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Research Article

Optimizing Sowing Window for Cotton using CROPGRO-Cotton Model for South-Western Region of Punjab

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ABSTRACT

Utilizing simulated values of seed cotton yield, the CROPGRO-Cotton model was utilised to optimize sowing period. To optimize sowing window for the Bt cotton hybrid "NCS 855 BGII," a total of twelve sowing environments were put up at intervals of six days between May 1 and June 6. Results showed that compared to a normally planted crop, delayed sowing resulted in a larger deviation in the simulated value of seed cotton yield (25th May: R^2 =0.54) than normal sowing (01st May: R^2 =0.66). While the overall higher values of R^2=0.80 and d-Stat.=0.76 demonstrated close agreement in simulated value over observed. Additionally, the study year of 2014 (0.42%) had the least difference in the simulated seed cotton production compared to the observed yield, which was followed by 2017 (4.25%) and 2016 (11.92%). For the study years 2014, 2016, and 2017, respectively, simulated seed cotton yields were revealed in the range of 2440 and 3194, 2418 to 3430, and 2497 to 3473 kg ha^{-1}, with the values of R^2 and RMSE finding in the range of 0.28 to 0.97 and 278.54 to 841.52, respectively. However, higher seed cotton yields were discovered between 19th April and 13th May for sown crop having less RMSE. Seed cotton yield was revealed to have dropped at too early as well as late sowing of crop with larger value of RMSE.

Key words: CROPGRO-cotton model, Sowing window, Seed cotton yield, *Bt* cotton hybrid

Introduction

One of the most significant sources of fibre, nutrition, and feed, cotton—also known as the "king of fibres" or "White Gold"—plays a crucial role in farming and the country's modern economy. According to its chemical composition, cotton is made up of 91.0% cellulose, 7.85% water, 0.55% protoplasm pectin, 0.40% waxes and fatty material, and 0.20% mineral salt (Wakelyn *et al.,* 2006). During the 2017–18 crop year, cotton was produced on 33.38 million ha of land, yielding around 121.37 million 480 lb bales per hectare (Anonymous, 2017). In terms of cotton producing nations, India gathered the most cotton, or 12.3 million hectares, followed by the United States, China, and Pakistan. Australia reported the highest output, with 2202 kg ha^{-1}, followed by China (1761 kg ha^{-1}) and Brazil. (1555 kg ha^{-1}) (Anonymous, 2017).

According to estimates from the Cotton Advisory Board, cotton output in India was anticipated to generate 377 lakh 170 kg bales from 122 lakh hectares with a productivity of 524 kg lint ha^{-1} for the 2017–18 growing season (Anonymous, 2017). Cotton is the second-largest kharif crop in Punjab, after rice, and is regarded as the main cash crop of the South-Western (S-W) part of the state. Punjab's cotton crop covered 3.85 lakh hectares in 2017–18, producing 12 lakh bales and yielding 529 kg ha^{-1} (Anonymous, 2017). Major cotton-growing regions in Punjab include Bathinda, Faridkot, Fazilika, Mansa, and Shri Muktsar Sahib. In terms of cotton

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productivity, Faridkot comes in second (839 kg ha^{-1}) (Anonymous, 2018).

For cotton growth and yield, the length of the growing season and the appropriate planting date are important factors (Saseendran *et al.,* 2016). The lengthening of the growing season as a result of climate change contributes to higher cotton yield (Wang *et al.,* 2006). The phenological phases of cotton have changed in recent decades due to the trend toward global warming. In this approach, choose the best planting date helps maintain a healthy local agricultural economy by advancing normal cotton growth and improving cotton yield.

A well-calibrated and verified crop simulation model can be used to identify the management strategies that are most important to the combined responses of soil, weather, and crop yield. A popular technology instrument for cotton strategic decision-making is CROPGRO-Cotton (Hoogenboom *et al*., 2010). This study's goal was to evaluate the CROPGRO-cotton model v4.6 in terms of seed cotton yield in order to optimise the sowing window for cotton crops grown under irrigation.

Materials and Methods

Study area and climate

The Punjab state's Bathinda district, also known as the cotton dominated area, is located in the state's fourth agro climatic zone (ACZ), at latitudes of 30°4′30″ and 30°21′20″ and longitudes of 74°47′50″ and 75°10′00″, respectively. The tropical steppe region has a hot, semi-arid environment during the summer (Ministry of Water Resources, 2013). 436 mm of rain falls there on average each year. The cold weather season lasts from December to February, when the low at night could reach 0°C, and the hot weather season, also known as the pre-monsoon, lasts from May to the last week of June, when the high temperature can occasionally reach above 47°C (Ministry of Water Resources, 2013). Most of the district's soil has a texture that ranges from loamy sand to sandy loam. Yadav *et al.* (2018) found that the soil fertility status of soils grown on different land forms in Bathinda district varied greatly and that the soils have low levels of readily accessible N, low to medium levels of readily available P, and medium to high levels of readily available K content. Weather variables, including minimum and maximum temperatures, morning and evening relative humidity, and rainfall, were measured during research periods at the university's agro-meteorological observatory, which is located about 20 m from the experimental site (Fig. 1; Table 1).

Experimental details

To enumerate the impact of different sowing window on cotton using CROPGRO-cotton model, field experiments were conducted at Punjab Agricultural University, Regional Research Station,

Table 1. Weather conditions during cotton growing season in 2014, 2016 and 2018: monthly mean daily minimum (T_{min}) and maximum temperature (T_{max}) and monthly total rainfall

Months	2014			2016			2017		
	T_{min} (°C)	T_{max} (°C)	Rainfall (mm)	Tmin (°C)	Tmax (°C)	Rain (mm)	Tmin (°C)	Tmax (°C)	Rain (mm)
Apr.	17.8	34.7	12.4	19.5	37.3	0.0	18.8	37.5	20.6
May	22.7	38.7	46.4	25.1	40.9	34.6	24.4	40.3	1.8
Jun.	27.5	41.8	23.8	27.9	40.3	33.5	25.3	36.8	177.3
Jul.	27.9	37.5	17.8	27.3	35.2	128.6	27.0	35.8	52.5
Aug.	26.6	36.5	34.4	26.0	33.6	361.7	26.0	34.8	106.6
Sep.	23.9	34.2	160.6	24.1	34.5	0.0	23.9	34.6	0.0
Oct.	18.2	32.6	0.0	18.3	34.2	0.0	17.2	34.1	0.0
Avg.	23.5	36.6	295.4	24.0	36.6	558.4	23.2	36.3	358.8
Obs. SCY		2887 kg ha^{-1}			2626 kg ha^{-1}			2868 kg ha^{-1}	
Sim. SCY		2875 kg ha^{-1}			2939 kg ha^{-1}			2990 kg ha^{-1}	

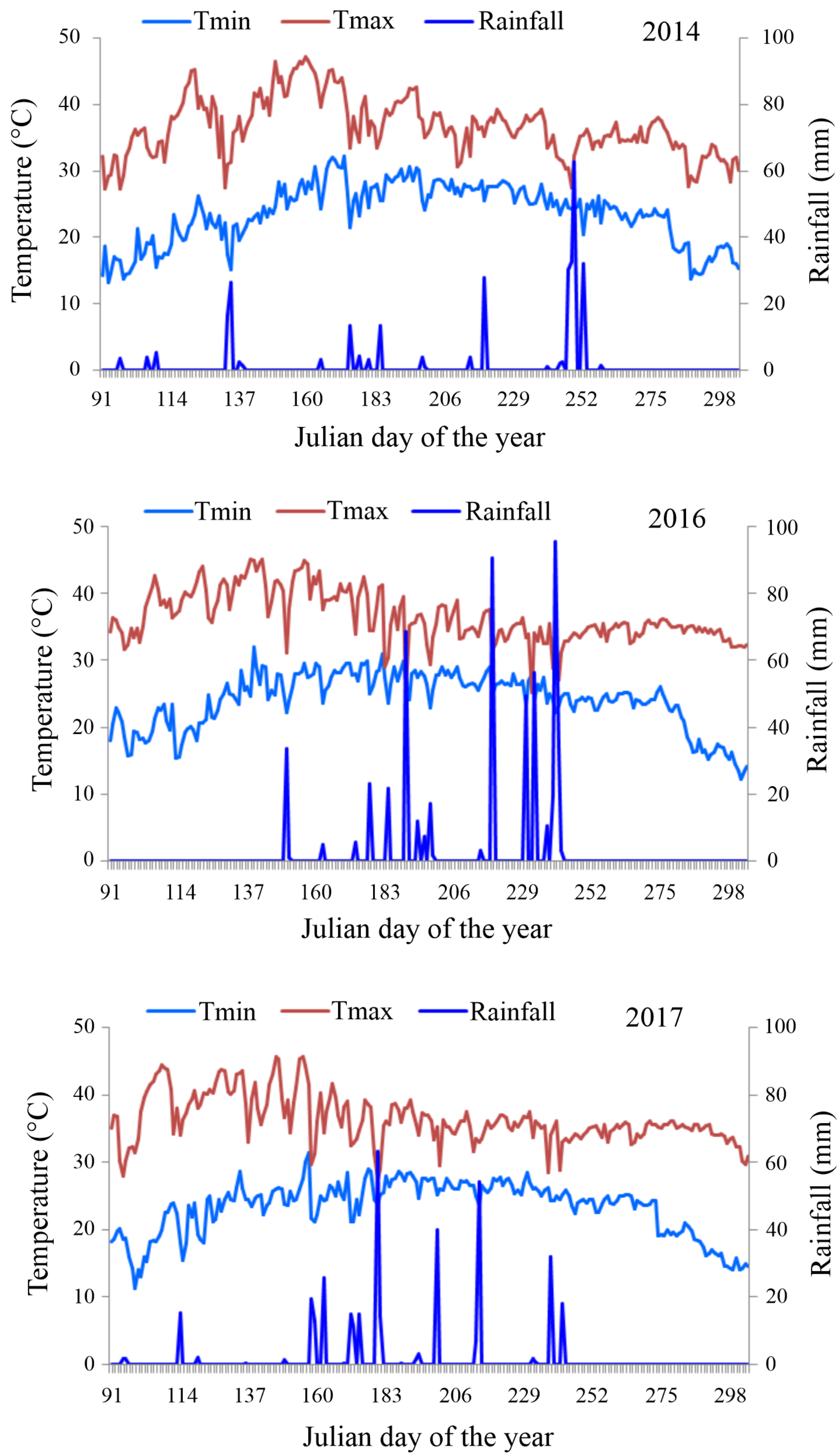

Fig. 1. Daily weather conditions of minimum and maximum temperature and rainfall recorded at agro-meteorological observatory of PAU Regional Research Station Bathinda during cotton growing period of 2014, 2016 and 2017

Bathinda (latitude 30°58′N, 74°18′E longitude, altitude 211 m above mean sea level) during *Kharif* 2014, 2016 and 2017 with two sowing environments as normal (D_1=May 01) and late sown crop (D_2=May 25) for the *Bt* cotton hybrid 'NCS 855 BGII' (Pal and Yadav, 2018), which was used as base yield in the present study for comparative as well as statistical analysis of the data between actual and simulated seed cotton yield for sowing window optimization. Normal as well as late sown criteria were followed using Punjab Agricultural University's "Package and Practices for *Kharif* crops". In which, observed seed cotton yield was 3289, 1940, 2953 and 3039 kg ha^{-1} for normal sowing, moreover, 2084, 966, 1972 and 2226 kg ha^{-1} for late sown crop for the study years 2014, 2015, 2016 and 2017, respectively (Pal and Yadav, 2018). The study year 2015 was not considered for optimization of sowing time of cotton, due to larger variation of >70% during 2015 between observed and simulated seed cotton yield because of whitefly infestation, that affected yield at large extent (Pal and Yadav, 2018).

CROPGRO-cotton model data

The CROPGRO-Cotton model was used to simulate how varied sowing settings might affect the yield of seed cotton. In order to optimize the sowing window for the region, a total of twelve sowing environments were set up at intervals of six days beginning on May 1 and continuing through June 6. GENCALC software and genotypic coefficients that have been previously calibrated and validated for the Bt cotton hybrid "NCS 855 BGII" based on experimental data from 2011–12 to 2013–14 by Pal *et al.* (2016) and Pal and Yadav (2018) were used to simulate seed cotton yield at various sowing dates. Furthermore, in this study inspite of calibrated genetic coefficient by Pal *et al.* (2016), an updated soil profile (Table 2) have been incorporated for the simulating seed cotton yield to determine climate-optimized sowing window for the region.

Results and Discussion

Observed vs. simulated seed cotton yield

With the CROPGRO-cotton model, the seed cotton yield for the crops sown on May 1st and May 25th, respectively, ranged from 3116 to 3443 and 2582

Table 2. Soil status of experimental site of Bathinda used for CROPGRO-cotton model

SLB	SLLL	SDUL	SSAT	SRGF	SSKS	SBDM	SLOC	SLCL	SLSI	SLHW	SAKE	SAPX	SLFE	SLMN	SLEC
5	0.06	0.15	0.41	1.00	1.46	1.35	0.34	2.70	2.50	8.55	241.00	14.00	5.60	4.20	0.32
15	0.06	0.15	0.41	1.00	1.46	1.38	0.33	3.10	2.40	8.61	280.00	15.00	5.50	4.50	0.30
30	0.06	0.15	0.41	1.00	1.41	1.38	0.29	4.40	2.20	8.65	285.00	14.70	5.50	4.20	0.29
60	0.06	0.15	0.41	0.63	1.61	1.61	0.29	4.40	2.20	8.66	285.00	14.30	5.45	4.00	0.28
90	0.05	0.14	0.41	0.10	2.24	1.62	0.27	4.42	2.10	8.77	286.00	14.00	5.30	3.82	0.26
160	0.09	0.18	0.44	0.10	1.99	1.63	0.25	4.43	2.10	8.87	287.00	14.00	4.00	3.56	0.26

Where, SLB = Depth, base of layer, cm; SLLL = Lower limit, cm^3 cm^{-3}; SDUL = Upper limit, drained, cm^3 cm^{-3}; SSAT = Upper limit, saturated, cm^3 cm^{-3}; SRGF = Root growth factor, soil only, 0.0 to 1.0; SSKS = Sat. hydraulic conductivity, macropore, cm h^{-1}; SBDM = Bulk density, moist, g cm^{-3} ; SLOC = Organic carbon, %; SLCL = Clay (<0.002 mm), %; SLSI = Silt (0.05 to 0.002 mm), %; SLHW = pH in water; SAKE = Potassium, exchangeable, kg ha^{-1}; SAPX = Phosphorus, extractable, kg ha^{-1}; SLFE = Iron, mg kg^{-1}; SLMN = Manganese, mg kg^{-1}; SLEC = Electric conductivity, dS m^{-1}

to 2680 kg ha^{-1}. For the May 1 and May 25 sown crops, respectively, the observed yield varied from 1940 to 3289 kg ha^{-1} and from 966 to 2226 kg ha^{-1} (Pal, 2018). The yield of seed cotton for the year 2014 at the regular planting date was found to be underestimated by the crop model, whereas the yield for the other years and sowing dates was overstated. Pal *et al.* (2016) reported similar findings for underestimating the yield of seed cotton. Delay in sowing led to a higher variance in the simulated value of seed cotton yield (25th May: R^2 =0.54) than with a normally sown crop (01st May: R^2 =0.66). (Fig. 2). However, the close proximity of the simulated value to the observed value was suggested by the overall higher values of R^2=0.80 and d-Stat. =0.76. (Fig. 2).

Hebbar *et al.* (2002) also looked at the fact that a late-sown crop (on August 3) had lower boll weight than an early-sown crop. Delay in sowing may result in a decrease in the time for full boll growth and maturity as well as a decrease in the number of bolls per plant due to unfavorable weather conditions and delayed sowing. Soomro *et al*. (2014) noted a higher yield in early-sown crops due to an increase of sympods per plant, boll size, and boll quantity.

Performance of CROPGRO-cotton model for optimizing sowing window

In order to establish the ideal sowing period for cotton, the CROPGRO-Cotton model was tested using experimental data from the Kharifs of 2014, 2016, and 2017. The results are presented in Table 3 and shown in Figs. 3 and 4.

Simulated seed cotton yields for the study years 2014, 2016, and 2017 were found to range between

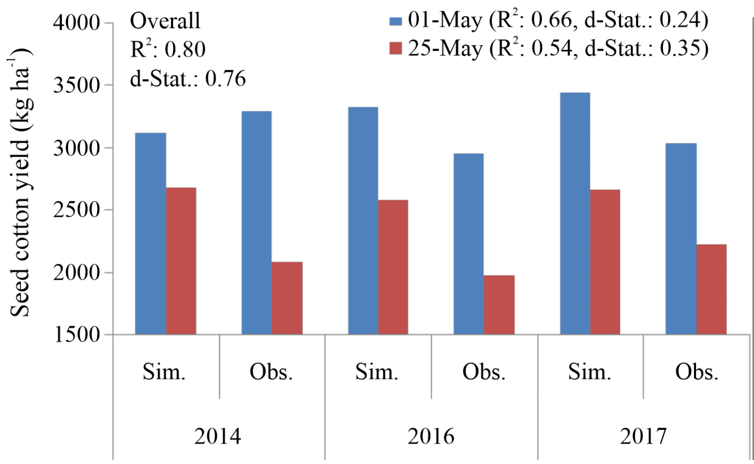

Fig. 2. Observed vs. simulated seed cotton yield (kg ha^{-1}) as influenced by dates of sowing at Bathinda during *Kharif* 2014, 2016 and 2017

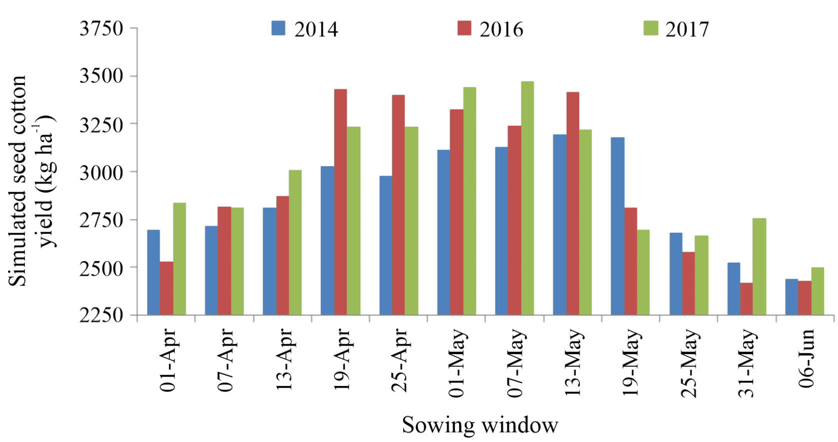

Fig. 3. Simulated seed cotton yield (kg ha^{-1}) as influenced by dates of sowing at Bathinda during *Kharif* 2014, 2016 and 2017

Table 3. Statistics of crop model for optimization of sowing window based on seed cotton yield as influenced by dates of sowing at Bathinda among study years of 2014, 2016 and 2017

Variable Name	Mean Observed	Mean Simulated	Ratio	Std. Dev. Observed	Std. Dev. Simulated	R^2	Mean Diff.	Mean . Abs.Diff	RMSE	d-Stat.	Total Number Obs.
Overall	2760	2935	1.08	489.09	324.08	0.44	174	381	436.86	0.69	36
2014	2887	2875	1.03	568.04	252.07	0.33	-13	427	500.21	0.62	12
2016	2626	2939	1.13	462.44	385.13	0.48	313	419	460.92	0.72	12
2017	2768	2990	1.09	383.25	310.66	0.59	222	298	331.49	0.77	12
01-Apr	3094	2689	0.87	142.51	125.49	0.28	-405	405	435.03	0.40	3
07-Apr	3094	2782	0.90	142.51	47.42	0.95	-312	312	364.59	0.35	3
13-Apr	3094	2899	0.94	142.51	81.54	0.30	-195	195	278.54	0.38	3
19-Apr	3094	3232	1.04	142.51	163.74	0.93	138	312	333.83	0.04	3
25-Apr	3094	3204	1.04	142.51	174.13	0.97	111	319	334.64	0.06	3
01-May	3094	3294	1.06	142.51	135.06	0.66	200	316	331.68	0.05	3
07-May	3094	3280	1.06	142.51	141.94	0.30	186	292	312.41	0.10	3
13-May	3094	3277	1.06	142.51	98.71	0.60	184	247	292.62	0.23	3
19-May	2094	2896	1.38	103.93	204.68	0.29	802	802	841.52	0.13	3
25-May	2094	2642	1.26	103.93	42.92	0.54	548	548	553.52	0.25	3
31-May	2094	2565	1.22	103.93	140.35	0.97	471	471	472.73	0.34	3
06-Jun	2094	2455	1.17	103.93	30.40	0.92	361	361	368.42	0.34	3

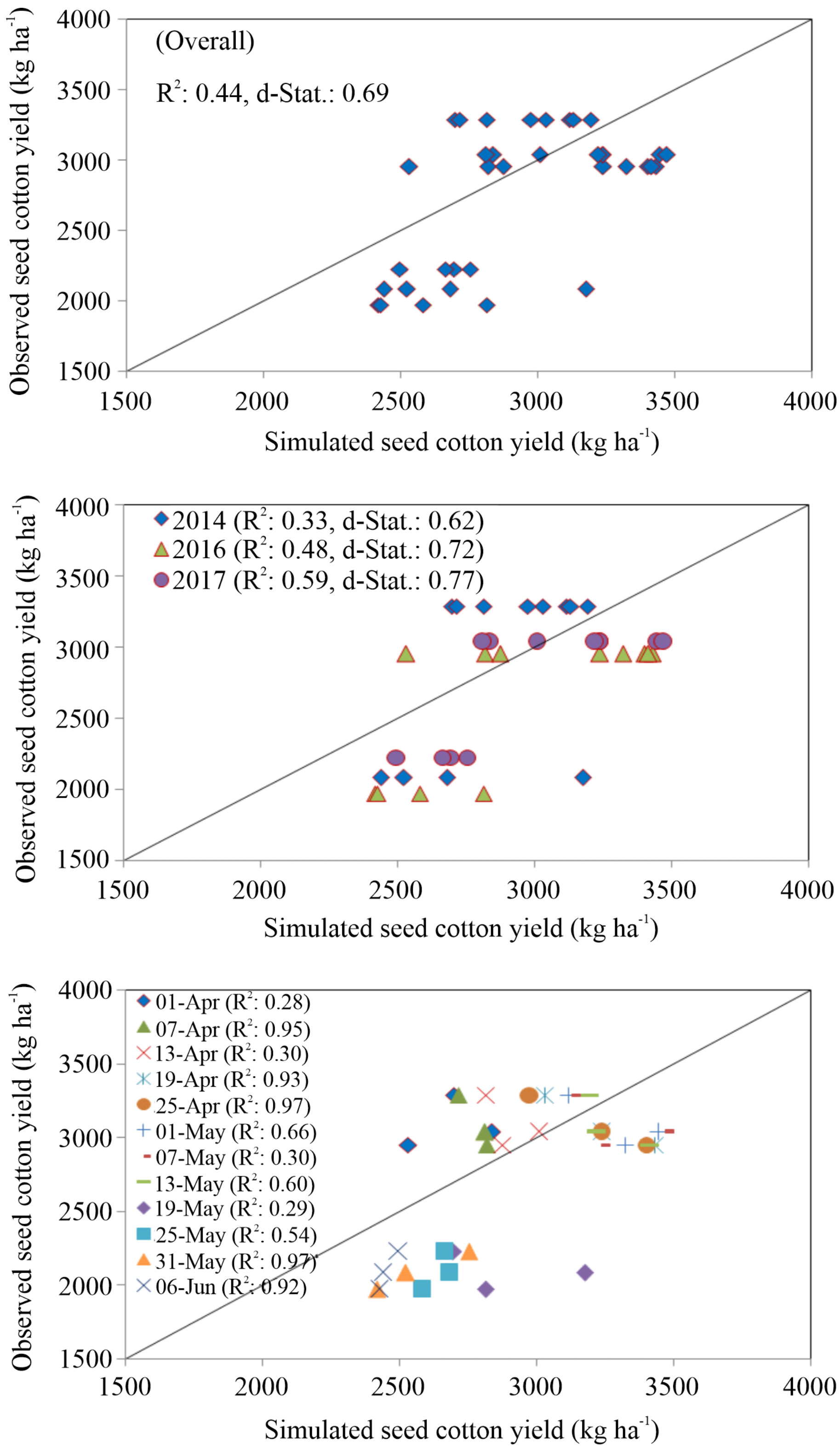

Fig. 4. Performance evaluation of simulated seed cotton yield over observed as influenced by dates of sowing at Bathinda among study years of 2014, 2016 and 2017

2440 and 3194, 2418 and 3430, and 2497 and 3473 kg ha^{-1}, respectively, across the twelve sowing settings beginning on April 1 and ending on June 6, respectively. From April 1 to April 13, when the crop was sown too early, the yield of simulated seed cotton was lower; however, from April 19 to May 13, when the crop was sown, the yield of simulated seed cotton was higher. After then, it was discovered that the crop sowed between May 19 and June 6 had a lower seed cotton yield (Fig. 3). Additionally, less variation between the observed and simulated seed cotton production was seen in 2014 (0.42%), followed by 2017 (4.25%), while the highest difference was recorded in 2016 (11.92%). (Table 3). According to Saseendran et al. (2016), the cotton model was able to reasonably mimic both the variable planting date and variable water regimes, with relative errors in seed cotton yield of 14% under rainfed conditions and 8% under irrigated conditions, respectively.

Additionally, the CROPGRO-cotton model revealed an overestimation for the majority of the twelve sowing times employed for the study, with the exception of the early-sown crop between 01 and 13 April (Table 3). On the other hand, the crop planted in 2016 and 2017 had a model overestimation, while the yield of simulated seed cotton during the study year of 2014 had a yield underestimation. Furthermore, data for overall were indicated very close proximity between simulated and observed seed cotton yield with R^2=0.44, d-stat.=0.69, and RMSE=436.86 among the twelve sowing dates utilised for optimization of best sowing time for cotton (Fig. 4; Table 3).

The value of R^2 (0.59) and d-stat. (0.77) was found to be greater in 2017 due to a lower variation in simulated seed cotton yield over observed, followed by 2016 (R^2=0.48, d-stat.=0.72), while lower values of R^2 and d-stat. were found in 2014 (R^2=0.33, d-stat.=0.62) (Fig. 4; Table 3). The RMSE value likewise revealed similar patterns and demonstrated a smaller difference between the simulated and observed values in 2017 (331.49), 2016 (460.92), and 2014. (500.21). Additionally, the values of R^2 and RMSE during the sowing window employed for the study, which extended from 01 April to 06 June, were found to be between 0.28 and 0.97 and 278.54 and 841.52, respectively. Early sowing before April 7 and late sowing after May 19 both had higher RMSE values reported (Fig. 4; Table 3).

Weather conditions of cotton growing season in 2014, 2016 and 2017

A total of 295.4 mm, 558.4 mm, and 358.8 mm of rain fell on cotton during the growth seasons of 2014, 2016, and 2017, respectively. These totals represented 79.7%, 90.2%, and 92.4% of the years' total rainfall (Table 1; Fig. 1). During which the months of September in 2014, August in 2016, and June in 2017 saw the heaviest rainfall. 2016 saw more rain than usual (558.4 mm). Additionally, throughout the growth season, minimum and maximum temperatures ranged from 13.2 to 32.2°C and 27.2 to 47.2°C in 2014, 12.2 to 32.0°C and 25.2 to 45.2°C in 2016, and 11.2 to 31.4°C and 27.4 to 45.6°C in 2017 (Fig. 1). Additionally, the average mean minimum and maximum temperatures in 2014, 2016, and 2017 were 23.5 and 36.6°C, 24.0 and 36.6°C, and 23.2 and 36.3°C, respectively (Table 1). Highest average minimum temperature was recorded throughout the crop period in the months of July (27.9°C), June (27.8°C), and July (27.0°C), while the highest average maximum temperature was recorded in the months of June (41.8°C), May (40.9°C), and May (40.3°C), respectively, in 2014, 2016, and 2017 (Table 1).

Bt cotton hybrids sown in May and June lowered the phenology of the crop and shortened the crop growth period as a result of higher minimum and maximum temperatures in May and June, followed by April month (Pal and Yadav, 2018), resulting in lower seed cotton yield in delayed sowing/late sown crop. Although more rainfall was obtained during the 2016 growing season, which also led to lodging of the crop, the 2014 rainfall's better distribution resulted in a larger seed cotton output than in the other years. Additionally, in 2014, proper rainfall distribution, particularly from the time the crop was in blossom until the time the bolls opened, encouraged higher growth and increased the output of seed cotton (Table 1; Fig. 1).

Conclusion

It is concluded that, delayed sowing caused a larger variation in simulated seed cotton yield than normal sowing did. In addition, the study year of 2014 saw less fluctuation in the simulated seed cotton yield than observed, whereas 2016 and 2017 saw more divergence. Among the twelve sowing conditions employed in this study, seed cotton yield was found to be decreased at early and late sowing of crops with higher values of RMSE, but higher seed cotton yields were discovered between the dates of sowing (19 April to 13 May) of crops with lower values of RMSE. Overall, based on the magnitude of difference between observed and simulated value, the CROPGRO–cotton model could able to determine climate-optimized sowing window for the region and suggested cotton sowing from 19th April to 13th May for the region.

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