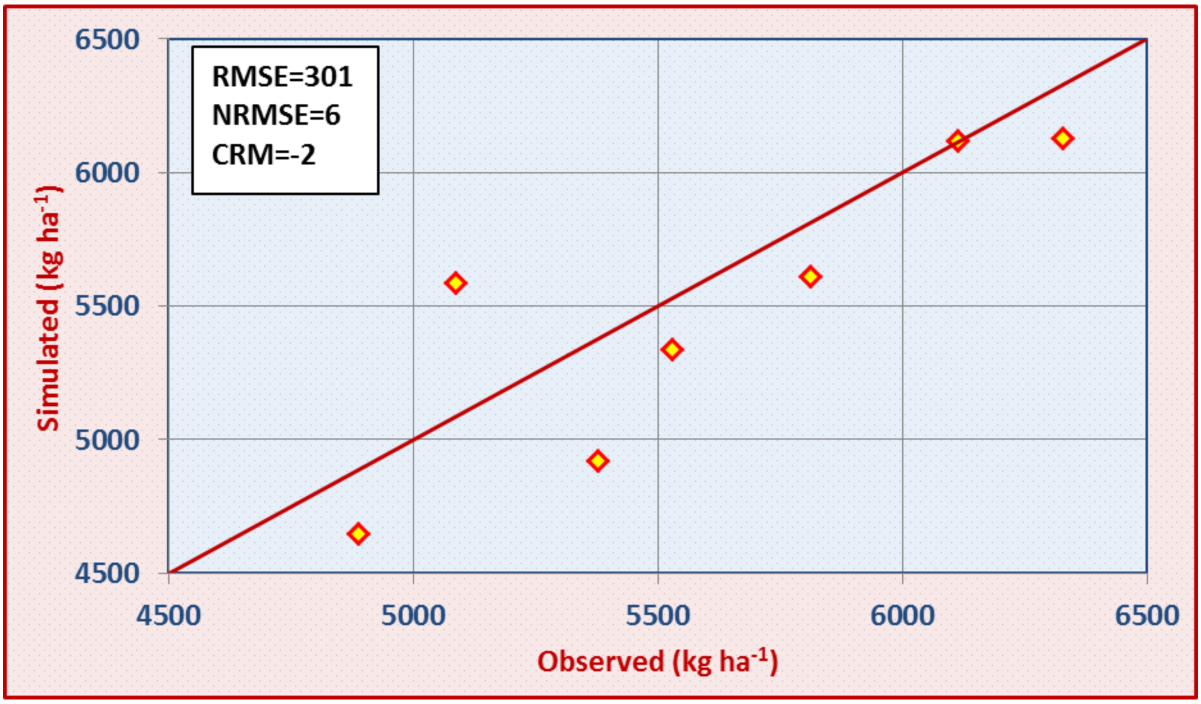

Fig. 5: Observed and simulated boll weight (kg ha^{-1}) of MRC-7201 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

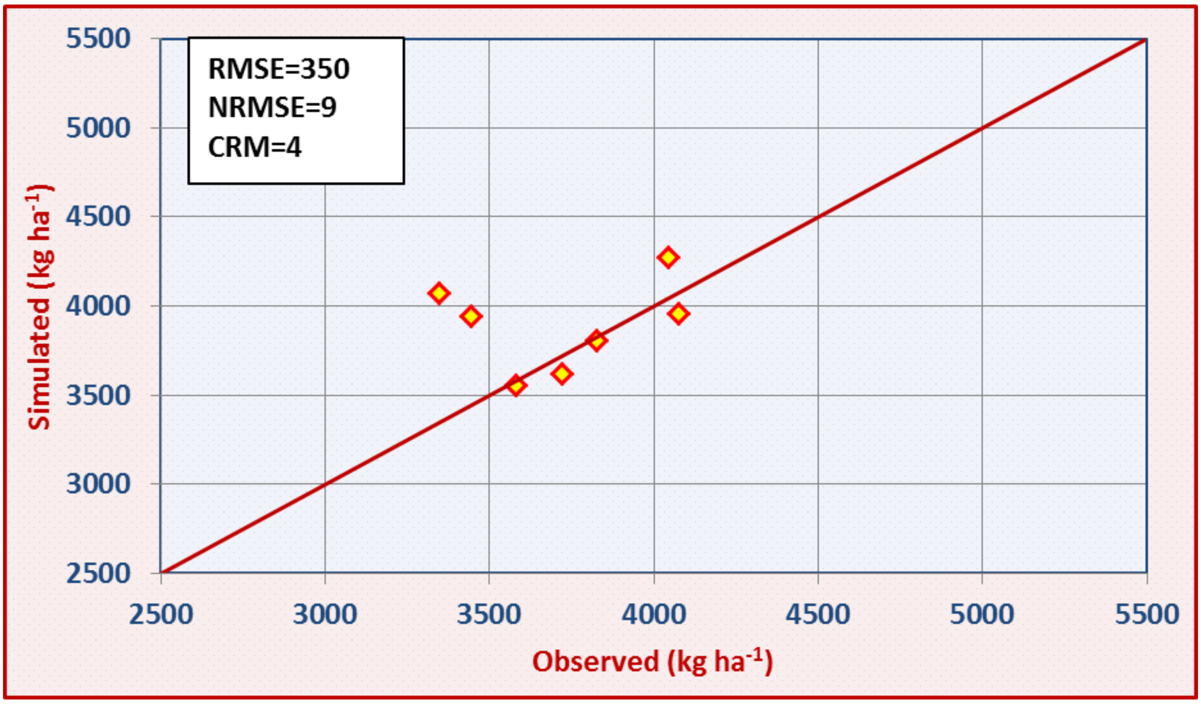

Fig. 6: Observed and simulated boll weight (kg ha^{-1}) of WGCV-48 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

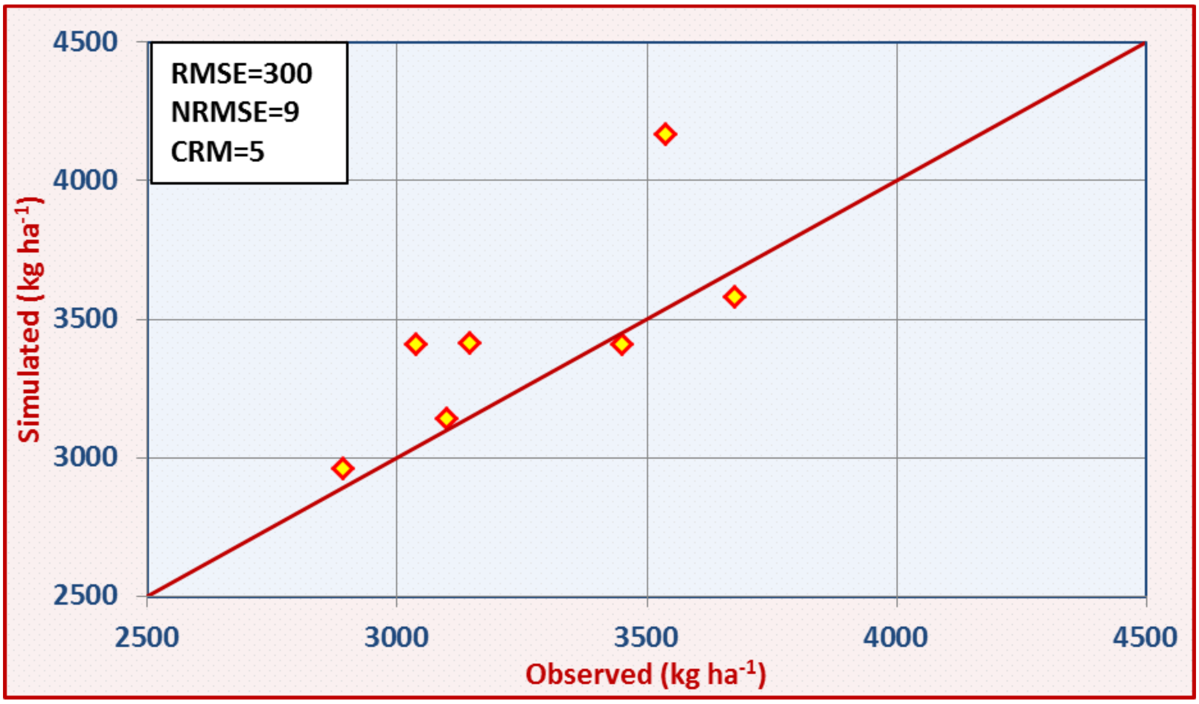

Fig. 7: Observed and simulated seed cotton yield (kg ha^{-1}) of MRC-7201 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

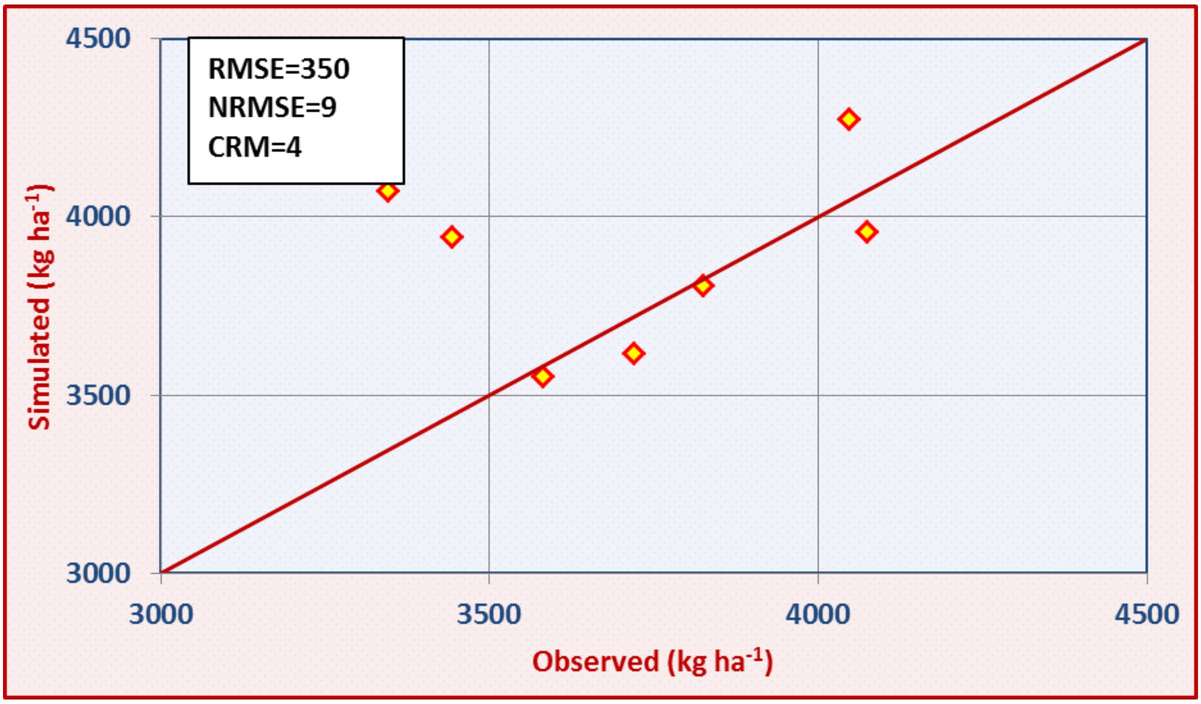

Fig. 8: Observed and simulated seed cotton yield (kg ha^{-1}) of WGCV-48 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

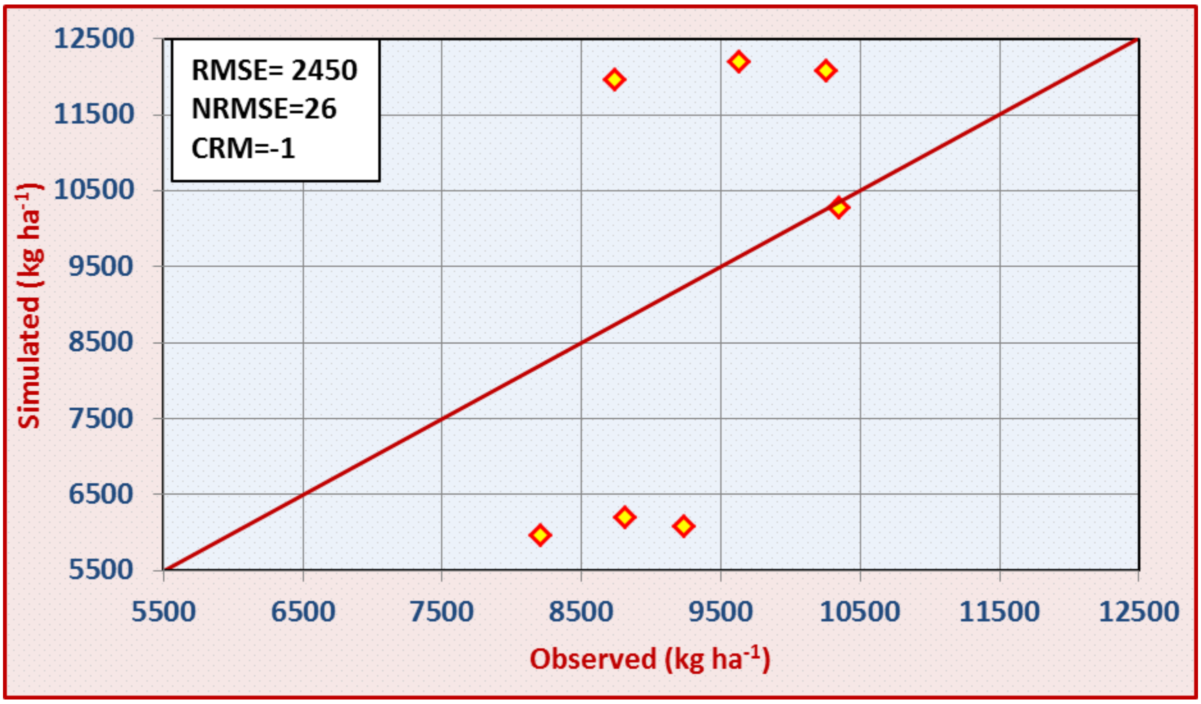

Fig. 9: Observed and simulated biomass (kg ha^{-1}) of MRC-7201 cultivar using CROPGRO- Cotton model at different plant densities and nitrogen levels

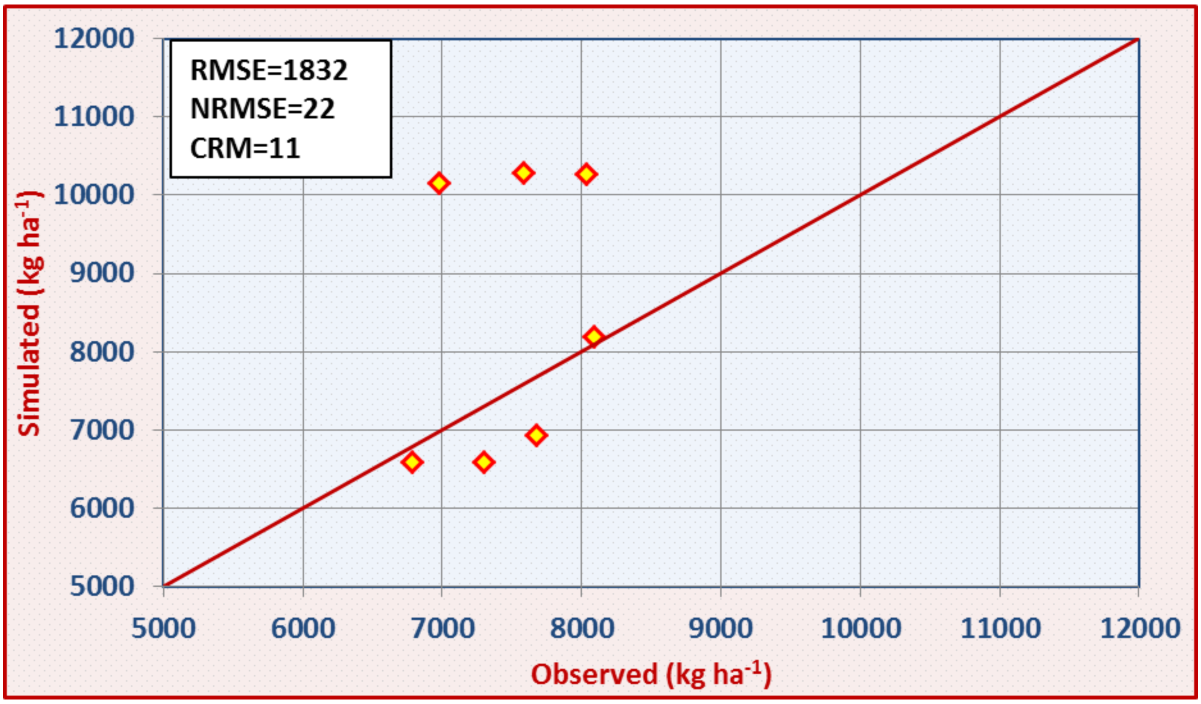

Fig. 10: Observed and simulated biomass (kg ha^{-1}) of WGCV-48 cultivar using CROPGRO- Cotton model at different plant densities and nitrogen levels

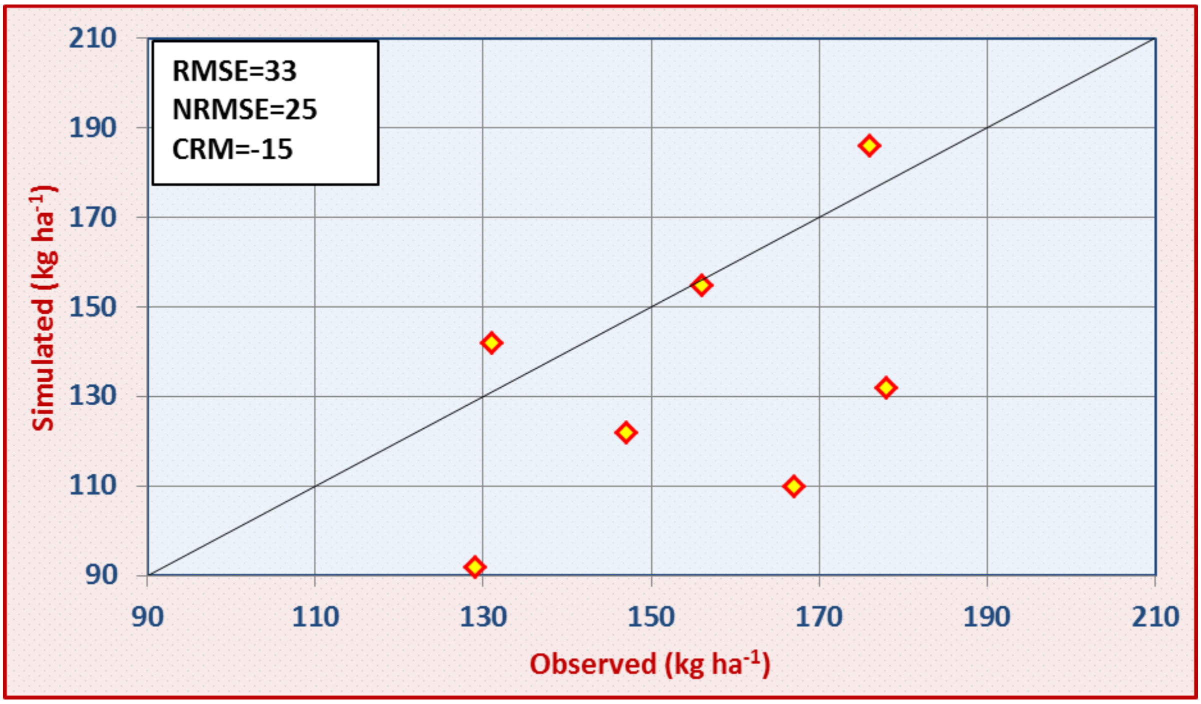

Fig. 11: Observed and simulated nitrogen uptake (kg ha^{-1}) of MRC-7201 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

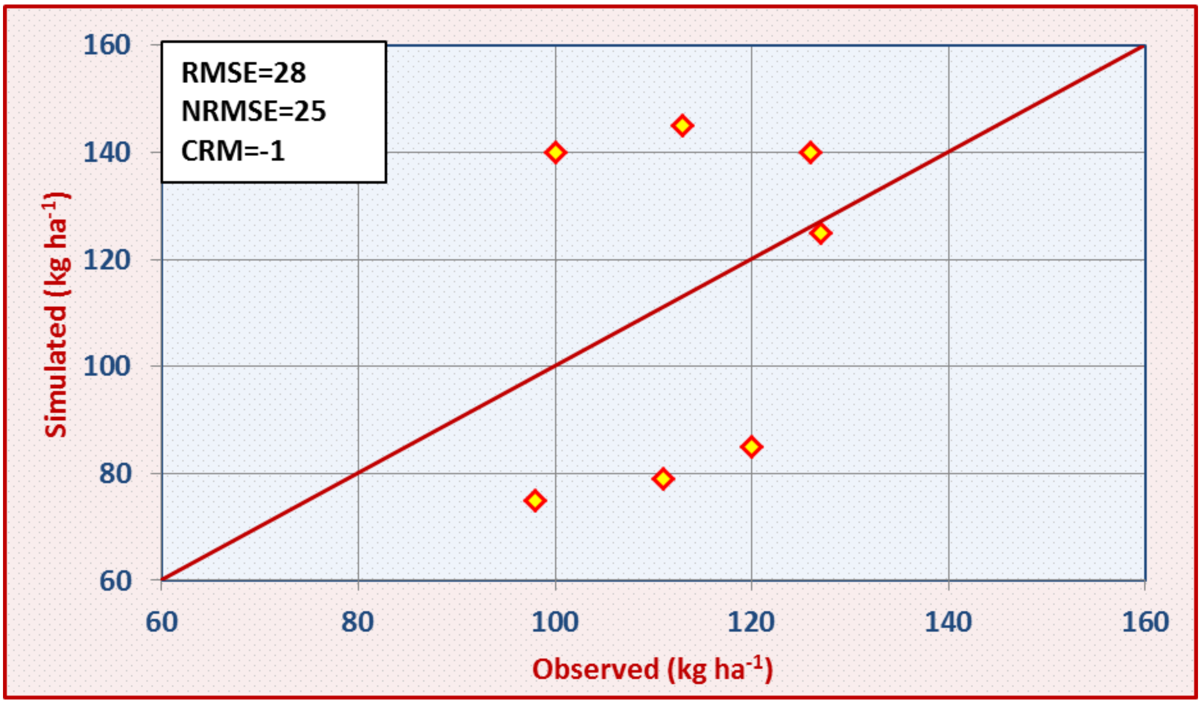

Fig. 12: Observed and simulated nitrogen uptake (kg ha^{-1}) of WGCV-48 cultivar using CROPGRO-Cotton model at different plant densities and nitrogen levels

CONCLUSION

In conclusion, the performance of CSM-CROPGRO-Cotton model under DSSAT v 4.6 was satisfactory for different parameters of the cotton. CROPGRO-Cotton model can be used as a research tool under variable agro-environments of Telangana State, India to improve the cotton yields as the validation results showed excellent simulation of LAI, phenology, biomass and seed cotton yield.

Acknowledgments

I, (T.Nagender) deem it as a great pleasure to express my heartfelt gratitude and respect to the advisory committee, Dr.D. Raji Reddy, Dr. G. Sreenivas, Dr. P. Leela Rani, Dr. K. Surekha, Dr.Akhilesh Gupta, Dr. P. D. Sreekanthfor constructive encouragement in planning and execution of research work.Financial support from the Department of Agronomy, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad is gratefully acknowledged.

REFERENCES

1. *Ali*,M.L., *Ali, M., Sattar*and *Ali, M.A.*, Response of seed cotton yield to various plant populations and planting methods. *Journal of Agriculture Research.* **48(2)**: 163-169.(2010).
2. *APTMA., World Cotton and non-Cotton Fibre Consumption. Available online at http://www.aptma.org.pk/Pak_Textile_Statistics/ repo.asp.* (2012).
3. Bouman, B.A.M., Van Keulen, H and Rabbinge, R., The ‘School of de Wit’ crop growth simulation models: a pedigree and historical overview. *Agricultural Systems*. **52:** 171-198 (1996).
4. Cammarano, D., Payero, J., Grace, P and Basso, B., Evaluating the CROPGRO-Cotton Model for Estimating Cotton Production.In the Australian Sub-Tropics.Presented in: International Annual Meetings. 16-19 Oct. American Society of Agronomy-Crop Science Society of America- Soil Science Society of America.*Pp*.106-107 (2011).
5. Fageria, N.K. and V.C. Baligar., *Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy*. **88:** 97-185 (2005).
6. *FAS., Oilseeds: World Markets & Trade. Jan.*, (2014).

7. *Firbank, L.G., Striking a new balance between agricultural production and biodiversity.Annals of Applied Biology.* **146(2):** 163-175 (2005).
8. Hanson, J.D., Generic crop production model for the root zone water quality model. In L. R. Ahuja (ed), The root zone water quality model. Highland Ranch, Colorado, Water Resource Publishing. *Pp*. 145-156 (2000).
9. Hanson, J.D., Rojas, K.W and Shaffer, M.J., Calibrating the root zone water quality model. *Agronomy Journal*. **91:** 171-177 (1999).
10. Hoogenboom, G., Jones, J.W and Boote, K.J., Modeling growth, development, and yield of grain legumes using SOYGRO, PNUTGRO, and BEANGRO: A Review.*Transactions of the American Society Agricultural Engineers*.**35:** 2043–2056 (1992).
11. Howard, D.D., Gwathmey, C.O., Essington, M.E., Roberts, R.K and Mullen, M.D. Nitrogen fertilization of no-till cotton on loess- derived soils. *Agronomy Journal*.**93:** 157–163 (2001).
12. Khadi, B.M., Santhy, V and Yadav, M.S., Highlights the advances in cotton biotechnology, the benefits and socioeconomic impacts.*Cotton Biotechnological Advances*. Zehr, U.B. (Ed.), XVI. *Pp*. 245. (2010).
13. Kumar, A., Pandey, V., Shekh, A.M and Kumar, M., Growth and Yield Response of Soybean (*Glycine max* L.)In Relation to Temperature, Photoperiod and Sunshine Duration at Anand, Gujarat, India.*American-Eurasian Journal of Agronomy*. **1(2):** 45-50 (2008).
14. Loague, K and Green, R.E., Statistical and graphical methods for evaluating solute transport models: Overview and application. *Journalof ContaminantHydrology*. **7:** 51-73 (1991).
15. Monteith, J.L., The quest for balance in crop modelling. *Agronomy Journal*. **88:** 695-697 (1996).
16. *Oosterhuis, D., Physiology and nutrition of high yielding cotton in the USA. InformaçõesAgronômicas.* **95:** 18-24 (2001).
17. Ortiz, B.V., Hoogenboom, G., Vellidis, G.K., Boote, Davis, R.F and Perry, C., Adapting the CROPGRO cotton model to simulate cotton biomass and yield under southern root-knot nematode parasitism. *Transactions of theAmerican Society of Agricultural and Biological Engineers*. **52:** 2129-2140 (2009).
18. Prasad, M., Nitrogen, phosphorus and sulphur requirement of cotton *(Gossypiumhirsutum) Gobi sarson (Brassica napus, sub spoleifera var. annua) rotation.Indian Journal of Agronomy*. **43:** 612-615. (2000).
19. Read, J.J., Reddy, K.R and Jenkins, J.N., Yield and fibre quality of Upland cotton as influenced by nitrogen and potassium nutrition.European *Journal of Agronomy*.**24:** 282-290 (2006).
20. Rossiter, D.G., Biophysical models in land evaluation. In Land Use and Land Cover, Encyclopedia of Life Support System (ed. Verheye, W.), (EOLSS-UNESCO) Eolss Publishers, Oxford, UK,(2003).
21. Rutto, E., Arnall, B.D., May, J. L., Butchee, K and Raun, W.R., Ability of cotton *(Gossypiumhirsutum L.)* to recover from early season nitrogen deficiency.*Journal of Cotton Sciences.* **17:** 70-79 (2013).
22. Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R and Hauck, L.M., Validation of the SWAT model on a large river basin with point and nonpoint sources.*Journal of American Water Resources Association*. **37(5):** 1169–1188 (2001).
23. Surya, K., Bi, Y.M and Rothstein, S.J., Understanding plant response to nitrogen limitation for the improvement of crop nitrogen use efficiency.*Journal of Experimental Botany*. **62(4):** 1499-1509 (2010).
24. Thorp, K., Ale, S., Bange, M., Barnes, E., Hoogenboom, G., Lascano, R and Rajan, N., Development and Application of

Process-based Simulation Models for Cotton Production: A Review of Past, Present, and Future Directions. *Journal of Cotton Sci*ence. **18:** 10–47 (2014a).

25. Thorp, K.R., Barnes, E.M., Hunsaker, D.J., Kimball, B.A., White, J.W., Nazareth, V.J and Hoogenboom, G., Evaluation of CSM-CROPGRO-Cotton for simulating effects of management and climate change on cotton growth and evapotranspiration in an arid environment.Transactions of*American Society of Agricultural Engineers.* **57:** 1627–1642 (2014b).
26. Wajid, A., Ahmad, A., Hussain, M., Rahman, M.H., Khaliq, T., Mubeen, M., Rasul, F., Bashir, U., Awais, M., Iqbal, J., Sultana, S.R and Hoogenboom, G., Modelling growth, development and seed cotton yield for varying nitrogen increments and planting dates using DSSAT. *Pakistan Journal of Agricultural Sciences.* **51(3):** 641-649 (2014).
27. Wallach, D and Goffinet B., Mean squared error of prediction as a criterion for evaluating and comparing system models. *Ecological Modelling*. **44:** 200-306. (1989).
28. Willmott, C.J., Some comments on the evaluation of model performance. Bulletin.*American Meteorological Society.* **63:** 1309–1313 (1982).
29. Xevi, E., Gilley, J and Feyen, J., Comparative study of two crop yield simulation models.*Agricultural Water Management.* **30:** 155-173 (1996).
30. Zaxosa, D., Kostoulaa, S., Khaha, E.M., Mavromatisa, A., Chachalisb, D and Sakellarioua, M., Evaluation of seed cotton (*Gossypium hirsutum* L.) production and quality in relation to the different irrigation levels and two row spacings. *International Journal of Plant Production.* **6(1):** 129-148 (2012).