Journal of
Agriculture and Biology
ISSN: 3007-1755 (Print), 3007-1763 (Online)

Research Article

Influence of Cotton Plant Density on Insect Pest Phenology under Changing Climate Scenario

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ABSTRACT

Agriculture significantly contributes to Pakistan's economy. Pakistan is the world's fifth-largest producer of cotton, after China, United States, Brazil and India. Cotton consumption has risen in response to a significant increase in global population. However, Pakistan's cotton production is declining due to changing environmental conditions, pest outbreaks, insecticide resistance and pest resurgence. To improve cotton cultivation and productivity, a study was conducted at Cotton Research Institute, Multan, to assess the response of different insect pests to varying planting densities. Data on the populations of whitefly, thrips, jassid, dusky cotton bugs, dusky cotton bugs and pink bollworm were recorded weekly across different plant spacings. Additionally, population of natural enemies and meteorological data were also recorded throughout the cotton growing season at these densities. Compact type cotton variety was sown using randomized complete block design (RCBD) with five treatments (T_1-T_5), each corresponding to different plant spacings of 6, 9, 12, 15 and 18 inches, respectively; each treatment was replicated three times. The results revealed that the population of whitefly, jassid, thrips, and dusky cotton bug differed significantly across the plant densities. The highest populations of these sucking insect pests (whitefly 5.87, jassid 2.34, thrips 1.98 and dusky cotton bug 3.86) were observed in T_1 (plant spacing = 6 inches), whereas the lowest populations (whitefly 4.02, jassid 0.11, thrips 1.14 and dusky cotton bug 2.90) were recorded in T_5 (plant spacing = 18 inches). Pink bollworm populations did not differ significantly among treatments. The population of ants, green lacewings, lady bird beetles, and spiders differed significantly among treatments, while population of these *Geocoris* and *Orius* bugs did not show significant difference at any plant density. In T_1, the populations these beneficial insects were highest, whereas they were lowest T5. These results suggest that planting cotton at a 6-inche spacing could enhance production and minimize pest population through increased activity of natural enemies. This study may also be helpful in integrated pest management (IPM) for the control of pest population.

Keywords: Non chemical Insect pest management, Sucking pest management, Integrated pest management (IPM), Optimum cotton plant spacing

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Article History
Received: September 21, 2025
Accepted: December 20, 2025
Published: February 07, 2026

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is a major source of fiber that is fluffy and soft in nature. The cotton fiber is made of cellulose, traces of wax, fat, pectin, and water (Dey *et al.*, 2021). The shrub-like plant is indigenous to tropical and subtropical areas of the world, like USA, Africa, Egypt, India, and Pakistan (Maria et al., 2013)

https://doi.org/10.55627/agribiol.004.01.1829

The greatest number of wild cotton types may be found in Mexico, Australia, and Africa. Cotton was first domesticated in its modern form in both the old and new worlds independently. Cotton is an essential part of people lives and provides benefits to them from birth till death (Stenton et al., 2021). Pakistan is the world's third-largest consumer of cotton and yarn, while fifth-largest producer in the world (Kayani et al., 2013). In Pakistan cotton is grown on area of 2.52 million hectares with production of 610.2 million bales (Ali et al.., 2025). In 2021, the share of cotton in GDP was decreased from 9% to 0.8% (Jamil et al.., 2022).

Insect pests of cotton are classified into two categories as sucking insect pests such as *Bemisia tabasia, Amrasca biguttula*, *Thrips tabaci* and chewing pest especially *Pectinophora gossipella* (Prasad *et al*., 2008). Among the sucking insect pests complex the *B. tabaci*, *Aphis gossypii* and *Amrasca devastans* are causing major problem to the cotton crop (Sahu and Samal 2020; Hussain et al., 2021). Due to the higher incidence of pest complex, the average yield was reduced and cannot be compared with a national average yield (Castella et al., 2005). According to the reports, the production of seed cotton has decreased by 22.85% as a result of sucking bugs (Taherkhani and Hasanzadeh 2018). In Pakistan, cotton crops are attacked by many insect pests, resulting in a yield reduction of 26-29% (Amin et al., 2018). Cotton is attacked by various sucking and chewing insect pests due to monoculture cultivation by some farmers over the years. The chewing and sucking pests cause 8.45 and 16.55 quintal ha-1, cotton yield losses (Sharma et al., 2017). According to previous reports, Jassid reduced cotton output by 18.78% similarly; the whitefly vector of CLCV indirectly infects cotton by secreting honeydew and transmitting cotton leaf curl viral diseases that caused up to 38.7% cotton yield loss in Pakistan (Farooq et al., 2020). Thrips-free plants produced 40% more lint than thrips-infected plants. About 184 insect pests have been identified in cotton, which results in a 30-80% yield loss. The bollworm complex is one of these pests and is a severe threat to the cotton production system (Sharma and Ortiz 2006).

Increasing plant density is an important strategy to increase cotton yield (Gutierrez et al., 2015). For more than a century, significant research has been conducted to identify the ideal plant population for agronomic traits in order to maximize yield and quality. Plant density is a persistent concern for crop production enhancement since it is the most active factor and is important to crop management practice (Shivanna et al., 2011). Crop yield would be reduced in different crops due to non-registered cultivars, bad environmental conditions and both high and low plant densities (Wahab*,* 2009). Plant spacing has the potential to influence plant growth pattern, boll development, and crop maturity by influencing the soil moisture loss, radiation interception, relative humidity, and air movement. Wider spacing may lead to increased weed growth (Lykouressis et al., 2005), luxuriant growth that reduces seed cotton output, and less efficient harvesting (Ruban 2018). On the other hand, low plant spacing may increase the competition of food (nutrients), reduces the moisture level, and even encourage the buildup of pest population in the canopy which resulting in the low production of cotton yield (El-Ramady et al., 2015). Plant canopy is a benefit of closer row spacing and higher plant densities (Wahab*,* 2009), which reduces weed competition (Cadoux et al., 2015), increases early-season light interception, reduces soil water evaporation, and may even increase cotton yield (Bale et al., 2002). Previous study showed that highest yield was observed after cultivation of registered variety BH-160 with recommended spacing at Toba-Tek Singh (Ali et al., 2019). Rains above average create impact on cotton yield. Various crop densities could perform differently in high rainy seasons and these may have different impact on insect pest populations and natural enemies.

Weather has a significant impact on insect population fluctuations (Bhute et al., 2012). Pest prediction is the most effective methods for the monitoring and managing of harmful insect's pest in an area where pest management costs are relatively high (Wu and Guo, 2005). The population of jassid, thrips, whitefly, and dusky cotton bug previously compared with weather conditions (Dhillon and Sharma 2013). According to the findings, relative humidity had a positive correlation with all of the insects. Moreover, resurgence of dusky cotton bug as a new pest on cotton crops was also previously been investigated. Maximum temperature has a negative linear relationship with whitefly population, Rainfall showed a negative linear regression (1.3 to 3.4%) impact on the jassid population (Hameed et al., 2014). Cotton bollworm prefers a hot and humid environment, with an optimal temperature of 25 to 28 °C and a relative humidity of more than 70%, which is most conducive for reproduction (Machekano et al., 2018). Drought conditions are not favorable for eggs hatching and larval development. High temperature of June and August is favorable for the development of cotton bollworms but heavy rain is a population decreasing factor (Huang and Hao 2018). Therefore, present research was conducted to assess the plant densities and climate effects on the population of various important insect pests.

MATERIAL AND METHODS

Experimental Area

Research trial regarding insect response to different plant densities under climate change was conducted at Cotton Research Institute, Multan. Bt cotton variety MNH-1020 was grown.

Experimental Design

The experiment was conducted by using randomized complete block design (RCBD) with five treatments and three replications. Total experimental area was comprised of 98×90 ft² with bed length of 30 ft. that indicated one replication and experiment was replicated thrice with path width (between each bed) 2.5 ft. Each treatment was consisting of 7 rows with distance between row to row 2.5 feet and seed was sown at 5 different plant densities e.g., 6, 9, 12, 15, and 18 inches.

Seed Treatment

Five kg seed was delinted with H_2SO_4 and washed with distilled water. Delinted seed was treated with hombre ultra® a product of Bayer (Imidacloprid 360 G/l+ Tebuconazole 12.5 G/l) to prevent seed born and soil borne diseases and also provides protection against sucking pest at early stage.

Seed Bed Preparation

In order to prepare the seedbed for sowing, a pre-soaking irrigation was applied to a depth of 10 cm. A tractor-mounted tiller was used to cultivate the fine seed bed four times to a depth of 10–12 cm, followed by the application of three planks once the soil had reached the required level of moisture. With a tractor mounted ridger, the ground was leveled and laid out into ridges and furrows. On the same day, the furrows were manually seeded with delinted cotton seeds in the moist soil in their respective locations. To ensure effective seed emergence, the furrows were re-irrigated 72 hours after the initial irrigation.

Sowing of Crop

Cotton was sown on 28 April 2022 at different plant densities. The process of sowing was done manually. Two to three seeds were placed in each hole.

Thinning

Manually thinning of cotton was done at four-leaf stage of plant in order to maintain the prescribed plant spacing and to get the required plant population.

Plant Protection Measures

With chemical management, insect pests were kept below the threshold level. To keep below ETL, the sucking insects and bollworm (Pink bollworm especially) was control using chemicals.

Harvesting/Picking

During the whole cropping season of cotton only two picking were done. First picking was done on September 9, 2022, and second picking was done on October 12, 2022.

Data Collection of Sucking Insect Pests

The data of sucking insect pests was gathered by randomly selecting ten plants through whole season. 15 Leaves from upper, middle, and lower side were selected (5 leaves from each side) and counted numbers of sucking insect pests at morning time. Data of sucking insect pest i.e., jassid, whitefly and thrips was recorded on per leaf basis following leaf turn method.

Data Collection of Chewing Insect Pest

Data of pink bollworm infestation was taken from rosette flowers and green bolls. Twenty-five green bolls were plucked from 10 plants from each plot (called as replication). Immature cotton bolls were dissected after 4 days of collection to see the pink bollworm infestation**.** Data of pink bollworm was recorded on percentage basis.

$$\text{The formula of pink bollworm infestation} = \frac{\text{Infested flower/bolls}}{Total\ flower/bolls} \times 100$$

Data Collection for Natural Enemies

The data of natural enemies like spiders, *C. carnea*, etc. were taken carefully observing the whole plant. Ten plants were observed from each replication.

Weather Data Collection

Meteorological data was taken from meteorological station of Cotton Research Institute, Multan. Correlation of insect pests and beneficial insects with weather parameters (temperature, rainfall, relative humidity) was done.

Statistical Analysis

The data of sucking, chewing insect pests and natural enemies was analyzed by using analysis of variance (ANOVA). All the statistical analysis was performed by using statistical analysis software (Statistix 8.1 and XL statistic using this model ANOVA, correlation and descriptive analysis). Means were separated using Tukey's Kramers HSD test at 5% level of significance.

RESULTS

Whitefly

The data (Table-1) revealed that plant density had significant effect (P Value: 0.000) on the population of whitefly. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of whitefly (5.87/leaf & 5.31/leaf) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (4.84/leaf & 4.46/leaf). Minimum population of whitefly was observed in $T_{5\,(18'')}$ (4.02/leaf) after comparison with other treatments.

Jassid

The data (Table-1) revealed that plant density had significant effect (P Value: 0.000) on the population of jassid. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of jassid (2.34/leaf & 1.79/leaf) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (1.45/leaf & 1.24/leaf). Minimum population of jassid was observed in $T_{5\,(18'')}$ (0.11/leaf) after comparison with other treatments.

Thrips

The data (Table-1) revealed that plant density had significant effect (P Value: 0.000) on the population of thrips. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of thrips (1.98/leaf & 1.64/leaf) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (1.57/leaf & 1.21/leaf). Minimum population of thrips was observed in $T_{5\,(18'')}$ (1.14/leaf) after comparison with other treatments.

Dusky Cotton Bug

The data (Table-1) revealed that plant density had significant effect (P Value: 0.000) on the population of dusky cotton bug. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of dusky cotton bug (3.86/leaf or Boll & 3.60/leaf or Boll) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (3.35/leaf & 3.18/leaf or Boll). Minimum population of dusky cotton bug was observed in $T_{5\,(18'')}$ (2.90/leaf or Boll) after comparison with other treatments.

Pink Bollworm

The data (Table-1) revealed that no significant difference existed in the level of pink bollworm infestation in plant spacing treatments (P > 0.05). The infestation at all the plant densities was statistically the same. Maximum infestation 16.52/25 Boll has been recorded in T_5 (18″) that is followed by 15.87/25 Boll has been recorded in $T_{5\,(15'')}$. Minimum infestation 15.57/25 Boll was recorded in $T_{1\,(6'')}$ and $T_{3\,(12'')}$.

Table 1. Mean population of insect pests among different plant densities of cotton

Treatments	Whitefly	Jassid	Thrips	DCB	PBW
6 inches	5.87 (A)	2.34 (A)	1.98 (A)	3.86 (A)	15.57 (A)
9 inches	5.31 (B)	1.79 (B)	1.64 (B)	3.60 (B)	15.76 (A)
12 inches	4.84 (C)	1.45 (C)	1.57 (B)	3.35 (C)	15.57 (A)
15 inches	4.46 (D)	1.24 (D)	1.21 (C)	3.18 (C)	15.87 (A)
18 inches	4.02 (E)	0.11 (E)	1.14 (C)	2.90 (D)	16.52 (A)

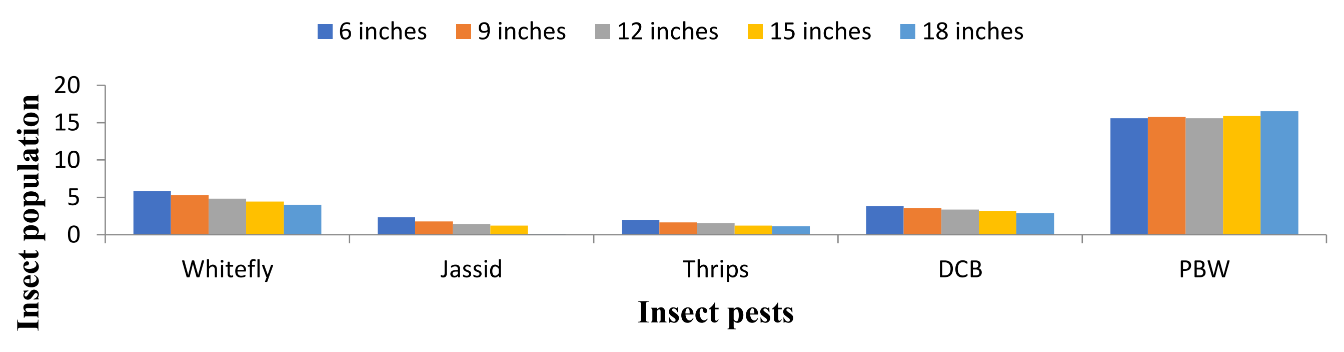

Figure 1. Insect pest population among various plant densities.

Ants

The data (Table-2) revealed that plant density had significant effect (P Value: 0.000) on the population of ants. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of ants (1.91/ Plant & 1.74/ Plant) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (1.60/ Plant & 1.23/ Plant). Minimum population of ants was observed in $T_{5\,(18'')}$ (1.18/ Plant) after comparison with other treatments.

Chrysoperla carnea

The data (Table-2) revealed that plant density had significant effect (P Value: 0.000) on the population of *Chrysoperla carnea*. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of *C. carnea* (1.53/ Plant & 1.42/ Plant) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (1.25/ Plant & 1.25/ Plant). Minimum population of *C. carnea* was observed in $T_{5\,(18'')}$ (1.11/ Plant) after comparison with other treatments.

Geocoris

The data (Table-2) revealed that plant density had significant effect (P Value: 0.102) on the population of *Geocoris*. The treatments $T_{1\,(6'')}$, $T_{3\,(12'')}$ and $T_{4\,(18'')}$ with plant spacing had more population of *Geocoris* (1.96/ Plant, 1.98/ Plant & 1.98/ Plant) than $T_{2\,(9'')}$ (0.91/ Plant). Minimum population of *Geocoris* was observed in $T_{5\,(18'')}$ (0.89/ Plant) after comparison with other treatments.

Ladybird Beetle

The data (Table-2) revealed that plant density had significant effect (P Value: 0.000) on the population of ladybird beetle. The treatments $T_{1\,(6'')}$, $T_{2\,(9'')}$ and $T_{5\,(18'')}$ with plant spacing had more population of ladybird beetle (1.21/ Plant, 1.00/ Plant & 1.00/ Plant) than $T_{3\,(12'')}$ (0.98/ Plant). Minimum population of ladybird beetle was observed in $T_{4\,(15'')}$ (1.18/ Plant) after comparison with other treatments.

***Orius* Bug**

The data (Table-2) revealed that plant density had significant effect (P Value: 0.099) on the population of *Orius* bug. The treatments $T_{1\,(6'')}$, $T_{2\,(9'')}$ and $T_{5\,(18'')}$ with plant spacing had more population of *Orius* bug (1.00/ Plant, 0.96/ Plant & 0.96/ Plant) than $T_{3\,(12'')}$ (0.93/ Plant). Minimum population of *Orius* bug was observed in $T_{4\,(15'')}$ (0.89/ Plant) after comparison with other treatments.

Spider

The data (Table-2) revealed that plant density had significant effect (P Value: 0.000) on the population of spider. The treatments $T_{1\,(6'')}$ and $T_{2\,(9'')}$ with plant spacing had more population of spider (1.63/ Plant & 1.53/ Plant) than $T_{3\,(12'')}$ and $T_{4\,(15'')}$ (1.37/ Plant & 1.32/ Plant). Minimum population of spider was observed in $T_{5\,(18'')}$ (1.19/ Plant) after comparison with other treatments.

Treatments	Ants	*Chrysoperla carnea*	*Geocoris*	ladybird beetle	*Orius*	Spider
6 inches	1.91 (A)	1.53 (A)	0.96 (A)	1.21 (A)	1.00 (A)	1.63 (A)
9 inches	1.74 (AB)	1.42 (A)	0.91 (A)	1.00 (B)	0.96 (A)	1.53 (AB)
12 inches	1.60 (B)	1.25 (B)	0.98 (A)	0.98 (B)	0.93 (A)	1.37 (BC)
15 inches	1.23 (C)	1.25 (B)	0.98 (A)	0.96 (B)	0.89 (A)	1.32 (C)
18 inches	1.18 (C)	1.11 (B)	0.89 (A)	1.00 (B)	0.96 (A)	1.19 (C)

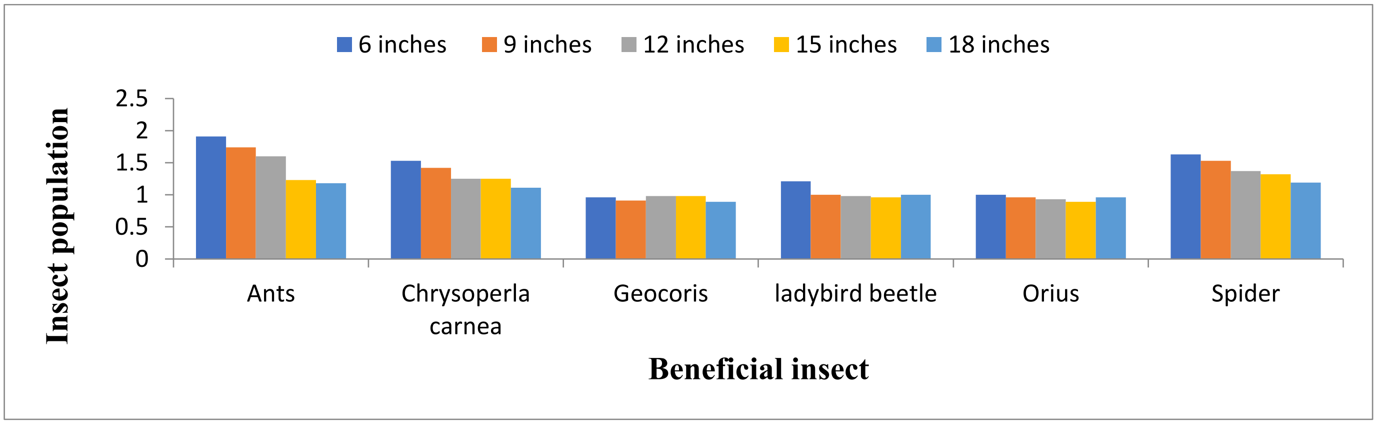

Figure 2. Beneficial insect population among various plant densities.

Correlation of Weather Parameters on Insect Pests at Different Plant Densities

Correlation of weather parameters on insect pests at P-P 6 inches spacing

In 6 inches of plant to plant spacing whitefly and jassid were positively correlated at maximum temperature while negatively correlated with thrips dusky cotton bug and pink bollworm. All insect pests are positively correlated with minimum temperature except dusky cotton bug which was negatively correlated to the minimum temperature. Relative humidity was negatively correlated with the population of whitefly, jassid, thrips, dusky cotton bug and pink bollworm. All insect pests are negatively correlated with rainfall except thrips which was positively correlated to the minimum temperature as shown in (Table 3).

Table 3. Correlation of weather parameters on insect pests at 6 inches plant density.

Insect	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
Whitefly	0.067	0.19	-0.56	-0.064
Jassid	0.52	0.016	-0.16	-0.11
Thrips	-0.012	0.158	-0.51	0.28
DCB	-0.22	-0.067	-0.23	-0.42
PBW	-0.32	0.039	-0.49	-0.22

Correlation of Weather Parameters on Insect Pests at P-P 9 Inches Spacing

In 9 inches of plant to plant spacing the maximum temperature was positively correlated with the population of whitefly and jassid while the negative correlation was observed in the population of thrips, dusky cotton bug and pink bollworm. All insect pests are positively correlated with minimum temperature except dusky cotton bug which was negatively correlated to the minimum temperature. Relative humidity was negatively correlated with the population of whitefly, jassid, thrips, dusky cotton bug and pink bollworm. All insect pests are negatively correlated with rainfall except thrips which was positively correlated to the rainfall as shown in (Table 4).

Table 4. Correlation of weather parameters on insect pests at 9 inches of plant to plant spacing.

Insect	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
Whitefly	0.038	0.20	-0.63	-0.078
Jassid	0.34	0.22	-0.35	-0.022
Thrips	-0.105	0.019	-0.39	0.17
DCB	-0.203	-0.086	-0.25	-0.42
PBW	-0.32	0.048	-0.53	-0.24

Correlation of Weather Parameters on Insect Pests at P-P 12 Inches Spacing

In 12 inches of plant to plant spacing the maximum temperature was positively correlated with the population of whitefly and jassid while the negative correlation was observed in the population of thrips, dusky cotton bug and pink bollworm. All insect pests are positively correlated with minimum temperature except the population of thrips and dusky cotton bug which was negatively correlated to the minimum temperature. Relative humidity was negatively correlated with the population of whitefly, jassid, thrips, dusky cotton bug and pink bollworm. All insect pests are negatively correlated with rainfall except thrips which was positively correlated to the rainfall as shown in (Table 5).

Table 5. Correlation of weather parameters on insect pests at 12 inches of plant to plant spacing.

Insect	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
Whitefly	0.003	0.24	-0.65	-0.092
Jassid	0.39	0.12	-0.26	-0.046
Thrips	-0.040	-0.055	-0.38	0.43
DCB	-0.24	-0.057	-0.22	-0.38
PBW	-0.34	0.037	-0.52	-0.19

Correlation of Weather Parameters on Insect Pests at P-P 15 Inches Spacing

In 15 inches of plant to plant spacing the maximum temperature was positively correlated with the population of jassid and thrips while the negative correlation was observed in the population of whitefly, dusky cotton bug and pink bollworm. All insect pests are positively correlated with minimum temperature except dusky cotton bug which was negatively correlated to the minimum temperature. Relative humidity was negatively correlated with the population of whitefly, jassid, thrips, dusky cotton bug and pink bollworm. All insect pests are negatively correlated with rainfall except the population of jassid and thrips which was positively correlated to the rainfall as shown in (Table 6).

Table 6. Correlation of weather parameters on insect pests at 15 inches of plant to plant spacing.

Insect	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
Whitefly	-0.037	0.25	-0.64	-0.050
Jassid	0.27	0.17	-0.26	0.0015
Thrips	0.025	0.037	-0.39	0.168
DCB	-0.23	-0.079	-0.25	-0.418
PBW	-0.33	0.068	-0.53	-0.22

Correlation of Weather Parameters on Insect Pests at P-P 18 Inches Spacing

In 18 inches of plant to plant spacing all insect pests are negatively correlated with maximum temperature except jassid which was positively correlated to the maximum temperature. The minimum temperature was positively correlated the population of whitefly and jassid while negatively correlated to the population of thrips, dusky cotton bug and pink bollworm. Relative humidity was negatively correlated with the population of whitefly, jassid, thrips, dusky cotton bug and pink bollworm. All insect pests are negatively correlated with rainfall except the population of jassid and thrips which was positively correlated to the rainfall as shown in (Table 7).

Table 7. Correlation of weather parameters on insect pests at 18 inches of plant to plant spacing.

Insect	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
Whitefly	-0.056	0.24	-0.68	-0.039
Jassid	0.30	0.019	-0.230	0.12
Thrips	-0.17	-0.18	-0.235	0.308
DCB	-0.23	-0.063	-0.235	-0.403
PBW	-0.28	0.094	-0.55	-0.207

Yield Comparison Among Various Plant Densities

Table 8. ANOVA Table (RCBD).

Source	DF	SS	MS	F-Value
Treatments	4	54.90	13.73	1614.7
Replications	2	0.01	0.005	0.62
Error	8	0.068	0.0085	-
Total	14	54.98	-	-

The comparison of the variance (ANOVA) within the Randomized Complete Block Design (RCBD) indicated that the plant density significantly influenced yield with a high level of significance ($F = 1614.7$; $p \leq 0.05$). The calculated F-value of the treatments was significantly higher than the tabulated F-value in 5% level of significance ($F_{4,8} = 3.84$), which indicated that the differences between the treatment means was not as a result of random variation but was largely caused by the influence of plant spacing. The effect (non-significant) of replication indicated that environmental conditions at the three replications were rather stable, and blocking partially managed field variability. The small error mean square (MSE = 0.0085) is an additional indicator of high experiment precision and reliability of the data that was gathered. Least significant difference (LSD) test at the level of 5 percent probability (LSD = 0.17 kg) showed that the mean of all the treatment types was significantly different. The maximum yield (12.18 kg) was obtained in 6-inch plant

https://doi.org/10.55627/agribiol.004.01.1829

spacing which was statistically better compared to the wider spacing. The yield decreased gradually as the spacing between the plants increased with the lowest yield (6.57 kg) being attained at 18 Inches plant spacing.

Table 9. Mean Yield comparison among various plant densities.

Treatments	Yield in kg
6 inches	12.18 ± 0.05 (A)
9 inches	7.84 ± 0.05 (B)
12 inches	9.56 ± 0.05 (C)
15 inches	8.17 ± 0.05 (D)
18 inches	6.57 ± 0.05 (E)

This increased performance of the 6 inch-spacing can be explained by the fact that the plant population per unit area was higher leading to an increase in the effective use of available resources including light, nutrients, water and space. Conversely, increased spacing decreased plant population, hence the yield-per-plot decreased in the end, although there might have been a reduction in inter-plant competition. Overall, the findings are evident to suggest that the closer plants to each other has a great influence on yield in the specified experimental conditions. Thus, the most productive and statistically better treatment of plant density was observed to be 6-inch spacing out of the tested densities.

DISCUSSION

Variability in cotton production over time is influenced by agronomic and weather-related factors in site-specific soil conditions. One of the most crucial agronomic practices in cotton production is plant density. However, the relative importance of each factor remains unclear. For more than a century, significant research has been conducted to identify the ideal plant population for upland cotton in order to maximize yield and quality. According to numerous researches, plant populations between 49,000 and 256,000 plants per hectare produce the maximum yields. One of the factors contributing to Asiatic cotton's low yields is planting with a wide spacing. By using compact spacing and a high planting density, yield levels can be increased (Chapepa et al., 2020).

The results revealed that the population of whitefly, jassid, thrips, and dusky cotton bug was statistically significant at different plant densities when compared with each other. Highest population of sucking pests was recorded at narrow plant spacing and lowest populations were recorded in at wider plant spacing. These result are comparable with the finding of Majeed et al., (2016) who reported that the population of insect pests in the narrow plant spacing is high, while wider plant spacing (low plant density) have low pest attack. The 6-inch spacing yield increases can be best explained by an increased number of plants per unit area (increased number of bolls per m^2 even though bolls per plant may reduce), increased interception of photosynthetic active radiations (PAR) at the start of the season, increased population biomass growth, and improved crop-weed competition. The effects of these changes are more habitat suitability and resource concentration by sap-sucking insects, more guarded areas of feeding/oviposition, and potentially decreased weather and dispersal mortality. Higher densities of sucking pests are recorded in the closer spacing as observed in several field studies in South Asia which is in line with this mechanism. These result are dissimilar to the finding of Arif et al., (2006), who reported that the population of sucking pest (whitefly, jassid and thrips) was decrease with the increase in plant density (Narrow spacing).

The population of pink bollworms in all treatments was non-significant at different densities. These result are in a line with the finding of Sarwar and Sattar, (2016), who reported that there was no significant difference at different plant densities on the population of pink bollworm in treated field and control of cotton. This lower PBW response was mainly to (i) management and materials that minimize statistical differences between spacing treatments (Bt cotton background or sprays), (ii) PBW biology (rapid internal boll entry following egg hatch causes PBW less sensitive to leaf-canopy microclimate and also less susceptible to suppression/measurement using conventional foliar sampling), (iii) monitoring resolution (boll dissection intensity and timing is strongly predictive of power to detect differences). Experience in Pakistan has shown that even with a low level of Cry toxin expression and / or resistance, PBW pressure might be high in Bt cultivars, but the development of spacing effects is determined largely by insecticide timing, availability of bolls and the design of sampling. These results are also in accordance with the findings of Naik et al., (2018) who investigated that the population of PBW was statistically non-significant among various plant spacing.

The population of ants, green lacewing, lady bird beetle, and spiders was significant different while the population of *Geocoris* and *Orius* bug was non-significant in all treatments at all tested plant densities. In high plant density, the population of ants, green lacewing, lady bird beetle, and spiders was highest and it was lowest in low plant density at different densities. These result are comparable with the finding of Solangi et al., (2011), Rosenheim et al., (1993) and Arshad et al., (2015) who reported that the population of lacewing, spider and ladybird beetle was significantly increase while the population of *Geocoris* and *Orius* bug was significantly reduced among various plant densities.

The results revealed that whitefly population had a negative correlation with high temperature and relative humidity. While whitefly population had a positive correlation with minimum temperature and rainfall. These results are comparable with the finding of other researchers who reported that the whitefly negative correlation with maximum relative humidity and significant negative correlation with weekly total rainfall. There was a significant and negative relationship between the highest temperature and the whitefly population and a significant and inverse relationship between the morning and evening relative humidity (Ghosh et al., 2014; Motswagole et al., 2019).

Jassid population had a negative correlation with rainfall while jassid had a positive correlation with maximum temperature minimum temperature and relative humidity. The thrips population had a negative correlation with maximum temperature, rainfall and relative humidity but was a positive correlation with minimum temperature. DCB had positive correlation with maximum temperature and relative humidity. While there were negative correlation with minimum temperature and rainfall. These results are in accordance with the findings of Bhute et al., (2012) who reported that leafhopper population showed negative correlation with relative humidity. In case of thrips these results opposite to the findings of Gosalwad et al., (2009) who reported that thrips exhibited significant positive correlation with bright sunshine hours. PBW had a positive correlation with a minimum temperature and rainfall but negativity correlated with maximum temperature and relative humidity. These results are comparable with the findings of Jamil et al., (2022) who reported that bollworm infestation and abiotic factors were correlated, with a non-significant negative connection for rainfall and evening relative humidity. It may have occurred because the prevailing physical environmental conditions and crop stand strongly influence the occurrence and development of these insect pests (Fenoglio *et al.,* 2013; Atakan et al., 2021).

One of the main mechanistic processes is physical: with decreased plant spacing, the canopy is closed sooner and denser, and it alters the within-canopy air movement, temperature, and relative humidity. Greater planting density in general crop canopies is associated with more within-canopy relative humidity and lower maximum temperatures especially in the middle/lower canopy where there is a restriction of airflow. The narrow spacing created a more buffered in-crop climate (reduced wind, increased shade, less variable humidity) resulting in a higher probability of survival of eggs/immatures, decreased desiccation, and less death as caused by weather. Narrow spacing leads to an increase in the plant population leaf area index (LAI) and the persistence of the foliage, while individual plant leaf area tends to decrease (i.e. per-plant compensation). In an experiment of cotton density measurement of LAI and light interception, the LAI increased with increasing density, and high density stands significantly high LAI compared to low density stands, and canopy light interception was greater at high density (Khan et al., 2017). However, it is not always to get greater yield from narrow spacing. Increased density may cause self-shading and an increase in the favorability of pests and also a decrease in the weight of bolls or fiber quality. The location specific optimum is necessary as an area with different cultivar structure, fertility, irrigation and season duration. In a cotton canopy-microenvironment study, it was concluded that the highest yield was recorded at a moderate density of the plants due to the production of more bolls per unit area, and a conducive canopy microenvironment to yield formation (temperature, RH, light transmittance).

CONCLUSIONS

The maximum yield was obtained when cotton was planted with 6-inch spacing though the spacing also favored the existence of sucking pests. Spacing (18 inches) decreased the pest population but yield was also lowered. Higher densities of natural enemies with increased natural spacing indicate that high-density canopy planting could increase the biological activity in crop canopies. This is the reason why optimal spacing must be chosen not only according to the benefits of yield or pest pressure but also according to the integrated pest management techniques.

ACKNOWLEDGEMENTS

Not applicable.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

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