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OPTIMIZATION OF PLANTING DATE AND DENSITY OF COTTON THROUGH CROP MECHANISTIC MODEL AND FIELD EXPERIMENTATION IN SEMI-ARID CONDITIONS

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Abstract

Climate variability and trend affect crop growth, development, and ultimately seed yield. Selection of appropriate planting date and density is essential for improving crop performance under changing climate. A field experiment was conducted under semi-arid climatic conditions to evaluate the performance of cotton crop under different planting dates viz. 22nd April, 7th May, 22nd May and 6th June and densities viz 88890, 59260 and 44445 plants/ha. Treatments were arranged by using randomized complete block design with split plot arrangement. The phenological parameters i.e., square initiation, flower initiation, boll formation and boll opening and yield- and yield- components i.e., number of bolls per plant, monopodial branches, sympodial branches, seed cotton yield and seed index were significantly affected by planting dates and densities. Results showed that maximum seed cotton yield (3464 kg ha^{-1}) was recorded when cotton was sown on 22nd April. However, plant population also affected cotton crop significantly. Maximum seed cotton yield (2751 kg ha^{-1}) was recorded for 22.5 cm planting density followed by 15 cm and 30 cm. Furthermore, OZCOT-DSSAT cotton model showed that the simulated phenological parameters with the average error of 9%, 3% and 4% in days to flowering, day to maturity and seed cotton yield, respectively. In sum, simulated data and observed data showed cotton could be planted on 22nd April with 59260 plants/ha to achieve maximum productivity.

Key words: Cotton, Phenology, Planting date, Planting density, DSSAT.

Introduction

It is predicted that climate change makes agricultural systems more vulnerable (Rosenzweig *et al*., 2014; Afzal e*t al.,* 2023) because of the frequency of extreme weather events, the change in rainfall patterns, and an increase in temperature (Ahmad *et al*., 2015; Nasim *et al*., 2016). Cotton is an important crop of semi-arid climates (Singh *et al.,* 2022). Temperature beyond this limit decreases the number of flowers and bolls maturation percentages (Singh *et al*., 2007) and overall, the cotton yield (Nasim *et al*., 2011; Luo *et al*., 2014; Nasim *et al*., 2016; Rahman *et al*., 2017). Globally, cotton is a significant commercial and fiber crop which is commonly cultivated for oils, lint, and meal (Dirbas *et al.,* 2023). In Pakistan, one of the most extensively cultivated cash crops is cotton which provides an excellent raw material source for the manufacturing of textiles (Constable & Bange, 2015; Kumar *et al.,* 2023). This crop contributes about 0.8% in GDP and 4.5% in agriculture value addition (Anon., 2019). While, cotton crops indetermined growth pattern displays numerous morphological changes under variable environmental conditions, planting densities and sowing dates (Mao *et al*., 2015). Planting time is significant in achieving the highest seed cotton yield, particularly under changing climatic conditions of different agricultural ecological regions (Ali *et al*., 2009: Deho *et al*., 2012; Chen *et al*., 2014*)*. In Pakistan, the country which is more pronounced to climate change, selection of appropriate sowing time becomes a key factor in determining the cotton yields (Ali *et al*., 2009; Huang, 2016). Too early or late sown cotton recorded a substantial decline in its productivity (Arshad *et al*., 2007; Khan *et al*., 2017). Previously, Iqbal *et al*., (2018) recorded a 40% increase in flower development in cotton crop that was planted early in comparison to a later crop. Likewise, a significant increase by 10% in flowers production, 23% in bolls and 35% in the cotton crop yields and cotton crops sown early were compared to those planted later (Arshad *et al*., 2007: Braunack *et al*., 2012). Furthermore, in addition to sowing dates, the growth as well as yield of the cotton crop are also influenced by higher population. For example, Khan *et al*., (2017) evaluated the influence of planting dates and higher population and early sowing with higher populations represented significantly higher yield and related traits when compared with late-sown crop with lower population.

Planting geometry also influences N uptake and its translocation into different plant organs (Jiang *et al*., 2013). Dense population reduces the temperature and airflow beneath the canopy, among other factors, planting density is very important determining three-dimensional distribution of plants (Mao *et al.*, 2015). In addition, it is well demonstrated that too dense populations reduce the boll number and weights (Singh *et al.*, 2007). Too low and high planting densities reduce plant height, canopy structure, and yield of cotton crops. Thus, optimum planting density is become the most significant factor for enhancing cotton crop production while also increasing its quality (Zhi *et al.*, 2016). Furthermore, during recent years, studies on cotton management, genetic research, crop enhancement, irrigation water management, and climates also used crop models including the Cropping System Model (CSM) and Decision Support System for Agro technology Transfer (DSSAT) to predict crop productivity under changing climatic scenarios (Khan *et al.*, 2017). Among the stimulated models, the CSM-CROPGRO-Cotton Model is commonly being used to predict the development, growth, and yield of cotton crops (Wajid *et al.*, 2014), including Pakistan. Therefore, the objectives of the study was to optimize sowing date and planting density under field conditions for maximizing seed cotton yield as well as through simulation technique. The DSSAT model was applied to optimize the sowing date and planting density to maximize cotton yield under semi-arid conditions.

Material and Methods

Experimental site: The field experiment was conducted during summer 2019 at the Agronomy Research Farm (31.45° N, 73.13°E and 186 m above sea level) of University of Agriculture, Faisalabad. The experimental site has semi-arid, hot, and humid summer with temperature range of 26.9-45.5°C and dry cool winters with temperature range of 4.1-19.4°C (Table 1 and Fig. 1). In this season, most of the rainfall concentrated during the monsoon season (July-August) with a mean value of 230 mm.

Table 1. Average monthly weather data during the crop season.

Month	Average temperature (°C)	Relative humidity (%)	Rainfall (mm)	Sunshine (hr)
March	27.8	42.5	31.2	9
April	31.4	46.5	39.1	10.1
May	34.9	47.8	35.5	10.1
June	33	62.7	102.8	7.4
July	33.2	72.5	80.9	7.7
Aug	35.6	70.6	56.2	7.3
Sep	33.4	70.2	70.3	7.1
Oct	32.8	70.1	21.8	8.3
Nov	25.8	70.8	28.6	7.7

Experimental details: The experiment was laid out in a randomized complete block design (RCBD) under a split-plot arrangement, and each experimental unit was 8 m × 3 m in size. The cottonseed was sown at 75 cm distance among the rows though dibbling method. As treatments, various plant populations viz. 88890, 59260, and 44445 plants/ha were maintained under main plots while planting times viz., S1 (22nd April), S2 (7th May), S3 (22nd May), and S4 (6th June) were under subplots. Each treatment was replicated for three times with a seed rate of 20 kg ha^{-1}. Following the harvest of previous wheat crop, the land was plowed twice with a tractor-drawn moldboard plough and then sown. Immediately after sowing, low irrigation was applied to get better germination. Four days after first irrigation, another irrigation was applied to ensure sufficient emergence. Recommended dose of fertilizers i.e., 150, 125 and 100 kg ha^{-1} N, P_2O_5, and K_2O was applied by using urea (46% N), diammonium phosphate (18% N, 46% P), and sulfate of potash (50% K_2O), respectively. Whole fertilizer was applied with three equals splits at square, flower initiation, and boll formation stages. A selective broad-spectrum herbicide (Pendimethlain + Glyphosate) was applied as a pre-emergence to control weeds. A minor attack of whitefly and thrips at the early stage of growth was controlled by using post-emergence insecticide (Sitara 25% + WP Buprofezin @ 1600 mL ha^{-1}). Likewise, the attack of armyworm at lateral stages was controlled by spraying Leufenuron @1200 mL ha^{-1}. The crop was harvested twice on 22nd October and 2nd November. Two manual pickings were done in entire plots.

Data collection: An area of 1.5 m x 8 m was selected in each experimental unit, and a subsample of five plants was taken into consideration to calculate the yield along with its parameters. The plant height was determined using a meter rod. On five selected plants, the average number of monopodial and sympodial branches per plant was recorded. An electric balance was used to measure the 100-seed weight. Before ginning, seed cotton samples were sun-dried, and thereafter cleaned. Five plants were tagged in each experimental unit to calculate total number of days require to reach various stages including the maturity stage.

Weather data: The meteorological station provided all weather data, such as the minimum and maximum daily temperatures, the number of hours of sunshine, and the amount of rainfall at University of Agriculture Faisalabad.

Crop growth modeling: Observed growth data were compared with simulated data for data evaluation. The calibration of the model is a vital step in modifying its parameters to the specific agro-climatic conditions in the area. Genetic coefficients for three planting density (15, 22.5 and 30 cm) were determined and adjusted. Analysis data of model calibration to observed and simulated results of best performed sowing date (22nd April) and planting density (22.5 cm). Then, simulation results were being tested using following statistical indices:

$$RMSE = \left[\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}\right]^{0.5}$$

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

$$MPD = \left[\sum_{i=1}^{n}\left(\frac{|O_i - P_i|}{O_i}\right)100\right]/n$$

$$R^2 = 1 - \left[\frac{\sum_i (O_i - P_t)^2}{\sum_i (O_i - \bar{O})^2}\right], \; 0 \le d \le 1$$

where, RMSE denote root mean square error, MPD denotes mean predicted deviation, and d indicates index of agreement.

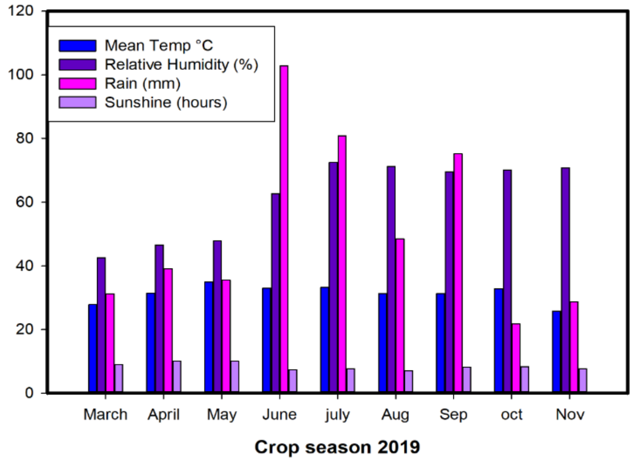

Fig. 1. Mean temperature (°C), relative humidity (%), sunshine (hr) and rainfall (mm) during crop season 2019.

Statistical analysis

All recorded data were statistically analyzed using software statistics 8.1 with Fisher's analysis of variance technique. Least significant difference test at 5% probability level applied to compare with treatment means.

Results

The effect of planting date and density on the square initiation: Results showed that planting dates had a significant effect on the 1st square initiation (Table 2). A significant and maximum value (47.78) was recorded for planting date of S1. A significantly minimum value (35.78) was recorded when cotton was sown on S4. Planting densities showed no significant effect on the 1st square initiation. The significantly maximum value was achieved as 42.92 which was statistically in PAR with (42.83) when planting density was used as 22.5 cm and 30 cm respectively. The least significant value was recorded as (42.50) when 15 cm spacing was used. The 1st square's initiation had no significant effect on the interaction between planting densities and sowing dates.

The effect of planting date and density on the flower initiation: Data showed that interaction of sowing dates and planting densities did not significantly affect the formation of the 1st flower (Table 2). A significantly and maximum value (61.67) was recorded when cotton was sown on S1 with 22.5 and 30 cm distance between the plants. Significantly minimum value (41.0) was recorded when cotton was sown on S4 at both 22.5 cm and 30 cm distance. Planting densities had no significant effect on 1st flower initiation. Overall, crop planted on S1 recorded significantly highest values than other ones.

The effect of planting date and density on the boll Formation: The maximum number of days to first boll formation (80) in S1 that were more than S2 (72), S3 (68) and S4 (63) days respectively (Table 2). The planting densities had no significantly effect on the boll formations. The comparison of means showed that planting density 30 cm maximum days (71) and while the minimum number of days in 15 cm (70) and was taken by the density 22.5 cm (70 days) that was statistically par. The interaction of both planting dates and plant population showed -non - significant effect on the boll formation. From the result it has been seen that crop has planted on S1 proved more beneficial because this sowing date take optimum number of days to reach boll formations stage.

The effect of planting date and density on the boll opening: Planting dates had a significant effect on the 1st boll formation of cotton (Table 2). A significantly maximum value of (80.00) was recorded for S1. Significantly the least value (63.11) was recorded when cotton was sown on S4. Planting densities showed no significantly effect on the 1st boll formation of cotton. The significantly maximum value was achieved as (71.16) which was statistically in PAR with (70.95) when planting density was used as 30 cm and 22.5 cm respectively. The least significant value was recorded as (70.75) when 15 cm spacing was used. Interaction of both planting dates and planting densities did not significant effect on the 1st boll formation of cotton. Interaction of planting date and planting density did not significantly affect the formation of 1st boll opening of cotton. Significantly a maximum value (116.00) was recorded when planting date and planting density was used as S1 at 22.5 cm and 30 cm both. Significantly the least value (85.67) was recorded which was statistically not in PAR with (87.67) for S4 at 15 cm and S2 at 30 cm respectively. Planting density showed also significantly on the 1st boll opening of cotton.

The effect of sowing date and density on the number of plants: Result showed the significant effect of planting dates (Table 3) regarding the number of cotton plants (m^{-2}). A significantly maximum value (8.05) was recorded when the cotton was sown on S1. The least significant value was recorded as (3.54) while using the sowing date as S4. The number of plants was significantly affected by planting densities. Interaction of planting dates and planting densities had no significant effect on the number of plants.

The effect of sowing date and density on the monopodial branches: The planting dates had a significant effect on the monopodial branches (Table 3). The significantly maximum value (3.69) was achieved for S1. Significantly least value of monopodial was achieved when planting dates was used as S4 and S3 respectively. Data presented in table 3 showed did not show significant results of planting densities on the monopodial branches. A significantly a maximum value (2.85) was attained at 22.5 cm spacing, while the least significant value of (2.69) was achieved at 15 cm planting density. Interaction of planting dates and planting densities had no significant effect on the monopodial branches. In this study, the maximum number of monopodial branches were recorded in the early planting of cotton because early sowing of crops attains the maximum number of days to complete their growth period (Table 3).

Table 2. The effect of planting date and plant population on the cotton phenology.

Planting density	Sowing date	Planting to first square initiation (days)	Planting to first flower (days)	Planting to first boll formation (days)	Boll maturation period (days)
15 cm	22nd April	48.00	60.67	80.00	115.67
	7th May	47.67	56.00	73.33	103.00
	22nd May	39.67	47.00	67.33	93.67
	6th June	34.67	41.00	67.33	85.67
	Mean	**42.50A**	**51.33A**	**70.75A**	**99.50B**
22.5 cm	22nd April	48.33	61.67	80.33	116.00
	7th May	46.67	55.00	72.33	104.33
	22nd May	40.67	47.00	68.00	94.67
	6th June	36.00	41.00	68.00	86.67
	Mean	**42.92A**	**51.17A**	**70.91A**	**100.42AB**
30 cm	22nd April	47.00	61.33	79.67	115.33
	7th May	46.67	54.33	72.00	104.67
	22nd May	41.00	48.33	69.00	95.67
	6th June	36.67	42.33	71.16	87.67
	Mean	**42.83A**	**51.58A**	**71.16A**	**100.83A**

Means having different letters are statistically significant at $p<0.05$

The effect of planting date and density on the sympodial branches: Results showed a significant effect of planting dates on the sympodial branches of cotton (Table 3). A significantly maximum number of sympodial branches (33.71) was recorded when the planting date was used as S4. the minimum value (23.72) was recorded while using the planting date as S1. Interaction of planting dates and planting densities had no significant effect on sympodial branches of cotton. Sowing dates and planting densities had no significantly effect on sympodial branches of cotton (Table 3).

The effect of planting date and density on the total number of bolls: The total number of bolls had been significantly affected by the planting date (Table 3). The total number of bolls was not significantly increased by the effect of planting dates and planting densities. The total number of bolls per plant was not significantly affected by the interaction between planting date and plant density. A significantly a maximum value (48.40) was recorded when planting date and plant density was used as S1 at 30 cm. The minimum value (28.03) was recorded as when cotton was sown on S4 at 30 cm. Interaction of sowing densities and the number of bolls per plant was significantly affected by the planting dates (Table 3).

The effect of planting date and density on the plant height (cm): Data showed that planting dates had significant effects on the cotton plant height (Table 3). A significantly maximum (146.56) plant height was recorded on S1. A significantly minimum plant height (119.11) was recorded on S4 which was statistically in par with S3 and S2 respectively. Interaction of sowing dates on different planting densities had no significant effect on the plant height.

The effect of planting date and density on the seed cotton yield (kg ha^{-1}): The present findings showed that planting dates had significant effects on cotton seed yield (Table 3). The significantly maximum (3196.94 kg ha ^{1}) cotton seed yield was recorded for planting date of S1. A significantly minimum seed cotton yield (2116.67 kg ha^{-1}) was recorded when cotton was sown on S4. Planting densities also significantly increased seed cotton yield, and the maximum value (2751.18 kg ha^{-1}) was recorded at planting density 22.5 cm respectively. A significantly less cotton seed yield (2540 kg ha^{-1}) was attained at planting density 30 cm. The cotton seed yield was not significantly affected by the interaction between planting density and planting dates (Table 3).

The effect of planting date and density on the seed index (g): Given results presented a significant effect of planting dates on the seed index of cotton (Table 3). Significantly maximum value (7.87 g) was achieved as when the crop was sown on S1. A significantly minimum value (6.94 g) of seed index was achieved at S4 which was statistically par with S3 (7.21 g) respectively. Data presented in Table 3 did not show significant results of planting density on seed index. Significantly a maximum value (7.48 g) was attained at 22.5 cm spacing, while a least significant value (7.31g) was achieved at 15 cm distance. Interaction of planting dates and planting densities had no significant effect on the seed index (Table 3).

The effect of planting date and density on the ginning out turn (GOT %): Results showed the significant effect of planting date on the GOT of cotton (Table 3). Significantly a maximum data (39.46) was recorded when the planting date of S1. The least significant value (36.02) was recorded when cotton was sown on S4. Planting densities did not show a significant effect on a GOT of cotton. Interaction of planting dates and planting densities had no significant effect on the GOT of cotton.

Crop modeling: Crop phenology (days to flowering and maturity) and final crop yield were predicted by using the CROPGRO-Cotton model (seed-cotton yield). Data showed that the model predicted by using the three-day difference to anthesis as observed in the field with a 5.45% accuracy, a 0.87% RMSE, and a 5.45% MPD for the S_1D_2 (Table 4). Calibration data for days to physiological maturity showed an error rate of 0.53%, and RMSE of 0.58%, and an MPD of 1.03%. The observed and simulated seed cotton yields were 3464 kg ha^{-1} and 3470 kg ha^{-1}, with a 0.17% error, RMSE of 1.73, and MPD of 0.17 respectively (Table 4).

Table 3. The effect of planting date and density on yield related components.

Planting density	Sowing date	Number of plant (m^{-2})	Number of total bolls ($plant^{-1}$)	Number of monopodial branches ($plant^{-1}$)	Number of sympodial branches ($plant^{-1}$)	Seed cotton yield ($kg\ ha^{-1}$)	Plant height (cm)	Seed index (g)	Ginning out turn (%)
15 cm	22nd April	8.05	45.73	3.53	22.89	3017.50	142.00	7.80	39.09
	7th May	7.86	36.13	2.80	25.40	2658.61	125.67	7.48	38.01
	22nd May	7.72	35.00	2.30	28.47	2380.55	122.67	7.11	36.58
	6th June	7.62	28.38	2.13	32.49	2176.94	120.00	6.87	35.78
	Mean	**7.81A**	**36.31A**	**2.69A**	**27.31B**	**2558.40AB**	**127.58A**	**7.31AB**	**37.36A**
22.5 cm	22nd April	5.30	52.00	3.80	23.94	3464.17	150.00	7.95	39.87
	7th May	5.16	36.67	3.33	26.31	3013.33	135.00	7.65	38.54
	22nd May	4.81	36.40	2.33	29.87	2385.55	121.00	7.31	37.23
	6th June	4.60	28.18	1.93	33.83	2141.67	118.67	7.01	36.28
	Mean	**4.97B**	**38.31A**	**2.85A**	**28.49AB**	**2751.18A**	**131.17A**	**7.48A**	**37.98A**
30 cm	22nd April	4.14	48.40	3.73	24.33	3109.17	147.67	7.88	39.42
	7th May	3.97	36.47	3.27	27.47	2678.06	129.67	7.54	38.21
	22nd May	3.65	34.53	2.13	30.60	2344.72	120.33	7.22	36.87
	6th June	3.54	28.03	1.93	34.80	2031.39	118.67	6.95	36.02
	Mean	**3.93C**	**36.86A**	**2.77A**	**29.30A**	**2540.83B**	**129.08A**	**7.39B**	**37.63A**

Means having different letters are statistically significant at $p<0.05$

Table 4. Analysis data of model calibration to observed and simulated results of best performed sowing date (22nd April) and planting density (22.5 cm).

	Sim.	obs.	Err %	RMSE	MPD
Days to anthesis	58	55	5.45	0.87	5.45
Days to physiological maturity	188	187	0.53	0.58	1.03
Seed cotton yield ($kg\ ha^{-1}$)	3470	3464	0.17	1.73	0.17

RMSE= Root mean square; Error, MPD = Mean percent difference, Sim = Simulation, Obs = Observed, Err = Error

Days to anthesis: Days to anthesis were accurately predicted by the model evaluation results. Our findings presented simulated and observed days to flower initiation values for four planting dates and three planting densities (Table 5). After evaluating days to anthesis, S_1D_2 showed a 5.45% difference and with a RMSE of 4.44, MPD of 9.19, and the average error of 48.27%. As is the case of 15 cm, the model accurately predicted days until anthesis after planting. The error differences in 15 cm for anthesis were 7.41, 3.64, 13.04, and 12.50 for 22nd April 7th May, 22nd May and 6th June respectively. For 30 cm, additionally, good evaluation results were found for different planting dates. The difference in days to anthesis were 5.45, 7.55, 10.64, and 9.76 calculated in 1st, 2nd, 3rd, and 4th sowing. The average simulated anthesis days and observed were 52 days and with an average error difference of 9.19%. The D-index (statistical indices) was 0.87 in both cases. Different phenological (flower initiation) responses may be caused by differences in growing environmental situations at various fine cotton varieties have different germination ages.

Days to physiological maturity: Days till physiological maturity were within the range of good accuracy, according to the model evaluation results, with a mean error of 2.69% for planting dates and planting densities (Table 5). The D-index, the RMSE, and the MPD values of 0.78%, 7.94% and 4.07% respectively. As in case of 15 cm, after planting, the model performed an excellent task of evaluating days to physiological maturity. The average of observed and simulated values was 172% and 177% respectively. For 30 cm, similarly good results for different planting dates. The time required till physiological maturity is different were 2, 3, 7, and 13 calculated on 22nd April 7th May, 22nd May and 6th June.

Seed cotton yield: After calibration crop model was evaluated for seed cotton yield against planting dates and planting densities, and for this agronomic parameter, the simulation results were quite precise. Model evaluation regarding seed cotton yield for S1D2 (22.5 cm) showed an error difference between the model and the simulation of 5.57, 7.57, -4.83, and 8.27 % on 22nd April, 7th May, 22nd May and 6th June, respectively, while, in S2 model under simulated seed cotton yield with an error difference of -6.41% (Table 6). Furthermore, the mean error difference was 4.05 % collectively in all planting dates. Statistical indices calculation and RMSE were 0.93 and 201.45 and the MPD was 7.7%. Seed cotton yield simulation for D1 (15 cm) was also quite satisfactory. Error difference was 6.13, -6.41, 6.09 and 10.02% was measured in all sowing dates of 15 cm. Moreover, the average of observed and simulated values was 2584 and 2689 $kg\ ha^{-1}$. Evaluation results regarding D3 (30 cm) demonstrated that crop model over simulated seed cotton yield with error percent of 8.78, 6.39, 11.22 and -8.9% for 22nd April, 7th May, 22nd May and 6th June while in case of S4 model under simulated paddy yield with percent difference of -8.9%. Although the mean value of error difference was 4.05%. The calculated RMSE value was 201.45 kg ha^{-1}.

Discussion

According to the current research, the maximum number of days required for the first square formation in S1 and S4 was 48 days and 36 days, respectively. The longest period of time required for the first flower to form (61 days) in S1 and 41 days in S4. The longest period of time needed for the first boll to form (63 days in S4 and 80 days in S1). These findings support Huang and Ji (2016) who found that phenological events increased in response to high temperature. These results are correlates with the findings of Bilal (2017) who recorded 39 days to reach the first square initiation stage during his study. Similarly, Rehman (2017) also found the same trend in their results. Our results are in line with Abbas *et al.* (2018) who found the significant effects of sowing date on the formation of 1st flower of cotton; while plant spacing had no significant effect on 1st flower formation. Previously, Hebbar *et al*., (2013) also stated that late sowing leads to a reduction in the period from emergence to square off and from flowering to boll opening. Our results are in line to Rehman (2017) who noted 66 numbers of days to start the flowering stage when the crop was sown on 15th April. Further, they observed 60-70 days to initiate flowering in six different sowing windows under Faisalabad condition. These findings are similar to Rehman (2017) who observed 80-95 days to initiate boll formation in his study. Further, Bilal (2017) also observed the same trend in his study. My results are similar to Abbas *et al*., (2018) date of sowing had a significant effect on 1st boll opening. A significantly maximum value of 83.25 was recorded when the sowing date was 1st May. Significantly least value 81.83 was recorded by using sowing date as 1st June which was statistically on par with 82.41 on 15th May. Plant spacing also significantly affects the 1st boll opening.

Table 5. Comparison of simulated and observed days to anthesis and physiological maturity at different planting dates and planting density of cotton.

Treatments	Days to flower initiation			Days to physiological maturity		
	Obs.	Sim.	Err (%)	Obs.	Sim.	Err (%)
S1D1	54	58	7.41	184	186	1.09
S1D3	55	58	5.45	184	187	1.63
S2D1	55	57	3.64	180	183	1.67
S2D2	54	57	5.56	180	183	1.67
S2D3	53	57	7.55	180	183	1.67
S3D1	46	52	13.04	168	175	4.17
S3D2	46	52	13.04	168	175	4.17
S3D3	47	52	10.64	168	175	4.17
S4D1	40	45	12.5	158	171	8.23
S4D2	40	45	12.5	158	171	8.23
S4D3	41	45	9.76	158	171	8.23
Average	48.27	52.55	9.19	172.73	176.91	2.69
D-Index		0.87			0.78	
MPD		9.19			4.07	
RMSE		4.44			7.94	

Sim= Simulation, Obs= Observed, Err= Error

Table 6. Comparison of simulated and observed days to SCY at different sowing dates and planting density of cotton.

Treatments	SCY (kg ha^{-1})		
	Obs.	Sim.	Err (%)
S1D1	3017	3202	6.13
S1D3	3109	3382	8.78
S2D1	2840	2658	-6.14
S2D2	3013	3241	7.57
S2D3	2678	2849	6.39
S3D1	2380	2525	6.09
S3D2	2506	2385	-4.83
S3D3	2344	2607	11.22
S4D1	2176	2394	10.02
S4D2	2141	2318	8.27
S4D3	2220	2021	-8.96
Average	2584.00	2689.27	4.05
D-Index		0.93	
MPD		7.7	
RMSE		201.45	

Roche *et al*., (2003) reported that although canopy closure was earlier in cotton cultivated in ultra-narrow rows (UNR), There was not an increase in growth or development as a result of this early canopy closure because large populations resulted in intense competition for photo-assimilates. Our results are contradictory with Abbas *et al*., (2018) that the date of sowing did not affect plant population while plant spacing significantly affect the population of cotton plants. Further, Abbas *et al*., (2018) also found that the number of bolls was significantly enhanced by the effect of sowing date and planting density. Interaction of plant spacing and sowing date had significantly affected the number of bolls ($plant^{-1}$). Our findings are in line to the Abbas *et al*., (2018) that the date of sowing had a significant effect on monopodial branches. The significantly maximum value was achieved as 1.62 the crop was statistically at par when it was sowed on April 15th with 1.31; where, the sowing date was 1st May. The interaction of both factors (sowing date and planting density) was found to be non-significant in this study. These results are not similar to Abbas *et al*., (2018) with about the significant effect of sowing date on sympodial branches of cotton. Sympodial branches are boll-bearing branches, so more the sympodial branches there were be more bolls per plant which contributes to yield enhancement (Khan *et al*., 2017). The interaction between both of the components determines the number of sympodial branches behaved statistically non-significant. The result showed that the maximum number of sympodial branches were recorded when the crop was planted on 6th June while the lowest number of sympodial branches were observed on (22nd April). Total dry matter partitioning was connected to the number of sympodial branches. The number of sympodial branches decreased when the planting density was increased (Paslawar *et al*., 2015; Shekar *et al*., 2015). Normal planting density resulting in a better source-sink connection increases seed cotton yield (Singh & Rathore, 2007; Jahedi *et al*., 2013; Paslawar *et al*., 2015). These findings are similar to Abbas *et al*., (2018) stated that the date of sowing had a significant effect on cottonseed yield. Plant spacing also significantly increased seed cotton yield, interaction of planting date; however, planting densities had no significant effect on cottonseed yield. Planting density and cotton cultivars had no significant effect on the height of the cotton plants. Crops sown early on 10th May produced the longest plants, while those late sown on 20th June produced the smallest height which ultimately less yield (Ali *et al*., 2011). Plant height achieved its maximum with wider spacing (Singh *et al*., 2015). While increasing planting density above the optimum planting density resulted in lower cotton plant height (Zhang *et al*., 2014).

According to Reddy & Kumar (2010), the ginning % was not affected by population density. The results proved that early sowing enhanced the percentage of GOT rather than late. It is also confirmed from the literature that late sowing significantly reduced the GOT (Wajid *et al*., 2013; Iqbal and Khan, 2011). This appears to conflict with Darawsheh *et al*., (2007) who found that plants with higher planting densities in narrow rows produced lower fiber proportions and greater seed proportions. Plants with larger plant spacing produced greater seed index (Dhillon *et al*., 2006). These findings are in contrast with Ali *et al*., (2005) who found that each delay in planting produced a significantly higher seed index. Crop decisions regarding cultivation that reduce environmental issues may be adopted by cotton growers; while, maximizing the use of scarce resources (Hoogenboom, 2004; Nasim *et al*., 2016), with the use of the CROPGRO-Cotton module in DSSAT (Hoogenboom *et al*., 2011). The calibration of model was done with data (Days to anthesis, Days to physiological maturity and Seed cotton yield) collected during 2019 at Faisalabad against treatment 22nd April sowing, 22.5 cm planting density and the areas of trials showed the best performance.

Conclusion

Optimizing agricultural production techniques, such as planting date and density, is principal for ensuring both sustainability and profitability in cotton farming, especially under semi-arid conditions. This research, employing a combination of crop mechanistic models and field experimentation, provides critical insights into these parameters for cotton cultivation. Planting densities too showed significant implications for crop yield. An optimum planting densities was identified, beyond which there was a notable reduction in yield due to increased competition for resources such as sunlight, water, and nutrients. Sowing dates and planting density had a great influence on the development and growth of the cotton crop. Sowing date of 22nd April with 59260 plants per hectare is the best strategy for getting a better yield of cotton yield and yield components. Furthermore, the OZCOT cotton model showed that the model simulated phenological parameter with the average error of 9.19%, 2.69 %, and 4.05% in days to flowering, day to maturity, and yield respectively. In conclusion, a comprehensive understanding of cotton agriculture in semi-arid environments has been made possible by a combination of crop mechanistic models and field research. In order to ensure the comprehensive development of cotton farming techniques suited to semi-arid climates, future study could also focus on optimizing other agronomic practices in addition to planting date and densities.

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