MAUSAM, **72**, 3 (July 2021), 627-634

633.51

Cotton phenology and production response to sowing time, row orientation and plant spacing using CROPGRO-cotton model

ABHISHEK DHIR, R. K. PAL*, P. K. KINGRA, S. K. MISHRA** and S. S. SANDHU

Department of Climate Change and Agricultural Meteorology, Ludhiana – 141 004, Punjab, India

**Punjab Agricultural University, Regional Research Station, Bathinda – 151 001, Punjab, India*

***Punjab Agricultural University, Regional Research Station, Faridkot – 151 203, Punjab, India*

(*Received 2 November 2020, Accepted 5 March 2021*)

e mail : gauravdhir45@gmail.com

सार – प्रस्तुत शोध पत्र में फसल की वृद्धि तथा सूक्ष्म जलवायविक परिवर्तन के फलस्वरूप उत्पादन का अनुमान लगाने के लिए कपास की फसल हेतु एक उपकरण के रूप में DSSAT मॉड्यूल का मूल्यांकन किया गया। इस संदर्भ में, पंजाब के बठिंडा और फरीदकोट में खरीफ 2018 के दौरान बीटी-कपास हाइब्रिड RCH 773 BGII को बुवाई की तीन तिथियों (30 अप्रैल, 15 मई तथा 30 मई), दो पंक्ति अभिविन्यास (उत्तर-दक्षिण और पूर्व-पश्चिम) तथा तीन पौधों की दूरी (67.5 से. मी × 45.0 से. मी., 67.5 से. मी. × 60.0 से. मी. तथा 67.5 से. मी. × 75.0 से. मी.) के साथ फैक्टोरियल स्प्लिट प्लॉट डिज़ाइन में बोया गया तथा तीन बार दोहराया भी गया। अनुकारी घटना-विज्ञान (simulated phenology) के संदर्भ में मॉडल आउटपुट और वास्तविक आंकड़ों के बीच अधिक निकटता दिखाई दी तथा प्रफुल्लन और परिपक्वता के लिए R^2 का मान क्रमशः बठिंडा में 0.51 और 0.61 तथा फरीदकोट में 0.43 और 0.87 पाया गया। अध्ययन स्थलों में, मॉडल तथा वास्तविक आंकड़ों के बीच LAI का मान क्रमशः 2.7 से 3.7 और 1.8 से 3.0 तक था। बठिंडा और फरीदकोट में अनुकारी कपास उत्पादन 30 अप्रैल (3053 और 3274 कि.ग्रा. प्रति हेक्टेयर) को बोई गई फसल में 30 मई (2392 और 2511 कि.ग्रा. प्रति हेक्टेयर) को बोई गई फसल की तुलना में सार्थक रूप से काफी अधिक पाया गया, जिसमें d-stat के उच्चतम मान (बठिंडा के लिए 0.84 और फरीदकोट के लिए 0.89) तथा R^2 (बठिंडा के लिए 0.75 और फरीदकोट के लिए 0.83) का मान भी अधिक पाया गया। इसके अलावा, दोनों स्थानों पर कपास का उच्चतम उत्पादन पूर्व-पश्चिम पंक्ति अभिविन्यास के अंतर्गत पौधों के मध्य व्यापक रिक्त स्थान (67.5 × 75 से. मी.) के साथ अनुकार किया गया। समग्र रूप से, कपास के घटना विज्ञान और उत्पादन के पूर्वानुमान के लिए CROPGRO - कपास मॉडल का उपयोग अनुसंधान उपकरण के रूप में तथा बदलती जलवायविक परिस्थितियों में कपास की उत्पादकता को बनाए रखने हेतु स्थल विशेष के चयन की रणनीतियों जैसे बुवाई का उपयुक्त समय, पंक्ति अभिविन्यास तथा पौधों के मध्य रिक्त स्थान आदि का पता लगाने के लिए किया जा सकता है।

ABSTRACT. The DSSAT module for cotton crop has been evaluated as a tool to predict the crop growth and yield response to microclimatic modifications. In this context, multi-location field experiments were laid out at Bathinda and Faridkot, districts of Punjab during *Kharif* 2018 with Bt-cotton hybrid RCH 773 BGII and sown at three times, *i.e.*, April 30, May 15 and May 30 with two row orientations (North-South : N-S and East-West : E-W) and three plant spacing's (67.5 cm × 45.0 cm, 67.5 cm × 60.0 cm and 67.5 cm × 75.0 cm) in factorial split plot design and replicated by three times. The model output in terms of simulated phenology showed close proximity over observed value having R^2 of 0.51 and 0.61 at Bathinda and 0.43 and 0.87 at Faridkot anthesis and maturity, respectively. Among study locations, observed and simulated LAI ranged from 2.7 to 3.7 and 1.8 to 3.0. Simulated seed cotton yield was found significantly higher with the crop sown on 30th April (3053 and 3274 kg ha^{-1}) than 30th May sowing (2392 and 2511 kg ha^{-1}) at Bathinda and Faridkot, respectively, which was in good agreement with observed yield having higher value of d-stat (0.84 for Bathinda and 0.89 for Faridkot) and R^2 (0.75 for Bathinda and 0.83 for Faridkot). Moreover, higher seed cotton yield was simulated under East-West row direction along with wider plant spacing (67.5 × 75 cm) at both locations. Overall, CROPGRO-cotton model can be used as research tool for the prediction of cotton phenology and yield and to explore site-specific adoption strategies such as appropriate sowing time, row orientation and plant spacing to sustain cotton productivity under changing climatic conditions.

Key words – CROPGRO-cotton model, Bt cotton hybrid, Sowing dates, Row orientation, Plant spacing, Phenology and seed cotton yield.

1. Introduction

The economy of India is fundamentally reliant on the farming sector. Cotton, being one of the most significant sources of fiber, food and feed, assumes a crucial place in rural and modern economy of India broadly known as the 'White Gold' or 'king of fibres'. The principle reason for cotton cultivation is fiber production. Cotton production assumes a fundamental place in Indian economy, as it provides work to a huge number of farmers and employees in the domestic textile industries. In India, it is evaluated that more than 5.8 million farmers are occupied with cotton production and around 40-50 million individuals are employed directly or indirectly by the cotton business (Kannan *et al*., 2017). To maintain sustainability of cotton production system, more precise water, nutrition and plant growth management are required. During 2017-18, cotton production was expected to be 377 lakh bales of 170 kg from 122 lakh hectares with a productivity of 524 kg lint ha^{-1} (Anonymous, 2017). Cotton, being considered as a predominant cash crop of the South-Western (S-W) region of Punjab, occupied 3.85 lakh ha area with 12 lakh bales production and 529 kg ha^{-1} productivity during 2017-18 (Anonymous, 2017).

To minimize the adverse affect of weather on cotton, there is a need to develop suitable adaptation strategies. For that, microclimatic modifications can be effective adaptation strategy. Alteration in sowing time, spacing and row orientation and appropriate cropping systems etc. are some of the microclimatic modification techniques that can be applied to make the optimum microclimate for optimum growth and development of crop (Kingra and Kaur, 2017; Sharma *et al*., 2018).

Cropping System Model-Crop Growth (CSM-CROPGRO)-Cotton is broadly used as a technological tool in favor of strategic decision-making that can be used for dryland as well as irrigated conditions to simulate the growth and development of cotton (Hoogenboom *et al*., 2010; Jones *et al*., 2003). CROPGRO-cotton model is also useful to simulate growth and development of cotton crop on daily scale and photosynthesis on hourly basis. CROPGRO-cotton model has been applied for a number of studies which includes cotton biomass and yield under different planting dates, varying nitrogen levels, temperature regimes, agronomic as well as economic evaluation of irrigation strategies and setting genetic coefficient under different dates of sowing for crop varieties (Pal *et al*., 2016; Kumar *et al*., 2017).

2. Materials and method

2.1. *Climatic conditions of the study regions*

The region of Bathinda (latitude 30.58° N, longitude 74.18° E, altitude 211 m above mean sea level) and Faridkot (latitude 30°40′ N, longitude 74°44′ E, altitude 200m above mean sea level) lies in the extreme South-West portion of Punjab. The annual normal rainfall of Bathinda and Faridkot is about 436 mm (65% rainfall received during S-W monsoon) and 433 mm (71% rainfall received during S-W monsoon season from July to September). Dust storms are a regular feature in summer season when the mercury sometime touches over 47.0 °C in the peak summer in May-June, however, in winter during December and January, the minimum temperature at night touches zero degree centigrade. The soil is mostly sandy at both the stations. The soil is moderately dark coloured and well drained. The N, P and K contents in the soil of both the districts are low, low to medium and medium to high respectively. The soils have sufficient contents of Fe, Cu, Zn and Mn for supply to crops (Yadav *et al*., 2018).

2.2. *Experimental details*

The field experiment was conducted in different Agroclimatic zones of Punjab at Punjab Agricultural University (PAU) Regional Research Station, Bathinda and Faridkot during the *kharif* 2018. The main plot treatments consisted of three sowing dates (April 30, May 15 and May 30) and two row orientations (North-South and East-West) and the sub plots consisted of three plant spacings (67.5 × 45 cm, 67.5 × 60 cm and 67.5 × 75 cm). Total fifty four treatment combinations were tested in factorial split plot design with three replications.

2.3. *Calibration and validation of the model*

Model calibration involves change in model parameters or coefficients in a utilitarian relationship so that the model conduct matches with actual information. CROPGRO-cotton model which is one of the crop modules in the cropping system model (CSM) framework of the DSSAT, was used to develop genotypic coefficients of *Bt* cotton hybrid (RCH 773 BG II) using field experimental data of Bathinda during *kharif* 2018 having 18 treatments and to compare the output of CROPGRO-cotton model with the ground truth data of the field experiment of Faridkot under modified microclimate. Different genetic coefficients depict the phenology and yield of a specific cultivar. The derived genetic coefficients of cotton cultivar RCH 773 BGII used in CROPGRO-cotton model along with description and units have been presented in Table 1**.**

TABLE 1

Description of genetic coefficients used in CROPGRO-cotton model

S. No.	Genetic coefficient	Abbreviation	Units	RCH 773 BGII
1.	Critical short day length bellow which reproductive development progresses with no day length effect	CSDL	Hour	23.00
2.	Slope of the relative response of development to photoperiod with time	PPSEN	1/hour	0.01
3.	Photothermal days from emergence to flower appearance	EM-FL	Photothermal days	47.00
4.	Photothermal days from beginning flower to beginning boll	FL-SH	Photothermal days	15.00
5.	Photothermal days from beginning flower to beginning seed	FL-SD	Photothermal days	19.50
6.	Photothermal days from beginning seed to maturity	SD-PM	Photothermal days	52.00
7.	Time between first flower (R1) and end of leaf expansion	FL-LF	Photothermal days	59.50
8.	Maximum leaf photosynthesis rate	LFMAX	mg $CO_2/m^2/s$	2.60
9.	Specific leaf area	SLAVR	cm^2/g	195.00
10.	Maximum size of full leaf	SIZLF	cm^2	330.00
11.	Maximum fraction of daily growth partitioned to seed + shell	XFRT	#	0.95
12.	Maximum weight per seed	WTPSD	G	0.200
13.	Photothermal days for seed filling per individual seed	SFDUR	Photothermal days	38.00
14.	Average seed numbers per boll	SDPDV	Number/pod	27.00
15.	Photothermal days to reach final boll load	PODUR	Photothermal days	12.00
16.	Threshing percentage(maximum ratio of [seed/(seed + shell)])	THRSH	Percentage	99.50
17.	Fraction protein in seeds	SDPRO	G	0.123
18.	Fraction oil in seeds	SDLIP	G	0.102

3. Results and discussion

3.1. *Comparison between observed and simulated phenology of cotton*

3.1.1. *Emergence (DAS)*

The data pertaining to observed and simulated days taken to achieve emergence of cotton in respect of different sowing dates, row orientations and plant spacings has been presented in Tables 2 and 7. It tends to be seen from the table that, for all the three parameters for example planting dates, row directions and plant spacings, the range of observed and simulated days to achieve emergence was found between 07-10 at Bathinda district (Table 2). Likewise, at Faridkot, observed and simulated days taken to accomplish emergence was found between 07 and 10. Under the two areas, it was noticed that, less number of days for emergence was recorded for the late sown crop under observed and simulated data. Watching lesser number of days for emergence with delayed planting is a result of diminishing of temperature with delayed planting during the period which decreases the days to accomplish emergence. At both the study locations, model was found to be underestimated at all the sowing environments and furthermore found less deviation among observed and simulated estimation of emergence having RMSE of 1.16 days for Bathinda and 0.71 days for Faridkot respectively, as appeared in Table 7. In regard of statistical analysis, among the treatments, the estimation of d-Stat (Bathinda 0.47, Faridkot 0.42) and R^2 (Bathinda 0.49, Faridkot 0.59) shows lesser error among observed and simulated days taken to accomplish emergence of cotton (Table 7).

3.1.2. *Anthesis (DAS)*

Observed and simulated days taken to accomplish anthesis extended from 53-65 DAS and 61-63 DAS for Bathinda and from 54-66 and 59-62 DAS for Faridkot (Table 3). At both the locations, the more number of observed and simulated days to anthesis were found with the earlier sown crop (30th April) followed by mid and late sown crop (15th May and 30th May). Among row directions, for early and mid sown crop (30th April and 15th May), less variations were noticed between observed and simulated days taken to accomplish anthesis, whereas during late sown crop (30th May). Besides, lesser variation among observed and simulated anthesis was seen with E-W row direction. It was seen that the actual deviation

TABLE 2

Comparison between observed and simulated days to attain emergence (DAS) during *kharif* 2018 as affected by various treatments

Treatments	Emergence (DAS) at Bathinda			Emergence (DAS) at Faridkot		
	Observed	Simulated	Deviation (days)	Observed	Simulated	Deviation (days)
$D_1O_1P_1$	10	10	0	10	10	0
$D_1O_1P_2$	10	10	0	11	10	-1
$D_1O_1P_3$	10	10	0	10	10	0
$D_1O_2P_1$	9	10	1	10	10	0
$D_1O_2P_2$	9	10	1	10	10	0
$D_1O_2P_3$	9	10	1	9	10	1
$D_2O_1P_1$	9	7	-2	9	8	-1
$D_2O_1P_2$	8	7	-1	9	8	-1
$D_2O_1P_3$	9	7	-2	9	8	-1
$D_2O_2P_1$	9	7	-2	10	8	-2
$D_2O_2P_2$	9	7	-2	9	8	-1
$D_2O_2P_3$	8	7	-1	9	8	-1
$D_3O_1P_1$	8	7	-1	8	8	0
$D_3O_1P_2$	8	7	-1	8	8	0
$D_3O_1P_3$	7	7	0	8	8	0
$D_3O_2P_1$	7	7	0	8	8	0
$D_3O_2P_2$	7	7	0	7	8	1
$D_3O_2P_3$	8	7	-1	8	8	0

TABLE 3

Comparison between observed and simulated days to attain anthesis (DAS) as affected by various treatments

Treatments	Anthesis (DAS) at Bathinda			Anthesis (DAS) at Faridkot		
	Observed	Simulated	Deviation (days)	Observed	Simulated	Deviation (days)
$D_1O_1P_1$	65	63	-2	66	62	-4
$D_1O_1P_2$	64	63	-1	65	62	-3
$D_1O_1P_3$	65	63	-2	65	62	-3
$D_1O_2P_1$	64	63	-1	65	62	-3
$D_1O_2P_2$	63	63	0	64	62	-2
$D_1O_2P_3$	64	63	-1	64	62	-2
$D_2O_1P_1$	63	61	-2	64	60	-4
$D_2O_1P_2$	61	61	0	62	60	-2
$D_2O_1P_3$	62	61	-1	63	60	-3
$D_2O_2P_1$	63	61	-2	63	60	-3
$D_2O_2P_2$	63	61	-2	63	60	-3
$D_2O_2P_3$	62	61	-1	62	60	-2
$D_3O_1P_1$	58	62	4	59	59	0
$D_3O_1P_2$	56	62	6	56	59	3
$D_3O_1P_3$	55	62	7	56	59	3
$D_3O_2P_1$	57	62	5	58	59	1
$D_3O_2P_2$	55	62	7	56	59	3
$D_3O_2P_3$	53	62	9	54	59	5

TABLE 4

Comparison between observed and simulated days to attain maturity (DAS) as affected by various treatments

Treatments	Maturity (DAS) at Bathinda			Maturity (DAS) at Faridkot		
	Observed	Simulated	Deviation (days)	Observed	Simulated	Deviation (days)
$D_1O_1P_1$	177	158	-19	168	159	-9
$D_1O_1P_2$	175	158	-17	164	159	-5
$D_1O_1P_3$	175	158	-17	168	159	-9
$D_1O_2P_1$	177	158	-19	165	159	-6
$D_1O_2P_2$	176	158	-18	165	159	-6
$D_1O_2P_3$	177	158	-19	164	159	-5
$D_2O_1P_1$	164	155	-9	164	155	-9
$D_2O_1P_2$	164	155	-9	162	155	-7
$D_2O_1P_3$	165	156	-9	161	155	-6
$D_2O_2P_1$	163	155	-8	164	155	-9
$D_2O_2P_2$	162	155	-7	162	155	-7
$D_2O_2P_3$	163	156	-7	163	155	-8
$D_3O_1P_1$	152	155	3	154	153	-1
$D_3O_1P_2$	151	155	4	154	153	-1
$D_3O_1P_3$	150	155	5	152	153	1
$D_3O_2P_1$	152	155	3	155	153	-2
$D_3O_2P_2$	153	155	2	156	153	-3
$D_3O_2P_3$	151	155	4	152	153	1

among observed and simulated anthesis extended from - 2 to 9 and - 4 to 5 at Bathinda and Faridkot, respectively. In context of plant spacings, variation was found to be more under wider spacing (67.5 × 75cm), while lesser variation was found for closer spacings (67.5 × 60cm, 67.5 × 45cm) between observed and simulated days to attain anthesis for both the locations of study. Moreover, less error was noticed under closer spacing between observed and simulated days to achieve anthesis for both the research stations (Table 3).

In respect of statistical analysis, the value of d-Stat was recorded 0.23 and 0.53, R^2 0.51 and 0.43 with RMSE of 4.61 and 3.26 for Bathinda and Faridkot, respectively (Table 7). Pal and Yadav (2018) calibrated and validated CROPGRO-cotton model for growth and yield parameters of cotton and demonstrated that the percent root mean square error (%RMSE) ranged from 3.6-5.8% for quite a long time to accomplish anthesis. In addition to this they demonstrated the decrease in simulated estimation of anthesis with late planting. Arshad*et al.*(2017) also showed that root mean square (RMSE) values ranged from 0.57 to 1.94 for different cotton cultivars.

3.1.3. *Maturity (DAS)*

Among treatments, observed and simulated days to accomplish maturity varied from 150-177 and 155-158 for Bathinda and between 152-168 and 153-159 for Faridkot (Table 4). Besides, the actual deviation varied from -19 to +2 and - 9 to +1 for Bathinda and Faridkot, respectively. More number of days were simulated just as observed maturity was recorded in the early sown crop (30th April) and declined with delay in sowing. Comparable examination was likewise directed by Pal and Yadav (2018) as they demonstrated decrease in number of days for maturity with delayed planting and furthermore showed that the percent root mean square error (%RMSE)ranged from 9.3-15.6% for a considerable length of time to accomplish maturity among observed and simulated values. The simulated maturity was seen closer to observed in third date of planting (30th May) as contrast with first and second planting dates, at both the areas having RMSE estimation of 13.56 and 9.78 days for Bathinda and Faridkot, respectively, while, essentially higher positive estimation of R^2 was found for Bathinda (0.61) and Faridkot (0.87) (Tables 7). Kumar *et al.*,

TABLE 5

Comparison between observed and simulated maximum leaf area index (LAI) as affected by various treatments

Treatments	Maximum LAI at Bathinda			Maximum LAI at Faridkot		
	Observed	Simulated	Actual deviation	Observed	Simulated	Actual deviation
$D_1O_1P_1$	3.7	2.2	-1.5	3.6	3.0	-0.6
$D_1O_1P_2$	3.5	2.2	-1.3	3.5	3.0	-0.5
$D_1O_1P_3$	3.1	2.2	-0.9	3.0	3.0	0
$D_1O_2P_1$	3.5	2.2	-1.3	3.5	3.0	-0.5
$D_1O_2P_2$	3.4	2.2	-1.2	3.3	3.0	-0.3
$D_1O_2P_3$	3.0	2.3	-0.7	3.0	3.0	0
$D_2O_1P_1$	3.6	2.0	-1.6	3.5	2.4	-1.1
$D_2O_1P_2$	3.5	2.0	-1.5	3.5	2.4	-1.1
$D_2O_1P_3$	3.2	2.0	-1.2	3.1	2.4	-0.7
$D_2O_2P_1$	3.5	2.0	-1.5	3.5	2.4	-1.1
$D_2O_2P_2$	3.4	2.1	-1.3	3.3	2.4	-0.9
$D_2O_2P_3$	3.2	2.0	-1.2	3.1	2.4	-0.7
$D_3O_1P_1$	3.0	1.9	-1.1	3.0	2.2	-0.8
$D_3O_1P_2$	3.2	1.8	-1.4	3.2	2.1	-1.1
$D_3O_1P_3$	2.9	1.8	-1.1	2.9	2.0	-0.9
$D_3O_2P_1$	2.9	1.9	-1.0	2.9	2.0	-0.9
$D_3O_2P_2$	3.0	1.8	-1.2	3.0	2.1	-0.9
$D_3O_2P_3$	2.7	1.8	-0.9	2.7	2.1	-0.6

TABLE 6

Comparison between observed and simulated seed cotton yield (kg ha^{-1}) as affected by various treatments

Treatments	Seed cotton yield (kg ha^{-1}) at Bathinda			Seed cotton yield (kg ha^{-1}) at Faridkot		
	Observed	Simulated	% Deviation	Observed	Simulated	% Deviation
$D_1O_1P_1$	2973	2978	0.2	3243	3159	-2.6
$D_1O_1P_2$	3024	2977	-1.6	3284	3274	-0.3
$D_1O_1P_3$	3155	3053	-3.2	3359	3206	-4.5
$D_1O_2P_1$	3190	3006	-5.8	3390	3162	-6.7
$D_1O_2P_2$	3388	2895	-14.6	3454	3270	-5.3
$D_1O_2P_3$	3490	3053	-12.5	3490	3206	-8.1
$D_2O_1P_1$	2806	2761	-1.6	2804	2853	1.7
$D_2O_1P_2$	2902	2805	-3.3	2853	2782	-2.5
$D_2O_1P_3$	3002	2788	-7.1	2856	2799	-2.0
$D_2O_2P_1$	3103	2761	-11.0	2902	2889	-0.4
$D_2O_2P_2$	3116	2809	-9.9	3003	2788	-7.2
$D_2O_2P_3$	3132	2814	-10.2	3155	2800	-11.3
$D_3O_1P_1$	2237	2366	5.8	2476	2453	-0.9
$D_3O_1P_2$	2246	2385	6.2	2522	2511	-0.4
$D_3O_1P_3$	2513	2392	-4.8	2671	2509	-6.1
$D_3O_2P_1$	2530	2362	-6.6	2743	2464	-10.2
$D_3O_2P_2$	2667	2380	-10.8	2796	2494	-10.8
$D_3O_2P_3$	2730	2382	-12.7	2832	2484	-12.3

TABLE 7

Statistics for the evaluation of the model for simulation of phenology and yield of cotton at Bathinda and Faridkot

Variable Name	Mean Obs.	Mean Sim.	Std. Dev. Obs.	Std. Dev. Sim.	R^2	RMSE	d-Stat.	Total Obs.
Bathinda								
Emergence (DAS)	9	8	0.98	1.45	0.49	1.16	0.47	18
Anthesis (DAS)	61	62	3.81	0.82	0.51	4.61	0.23	18
Maturity (DAS)	164	156	10.12	1.37	0.61	13.56	0.35	18
LAI maximum	3.24	2.04	0.28	0.17	0.38	1.27	0.24	18
Seed cotton Yield (kg ha^{-1})	2900	2720	345.94	258.40	0.75	253.82	0.84	18
Faridkot								
Emergence (DAS)	9	9	0.99	0.97	0.59	0.71	0.42	18
Anthesis (DAS)	61	61	3.71	0.94	0.43	3.26	0.53	18
Maturity (DAS)	161	155	5.23	2.83	0.87	9.78	0.14	18
LAI maximum	3.2	2.49	0.26	0.37	0.39	0.92	0.19	18
Seed cotton Yield (kg ha^{-1})	2991	2839	309.74	299.44	0.83	198.34	0.89	18

(2017) also noticed contrast among observed and simulated days taken to maturity as 0.6 to 1.0 days.

3.2. *Comparison between observed and simulated maximum leaf area index*

The observed and simulated maximum LAI ranged from 2.7 to 3.7 and 1.8 to 2.3 respectively, at Bathinda and from 2.7 to 3.6 and 2.0 to 3.0 respectively, at Faridkot (Table 5). Among various planting times, row directions and plant spacings, very little variation was recorded among observed and simulated maximum LAI both at Bathinda and Faridkot. In addition to this the model underestimated LAI for all the treatments at both the locations. In respect of statistical analysis, the estimation of d-Stat was recorded 0.24 and 0.19, R^2 0.38 and 0.39 and RMSE 1.27 and 0.92 for Bathinda and Faridkot, respectively (Table 7). The outcomes were in similarity with Arshad *et al.* (2017) who observed RMSE from 0.23-0.40 for LAI. The correlation coefficient was almost same at Bathinda (0.38) and Faridkot (0.37) (Table 7). Pal *et al.*, (2016) used CROPGRO-cotton model to simulate response of *Bt* cotton sown on different dates and showed that model was not found able to simulate maximum leaf area index having % RMSE of 7.07.

3.3. *Comparison between observed and simulated seed cotton yield (kg ha^{-1})*

The observed and simulated seed cotton yield varied between 2237-3490 kg ha^{-1} and 2362-3053 kg ha^{-1}at Bathinda, while it was 2476-3490 kg ha^{-1} and 2453-3274 kg ha^{-1} for Faridkot (Table 6). The highest simulated seed cotton yield was observed in the crop sown on 30th April (3053 and 3274 kg ha^{-1} for Bathinda and Faridkot) which was significantly higher than 30th May sowing (2392 and 2511 kg ha^{-1} for Bathinda and Faridkot). The simulated seed cotton yield reduced as sowings were delayed at both the areas. In the context of row directions, somewhat higher simulated seed cotton yield was found under E-W sown crop than N-S sown crop at both the investigation areas. Among the spacings highest simulated seed cotton yield was observed under wider spacing (67.5 × 75 cm) and lowest with spacing of 67.5 × 45 cm (Table 6).

Seed cotton yield was decreased by 6.0 and 13.1% due to delay in sowing by 15 days from April 30 to May 15 and further reduction in seed cotton yield by 17.4% and 8.7% was also observed with further delayed sowing from May 15 to May 30 at Bathinda and Faridkot, respectively. Moreover, delay in sowing by one month from April 30 to May 30, caused reduction in seed cotton yield by 22.36% and 20.37% at Bathinda and Faridkot, respectively. Among the treatments, simulated seed cotton yield was underestimated by 1.6-12.7% for Bathinda and 0.3-12.3% for Faridkot. Higher deviation was observed with crop sown under E-W row orientation in all the sowing dates. Lesser deviation in simulated seed cotton yield indicated better performance of the model which also indicated higher value of d-stat (0.84 for Bathinda& 0.89 for Faridkot) and R^2 (0.75 for Bathinda and 0.83 for Faridkot) (Tables 7). Similar, results were observed by Pal *et al*. (2016) who observed RMSE of 193.29 kg ha^{-1} and high correlation coefficient (0.979) between observed and simulated yield.

4. Conclusions

It is concluded that, under both the study locations, lesser number of days for emergence was recorded for the late sown crop under observed and simulated conditions having lesser deviation with E-W row orientation at both the study regions. In case of plant spacings, more deviations for days to attain phenology were observed under wider spacing (67.5 × 75 cm). Crop sown on 30th April reported significantly higher simulated seed cotton yield than other sowing times and yield got declined as sowings were delayed as observed. Moreover, among all dates of sowing highest simulated seed cotton yield was observed under wider spacing (67.5 × 75 cm) and lowest under closer spacing (67.5 × 45 cm). Simulated seed cotton yield was found to be decreased with decrease in plant spacing at both the study locations. Overall, the simulated phenology and seed cotton yield under different sowing dates, row orientations and plant spacings were in good agreement with actual data. Hence, the model can be used to develop site-specific adaptation strategies for adjustment of sowing date, row orientation and plant spacing for better yield.

Acknowledgement

Authors gratefully acknowledge Director, PAU Regional Research Bathinda and Faridkot for providing facilities to conduct field experiment. The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Anonymous, 2017, United States Department of Agriculture, Annual Report available online at https://www.usda.gov/topics/data.

Arshad, M. N., Ahmad, A., Wajid, S. A., Jehanzeb, M., Cheema, M. and Schwartz, M. W., 2017, "Adapting DSSAT model for simulation of cotton yield for nitrogen levels and planting dates", *Agron. J.*, **109**, 6, 2639-2648.

Hoogenboom, G., Jones, J. W., Wilkens, R. W., Batcheloro, W. D., Hunt, L. A., Boot, K. J., Singh, U., Uryaswv, O., Bowen, W. T., Gijsman, A. J., du Toit, A., White, J. W. and Tsuji, G. Y., 2010, Decision support system for Agro-technology Transfer version 4.5 [CD- ROM] University of Hawaii.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boot, K. J., Batchelor, W. D., Hunts, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J. and Ritchie, J. T., 2003, "DSSAT cropping system model", *Eur. J. Agron.*, **18**, 235-265.

Kannan, V., Srinivasan, G., Babu, R.,Thiyageshwari, S. and Sivakumar, T., 2017, "Effect of biochar, mulch and ppfm spray on leaf relative water content, leaf proline, chlorophyll stability index and yield of cotton under moisture stress condition", *Int. J. Curr. Microbiol App. Sci.*, **6**, 604-611.

Kingra, P.K. and Kaur, H., 2017, "Microclimatic modifications to manage extreme weather vulnerability and climatic risks in crop production", *J. Agri. Physics*., **17**, 1-15.

Kumar, S., Niwas, R., Khichar, M. L., Singh, A., Kumar, Y. and Abhilash, 2017, "Genetic Coefficient and Validation of DSSAT Model for Cotton under Different Growing Environments", *Int. J. Curr. Microbiol. App. Sci*., **6**, 4, 1031-1041.

Pal, R. K. and Yadav, B. K., 2018, "Effect of soil variability on seed cotton yield using CROPGRO-Cotton model for Bathinda district of Punjab", *Prog. Res. An Int. J.*, **13**, 4, 339-342.

Pal, R. K., Kataria, S. K. and Singh, P., 2016, "Response of seed cotton yield to temperature and solar radiation as simulated with CROPGRO-cotton model", *Prog. Res. - An Int. J*., **11**, 262-264.

Sharma, A., Khichar, M. L., Ram, P. R., Premdeep, N. and Kumar, S., 2018, "Quantification of microclimate of cotton hybrids under different sowing environments", *J. Pharmacogn Phytochem*, **7**, 2, 1032-1040.

Yadav, B. K., Sidhu, A. S. and Kumar, D., 2018, "Distribution and indexation of plant available nutrients in Bathinda district of south-west Punjab, India", *J. Soils and Crops*, **28**, 1, 8-18.