frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 12 January 2026
DOI 10.3389/fsufs.2025.1642618

OPEN ACCESS

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RECEIVED 06 June 2025
REVISED 09 December 2025
ACCEPTED 22 December 2025
PUBLISHED 12 January 2026

CITATION
Shravika L, Ananda N, Sreenivas G, AjayaKumar MY, Umesh MR, Veeresh H and Rajkumar RH (2026) Sensitivity analysis of DSSAT CROPGRO-cotton model under different growing environments.
Front. Sustain. Food Syst. 9:1642618.
doi: 10.3389/fsufs.2025.1642618

Sensitivity analysis of DSSAT CROPGRO-cotton model under different growing environments

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Background factors such as vagaries in monsoon, unsuitable soil, inappropriate sowing time, non-adoption of recommended technologies, especially plant geometry and fertilizer use, are limiting cotton production at farmers' fields. The yield gaps can be reduced with better crop management, such as optimum date of sowing, plant spacing, and nitrogen. Against this background, the current investigation was carried out to test and validate the model in the Raichur area of Karnataka, India for the dynamic simulation of cotton development, growth, and seed cotton yield under varied sowing times, plant densities, and nitrogen levels. The model was calibrated using observed data on phenology and yield components from the experiments conducted at the Main Agricultural Research Station, Raichur, during the *kharif* periods 2022–23 to 2023–24. The CSM-CROPGRO-Cotton model performed well under different dates of sowing, plant densities, and nitrogen levels for the simulation of phenology; the model performance was fair for the simulation of seed cotton yield, biomass, and nitrogen uptake for cultivar US7067. The model application through seasonal analysis was also used to confirm the results of the CROPGRO-Cotton model validation using the past 30 years of weather data. Optimum sowing time for predicting higher seed cotton yield was at the second fortnight of June under semi-arid conditions. In the case of plant population from 12,345 plants ha^{-1} (90 cm × 90 cm) to plant density of 74,074 plants ha^{-1} (90 cm × 15 cm), an increased seed cotton yield was predicted. The incremental increase in nitrogen level from 100 to 250 kg N ha^{-1} did not show much influence on predicted mean seed cotton yield. However, a higher mean seed cotton yield (1,682 kg ha^{-1}) was predicted with higher levels of nitrogen application, i.e., 250 and 300 kg N ha^{-1}. The CROPGRO-Cotton model applicability for the research area was evident from its calibration and validation in the Karnataka semi-arid environment. Using a seasonal analysis tool, the CROPGRO-Cotton model results demonstrated a clear path to increased seed cotton yield.

KEYWORDS

cotton, *Gossypium hirsutum* L., CSM-CROPGRO-cotton, simulation, calibration, validation

Introduction

The simulation of crop growth, development, and yield is accomplished through evaluating the growth rate, the stage of crop development, and the partitioning of biomass into growing organs. All these processes are dynamic and are affected by environmental and cultivar-specific factors. The description of key processes in crops provides a means of quantifying how cultivars differ and helps to provide a system of simulating grain yield production using crop models (Kiniry et al., 2001). Crop simulation models have been widely used to study the effect of intra-seasonal variation in temperature on yields of wheat in India (Patil et al., 2018a,b) have reported the effect of intra-seasonal variation of temperature on tuber yield of potato and seed yield of pigeonpea in Gujarat using decision support system for agrotechnology transfer (DSSAT) group of models. All studies reported the importance of calibrating the CSM-CROPGRO-Cotton model for particular cultivars and growing regions for successful model implementation.

India is the largest producer of cotton, accounting for approximately 24.97% of the world's cotton production. It has the distinction of having the largest area of 12.6 million ha under cotton and ranks first in production with 36 million bales (1 bale = 170 kg). The productivity is approximately 486 kg ha^{-1}, which is, however, much below the world's average productivity of 759 kg ha^{-1} (Gyan et al., 2023).

Crop models effectively integrate numerous factors affecting crop environment and yield. They are not only used to predict yield but also to evaluate the variability and risks of various management strategies over a range of locations and climatic conditions (Tsuji et al., 1994). Recently, the DSSAT crop models, such as CERES and CROPGRO, have been extensively validated and applied in various research areas and production environments (Wang et al., 2003). The validated CROPGRO-Cotton model could be used to simulate crop yield and other output variables reliably in different environments (Singh, 1989).

Given the crop's sensitivity to environmental variables, particularly under the growing stress of climate change, adopting site-specific and climate-resilient management strategies becomes increasingly important. Proper agronomic management not only enhances yield potential but also conserves natural resources, reduces production costs, and minimizes environmental impacts, contributing to long-term agricultural sustainability and economic viability for cotton growers.

Environmental conditions can influence the yield in the same sowing date, plant density, and nitrogen levels in different years; therefore, only one field experiment cannot bring conclusive results for choosing the best sowing date, plant density, and nitrogen levels. This problem can be solved using historical climatic series with the help of the seasonal analysis tool of crop models for estimating yield in such a way that the choice of the optimum sowing date, plant density, and nitrogen levels is based on a probabilistic level.

If the calibrated models stand the test of validation with independent data sets, they can be potentially used as tools to support operational, tactical, and strategic decision-making for on-farm crop management (Matthews et al., 2002).

Materials and methods

Experimental site and cultivars, design, and agronomic practices

The experiments were conducted at the Main Agricultural Research Station (MARS) Farm, University of Agricultural Sciences (UAS), Raichur, India. Geographically, the experimental site was situated in the North-Eastern Dry Zone (Zone 2) of Karnataka is located on a latitude of 16° 12′ North, a longitude of 77° 20′ East and at an altitude of 407 m above the mean sea level. The experiment was laid out in a split-plot design with three replications, comprising 24 treatment combinations on sandy loam soils. The main plot consisted of two dates of sowing (D), *viz.* D_1: Second fortnight of July, D_2: First fortnight of August, sub plot consist of three plant densities (S) *viz.*, S_1: 18,518 plants ha^{-1} (90 cm × 60 cm), S_2: 24,691 plants ha^{-1} (90 cm × 45 cm), S_3: 37,037 plants ha^{-1} (90 cm × 30 cm) and the sub plot consist of four nitrogen levels (N), *viz.* N_1: 100% RDN application at basal and 30, 60, and 90 DAS, N_2: 100% RDN application at basal and 25, 50, 75, and 100 DAS, N_3: 75% RDN application at basal and 30, 60, and 90 DAS and N_4: 75% RDN application at basal and 25, 50, 75, and 100 DAS. Cultivar that was used for experimentation was SWCH 4749 BG-II (US7067) cotton hybrid.

CROPGRO-cotton model

Data were collected from the field experimentation to use as inputs to run the crop simulation model. In addition, crop management data, weather data and soil data were required to run the model. After data collection, input files for weather (Temperature, Rainfall, Solar radiation), soil (soil profile characteristics), genotype (cultivar details), and crop management (dates of different operations performed in crop cultivation) were created for a specified simulation experiment, the CROPGRO-Cotton model was run, and output files were generated. These simulation results were compared with the observed data.

Statistical analysis to evaluate the CROPGRO-cotton model performance

CROPGRO-Cotton model simulation performance was evaluated by calculating different test statistics, such as root mean square error (RMSE) (Wallach and Goffinet, 1989) for all treatments. Statistical-based criteria provide a more objective method for the evaluation of the performance of the models (Ducheyne, 2000). Time course simulation of crop biomass and yield was assessed by an index of agreement (d) (Willmott, 1982), that is, an aggregate over all indicators. These measurements were calculated as follows:

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

$$\mathrm{RMSE} = \left[\sum_{i=1}^{n} \left(p_i - o_i \right)^2 / n \right]^{0.5},$$

where P_i and O_i are the predicted and observed values for the studied variables, respectively, and 'n' is the number of observations. Model performance improved as the *d* value approaches unity while the RMSE approaches zero. A smaller RMSE indicates a lower deviation between the simulated and the observed values.

Normalized RMSE (NRMSE) gives a measure (%) of the relative difference between simulated versus observed data. The simulation is considered excellent with a normalized RMSE less than 10%, good if the normalized RMSE is greater than 10% and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30% (Loague and Green, 1991). The NRMSE was calculated using the following equation.

$$\text{Normalized root mean square error} = \left[\frac{RMSE}{O_i}\right] \times 100$$

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 the formula.

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

where Oi and Pi 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 toward overestimation (Xevi et al., 1996).

Application of the CROPGRO-cotton model

Once a model was calibrated and validated for use in a particular location or situation, it can be used to evaluate management strategies, such as cultivar selection, planting practices, and nutrient applications under various weather patterns and field conditions (Yang et al., 2008).

The CROPGRO–Cotton model was used for long-term simulations of the crop yield to determine the suitable planting date, optimum plant density, and optimum nitrogen levels for cotton in the Raichur region. The seasonal analysis tool was run using 30 years of observed historical weather data (1994–2023) to assess the best management option to maximize seed cotton yield with two planting dates from July to August, three plant densities starting from 18,518 to 37,037 plants ha^{-1}, and two nitrogen levels from 135 to 180 kg N ha^{-1} under the Raichur region. In addition, the seasonal analysis tool available in DSSATv4.7 was used to simulate seed cotton yield under different scenarios (6 dates of sowing × 6 plant densities × 7 nitrogen levels) starting from sowing of cotton on first fortnight of June to Second fortnight of August at 15 days interval and plant densities starting from 12,345 plants ha^{-1} (90 cm × 90 cm) to 28,571 plants ha^{-1} (90 cm × 15 cm) and nitrogen rates ranging from 0 to 300 kg ha^{-1} with an incremental increase of 50 kg ha^{-1} for a semiarid environment. The simulation results were analyzed using the strategy analysis program of DSSAT (Thornton and Hoogenboom, 1994; Hoogenboom et al., 2012) to compare percentile distributions for seed cotton yield. Measurements obtained from the experimental site during the years 2022–23 and 2023–24 were used as initial conditions for a series of model runs.

Biophysical and strategic analysis options were used to compare the results under different options. Seed cotton yield under different dates of sowing, plant densities, and nitrogen levels compared by percentile distribution for each level of dates of sowing, plant densities, and nitrogen scenarios. The data were analyzed statistically, applying the analysis of variance technique using SPSS. Critical difference for examining treatment means for their significance was tested with Tukey's (HSD) test using OPSTAT. Tukey's HSD is important as it enables researchers to precisely identify which treatments differ significantly, while effectively controlling for statistical errors arising from multiple comparisons.

Results and discussion

Calibration of genetic coefficients

Genetic coefficients are mathematical constructs that are designed to mimic the phenotypic outcome of genes under different environments. CROPGRO-Cotton model requires a set of 18 eco-physiological coefficients for the simulation of phenology, growth, and seed cotton yield of the cultivar. Since such data are cultivar-specific and were not available for US7067, the genetic coefficients for US7067 were estimated by repeated iterations, as suggested by Hunt et al. (1993) until a close match was observed between simulated and observed phenology, growth, and yield. The genetic coefficients were calculated with data (which includes phenology, biomass, and seed cotton yield) collected from the experiments conducted at the University of Agricultural Sciences, Main Agricultural Research Station, Raichur, during the years of 2022–23 to 2023–24 (unpublished data). The genetic coefficients determined through model calibration using the identical conditions as those of field experiments for cotton cultivar US7067 are presented in Table 1.

These generated coefficients were used in subsequent model validation and application. The model performed well in the simulation of growth, phenology, cotton seed yield, and seed cotton yield (Table 2) during the calibration process across all the sowing dates, plant densities, and nitrogen levels for US7067. Calibration results showed that the model predicted a difference of only a day between the observed and simulated number of days to flowering for the US7067 cultivar with an RMSE of 2.0 days across different dates of sowing, plant densities, and nitrogen levels. CROPGRO-Cotton simulated a difference of 10 days between simulated and observed number of days from planting to physiological maturity with an RMSE of 2.4 days. For phenology calibration, the model recorded 0.9 and 0.97 d-stat values for the number of days to flowering and the number of days to physiological maturity, respectively. While seed cotton yield (kg ha^{-1}) with the RMSE value of 351 kg ha^{-1}, and d-Stat was 0.76 for the US 7067 cultivar.

Model validation

CROPGRO-Cotton model was validated using an independent data set collected during the years 2022 and 2023 against sowing dates, plant densities, and nitrogen levels under variable weather conditions. The corresponding simulation results were depicted in figures wherever necessary.

TABLE 1 Genetic coefficients of the US7067 cotton cultivar used for the CROPGRO-cotton model.

Sl. no.	Parameter	Description of coefficients	Value
1	CSDL	Critical short day length below which reproductive development progresses with no day length effect (for short day plants)	23.0
2	PPSEN	Slope of the relative response of development to photoperiod with time (positive for short-day plants)	0.01
3	EM-FL	Time between plant emergence and flower appearance (R_1)	44.46
4	FL-SH	Time between first flower and first pod (R_3)	15.70
5	FL-SD	Time between first flower and first seed (R_5)	17.73
6	SD-PM	Time between first seed (R_5) and physiological maturity (R_7)	49.80
7	FL-LF	Time between the first flower (R_1) and the end of leaf expansion	78.02
8	LFMAX	Maximum leaf photosynthesis rate at 30 °C, 350 vpm CO_2, and high light	0.963
9	SLAVR	Specific leaf area of cultivar under standard growth conditions	177.0
10	SIZLF	Maximum size of a full leaf (three leaflets)	294.2
11	XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	0.650
12	WTPSD	Maximum weight per seed	0.17
13	SFDUR	Seed filling duration for pod cohort at standard growth conditions	14.0
14	SDPDV	Average seed per pod under standard growing conditions	18.01
15	PODUR	Time required for cultivar to reach final pod load under optimal conditions	16.5
16	THRSH	Threshing percentage. The maximum ratio of (seed/(seed + shell)) at maturity	70.0
17	SDPRO	Fraction protein in seeds	0.143
18	SDLIP	Fraction oil in seeds	0.100

TABLE 2 Observed and predicted phenology, biomass, and seed cotton yield after the calibration of the CROPGRO-cotton model.

Variable	Observed	Simulated	RMSE	*d*-Stat
Flowering (days)	59	60	2.0	0.90
Maturity (days)	153	155	2.4	0.97
Total biomass (kg ha^{-1})	5,824	6,291	1,024	0.70
Seed cotton yield (kg ha^{-1})	2,475	2,112	351	0.76

Data of 2022–23 and 2023–24 were used for calibration of the model.

Days to flowering

Observed data on days to flowering in cotton were compared with simulated values of the CROPGRO-Cotton model using test statistics and depicted in Figure 1. Simulated values for days to flowering of the CROPGRO-Cotton model were very close to the observed data, with an RMSE value of 4.08 days, indicating closer simulation with low variation. The coefficient of residual mass (CRM) value of −0.05 explained that a negative CRM value indicated the tendency of the model to overestimate the number of days to flowering by 0.5%. Under the present study, simulation of days to flowering was considered excellent as the NRMSE value (7%) was less than 10%.

The present results were in conformity with results obtained at 10 locations in New South Wales and Queensland, Australia as the CROPGRO-Cotton model predicted the occurrence of flowering and maturity with RMSE values of 20 and 3.64 days, respectively, which showed the accuracy of the model in prediction (Cammarano et al., 2012). Similar results were also reported by Modala et al. (2015), as simulated dates of flowering, 50% boll opening, and physiological maturity fell within the range of observed dates in the Texas Rolling Plains, USA.

Days to physiological maturity

The observed values for days to physiological maturity of cotton under different dates of sowing, plant densities, and nitrogen levels was compared with the simulated values of the CROPGRO-Cotton model and analyzed using test statistics and depicted in Figure 2.

A perfect match was noticed between the observed and simulated values for days to physiological maturity, with RMSE and NRMSE values of 7.4 days and 5%, respectively. The CRM value of −0.04 showed a tendency of the model to overestimate the days to physiological maturity by 0.4%. The simulation was considered excellent as the NRMSE value (5%) was less than 10%. The results obtained from this experiment were in line with the results of Wajid et al. (2014), where the CROPGRO-Cotton model was able to reasonably predict the days to maturity under different nitrogen levels with a deviation of 2 days.

Total biomass

Simulated values of the CROPGRO-Cotton model were compared with the observed above-ground biomass at harvest of cotton under

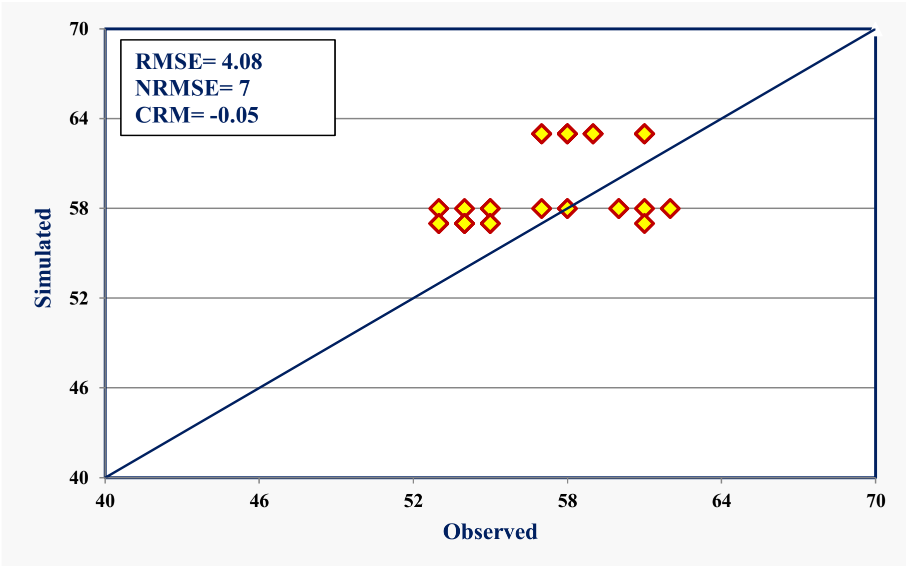

FIGURE 1
Simulated and observed flowering days [days after sowing (DAS)] of *Bt* cotton using the CROPGRO-Cotton model under different dates of sowing, plant densities, and nitrogen levels.

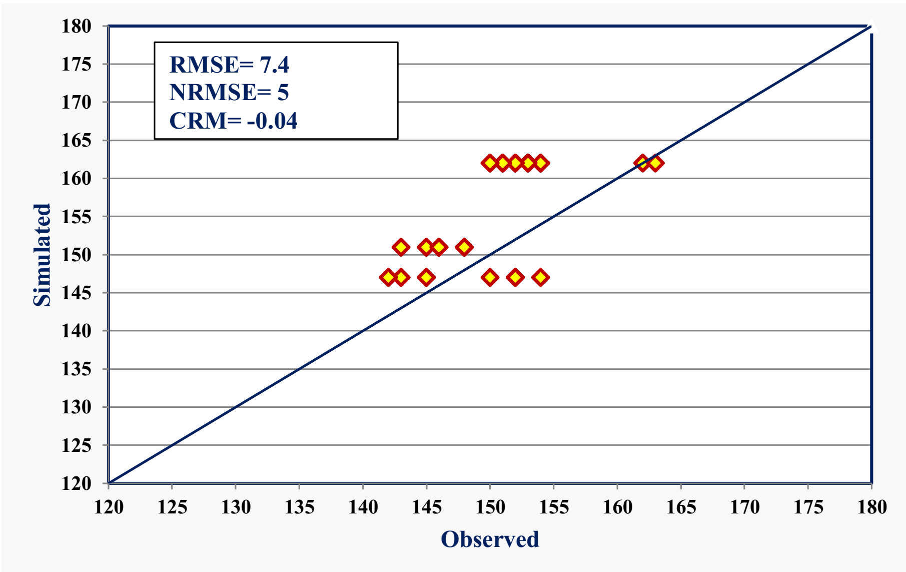

FIGURE 2
Simulated and observed maturity day (DAS) of *Bt* cotton using CROPGRO-cotton model under different dates of sowing, plant densities, and nitrogen levels.

different dates of sowing, plant densities, and nitrogen levels (Figure 3).

The simulation of above-ground biomass was considered good with an NRMSE value of 19%, an RMSE value of 1,292 kg, and a CRM value of 0.04. Positive CRM value showed the tendency of the model to under-predict the above-ground biomass by 4%. Reasonable prediction of above-ground biomass across different dates of sowing, plant densities, and nitrogen levels indicated that the model could predicted dry matter production during the growing season as good, with an NRMSE value of less than 20%.

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

Experimental data obtained on seed cotton yield under different dates of sowing, plant densities, and nitrogen levels were compared with simulated values of the CROPGRO-Cotton model, analyzed statistically, and depicted in Figure 4.

Simulated seed cotton yield was closely matched with the observed data, with an RMSE value of 415 kg and an NRMSE value of 22%, showing a fair model simulation. However, the positive CRM value (0.003) indicated the tendency of the model to under-predict the seed

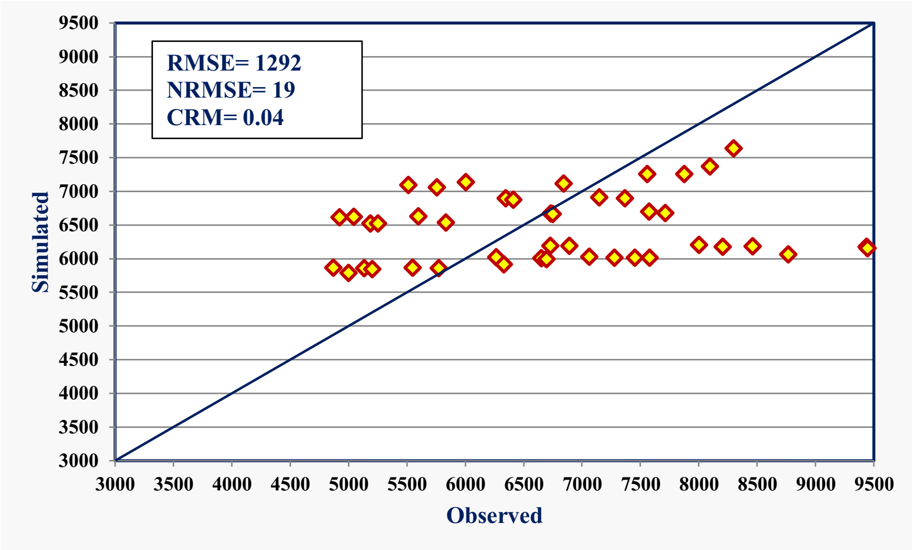

FIGURE 3
Simulated and observed above-ground biomass (kg ha^{-1}) of *Bt* cotton using the CROPGRO-Cotton model under different dates of sowing, plant densities, and nitrogen levels.

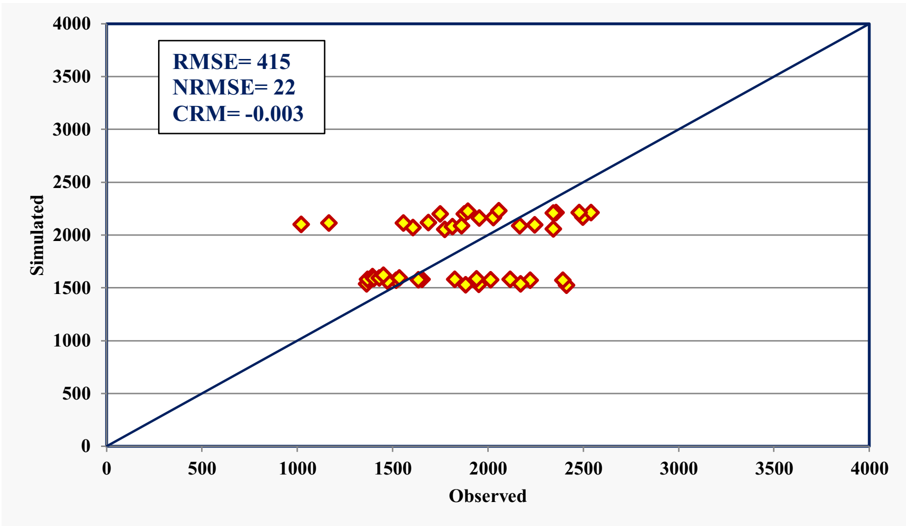

FIGURE 4
Simulated and observed seed cotton yield (kg ha^{-1}) of *Bt* cotton using CROPGRO-cotton model under different dates of sowing, plant densities, and nitrogen levels.

cotton yield by 0.3%. The results from model evaluation indicated an acceptable agreement between simulated and observed values for the seed cotton yield of the US7067 cotton cultivar in Raichur conditions.

Application of the CROPGRO-cotton model to identify optimum sowing time, plant density, and nitrogen level

Optimum sowing time for cotton

An analysis was carried out using the DSSAT seasonal analysis tool, and simulations were generated. The simulation scenarios of different sowing times that were subjected to a one-way analysis of variance and means were compared with Tukey's HSD test (Table 3). The higher mean seed cotton yield (1,741 kg ha^{-1}) was predicted with the second fortnight of June sowing, followed by the first fortnight of June and the first fortnight of July sowing, and it was significantly superior to the second fortnight of July, the first fortnight of August, and the second fortnight of August sowing. Lower mean seed cotton yield (524 kg ha^{-1}) was predicted with the second fortnight of August sowing, and it was at par with the first fortnight of August.

The graphical representation of simulation scenarios showed that the mean seed cotton yield was influenced by different dates of sowing (Figure 5). In the second fortnight of June, sowing exhibited considerably less variability with a high mean seed cotton yield than all other sowing

TABLE 3 Tukey's test (HSD) for seed cotton yield (kg ha^{-1}) under different sowing times.

Sowing time	Mean seed cotton yield (kg ha^{-1})	Tukey's grouping	
D1: First fortnight of June	1,681	A	
D2: Second fortnight of June	1,741	A	
D3: First fortnight of July	1,623	A	
D4: Second fortnight of July	1,483		B
D5: First fortnight of August	873	C	
D6: Second fortnight of August	524	C	

Mean values with the same letter are not significantly different.

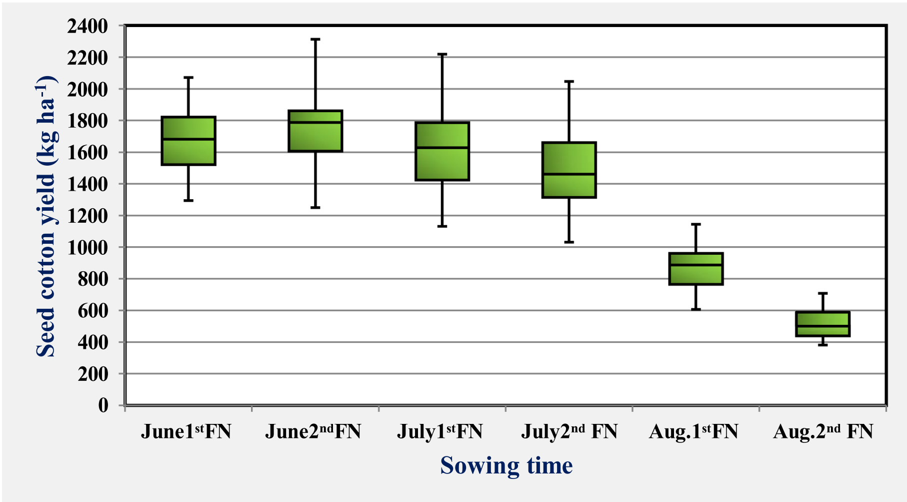

FIGURE 5
Simulated seed cotton yield for cotton under varied sowing dates (box limits represent the 25th and 75th percentiles, box central line represents the median, and whiskers represent the minimum and maximum values).

TABLE 4 Tukey's test (HSD) for seed cotton yield (kg ha^{-1}) under different plant densities.

Plant density	Mean seed cotton yield (kg ha^{-1})	Tukey's grouping	
P6:74,074 plants ha^{-1} (90 cm × 15 cm)	2,225	A	
P5:37,037 plants ha^{-1} (90 cm × 30 cm)	2005	A	
P4:24,691 plants ha^{-1} (90 cm × 45 cm)	1779		B
P3:18,518 plants ha^{-1} (90 cm × 60 cm)	1,681		B
P2:14,814 plants ha^{-1} (90 cm × 75 cm)	1,596	C	
P1:12,345 plants ha^{-1} (90 cm × 90 cm)	1,515	C	

Mean values with the same letter are not significantly different.

dates, as the smaller variance was associated with its assured average yield. At later dates of sowing (in August), a lower mean seed cotton yield was predicted.

Optimum plant density for cotton

Simulation results of varied plant densities were analyzed statistically and shown in Table 4. The higher mean seed cotton yield (2,225 kg ha^{-1}) was predicted with P6: 74,074 plants ha^{-1} (90 cm × 15 cm) and was at par with P5: 37,037 plants ha^{-1} (90 cm × 30 cm). However, P1: 12,345 plants ha^{-1} (90 cm × 90 cm) predicted a lower mean seed cotton yield (1,515 kg ha^{-1}) and was at par with P2: 14,814 plants ha^{-1} (90 cm × 75 cm).

The graphical representation of simulation scenarios showed that the mean yield increased consistently with an increase in plant densities up to P6: 74,074 plants ha^{-1} (90 cm × 15 cm). The box plots showed that crops grown at plant densities of P5: 37,037 plants ha^{-1} (90 cm × 30 cm) to P6: 74,074 plants ha^{-1} (90 cm × 15 cm) were considerably more variability than all other plant densities (Figure 6). Higher yields were obtained at higher plant densities, which might be due to the higher plant population.

Similarly, the simulation for optimum plant density in cotton through a seasonal analysis of the CROPGRO-Cotton model revealed an increase in seed cotton yield with increased plant population (Nagender et al., 2017).

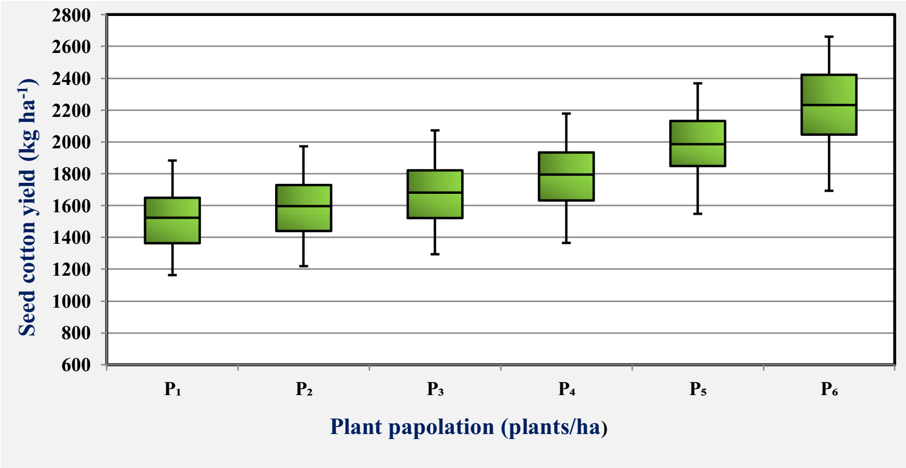

FIGURE 6
Simulated seed cotton yield for cotton under varied plant densities (box limits represent the 25th and 75th percentiles, box central line represents the median, and whiskers represent the minimum and maximum values).

TABLE 5 Tukey's test (HSD) for seed cotton yield (kg ha^{-1}) under different nitrogen levels.

Nitrogen (kg ha^{-1})	Mean seed cotton yield (kg ha^{-1})	Tukey's grouping	
N7: 300	1,682	A	
N6: 250	1,682	A	
N5: 200	1,681	A	
N4: 150	1,677	A	
N3: 100	1,663	A	
N2: 50	1,518		B
N1: 0	810		C

Mean values with the same letter are not significantly different.

Optimum nitrogen level for cotton

Simulation results of different levels of nitrogen were analyzed statistically and presented in Table 5. The highest mean seed cotton yield (1,682 kg ha^{-1}) was predicted with N6: 250 kg N ha^{-1} and N7: 300 kg N ha^{-1} and were on par with N3:100 kg N ha^{-1}, N4: 150 kg ha^{-1}, N5: 200 kg N ha^{-1}, which further indicates that there was no further increase in yield after application of 250 kg N ha^{-1}. However, a significantly lower mean seed cotton yield (810 kg ha^{-1}) was predicted with N1: 0 kg N ha^{-1}.

The simulation scenarios showed that the median seed cotton yield showed a significant difference by graded levels of nitrogen application from 0 kg N ha^{-1} to 100 kg N ha^{-1} (Figure 7). Further increases in nitrogen level from 150 to 250 kg ha^{-1} showed little effect in the mean seed cotton yield. Across all levels of nitrogen application, there was higher yield variability, indicating an increased downside risk for achieving low seed cotton yields.

Conclusion

The CROPGRO-Cotton model effectively simulated phenology and yield components of cotton under diverse management conditions, demonstrating its utility for strategic crop management. Early sowing (late June), high plant density (~74,000 plants ha^{-1}), and nitrogen application of 250 kg ha^{-1} were identified as optimal for maximizing seed cotton yield in semi-arid environments. These results provide a strong basis for model-assisted decision-making in cotton cultivation. Based on seasonal analysis using the CROPGRO-Cotton model, a higher seed cotton yield was obtained when the crop was sown in the second fortnight of July under semi-arid conditions of Karnataka. Based on seasonal analysis, the simulation scenarios showed that the median seed cotton yield increased consistently with an increase in plant densities. However, an incremental increase in nitrogen levels from 100 to 250 kg ha^{-1} did not show a significant influence on predicted seed cotton yield.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

LS: Writing – original draft, Writing – review & editing. NA: Writing – review & editing. GS: Writing – review & editing. MA:

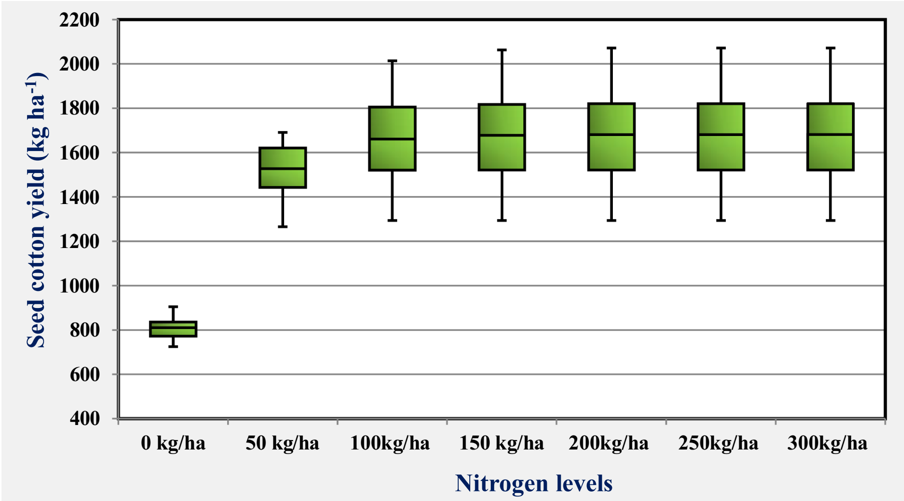

FIGURE 7
Simulated seed cotton yield for cotton under varied nitrogen levels (box limits represent the 25th and 75th percentiles, box central line represents the median, and whiskers represent the minimum and maximum values).

Writing – review & editing, Supervision, Validation. MU: Writing – review & editing. VH: Writing – review & editing. RR: Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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