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Adapting DSSAT Model for Simulation of Cotton Yield for Nitrogen Levels and Planting Dates

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ABSTRACT

The DSSAT module for Cotton Crop Modeling has been widely evaluated as a tool to predict the effect of climate change on productivity. A 2-yr multifactorial experiment was conducted at three locations of Pakistan (Faisalabad, Sahiwal, and Multan) to test and validate this model for dynamic simulation of growth, development, and seed-cotton (*Gossypium hirsutum* L.) yield of cultivars (3) at varying N increments (three levels) sown at two different timings (1 May and 1 June). The model was first calibrated with field data collected during 2014 based on the best performing treatment (May sown and 200 kg N ha^{-1}). Data of year 2015 was then used for further validation. Modeled values of various phenological attributes (e.g., days to anthesis and maturity) by model were reliable with recorded data, having root mean square error (RMSE) less than 2 d during both years. The RMSE values for total dry matter and seed-cotton yield were reasonably good (278–573 kg ha^{-1} and 237–422 kg ha^{-1}, respectively). Applying 1980 to 2015 climate histories for the three regions, we found Faisalabad to be vulnerable up to 23.0% reduction of yield followed by Multan (14.9%), whereas the Sahiwal region is modeled as much more resilient, with less than 5% predicted reductions in yield. Finally, we found that strategic cultivar choice and timing of planting can alleviate many of the adverse impacts of changing climates on cotton yield. We conclude that the DSSAT model can be effective as a tool to make strategic cotton planting choices under changing climates.

Core Ideas

- Experiment was conducted to test and validate DSSAT model for dynamic simulation of growth, development, and seed-cotton yield.
- Simulated values of days to anthesis, maturity, dry matter, and yield by model were reliable with recorded data.
- Seasonal analysis showed 23.0, 4.2, and 14.9% yield reduction at Faisalabad, Sahiwal, and Multan, respectively under future changing climate.
- Strategy analysis showed that May sown of cultivar FH-142 at Faisalabad and Sahiwal and MNH-886 at Multan with 200 kg N ha^{-1} can be a viable option to get maximum yield.

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The economy of Pakistan is critically dependent on the agricultural sector with cotton being the most important fiber crop. Cotton currently accounts for 1.5% in gross domestic product and 7.1% of value added in agriculture (Government of Pakistan, 2015). Pakistan is the world's fourth biggest cotton-producing country after China, India, and the United States.

Cotton crop is directly affected by both climate (e.g., growing season precipitation and humidity) as well as agricultural practices (e.g., genotypes cultivated, sowing time). Given observed trends in changing climate, it has become a primary concern to better understand how agricultural practices interact with climate so as to begin to predict how practices must change given future climate change, to maintain yield. These issues are particularly important in regions such as Pakistan where mean yield (560 kg ha^{-1}) is much lower than other major cotton-producing countries.

A series of experiments have been conducted to evaluate the impact of climatic factors and agronomic practice on cotton growth and yield (Ali et al., 2004; Arshad et al., 2007). However, leveraging long-term climatic observations and agricultural yield data, along with long-term experiments under various agro-ecological conditions of Pakistan, are needed to predict the capacity of agronomic management to compensate for climate variability and predicted climate change.

Three primary attributes impact cotton yield in Pakistan: weather (growing season temperature and moisture patterns), crop genetics (i.e., cultivars planted), and agricultural practices (ie, sowing date, fertilization levels). Weather significantly affects cotton growth and yield. Variations in daily temperature and moisture impact cotton from planting through harvest. Cotton yield also varies among cultivars that differ in how efficiently they convert radiant light to photosynthesis (Wajid et al., 2010). However, research on site specific and climate resilient cultivars can help maximize crop yield. Third, agricultural practices, can offset environmental stresses through adjusting planting times and fertilization application. Sowing date affects growth and development through the conversion of assimilates from biomass to economic yield (Luo et al., 2014).

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Abbreviations: LAI, leaf area index; SCY, seed cotton yield; TDM, total dry matter.

Early sown or late sown cotton can result in reduced biomass and yield depending on the weather. Adjustment of optimum sowing date can enhance biomass accumulation that ultimately leads to increased crop yield. Cotton seed yield can also be reduced through excess available N, which causes the shifting of balance between vegetative and reproductive growth by increasing vegetative growth (Howard et al., 2001). Nitrogen dose also relates to the photosynthetic activity depending on the climatic conditions (Arshad et al., 2016). Different scientists suggested different increments of N but appropriate use can increase yield as well as reduce cost of production.

Crop growth models allow factoring complex attributes of plant growth to study the interaction of environmental, physiological, and hereditary qualities and play a vital role in choosing agronomic management strategies (Mubeen et al., 2013). Crop growth models have been utilized widely during the last decade as a part of agriculture, to evaluate the response of crops to distinctive abiotic variation (Wajid et al., 2013). Similarly crop models can simulate responses of cotton from sowing through harvest for quantification of development and yield (Kakani et al., 2005). Model simulations are viewed as influential tools for studying the impacts of different aspects on quality characters in cotton crop (Jamieson and Semenov, 2000; Rinaldi et al., 2003). In addition to variety maturity profile and air temperature, cotton boll development period module also considers N nutrition variables and solar radiation in these models (Mahamood et al., 2003). According to Hoogenboom et al. (2011), solar radiation, minimum and maximum temperature, cultivar characteristics and components of crop management are the most important parameters in crop growth models. Li et al. (2009) worked on a semi empirical model and observed effect of N fertilizer on growth, development, and seed cotton yield.

The Cropping System Model (CSM)–CROPGRO-Cotton model is part of the suite of crop simulation models that simulates growth, development, and yield of cotton for different weather and soil conditions and management practices (Ortiz et al., 2009; Jones et al., 2003). CROPGRO-Cotton is a newly developed crop model and has many simulation options (Pathak et al., 2009). CROPGRO (DSSAT) is one of the first packages that allows modification of a weather simulator to evaluate the performance of models under projected future climate (Murthy, 2004).

We conducted this study with the objective to adapt CROPGRO-Cotton model for simulation of growth, development, and seed cotton yield under different climatic conditions. Our intent is to consider how projected future climatic variation may impact cotton yields. To understand this, we calibrate the model and evaluate important predictor variables using recent (1980–present) historical climate data and crop yield patterns to calibrate our model.

MATERIALS AND METHODS

A field experiment was conducted in 2014 and 2015 at three locations: Faisalabad (Agronomy Farm), Sahiwal (Cotton Research Station), and Multan (Central Cotton Research Institute) (Table 1). The experiment was conducted as a split-split plot design in both seasons with (a) two sowing dates (SD_1 = 1 May and SD_2 = 1 June) in main plots; (b) three cultivars (V_1 = FH-114, V_2 = FH-142, and V_3 = MNH-886) as subplots; and (c) three N levels (N_1 = 150 kg ha^{-1}, N_2 = 200 kg ha^{-1} (recommended dose/control) and N_3 = 250 kg ha^{-1}) as sub-subplots. Each experiment consisted of three replicates with a plot size of 3 by 10 m.

Crop Husbandry

The crop husbandry operations during both the seasons followed the normal recommendations of the Pakistan Agriculture Department with the exception of experimental treatment conditions. Sowing dates, varieties, and N levels were applied according to the treatments under study. Plots were sown uniformly at 30 cm plant-to-plant distance and 75 cm between rows, using the bed-furrow method with a seed rate of 25 kg ha^{-1}. Nitrogen in the form of urea was applied in three splits. Irrigation (seven irrigations of 75 mm each), weeding, and other agronomic practices were uniform for all the treatments and conformed to Agriculture Department standards.

Observations

Half of the area in each experimental plot was used for growth and remaining half was utilized for recording yield data. All plants were picked manually for plot yield estimation. Three randomly selected plants were harvested from each plot at 20 d intervals for growth data. Fresh weight of each fraction (stem, leaf, squares, flowers, and boll) was recorded. Samples were oven dried in an oven at 65°C to get a constant dry weight. Total dry matter (TDM) of plant was calculated at each harvest. A 10 g leaf sample was used to measure leaf area with leaf area meter (LICOR, model 3100) and converted to leaf area of whole plant.

Crop Growth Modeling

Field data were used to calibrate (2014) and validate (2015) the CROPGRO-Cotton model. Standard meteorological, soil, plant characteristic, and crop management data were obtained for respective locations and used as input data for the model. Decision Support System for Agro technology Transfer (DSSAT) was used for estimation of crop genetic coefficients using sensitivity analysis selecting the best treatment simultaneously at three sites.

Table 1. Soil and climatic attributes of three locations (Faisalabad, Sahiwal, and Multan).

Locations	Latitude °N	Longitude °E	Altitude	Climate	Soil pH	OM	P	K
			m			%	mL L^{-1}	
Faisalabad	31°26	73°04	184	Dry (semiarid)	8.0	0.35	3.2	180
Sahiwal	30°40	73°06	172	Wet (semiarid)	8.4	0.42	14.8	200
Multan	30°12	71°26	123	Dry (arid)	8.63	0.63	8.64	143

Model Calibration and Evaluation

Calibration is a process of adjusting model parameters to best replicate site-specific conditions. It is also useful to factor in genetic coefficients for new cultivars when, such as this case, there is information about the performance of different cultivars. Our model was calibrated with data (phenology, biomass, leaf area index [LAI], and yield) collected during 2014 for the 1 May sowing and 200 kg N ha^{-1} (SD_1N_2). We used this treatment combination for calibration because it performed the best in field trials at all locations. Cultivar coefficients included critical short daylength (CSDL) and PPSEN slope of the relative response to development to photoperiod with time to PODOR, the time required for cultivar to reach final pod load under optimal conditions (Photo thermal days). Fifteen coefficients control the phenology, growth, and seed cotton yield (Hoogenboom et al., 1994). We calculated coefficients for our three cotton cultivars (Table 2). To check the precision and accuracy of the model simulations, we compared model outputs from the field data for remaining 17 treatments. We used the data on phenology, development, and growth for year 2015 for validation of CROPGRO-Cotton model. Simulation performance was evaluated by calculating different statistical indices such as RMSE (Wallach and Goffinet, 1989), index of agreement (*d*) (Willmott, 1981) and correlation index or coefficient of determination (R^2) (Menard, 2000) across locations. For individual treatments error (%) between simulated and observed values were calculated. These measurements were calculated as:

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(Pi - Oi)^2}{n}}$$

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

$$R^2 = 1 - \left[\frac{\sum_{i} (Oi - Pi)^2}{\sum_{i} (Oi - Mi)^2} \right]$$

where P_i, O_i, and M_i are the predicted, observed, and mean values for studied treatments, respectively, and *n* is the number of observations. We used a linear regression between predicted and observed seed cotton yield and total dry matter at harvest to evaluate the validity of model by sites. Improving model performance is indicated as d and R^2 value proceed to one while RMSE and MPD approach zero.

Meteorology

Meteorological readings from each experimental site considered for this study were: maximum and minimum temperatures (°C), solar radiation (MJ m^{-2}), and precipitation (mm). Higher maximum temperature and less rainfall were

Table 2. Genetic coefficients for three cotton cultivars.

Ecotype no.	Variety name	CSDL†	PPSEN	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF	LFMAX	SLAVR	SIZLF	XRFT	WTPSD	SFDUR	SDPDV	PODUR
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
IB01	FH-114	23	0.01	51	22	24	55	72	1.40	137	260	0.70	0.180	35	25	8
IB02	FH-142	23	0.01	49	16	20	52	75	1.83	135	250	0.90	0.180	38	30	20
IB03	MNH-886	23	0.01	52	23	30	48	79	1.55	127	230	0.76	0.188	38	27	25

† CSDL = Critical short day length below which reproductive development progresses with no day length effect (for short day plants).
PPSEN = Slope of the relative response of development to photoperiod with time (positive for short day plants) (1 h^{-1}).
EM-FL = Time between plant emergence and flower appearance (R1) (photo thermal days).
FL-SH = Time between first flower and first pod (R3) (photo thermal days).
FL-SD = Time between first flower and first seed (R5) (photo thermal days).
SD-PM = Time between first seed (R5) and physiological maturity (R7) (photo thermal days).
FL-LF = Time between first flower (R1) and end of leaf expansion.
LFMAX = Maximum leaf photosynthesis rate at 30°C, 360 mL L^{-1} CO_2, and high light (mg CO_2 m^{-2}–s).
SLAVR = Specific leaf area of cultivar under standard growth conditions (cm^2 g^{-1}).
SIZLF = Maximum size of full leaf (three leaflets) (cm^2).
XRFT = 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 (no. pod^{-1}).
PODUR = Time required for cultivar to reach final pod load under optimal conditions (photothermal days).

reported in 2014 than in 2015 (13, 52, and 51% more rainfall at Faisalabad, Sahiwal, and Multan, respectively). These differences affected cotton growth and yield (Fig. 1).

RESULTS

The DSSAT Model performed well under climatic conditions of Faisalabad, Sahiwal, and Multan. The model predicts time to flowering, maturity, and yield better than some emergent properties like dry matter biomass using derived cultivar coefficients (Table 2). Phenology of cotton is altered most by planting date, but also a little by N treatment and cultivar. The model slightly under simulated seasonal LAI at Multan while slightly over simulated seasonal total dry matter at Faisalabad (Fig. 2). Evaluation results of crop phenology were good having R^2 value greater than 0.8 for most of the parameters (Fig. 3) and values close to the 1:1 line.

Days Taken to Flowering

The CROPGRO-Cotton under DSSAT realistically simulated days taken to flowering (Table 3) for the best treatment (SD_1N_2) almost equally for all three locations. The RMSE for calibrated treatment was 0.57, 0.81 and 0.81 for observed and simulated days to flowering of cultivars FH-114, FH-142, and MNH-886, respectively. At a lower dose of N (150 kg ha^{-1}), days taken to flowering were earlier than the crops having a higher dose of N (250 kg ha^{-1}). Similar trends were observed for all the cultivars. The crop model showed almost the same days of flowering as observed. Results from the crop model evaluation showed that the crop reached flowering stage between 65 and 69 d at Faisalabad, 67 to 70 d at Sahiwal and 65 to 69 d after sowing at Multan in all treatments for first May sown crop and 63 to 68 d at Faisalabad, 65 to 68 d at Sahiwal and 57 to 61 d after sowing at Multan in all treatments

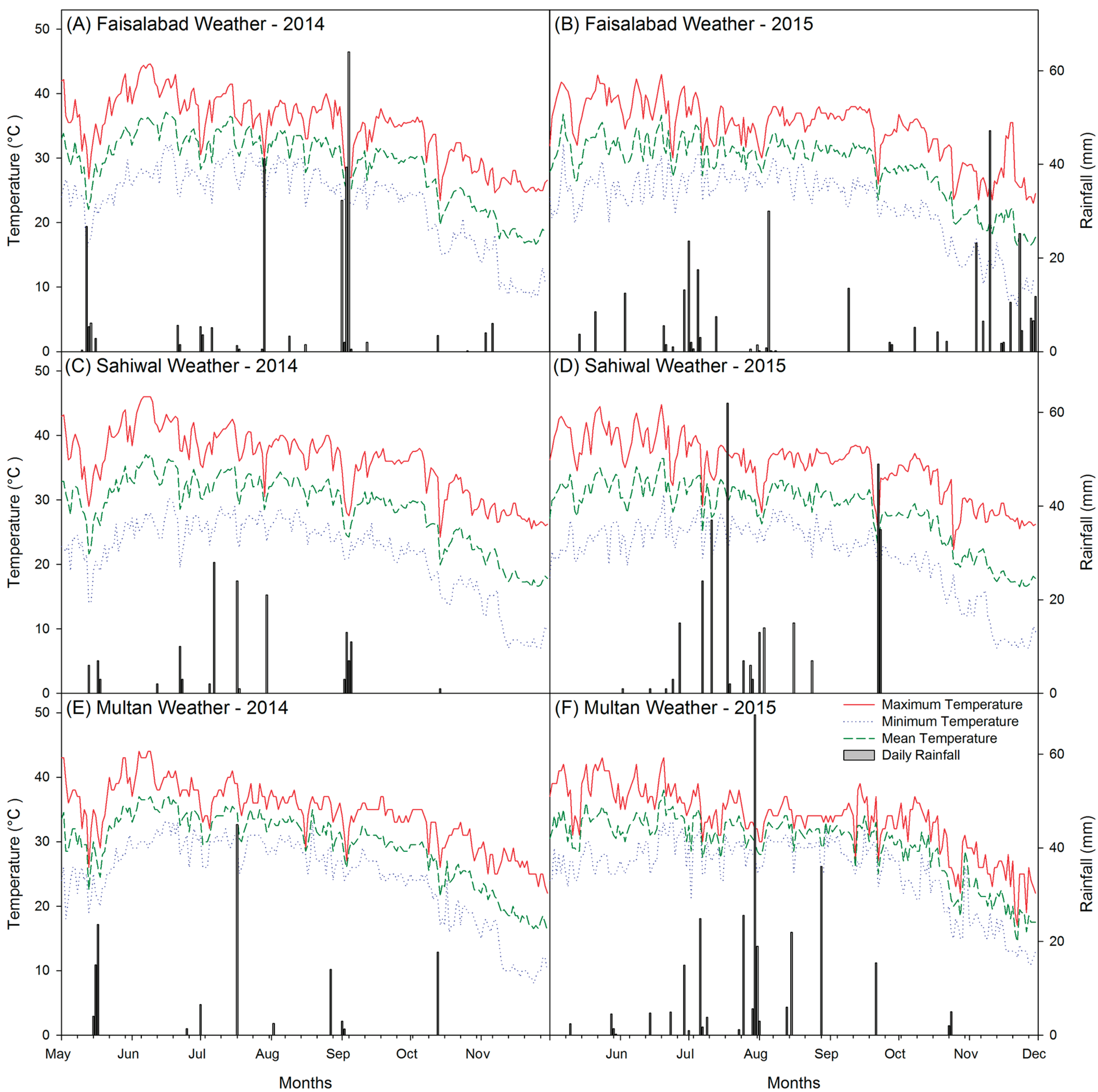

Fig. 1. Weather of summer season 2014 and 2015 for (A, B) Faisalabad, (C, D) Sahiwal, and (E, F) Multan, respectively.

for first June sown crop during 2014. On the other hand, observed days for 1 May and 1 June sown crop ranged from 65 to 68 d (Faisalabad), 66 to 69 d (Sahiwal), 56 to 61 d (Multan) and 61 to 68 d (Faisalabad), 65 to 67 d (Sahiwal), 57 to 61 d (Multan), respectively. Thus the DSSAT model worked well under three different environmental conditions. Root mean square error values of 1 May and 1 June sown crop were between 0.61 and 1.0 and 0.94 and 1.0, respectively, during 2014 (Table 4) while index of agreement (*d*) of 1May and 1 June sown crop was greater than 0.80 for all locations (Table 5).

Validation of model during year 2015 showed that the cotton crop sown on 1 May took 64 to 70 d (Faisalabad), 75 to 79 d (Sahiwal) and 66 to 72 d (Multan) days after sowing for flowering while the crop sown of first June takes 61 to 67 d (Faisalabad), 59 to 71 d (Sahiwal) and 58 to 67 d (Multan) days after sowing for flowering. The observed values ranged from 54 to 79 d for all locations, closer to model results. This confirms the usefulness of the model with an independent set of data. Root mean square error values of 1 May and 1 June sown crop were between 1.15 and 1.73 and 1.15 and 1.69, respectively during 2015 (Table 4). The index of agreement (*d*) of 1 May and 1 June sown crop was greater than 0.80 for all locations except 1 May sown crop at Sahiwal. At that location the *d* value was 0.74 (Table 5).

Days Taken to Crop Maturity

The model simulated same number of days for maturity as the observed ones for best treatment (Table 3). The crop sown on 1 May took more days to complete its growth period than the crop sown late on 1 June. According to model simulations, the May sown crop matured in 149 to 158 d (Faisalabad), 150 to 158 d

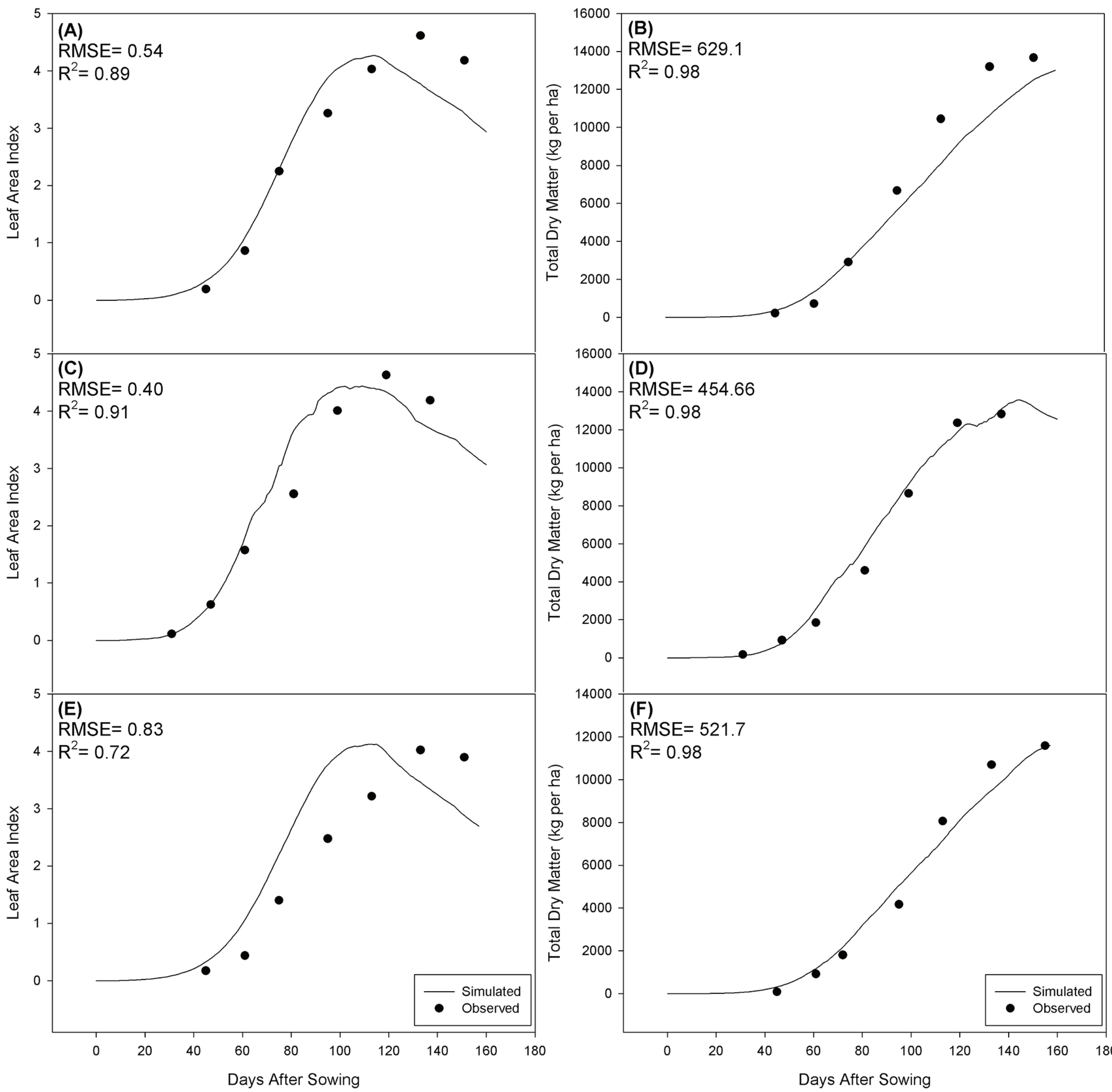

Fig. 2. Calibrated graphs of leaf area index and total dry matter for (A, B) Faisalabad, (C, D) Sahiwal, and (E, F) Multan for cultivar FH-142 with 200 kg ha^{-1} sown on 1 May.

(Sahiwal) and 156 to 161 d (Multan) whereas June sown crop matured in 143 to 151 d at Faisalabad, 147 to 153 d at Sahiwal and 145 to 152 d at Multan. The observations for May and June sown crop for maturity were 143 to 155 d (Faisalabad), 149 to 159 d (Sahiwal) and 143 to 160 d (Multan), respectively in year 2014, Thus the DSSAT model realistically simulated maturity date for all three environmental conditions. Higher N showed a 1 to 2 d delay in maturity according to simulation results. On the other hand, all the cultivars except FH-142 showed a difference of 1 d in simulated and observed. The model over simulated the number of days to maturity. Root mean square error values ranged between 1.06 and 1.45 and 1.56 and 1.97 for 1 May and 1 June sown crop respectively during this year (Table 4). The index of agreement (*d*) was greater than 0.80 except 1 June sown crop at Faisalabad (Table 5). Thus the model simulated crop maturity days quite well for Faisalabad and Multan while slightly over simulated the number of days for Sahiwal.

Validation results showed that cotton crop sown on 1 May took 159 to 162 d (Faisalabad), 161 to 169 d (Sahiwal) and 158 to 162 d (Multan) days after sowing for maturity. The crop sown on 1 June takes 146 to 156 d (Faisalabad), 153 to 167 d (Sahiwal) and 149 to 155 d (Multan) days from sowing to maturity. The observed values ranged from 145 to 169 d for all locations, somehow closer to simulation results. This ensured higher performance of the model. Root mean square error values of 1 May and 1 June sown crop were between 1.85 and 2.40 and 1.69 and 2.72, respectively, during 2015 (Table 4). The index of agreement (*d*) values of the 1 May and 1 June sown crops were greater than 0.80 for Faisalabad and Sahiwal. For Multan, the calculated *d* value was greater than 0.70 (Table 5).

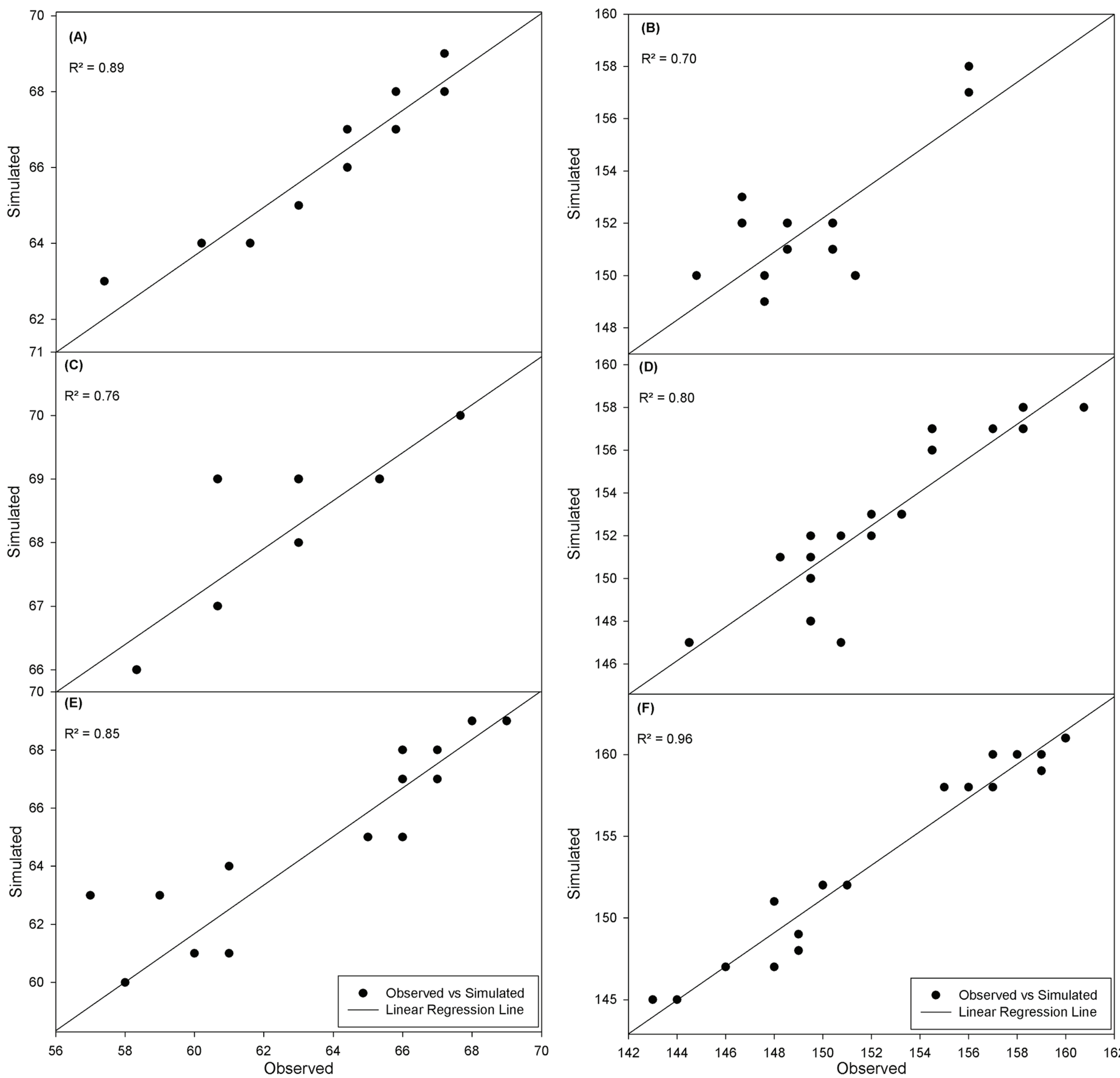

Fig. 3. Relationship between simulated and observed values of anthesis date and maturity date for cotton cultivars sown at (A, B) Faisalabad, (C, D) Sahiwal, and (E, F) Multan, respectively during growing season of 2014.

Leaf Area Index

The model slightly overpredicted LAI value for Multan while simulated almost the same value as measured for Faisalabad and Sahiwal. The calibrated values of LAI were 3.97, 4.42, 4.36 (observed) and 4.32, 4.28, 4.67 (simulated) having RMSE of 0.39, 0.23, 0.40 for cultivars FH-114, FH-142, and MNH-886, respectively. Higher N showed higher values of simulated LAI. Cultivar FH-142 showed higher LAI in simulated and observed results. Root mean square error ranged between 0.37 to 0.62 and 0.48 to 0.61 for 1 May and first1 June sown crop, respectively, while index of agreement (*d*) was greater than 0.70. The model showed LAI values slightly under simulated for 1 June sown crop. Validation results showed that the cotton crop sown on 1 May gave higher values of LAI at all locations as compared to crop sown on 1 June and observed values were somewhat closer to simulation results. The (MSE)of 1 May and 1 June sown crop was 0.21 to 0.61 and 0.40 to 0.51, respectively, during 2015 (Table 4). The index of agreement (*d*) values of 1 May and 1 June sown crop were greater than 0.75 for all locations except June sown crop at Sahiwal. There the calculated *d* value was greater than 0.70 (Table 5).

Total Dry Matter

The DSSAT model overestimated total dry matter (TDM) relative to the observed values indicating that cultivars FH-142 has greater potential for producing TDM. Simulated and observed TDM values were similar (Fig. 3). The model slightly under simulated TDM for Faisalabad. Overall calibrated value was 11608, 12691, 12607 (observed) and 11838, 12390, 12062 (simulated) having RMSE of 273, 407, and 581 kg ha^{-1} for FH-114, FH-142, and MNH-886, respectively. Higher N showed higher value of TDM according to simulation

Table 3. Comparison between simulated and observed values of different variables for year 2014.

Variables	Observed	Simulated	R^2	*d* statistics	RMSE
Cultivar FH-114					
Anthesis days	67	68	0.99	0.84	0.57
Total dry matter, kg ha^{-1}	11,608	11,838	0.99	0.91	273.54
Seed cotton yield, kg ha^{-1}	3,280	3219	1	0	153.27
Leaf area index maximum	3.97	4.32	0.22	0.29	0.39
Maturity days	159	160	0.90	0.90	0.92
Cultivar FH-142					
Anthesis days	65	66	0.75	0.80	0.81
Total dry matter, kg ha^{-1}	12,691	12,390	0.99	0.92	407.28
Seed cotton yield, kg ha^{-1}	4,195	3,903	0.82	0.84	448.40
Leaf area index Maximum	4.42	4.28	0.73	0.75	0.233
Maturity days	149	149	1	1	0
Cultivar MNH-886					
Anthesis days	69	69	0.25	0.63	0.81
Total dry matter, kg ha^{-1}	12,607	12,062	0.99	0.71	581.50
Seed cotton yield, kg ha^{-1}	3,601	3,259	0.70	0.65	401.01
Leaf area index Maximum	4.36	4.67	0.23	0.35	0.40
Maturity days	158	160	0.80	0.70	1.12

Table 4. Root mean square error (RMSE) of different cotton variables sown at three locations during 2014 and 2015.

	Faisalabad				Sahiwal				Multan			
	2014		2015		2014		2015		2014		2015	
Variables	SD_1†	SD_2	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2
Anthesis days	0.61	0.94	1.15	1.37	1	0.94	1.73	1.15	1	1	1.42	1.69
Total dry matter	278	496	573	562	515	534	499	512	467	490	567	516
Cotton yield	288	276	301	422	197	412	357	177	237	419	304	376
Leaf area index	0.37	0.53	0.21	0.45	0.62	0.61	0.61	0.51	0.39	0.48	0.32	0.40
Maturity days	1.06	1.97	2.40	1.69	1.45	1.85	1.85	1.82	1.11	1.56	2.02	2.72

† SD, sowing dates.

Table 5. *d*-Statistics value of different cotton variables sown at three locations during 2014 and 2015.

	Faisalabad				Sahiwal				Multan			
	2014		2015		2014		2015		2014		2015	
Variables	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2	SD_1	SD_2
Anthesis days	0.93	0.93	0.91	0.83	0.84	0.81	0.74	0.97	0.86	0.92	0.83	0.94
Total dry matter	0.98	0.93	0.95	0.94	0.94	0.95	0.97	0.93	0.97	0.95	0.94	0.93
Cotton yield	0.71	0.78	0.84	0.71	0.84	0.73	0.83	0.79	0.77	0.70	0.80	0.74
Leaf area index	0.72	0.70	0.83	0.77	0.71	0.71	0.78	0.71	0.73	0.77	0.78	0.82
Maturity days	0.96	0.74	0.94	0.93	0.94	0.80	0.88	0.97	0.87	0.90	0.76	0.77

results. Cultivar FH-142 showed higher TDM in simulated and observed results. Root mean square error values ranged between 278 and 515 and 490 and 534 for 1 May and 1 June sown crop, respectively. The index of agreement (*d*) was greater than 0.90 for both sowing crop at all locations.

The model was validated with second year experiment. The crop sown on 1 May had a higher value of TDM at all locations as compared to crop sown on first1 June and observed values were closer to simulation results which shows high efficiency of model. Root mean square error (RMSE) of 1 May and 1 June sown crop was between 499 and 573 and 512 to 562, respectively, during 2015 (Table 4) while index of agreement (*d*) of 1 May and 1 June sown crop was greater than 0.90 for all locations (Table 5).

Seed Cotton Yield

Calibrated data showed that model simulated higher seed cotton yield (SCY) for cultivar FH-142 having N dose of 200 kg ha^{-1}. Overall calibrated value of cultivars FH-114, FH-142, and MNH-886 was 3280, 4195 3601 (observed) and 3219, 3903, 3259 (simulated) having RMSE of 153.27, 448.40 and 401.01 kg ha^{-1}, respectively. Optimum N showed higher value of SCY for 1 May sown crop while higher dose of N showed higher value of SCY according to simulation results. Model evaluation results indicated a high performance of the model. Root mean square error ranged between 197 and 288 and 276 and 419 for 1 May and 1 June sown crop, respectively. The index of agreement (*d*) was greater than 0.70 for both sowing crop at all locations.

Validation results showed that RMSE values of 1 May and 1 June sown crop were between 301 and 357 and 177 and 422, respectively, during 2015 (Table 4). The index of agreement (*d*) of 1 May and 1 June sown crop was less than 0.70 for all locations expect for 1 May sown crop at Faisalabad and Multan having *d* value greater than 0.80 (Table 5).

Climate Change Impact Assessment

Climate change impact assessment was analyzed using seasonal analysis tool of DSSAT model and climatic scenario was based on climatological relationships that gives a clear description of future climate. Based on future rises in temperature, rising CO_2, and decreases in rainfall, different values of higher temperature (0.5–3.5°C), elevated CO_2 (360–560 mL L^{-1}) and change in rainfall pattern (20% increase and 20% decrease) were evaluated.

With elevated CO_2 level, SCY will be increased while rises in temperature or reduction in rainfall will reduce crop yield. Under 2°C rise in temperature, 460 mL L^{-1} CO_2 and 20% less rainfall in early century (until 2039), Fig. 4A depicts the climate change impact on cotton crop sown at Faisalabad. Model results showed that there will be 23% yield loss Fig. 4B depicts the climate change impact on cotton crop sown at Sahiwal and model results showed that there will be 4.3% yield reduction. Figure 4C depicts the climate change impact on cotton crop sown at Multan and model results showed that there will be 14.9% yield loss. Strategy analysis showed that timely sown of cotton cultivar FH-142 in May with 200 kg N ha^{-1} can be a viable option to get maximum yield at Faisalabad and Sahiwal and while MNH-886 sown on 1 May at Multan with 200 kg N ha^{-1} can perform best under future changing climate.

DISCUSSION

CROPGRO-Cotton under DSSAT has been tested by researchers for growth and yield simulation of crop sown under different climatic conditions with different crop management practices (Jones et al., 2003; Ortiz et al., 2009; Pathak et al., 2009). CROPGRO-Cotton is capable of estimating climatic impacts on cotton crop (Murthy, 2004). Quantification of climatic impact on Pakistani cotton with the model is vitally important. First year data for calibration and second year data for validation has been used in many researches (Mubeen et al., 2013; Wajid et al., 2013). It provides a basis to evaluate model accuracy under various agro-climatic conditions. Li et al. (2009) confirmed that CROPGRO-Cotton simulates days to flowering and maturity close to the observed values with RMSE lower than 3 d. The DSSAT model overestimated TDM indicating that there is a potential for cultivars to produce more TDM under these sets of agro-ecological conditions. Model validation with independent sets of data from three sites in second year was also good. Experimental results are in line with Ortiz et al. (2009). The model predicted growth, development, and SCY with acceptable RMSE and good agreement of *d* statistic between observed and simulated data.

There is alot of difference between climatic conditions of Faisalabad and Sahiwal (Table 1). Sahiwal is the best area for sowing cotton as far as climate and soil conditions. The TDM and SCYs are always higher at Sahiwal location comparative to Faisalabad, so any anomaly or climatic shock brings drastic change in yields. Model results showed higher yield loss at Faisalabad (23.0%) and Multan (14.9%) in the future with a 2°C temperature rise, 460 mL L^{-1} CO_2 and 20% less rainfall. This is due to the dry semiarid and arid climatic conditions, respectively, that may induce heat stress. Sahiwal has wet semiarid climatic conditions. Mean monthly temperature regimes were higher during the first year (2014) and low during second year (2015) at Faisalabad comparative to Sahiwal. This resulted in less decrease in SCY at Sahiwal vs. Faisalabad. Also accumulated rainfall during the peak crop season was higher in Faisalabad and remained low in Sahiwal. So, model predictions for Faisalabad and Sahiwal were contrary to each other because of the rise in mean monthly temperature and rainfall distribution. This resulted in more boll shedding and less yield with greater increase in temperatures at Faisalabad. Model results are in line with Kakani et al. (2005); Pettigrew (2008) and Singh et al. (2007) who confirmed that heat stress and other climatic shocks will reduce crop yield.

CONCLUSION

Cultivar FH-142 with N rate of 200 kg ha^{-1} performed well in growth and development under agro-climatic conditions of Faisalabad and Sahiwal while cultivar MNH-886 with N rate of 200 kg ha^{-1} performed well under Multan conditions sown on 1 May. CROPGRO under DSSAT Model calibrated and validated well for all locations. Under future climate, yield will be reduced 23.0, 4.2, and 14.9% yield will be reduced at Faisalabad, Sahiwal, and Multan, respectively in the early century (until 2039) due to 2°C rise in temperature with 20% less rainfall having an elevated CO_2 level of 460 mL L^{-1}. Strategy analysis showed that timely sown cotton cultivar FH-142 at Faisalabad and Sahiwal and MNH-886 at Multan in month of

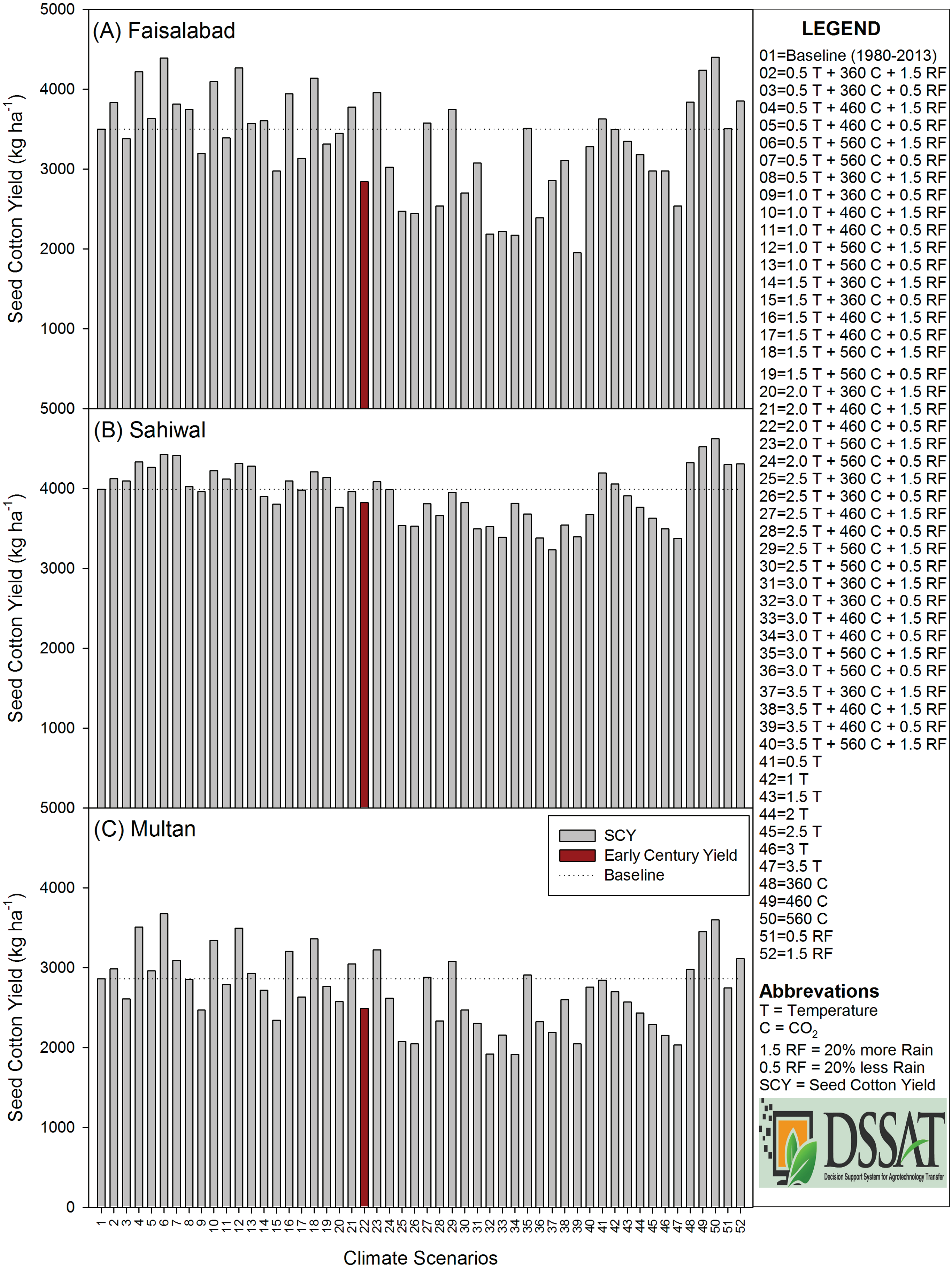

Fig. 4. Climate change impact on cotton yield at (A) Faisalabad, (B) Sahiwal, and (C) Multan.

May with 200 kg N ha^{-1} can be viable option to get maximum yield. The model can be helpful tool to predict crop yield under future climate to develop site-specific adaptation strategies for adjustment of sowing dates, irrigation, and fertilizer.

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