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Determination of yield, yield components and some physiological parameters under shading and normal growth conditions in cotton (*Gossypium hirsutum* L.)

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ABSTRACT

This research was carried out to determine the effects of shading on cotton yield, yield components and some physiological parameters in 5 different cotton (*Gossypium hirsutum* L.) varieties grown under normal development and shading conditions. In the experiment, 5 cotton varieties (DP 499, Stoneville 468, Stoneville 498, MAY 455, MAY 558) and 30% shade providing net were used as material. The statistical analysis showed that normal and shading conditions had significant effects on seed cotton yield, number of sympodial and monopodial branches, number of nodes of the first fruiting branch, number of nodes, HNR (height/node ratio), number of bolls and first picking percentage. It was determined that there were significant differences among the varieties in the number of nodes of first fruiting branch, number of sympodial branches, number of nodes, boll weight, seed cotton boll weight, ginning percentage and first picking percentage. Average seed cotton yield was 3537.75 kg ha-1 under normal development and 2638.15 kg ha-1 under shading conditions, and that the seed cotton yield decreased by 25.42% with shading. As a result of the study, it was found that shading led to decreases in seed cotton yield, the number of sympodial branches, the node of the first fruiting branch, and the total number of nodes. In contrast shading increased the number of monopodial branches, boll number, HNR, and first picking percentage. Shading did not positively affect cotton yield through mitigating the impact of high temperatures. However, at least two years of research are needed before a definitive recommendation can be made.

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Introduction

Cotton is an important industrial crop used as a primary input in the textile and food industries worldwide. Due to its high economic value, cotton is considered a strategic commodity that provides substantial employment opportunities and added value, particularly throughout the textile production chain. Globally, cotton is cultivated on approximately 31.87 million hectares, producing 24.36 million tons of cotton fiber with an average fiber yield of 763.5 kg ha^{-1} (Anonymous, 2023). In Türkiye, cotton is grown on approximately 467.000 hectares, producing 830.000 tons of cotton fiber with an average yield of 1780 kg ha^{-1} (Anonymous, 2024).

Approximately 60% of Türkiye's total cotton production originates from the GAP Region (Southeastern Anatolia Project). However, cotton production areas and production quantities fluctuate from year to year. Cotton is widely cultivated across many countries due to its extensive use as a textile raw material, livestock feed, and edible oil source. Considering that Türkiye consumes 1.63 million tons of cotton fiber, production is insufficient to meet demand, making imports necessary. Therefore, ensuring sufficient quantity and quality of cotton fiber is essential for maintaining and enhancing the competitiveness of Türkiye's textile industry in global markets. Increasing cotton yield per unit area is critical to reducing the fiber deficit and sustaining cotton production.

Climate change is expected to significantly affect agricultural production in the coming decades. Projections predict that atmospheric carbon dioxide levels will double during the 21st century, and that increases in other greenhouse gases, particularly carbon dioxide, will impact climatic parameters such as temperature and precipitation patterns. Türkiye is considered one of the most vulnerable to these changes (Anonymous, 2011). Therefore, it is inevitable that crops cultivated in the coming years will face more severe environmental conditions than at present. The growing global population, climate change–induced constraints on crop production, and the rising demand for fiber highlight the importance of research in this area. Heat waves and an increasing number of hot days and warm

nights have become more common in the main agricultural regions of the world. Although cotton is well adapted to semi-arid environments, it is highly sensitive to elevated temperatures during the flowering and boll development stages. Therefore, a thorough understanding of the effects of heat stress on different stages of plant growth and development, as well as the mechanisms of heat tolerance, is crucial for sustaining yield potential without compromising quality under high-temperature conditions (Saini et al., 2023).

Many factors influence plant productivity. Along with the genetic makeup of the seed, soil structure, and agricultural methods employed, climate parameters are among the most important factors affecting yield. Rising temperatures and changes in precipitation, resulting from climate change, whose impact is increasingly felt today, are having the greatest impact on the agricultural sector (Gürkan et al., 2017). Previous studies have suggested that C3 plants, including cotton, may be significantly affected by future climate change scenarios. Elevated atmospheric CO_2 concentrations have been shown to improve light-use efficiency in cotton. Cotton plants exhibit optimum growth at temperatures ranging from 27 to 32 °C, while maximum square and boll formation occurs under day/night temperature regimes of approximately 30/22 °C (Reddy et al., 1991; Reddy et al., 1992).

Plants' ability to achieve high productivity depends on their ability to photosynthesize. The optimum temperature for photosynthesis in cotton is around 35 °C, whereas assimilate production is inhibited at temperatures below 17 °C and above 47.5 °C (Babaeva and Asrorov, 1987). It has been determined that pollen grains lose their viability and abnormal cotyledon development occurs in bolls at temperatures of 38°C and above (Almeida, 1985). Boll production efficiency increases up to 30°C but declines rapidly thereafter; 32°C is the upper limit for boll set, and above this temperature, yield is negatively affected due to boll shedding (Ünay and Başal, 2005). For every 1°C increase in daily maximum temperature, fiber yield decreases by 1.1 kg per hectare. Consequently, a strong negative relationship has been demonstrated between high temperature and yield (Singh et al., 2007). In addition to heat temperatures, low temperatures and insufficient light intensity also adversely affect cotton growth and fiber quality in many production areas (Crozat et al., 1997; Shu et al., 2009). Atmosferic pollution and brown cloud formation also substantially reduce solar radiation, causing nearly a 40% decline in ultraviolet and visible light wavelengths (Ramanathan and Feng, 2009). These conditions decrease photosynthetically active radiation (PAR) and may significantly limit cotton productivity in many regions, where air pollution and overcast conditions frequently occur during the growing season (Zhao and Oosterhuis, 1998a; Yan et al., 2007).

Light, temperature, and humidity are among the most critical environmental factors affecting plant development. Sunlight plays a particularly important role in determining cotton yield and fiber quality. Plant growth and development are influenced not only by light intensity but also by light quality, including wavelength composition and radiation characteristics (Chen et al., 2019).

Appropriate light intensity is essential for optimal plant growth, development and physiological performance. Exposure to high-intensity light can result in excessive light energy, thereby reducing photochemical efficiency and causing photoinhibition in plants (Xue et al., 2023). Such conditions can subsequently have detrimental effects on plant health. Although previous studies have investigated the effects of shading on cotton yield, information regarding the timing and duration of shading applications during the growing season, as well as their effects on physiological responses and yield components, remains limited (Zhao et al., 2018).

This research was conducted to determine the effects of shading on yield, yield components, and some physiological parameters in cotton, and to identify changes in the examined characteristics in cotton plants grown under normal and shading conditions. Furthermore, this study investigated whether shading could mitigate the negative effects of high temperatures on cotton growth and productivity during cotton production.

Materials and Methods

The trial was conducted in the 2022 cotton growing season at the experimental site of the Faculty of Agriculture at Siirt University. Five cotton varieties (DP 499, Stoneville 468, Stoneville 498, MAY 455, and MAY 558) were used as experimental material in the study. The cotton varieties in the trial were planted at the normal planting time, and their growth was compared under normal growing conditions and shading conditions using a 30% shade net. The study was conducted using a split-plot design with four replications. The main plots in the study were normal and shading conditions, while five different cotton varieties constituted the subplots.

Table 1. Soil properties of the experimental area

Analysis	Analysis Results	Evaluation
pH	7.70	Slightly alkaline
EC	0.09 dS/m	Salt-free
Lime	%2.55	Slightly calcareous
Texture	Sand: 27.3%, Silt: 20.0%, Clay: 52.7%	Clayey
Organic Matter	%0.94	Very Little
Available Phosphorus	29.60 kg ha^{-1}	Very Little
Available Potassium	1366.50 kg ha^{-1}	Adequate
Nitrogen	%0.099	Low

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Characteristics of the Experimental Site

The experimental site was located in the Siirt University, Kezer Campus, in the city center of Siirt, at 37°58' North latitude, 41°51' East longitude, and 930 m above sea level. The experimental area is characterized by flat topography and medium-depth soil. The soil contains high amounts of clay minerals, which expand and swell during the winter months.

In the summer, cracks form at depths of 70-80 cm as a result of high temperatures and prolonged drought. During sowing preparations in the experimental area, soil samples were taken from 0-30 cm below the soil surface to determine certain properties and nutrient content of soil. The determined properties of soil are illustrated in Table 1. It is observed that the soil samples taken before planting have a clayey texture (52.7%) and slightly alkaline (7.70), electrical conductivity is salt-free (0.09 dS/m), slightly calcareous (2.55%), organic matter content is very low (0.94%), available phosphorus is very little amount (29.60 kg ha^{-1}), available potassium is sufficient (1366.50 kg ha^{-1}) and nitrogen amount is low (0.099%).

The climatic data for the study years and the long-term period are presented in Figures 1 and 2. The data indicate that the monthly average, minimum, and maximum temperatures in 2022 were higher than the long-term averages.

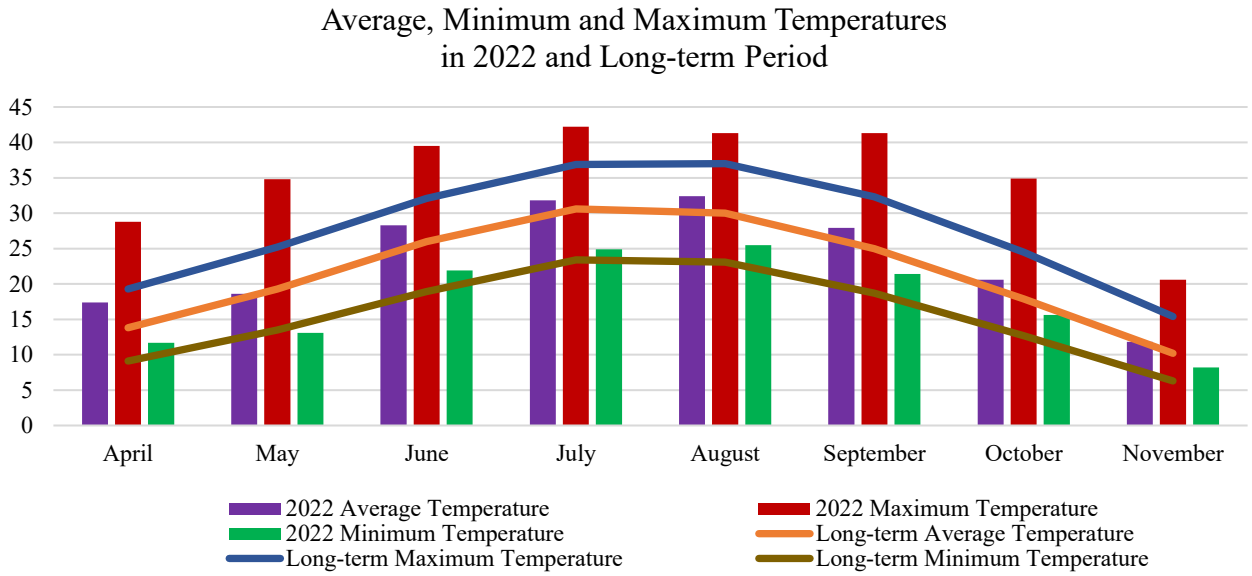

Figure 1. Average, Minimum and Maximum Temperature in 2022 and Long-term Period

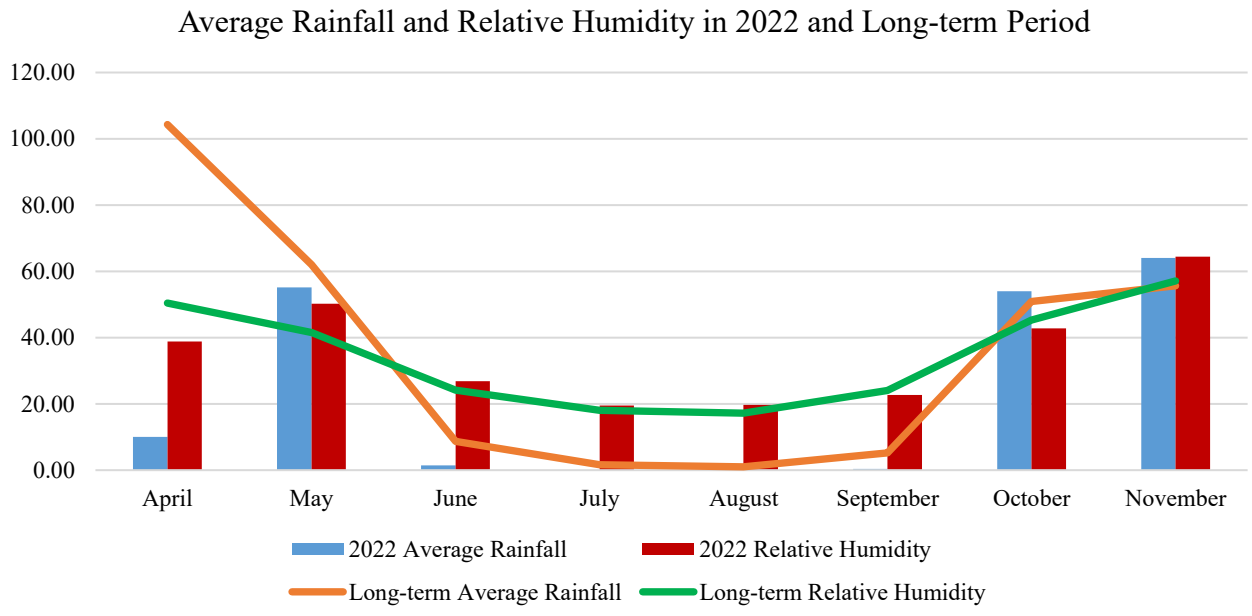

Figure 2. Average Rainfall and Relative Humidity in 2022 and Long-term Period

Agronomic Management

The experimental area was cultivated deeply with a plow in the fall and shallowly with a cultivator in the spring. Before planting, the field was prepared by two plowing operations. After the field was prepared for planting, plot boundaries were determined by subdivision. The trial was conducted according to a split-plot design with four replications. The main plots were treated with normal growing conditions and shade conditions, while the subplots were assigned to different varieties. Planting operations were carried out on May 13, 2022, using a trial planting machine. Each plot consisted of four rows, 6 m long and 2.8 m wide, covering a plot area of 16.8 m^2. Row spacing was maintained at 70 cm during planting, and thinning was performed to maintain a distance between plants of 15-20 cm, with 2 m spacing between blocks.

The area to be shaded was covered with black shade netting, providing 30% shade, and 2.5 m long pine poles, using steel tension wire. To achieve this, the poles were first driven into the experimental area, and then the shade netting was placed. The shade netting was closed from the top to reduce the effects of sunlight (*Figure 3*). Shading started at the beginning of flowering and continued until the end of boll maturation, after which the shade netting was removed from the experimental area.

Soil samples were collected from the trial area, soil analyses were performed, and the amount of fertilizer required by the plant was determined. Half of the required nitrogen and all of the phosphorus at planting (80 kg ha^{-1} N, 80 kg ha^{-1} P_2O_5) were applied to the band using a 20-20-0 compound fertilizer. The remaining half of the nitrogen (80 kg ha^{-1}) was applied as ammonium nitrate (33%) before the first irrigation. Crop management practices were carried out regularly during the trial, including weed and pest control throughout the plant development period. The drip irrigation method was used for irrigation, which started 40-45 days after planting and terminating at the 10% boll opening stage, completing the irrigation process (*Figure 3*).

Agronomical and Physiological Observations

Yield and yield components were determined from 10 randomly selected plants during the pre-harvest period. At these stage 20 bolls were collected and weighed to determine boll weight and seed cotton weight per boll and physiological traits were recorded during the peak flowering period (*Figure 3*).

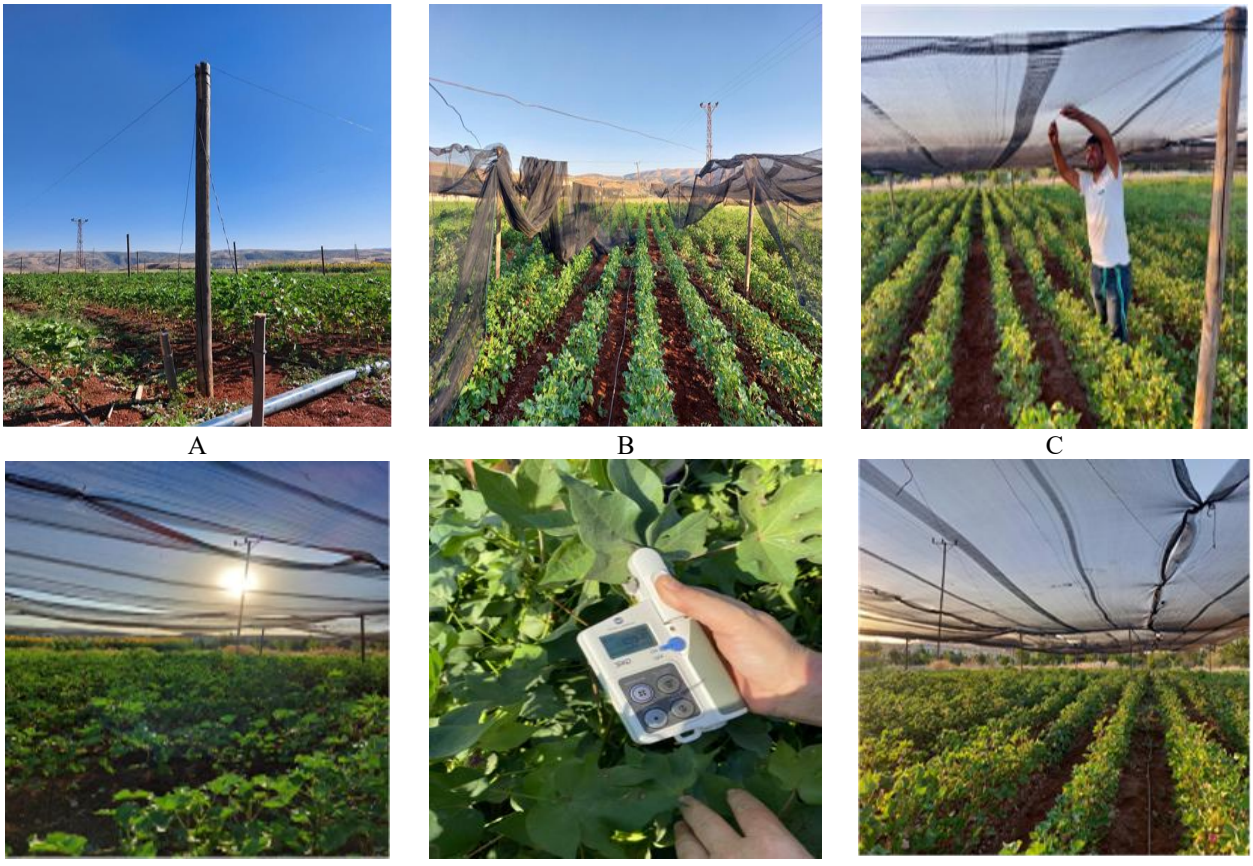

Figure 3. (a) Image of the experimental area (b) Image of the shading material (c) Covering the experiment with shading material (d) Cotton grown under shading, (e) Measurement of chlorophyll content with SPAD meter (f) Cotton maturation stage

Normalized Difference Vegetation Index (NDVI value): The normalized difference vegetation index (NDVI value) in each parcel was determined by measuring with the help of the Trimble GreenSeeker device.

Canopy Temperature: Leaf/canopy temperature was determined using a Spectrum Brand 2956 Model portable infrared thermometer.

Leaf chlorophyll content (SPAD value): The chlorophyll content was determined in the 5th, newly opened and fully grown leaves of 10 randomly selected plants from each plot using the Minolta SPAD-502 device (Johnson and Saunders, 2003).

Leaf Area: The top 5th newly opened and fully developed leaf of 3 randomly selected plants from each plot was drawn on A4 paper, then scanned with a scanner and the leaf area was determined with the help of the AutoCAD program.

All physiological measurements were taken between 12:00 and 2:00 PM, when the sun's rays were directly overhead.

Harvest

The harvest was carried out by hand-harvesting the middle two rows of four-row plots, which were then converted into total yield per hectare.

The first harvest was performed when at least 60% of the bolls were open (4 October 2022), and the remaining bolls were harvested manually in a second picking (18 October 2022). The harvested cotton was weighed, and yield was calculated on a plot basis.

Statistical analyses

Data were analyzed using the JMP statistical software in accordance with the experimental design. The differences between treatments were compared using Fisher's least significant difference (LSD) test at $P < 0.05$.

Results and Discussion

In the study, the results of the analysis of variance for the investigated traits, including mean of squares and $LSD_{(0.05)}$ test are presented in Table 2-4.

As shown in Table 2, statistically significant differences were found among treatments for seed cotton yield at the $P \leq 0.01$ level; however, variety and treatment x variety interaction were not significant. The average values of seed cotton yield of the varieties under normal development and shading conditions are given in Table 5. The average seed cotton yield was recorded as 3537.57 kg ha^{-1} under normal growing conditions and 2638.15 kg ha^{-1} under shading conditions. Seed cotton yield in normal growing conditions was higher than in that of shading conditions; cotton varieties experienced a 25.42% yield decrease when grown under shading conditions.

Seed cotton yield among the cotton varieties ranged from 2924.50 to 3236.08 kg ha^{-1}. The highest yield was recorded in the Stoneville 468 variety (3236.08 kg ha^{-1}), whereas the lowest yield was observed in the Stoneville 498 variety (2924.50 kg ha^{-1}); however, the differences among cultivars were not statistically significant. The findings of Chen et al. (2019) are consistent with the results of the present study, indicating that seed cotton yield decreases under shading conditions compared with full sunlight. Zhao and Oosterhuis (1998b) revealed that shading during the early squaring stage did not significantly affect cotton yield; however, shading imposed after the onset of first flowering increased fruit abscission, resulting in reduced yield. This observation is in agreement with the findings of the current study. Furthermore, Zhao et al. (2018) suggested that yield losses in cotton can be mitigated through the selection of cultivars tolerant to both low temperature and low light conditions. Similarly, Echer et al. (2019), in their study conducted in Brazil, reported no significant treatment × cultivar interaction, which is consistent with the results obtained in the present research.

It has been observed that shading reduces cotton yield, and this may be related to photosynthesis, as light is essential for photosynthesis. Chen et al. 2025 revealed that light intensity regulates plant growth and development primarily by altering the photosynthetic rate, significantly affecting growth metabolism, photosynthesis, and morphogenesis. Similar findings were obtained in this study.

The results of the variance analysis for plant height are presented in Table 2. Table 2 shows that there were no statistically significant differences in plant height between the treatments. In addition, neither the cultivar effect nor the treatment x cultivar interaction was found to be significant for this trait. As shown in Table 5 that the average plant height was 72.19 cm under normal growing conditions and 71.73 cm under shading conditions, with no statistically significant difference between the two treatments. Plant height among the cotton cultivars ranged from 69.89 to 73.37 cm.

Although the differences were not statistically significant, the highest plant height was recorded in the DP 499 cultivar (73.37 cm), while the lowest was recorded in the Stoneville 468 cultivar (69.89 cm). Echer et al. (2019) reported that shading during the early stages of plant development did not significantly influence plant height, possibly due to reduced carbohydrate accumulation and dry matter production. Zhao and Oosterhuis (2000) found that shading did not significantly affect plant height during the stages of flower bud formation, the onset and termination of flowering, or fruit development in cotton. They further indicated that the results of the present study confirm earlier findings suggesting that shading does not influence plant height. Similar results were also obtained in the current research.

For the number of monopodial branches, there were significantly differences between treatments at the $P \leq 0.01$ level, while the variety and the treatment x variety interaction were not significant (Table 2). The mean values of the number of monopodial branches under normal development and shading conditions are shown in Table 6. For this trait, there were statistical differences between the treatments at the 1% significance level, and the average value for the number of monopodial branches was 1.96 number $plant^{-1}$ under normal growth conditions and 6.25 number $plant^{-1}$ under shading conditions. The number of monopodial branches under shading conditions was higher than in normal growing conditions. The number of monopodial branches of the cotton varieties ranged from 3.75 to 4.36 per plant. While there were no significant statistical differences between the varieties, the highest number of monopodial branches was obtained from the DP 499, and the lowest from the MAY 455 variety. These findings in this study demonstrate that shading increased the number of monopodial branches.

The findings of Li et al. (2019), which reported that shading inhibited vegetative branching, appear to differ from the findings of the study. This may be due to differences in the timing and duration of shading, the level of shading, and the plant's developmental stage. The results of the variance analysis for the number of sympodial branches are given in Table 2. From the same table, it was observed that there were statistical differences at the 5% level between treatments and varieties, and the treatment x variety interaction was also significant at the same level ($p \leq 0.05$).

The average value for the number of sympodial branches in the experiment was 8.30 per plant under normal growth conditions, while the number of sympodial branches was 6.44 per plant under shading conditions (Table 6). Cotton varieties experienced a 22.4% decrease in the number of sympodial branches when grown under shading conditions. The number of sympodial branches of the cotton varieties ranged from 7.08 to 8.10 per plant, with the difference being significant. The highest value was recorded from STV 498 (8.10 per plant), while the lowest value was obtained from MAY 455 with 7.08.

The number of sympodial branches was affected by the treatment x variety interaction; the highest value was obtained from the STV 498 variety grown under normal growth conditions with 9.65 number plant^{-1}, while the lowest was obtained from the MAY 455 variety grown under shading conditions with 6.15 number plant^{-1}. The significance of the treatment x variety interaction indicates that the number of sympodial branches may change when the cotton varieties are grown under normal and shading conditions. The research results are similar to the findings of Li et al. (2019), who stated that the sympodial branch was significantly reduced in artificially shaded cotton plants compared to those without shading, and that the growth and development of the sympodial branch was significantly inhibited under shading.

Table 2. Analysis of variance for seed cotton yield and plant growth parameters

Source of Variation	DF	SCY	PH	MB	SB	NFF	NN	HNR
Model	15	606383	46.73	12.63	4.77	11.92	9.80	0.60
Replication	3	16798.5	88.29	0.86	5.20	0.82	5.01	0.02
Treatment	1	8089621**	2.19	183.35**	34.59*	161.44**	99.09*	7.79 **
ReplicationxTreatment&Random	3	75377.1	89.19	0.03	3.71	0.34	3.13	0.15
Variety	4	131816	13.84	0.51	1.39*	1.67**	4.80*	0.19
Treatment x Variety	4	50585.5	27.73	0.33	1.16*	1.82**	1.06	0.00511
Error	24	153399	16.60	0.65	0.34	0.39	1.63	0.10
General	39							

SCY: Seed Cotton Yield; PH: Plant Height, MB: Monopodial Branches, SB: Sympodial Branches, NFF: Node of First Fruiting, NN: Number of Nodes HNR= Height/Node Ratio,*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 3. Analysis of variance for yield components, ginning percentage and first picking percentage

Source of Variation	DF	BN	BW	SCBW	NSB	100 SW	GP	FPP
Model	15	14.83	0.60	0.49	10.78	0.45	1.63	74.26
Replication	3	24.09	0.49	0.21	10.63	0.47	1.63	62.23
Treatment	1	88.71*	0.32	2.05	2.55	1.51	0.42	454.28*
ReplicationxTreatment&Random	3	6.62	0.19	0.38	10.73	0.31	0.63	18.45
Variety	4	5.26	1.54**	0.86**	21.35	0.63	4.02**	85.85*
Treatment x Variety	4	5.13	0.11	0.02	2.43	0.10	0.27	18.54
Error	24	4.17	0.15	0.12	12.12	0.25	0.68	23.06
General	39							

BN: Boll Number, BW: Boll Weight, SCBW: Seed Cotton Boll Weight, NSB: Number of Seeds in the Boll, SW: Seed Weight, GP: Ginning Percent, FPP: First Picking Percentage. *, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 4. Analysis of variance for some physiological parameters

Source of Variation	DF	NDVI	Canopy Temperature	Chlorophyll Content	Leaf Area
Model	15	0.0027	6.97	6.58	148.56
Replication	3	0.00375	8.53	6.70	276.53
Treatment	1	0.01024	0.05	0.55	275.30
ReplicationxTreatment&Random	3	0.00535	22.93	10.65	178.90
Variety	4	0.00031	1.56	8.00	88.96
Treatment x Variety	4	0.00052	0.99	3.55	57.75
Error	24	0.0009	1.53	4.80	90.42
General	39				

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 5. Average values and groupings of seed cotton yield and plant height

	Seed Cotton Yield			Plant Height		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	3658.64	2740.79	3199.72	73.10	73.65	73.37
2. Stoneville 468	3558.50	2913.67	3236.08	69.14	70.65	69.89
3. Stoneville 498	3466.95	2382.05	2924.50	72.77	72.75	72.76
4. MAY 455	3502.71	2565.08	3033.90	75.30	68.40	71.85
5. MAY 558	3501.05	2589.15	3045.10	70.67	73.20	71.93
Mean	3537.57 a	2638.15 b	3087.86	72.19	71.73	71.96
CV (%)	12.68			5.65		
LSD $_{(0.05)}$ Treatment	276.08**			ns		
LSD $_{(0.05)}$ Variety	ns			ns		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Statistical differences were observed between treatments, varieties and treatment x variety interactions at the P≤0.01 significance level for the number of nodes on the first fruiting branch (Table 2). Under normal growing conditions, the average number of nodes on the first fruiting branch value was 8.83 number plant^{-1}, while under shading conditions, the average number of nodes on the first fruiting branch was 4.82 number plant^{-1} (Table 7). The value for normal growing conditions was higher than shading conditions, 45.41% decrease in the number of nodes on the first fruiting branch was observed when cotton varieties were grown under shading conditions. The number of nodes in the first fruiting branch of the cotton varieties varied between 6.15 and 7.31 number plant. It can be observed that the highest value was obtained from the DP 499, MAY 455 and MAY 558 varieties, and these cotton varieties shared the same group, while the lowest value was observed from the Stoneville 468 variety (6.15 number plant^{-1}).

The treatment x variety interaction was found to be significant for this trait; the highest number of nodes in the first fruiting branch was observed from the DP 499 variety (9.92 number plant^{-1}) under normal growth conditions, while the lowest value was obtained with 4.70 number plant^{-1} when the DP 499 and STV 498 varieties were grown under shading conditions. The significant treatment x variety interaction indicates that the values for the number of nodes on the first fruiting branch may change when the cotton varieties in the experiment are grown under normal growth and shading conditions. The number of nodes on the first fruiting branch is an important earliness criterion and a key indicator of yield formation, and can be affected by variety and weather conditions (Hake and Meredith, 1990). Liu et al. (2020) reported that they observed high values on the first fruiting branch nodes at low light intensity, and different results were obtained.

Table 6. Average values and groupings of number of monopodial and sympodial branches

	Number of Monopodial Branches			Number of Sympodial Branches		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	2.22	6.50	4.36	7.87 b	6.75 c	7.31 b
2. Stoneville 468	2.54	6.15	4.34	8.15 b	6.30 c	7.22 b
3. Stoneville 498	1.87	6.20	4.03	9.65 a	6.55 c	8.10 a
4. MAY 455	1.40	6.10	3.75	8.02 b	6.15 c	7.08 b
5. MAY 558	1.80	6.30	4.05	7.80 b	6.45 c	7.12 b
Mean	1.96 b	6.25 a	4.10	8.30 a	6.44 b	7.37
CV (%)	21.41			7.87		
LSD $_{(0.05)}$ Treatment	0.15**			1.94 *		
LSD $_{(0.05)}$ Variety	ns			0.59 *		
LSD $_{(0.05)}$ Tre x Var.	ns			0.84 *		

*, **, Significant at p ≤ 0.05 and p ≤ 0.01, respectively

Table 7. Average values and groupings of number of nodes of first sympodial branches and number of nodes

	Number of Nodes of First Fruiting Branch			Number of Nodes		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	9.92 a	4.70 d	7.31 a	18.30	15.35	16.82 a
2. Stoneville 468	7.46 c	4.85 d	6.15 c	16.46	13.80	15.13 b
3. Stoneville 498	8.47 b	4.70 d	6.58 bc	18.37	15.00	16.68 a
4. MAY 455	9.27 ab	4.85 d	7.06 ab	17.45	13.15	15.30 b
5. MAY 558	9.05 ab	5.00 d	7.02 ab	17.30	14.85	16.07 ab
Mean	8.83 a	4.82 b	6.82	17.57 a	14.43 b	16.00
CV (%)	9.09			8.00		
LSD $_{(0.05)}$ Treatment	0.57**			1.74*		
LSD $_{(0.05)}$ Variety	0.63**			1.31*		
LSD $_{(0.05)}$ Tre x Var.	0.90**			ns		

*, **, Significant at p ≤ 0.05 and p ≤ 0.01, respectively

Table 8. Average values and groupings of height/node ratio and number of bolls

	Height/Node Ratio			Number of Bolls		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	3.99	4.81	4.40	9.17	12.65	10.91
2. Stoneville 468	4.20	5.12	4.66	10.38	12.00	11.19
3. Stoneville 498	3.95	4.88	4.41	10.72	12.05	11.38
4. MAY 455	4.32	5.20	4.76	7.82	11.00	9.41
5. MAY 558	4.10	4.96	4.53	8.60	13.90	11.25
Mean	4.11 b	4.99 a	4.55	9.34 b	12.32 a	10.83
CV (%)	6.81			18.83		
LSD $_{(0.05)}$ Treatment	0.38**			2.57*		
LSD $_{(0.05)}$ Variety	ns			ns		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at p ≤ 0.05 and p ≤ 0.01, respectively

Table 2 shows that there are statistical differences at the 5% significance level between treatments and varieties in terms of node number, and the treatment x variety interaction is not statistically significant. The average values of the varieties under normal development and shading conditions are given in Table 7. It can be shown that statistical differences were found between treatments at the 5% significance level, with the number of nodes being 17.57 per plant under normal growth conditions and 14.43 per plant under shading conditions. Higher node numbers were obtained under normal growth conditions than under shading conditions. When cotton varieties were grown under shading conditions, a 17.87% decrease in the number of nodes occurred. The number of nodes in the cotton varieties ranged from 15.13 to 16.82 nodes per plant, with a statistically significant difference between the varieties at the 5% significance level. Among the varieties, the highest value was recorded from DP 499 (16.82 number plant^{-1}), followed by Stoneville 498 and MAY 558, which were placed in the same statistical group. The lowest value was observed from Stoneville 468 (15.13 number plant^{-1}). Reddy et al. (1997) revealed that the number of nodes and the length of nodes increased when the temperature was increased from 27 ºC to 30 ºC. Najeeb et al. (2015) reported that the number of nodes on the plant decreased with shading. The research findings are similar to those of Echer (2017), who reported that when shading was applied for 2 weeks from the beginning of flowering, the number of nodes decreased by 18.5% in mid-early varieties compared to late varieties.

The results of the variance analysis regarding the height/node ratio are given in Table 2. It can be seen that there are statistically significant differences at the 1% level between the treatments; it was determined that the variety and treatment x variety interaction was not statistically significant. The mean values of the height/node ratio of the varieties under normal growth conditions and shading conditions, and the groupings formed according to the LSD $_{(0.05)}$ test, are given in Table 8. Table 8 shows that statistically significant differences exist at the P≤0.01 level between the treatments. The average height/node ratio of the cotton varieties in the experiment under normal growth conditions was 4.11, while under shading conditions it was 4.99. When cotton varieties were grown under normal growth conditions, a decrease in height/node ratio occurred. The height/node ratio values of the cotton varieties in the experiment ranged from 4.40 to 4.76 cm/node. Although there were no significant differences between the varieties, the highest HNR was recorded from the MAY 455, and the lowest value was observed from the DP 499 variety. The treatment x variety interaction was found to be insignificant in terms of this characteristic.

It can be seen from Table 3 that there were statistically significant differences at the 5% significance level between the treatments for the number of bolls; however, variety and treatment x variety interaction were not significant. The mean values of the number of bolls under normal growth conditions and shading conditions are given in Table 8. The average boll number under normal growth conditions was 9.34 bolls/plant, while under shading conditions it was 12.32 bolls/plant. When cotton varieties were grown under normal growth conditions, a decrease of 24.18% in boll number was observed compared to shading conditions. The study showed that the number of bolls in the cotton varieties ranged from 9.41 to 11.38 bolls/plant. While there was no statistically significant difference between the varieties, the highest boll number was obtained from STV 498 (11.38 bolls/plant) and MAY 558 (11.25 bolls/plant) cultivars, and the lowest value was obtained from MAY 455 (9.41 bolls/plant).

Echer (2017) reported that shading reduced the number of bolls in early-ripening varieties, while Raphael et al. (2019) reported that shading affected fruit distribution in cotton, and that short-term shading during the early flowering period reduced the number of bolls. Sorour and Rassoul (1974) revealed that shading applied 3 weeks before the start of flowering increased the number of flowers but decreased the number of bolls by increasing the percentage of boll shedding. Zhao and Oosterhuis (1998b) reported that the most sensitive component to shading was the number of bolls. Similar findings were reported by Lv et al. (2013). In this study, it was observed that shading increased the number of bolls, and different results were obtained compared with the literature. This situation is thought to be due to the variety and method used in the experiment, the shade percentage of the shade netting, the shading time, duration and the climatic conditions. Another reason for this difference may be the temperature differences between the day and night under normal and shaded conditions. This situation may be related to the fact that shading leads to an increase in the number of monopodial branches and a decrease in the number of fruiting branches on the plant. In this study, the number of harvestable bolls per plant was recorded. In addition, shading increased the first-picking percentage, which is considered an important indicator of earliness and may also have influenced the number of bolls.

The results of the analysis of variance for boll weight are shown in Table 3. It was observed that there are statistically differences between varieties in boll weight at the 1% significance level, and that the treatment and treatment x variety interaction are not statistically significant. The boll weight values of the cotton varieties ranged from 5.86 to 6.96 g, with a statistically significant difference between the varieties at the 1% level. The highest value for boll weight was obtained from the MAY 455, and the lowest observed from the Stoneville 468 variety. It was observed that the treatment was not significant, and the average boll weight of the cotton varieties was 6.45 g under normal growth conditions and 6.63 g under shading conditions. While the results are consistent with those of Zhou et al. (2002), Echer (2017), and Najeeb et al. (2015), who reported that shading does not affect boll weight, the findings of Zhao and Oosterhuis (2000) indicate that shading reduces boll weight, shading during early flowering has little effect on boll weight, and shading during boll development reduces boll weight. The findings of Lv et al. (2013), which indicated that boll weight decreases with shading, also differ from the results of the research. This suggests that the effect of shading on boll weight may vary depending on the shading applied at different developmental stages of the plant.

As shown in Table 3 that there are significant differences at the p≤0.01 level among varieties for seed cotton boll weight, while the treatment and treatment x variety interaction were not significant.

Shading had no significantly effect on seed cotton boll weight, it was shown from the Table 9 that seed cotton boll weight was recorded as 4.78 g under normal growth conditions and 5.24 g under shading conditions, it was observed that there are statistically significant differences at the 1% level between varieties in terms of seed cotton boll weight, and the average values of varieties ranged from 4.53 to 5.32 g. The highest seed cotton boll weight was obtained from the MAY 455 variety (5.32 g), followed by the MAY 558 variety (5.24 g), and the lowest was recorded from the Stoneville 468 variety (4.53 g). The study shows that the treatment x variety interaction is not significant. These research findings are similar to those of Sorour and Rassoul (1974), who reported that shading did not create a significant difference in yield components.

The number of seeds per boll was recorded as 27.29 under normal growth conditions, while under shading conditions it was recorded as 27.80. It was observed that shading did not have a significant effect on the number of seeds per boll (Table 10). The number of seeds per boll in cotton varieties ranged from 24.96 to 29.22 seeds/boll. While there was no statistically significant difference between varieties, the highest number of seeds per boll was obtained from the DP 499 variety, and the lowest from the Stoneville 468 variety. It appears that there is no significant interaction between the treatment and variety in terms of this characteristic. In this study, shading did not affect the number of seeds in the boll. The findings of Zhao and Oosterhuis (1995), who stated that shading did not affect the number of seeds in the boll, are consistent with these research results.

Dusserre et al. (2002) reported that in a simulated shading study in a plant growing chamber, they obtained 28 seeds in the boll under full light and shading conditions, but the effects of shading were complex, and the number of seeds in the boll decreased significantly when the onset of shading coincided with anthesis.

Table 9. Average values and groupings of boll weight and seed cotton boll weight

	Boll Weight			Seed Cotton Boll Weight		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	6.70	6.49	6.59 ab	5.01	5.26	5.14 ab
2. Stoneville 468	5.66	6.06	5.86 c	4.27	4.79	4.53 c
3. Stoneville 498	6.31	6.52	6.41 b	4.56	5.09	4.82 bc
4. MAY 455	6.79	7.12	6.96 a	5.06	5.58	5.32 a
5. MAY 558	6.79	6.98	6.89 a	5.02	5.47	5.24 a
Mean	6.45	6.63	6.54	4.78	5.24	5.01
CV (%)	5.81			6.98		
LSD $_{(0.05)}$ Treatment	ns			ns		
LSD $_{(0.05)}$ Variety	0.39**			0.35**		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 10. Average values and groupings of number of seeds in the boll and 100 seed weight

	Number of Seeds in the Boll			100 Seed Weight		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	29.07	29.37	29.22	10.09	10.17	10.13
2. Stoneville 468	24.62	25.30	24.96	9.08	9.63	9.36
3. Stoneville 498	27.92	29.34	28.63	9.58	9.95	9.77
4. MAY 455	26.77	28.17	27.47	9.73	10.02	9.87
5. MAY 558	28.09	26.82	27.45	9.56	10.22	9.89
Mean	27.29	27.80	27.55	9.61	10.00	9.80
CV (%)	12.63			5.10		
LSD $_{(0.05)}$ Treatment	ns			ns		
LSD $_{(0.05)}$ Variety	ns			ns		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 11. Average values and groupings of ginning percentage and first picking percentage

	Ginning Percentage			First Picking Percentage		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	43.62	43.85	43.74 b	78.16	83.92	81.04 b
2. Stoneville 468	45.08	44.59	44.84 a	83.04	92.53	87.79 a
3. Stoneville 498	45.17	44.52	44.85 a	85.76	92.11	88.93 a
4. MAY 455	45.61	45.38	45.50 a	83.66	93.42	88.54 a
5. MAY 558	45.40	45.50	45.45 a	86.72	89.07	87.90 a
Mean	44.98	44.77	44.87	83.47 b	90.21 a	86.84
CV (%)	1.82			5.52		
LSD $_{(0.05)}$ Treatment	ns			4.29 *		
LSD $_{(0.05)}$ Variety	0.84**			4.94 *		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

It has been noted that shading reduces the number of seeds in the fruit in other crops (peas and soybeans) (Dusserre et al. 2002).

From Table 10, it was observed that there was no significant difference between the treatments for 100-seed weight; the mean of 100-seed weight under normal growth conditions was 9.61 g, while under shading conditions it was recorded as 10.00 g. The 100-seed weight values of the cotton varieties ranged from 9.36 to 10.13 g. Although there were no statistically significant differences between the varieties, the highest value was observed from the DP 499 variety (10.13 g), and the lowest value was observed from the Stoneville 468 variety (9.36 g). The study showed that the treatment x variety interaction was not significant. The findings of Chen et al. (2019), who revealed that shading leads to a decrease in rice seed weight, differ from the results of this research.

In terms of ginning percentage, it was observed that no significant difference between treatments. Under normal growing conditions, the ginning percentage was 44.98%, while under shading conditions, it was 44.77%, and similar values were obtained between the two treatments. It was determined that there were statistical differences between the varieties at the 1% significance level. The ginning percentage values of the varieties ranged from 43.74 to 45.50%, with the highest values obtained from MAY 455, MAY 558, Stoneville 498, and Stoneville 468, respectively, while the lowest value was obtained from DP 499. The treatment x variety interaction was not significant for ginning percentage. Similar results were obtained with Zhao and Oosterhuis (2000), who reported that shading had no significant effect on ginning percentage. Lv et al. (2013) reported that ginning percentage was minimally affected by shading. Echer (2017) revealed that shading caused a decrease in ginning percentage and that this trait is genetically controlled but can also be affected by environmental conditions.

The results of the variance analysis for the first picking percentage revealed that there were statistically significant differences between treatments and varieties in terms of first picking percentage at the 5% significance level, and that the treatment x variety interaction was not statistically significant. The mean values for the first picking percentage of the varieties under normal growing conditions and shading conditions, and the groupings formed according to the LSD $_{(0.05)}$ test, are presented in Table 11. The average first picking percentage for the cotton varieties was 83.47% under normal growing conditions, while the first picking percentage was 90.21% under shading conditions.

Normal growing conditions were in group B, while shading conditions were in group A. It was determined that the first picking percentage was higher when the cotton varieties were grown under shading conditions, and a 7.47% decrease in first picking percentage occurred when grown under normal growing conditions. The first-picking percentage of the cotton varieties ranged from 81.04 to 88.93%, with the highest value being obtained from the Stoneville 498, and the lowest from the DP 499 variety. Hu et al. (2016) reported that low light levels delay ripening in cotton. The findings of Sorour and Rassoul (1974) differ from the findings of the study, which indicated that when shading is initiated before flowering begins, earliness is significantly reduced, while when applied later after flowering, it is not significantly affected. Raphael et al. (2019) also differed from the study, stating that shading in cotton does not affect crop maturity.

Table 12. Average values and groupings of NDVI and canopy temperature

	NDVI			Canopy Temperature		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	0.75	0.71	0.73	30.57	31.37	30.97
2. Stoneville 468	0.74	0.70	0.72	30.15	30.35	30.25
3. Stoneville 498	0.73	0.73	0.73	29.95	29.67	29.81
4. MAY 455	0.76	0.71	0.74	30.67	30.70	30.68
5. MAY 558	0.74	0.71	0.72	31.07	29.95	30.51
Mean	0.74	0.71		30.48	30.41	30.44
CV (%)	4.10			4.04		
LSD $_{(0.05)}$ Treatment	ns			ns		
LSD $_{(0.05)}$ Variety	ns			ns		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 13. Average values and grouping of chlorophyll content and leaf area

	Chlorophyll Content (SPAD value)			Leaf Area		
Variety	Normal	Shading	Mean	Normal	Shading	Mean
1. DP 499	43.95	44.35	44.15	61.20	60.10	60.65
2. Stoneville 468	42.82	42.62	42.72	57.87	66.91	62.39
3. Stoneville 498	41.57	44.00	42.78	64.79	73.79	69.29
4. MAY 455	45.17	44.80	44.98	65.45	65.30	65.38
5. MAY 558	44.87	43.80	44.33	61.07	70.51	65.79
Mean	43.68	43.91	43.79	62.08	67.32	64.70
CV (%)	5.00			14.68		
LSD $_{(0.05)}$ Treatment	ns			ns		
LSD $_{(0.05)}$ Variety	ns			ns		
LSD $_{(0.05)}$ Tre x Var.	ns			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

The results of the variance analysis for the normalized difference vegetation index (NDVI value) are presented in Table 4. It was observed that there is no statistically significant difference in NDVI values among the treatments, and the cultivar and treatment x cultivar interaction is not statistically significant. The average NDVI value of the cotton varieties under normal growth conditions is 0.74, while the NDVI value under shading conditions is 0.71. It was observed from the Table 12 that there is no statistically significant difference in NDVI values between normal growth conditions and shading conditions. The NDVI values of the cotton varieties ranged from 0.72 to 0.74. While there was no statistically significant difference between the varieties, the highest NDVI value was obtained from the MAY 455 variety, and the lowest NDVI values were obtained from the Stoneville 468 and MAY 558 varieties. It was determined that the treatment x variety interaction was not significant in terms of NDVI value.

Table 4 shows that there is no statistically significant difference between the treatments in terms of canopy temperature. The study also indicated that the variety and treatment x variety interaction was not significant. The average canopy temperature for the cotton varieties under normal growth conditions is 30.48 ºC, while the canopy temperature under shading conditions is 30.41 ºC (Table 12). It was observed that no statistically significant difference in canopy temperature was obtained between normal growth conditions and shading conditions. The canopy temperature values of the cotton varieties ranged from 29.81 to 30.97 °C. While there was non-statistically significant difference among the varieties, the highest value was obtained from the DP 499 and the lowest value was obtained from the Stoneville 498 variety. Chen et al. (2019) reported differences in canopy temperature between the control and shading varieties in their research on rice.

It is shown that from Table 13, there are no statistically significant differences between the treatments in terms of chlorophyll content; the chlorophyll content recorded as 43.68 under normal growth conditions and 43.91 under shading conditions. The leaf chlorophyll content (SPAD) values of the cotton varieties ranged from 42.72 to 44.98. Although there was no significant statistical difference between the varieties, the highest SPAD value was obtained from the MAY 455 variety (44.98), and the lowest value was obtained from the Stoneville 468 variety (42.72). It was determined that the treatment x variety interaction was not significant in terms of chlorophyll content. Chlorophyll is essential for converting light energy into stored chemical energy and is known as an important indicator for evaluating leaf photosynthesis (Liu et al., 2015). Under shading conditions, different results were obtained compared to Zhao and Oosterhuis (1998b), who reported that 8 days of shading significantly increased the chlorophyll concentration in cotton leaves, decreased the net photosynthesis rate of the leaves, but did not significantly change the dark respiration rate. This indicates that the duration and period of shading can affect chlorophyll content. Abudourezike et al. (2019), in their study investigating the effects of shading and weak light on the physiological characteristics of cotton leaves during the flowering and boll formation period, reported that the functional leaf chlorophyll content (SPAD value) in the main stems decreased under shading and weak light. Chen et al. (2019) stated that the chlorophyll content of plant leaves grown under blue light was lower than that under red and white light.

Table 4 shows that there is no statistically significant difference between the treatments in terms of leaf area. The study also determined that the variety and treatment x variety interaction was not statistically significant. Under normal growing conditions, the average leaf area of the cotton varieties was 62.08 cm^2, while under shading conditions, the leaf area was 67.32 cm^2 (Table 13). The leaf area values of the cotton varieties in the experiment ranged from 60.65 to 69.29 cm^2. Although there was no statistically significant difference between the varieties and treatments, the highest leaf area was obtained from the STV 498 and the lowest leaf area was obtained from the DP 499 variety. Measurement or estimation of leaf area is essential for understanding crop responses to experimental treatments (Akram-Gharideri and Soltani, 2017). Chen et al. (2017) reported that leaf mass and carbohydrate content are related to photosynthesis and that leaves under shading were significantly reduced compared to control leaves at all growth stages. The reduction in leaf area in soybeans due to shading was reported by Wu et al. (2017) and differs from the research findings. Singhakumara et al. (2003) reported that shade-tolerant plants generally have a larger leaf area, higher chlorophyll content, and lower leaf mass per unit area.

Conclusion

It was determined that seed cotton yield, number of fruiting branches, number of nodes on the first fruiting branch, and number of nodes decreased with shading, while the number of monopodial branches, number of bolls, height/node ratio, and first picking percentage increased with shading. In the study, it was determined that seed cotton yield decreased by 25.42% with shading. Shading led to an increase in the number of monopodial branches and a decrease in the number of fruiting branches. Shading caused a decrease in the number of nodes in the plant, while it led to an increase in the height/node ratio. The study determined that the number of bolls increased with shading, but the increased number of bolls did not affect yield positively. Although the number of bolls increased with shading, a decrease in productivity was observed. Although the number of bolls is known as a yield component in cotton, it is not a single component that determines yield. The reason for the low yield despite the increasing number of bolls indicates that low light conditions caused by shading accelerate the bolls maturation and this may affect the production of assimilate delivered to the bolls. It was found that physiological parameters such as leaf chlorophyll content, NDVI value, canopy temperature, and leaf area were not affected by shading, and that the variety and treatment x variety interaction was not significant in terms of these physiological parameters. Shading was provided using shade netting that gave 30% shade, and continued from the beginning of flowering until the boll formation period. Reviewing previous studies indicates that the timing, duration, plant development stage, and intensity of shading can all affect the research results. The research suggests

applying short-term shading at different stages of plant development, using shading nets that provide varying levels of shade, investigating the shading height, and using light-colored shade nets instead of dark-colored ones. The results obtained in this study are based on findings from a single location and one year of experimentation; therefore, further studies conducted over at least two years are needed to provide more definitive recommendations."

Declarations

Author Contribution Statement

Omer Kardas: Data collection, investigation and writing the original draft preparation

Emine Karademir: Project administration, supervision, conceptualization, methodology, formal analysis, review and editing

Omer Kardas and *Emine Karademir*: Data collection and investigation

All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

"The authors declare no conflict of interest."

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References

Abudourezike, A., Wang, W., Bai, Y., Zhang, Y., & Gulimila, A. (2019). Effects of shading on the physiological characteristics of cotton leaves during cotton flower and boll formation periods, Xinjiang Agricultural Sciences, 56 (7), 1197-1206.

Akram-Ghaderi, F., & Soltani, A. (2007). Leaf area relationships to plant vegetative characteristics in

cotton (Gossypium hirsutum L.) grown in a temperate sub-humid environment. International Journal of Plant Production 1(1), 63-71. https://doi.org/10.22069/IJPP.2012.526

Almeida, F. C. G. (1985). Effect of short-term storage on viability of pollen from cotton, Gossypium hirsutum L. Field Crop Abstract, 40 (6), 4620.

Anonymous (2011). Cotton and climate change impacts and options to mitigate adaptations, International Trade Centre Technical Paper, 1-32.

Anonim (2023). Pamuk Durum Tahmin Raporu, Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü, Ankara, 1-34.

Anonim (2024). Pamuk Durum Tahmin Raporu, TEPGE Yayın No: 411, Ankara

Babaeva, T. N., & Asrorov, K. A. (1987). On thermoresistance of respiration of cotton reproductive organs, Field Crop Abstract, 41(8), 676.

Chen, B. L., Yang, H. K., Ma, Y. N., Liu, J. R., Lv, F. J., Chen, J., Meng, Y. L., Wang, Y. H., & Zhou, Z. G. (2017). Effect of shading on yield, fiber quality and physiological characteristics of cotton subtending leaves on different fruiting positions, Photosynthetica, 55 (2), 240-250. https://doi.org/ 10.1007/s11099-016-0209-7

Chen, H., Qiu-Ping, L., Zeng, Y., Deng, F., & Ren, W. (2019). Effect of different shading materials on grain yield and quality of rice, Scientific Reports, 9, 9992, 1-9. https://doi.org/10.1038/s41598-019-46437-9.

Chen, S., Zou, Y., Qi, Q., Zhao, C., Liu, S., Qiao, J., Yu, Y., Zhao, J., Li, S., Zou, Y., Li, X., Teng, J., Lv, H., & Yang, B. (2025). Moderate shading improves growth, photosynthesis, and physiological traits in Spuriopinella brachycarpa (Kom.) Kitag. Plants (Basel). 16;14(24):3824. https://doi.org/10.3390/plants14243824.

Crozat, Y., Judais, V., & Kasemsap, P. (1997). Survival of cotton fruiting forms after a temporary light reduction as affected by fruit age and plant structure. Proceedings of the Beltwide Cotton Conference New Orleans: National Cotton Council of America, 2, 1432-1435.

Dusserre, J., Crozat, Y., Warembourg, F. R., & Dingkuhn, M. (2002). Effects of shading on sink capacity and yield components of cotton in controlled environments, Agronomie, 22 (3), 307-320. https://doi.org/10.1051/agro:2001009.

Echer, F. R. (2017). Yield and fiber quality of cotton cultivars in response to shading, Colloquium Agrariae, 13 (2), 87-96. https://doi.org/10.5747/ca.2017.v13.n2.a163

Echer, F. R., Zanfolin, P. R. L., Moreira, A. C. M., Santos, A. C. P., & Gorni, P. H. (2019). Root growth and carbohydrate partitioning in cotton subjected to shading in the initial phase, Ciência Rural, 49, 01, e20180749. https://doi.org/10.1590/0103-8478cr20180749

Gürkan, H., Bulut, H., & Bayraktar, N. (2017). Effects of Increasing Drought on Sunflower and Cotton Yield Due to Climate Change. KSU Journal of Natural Science, 20, 216-221, https://doi.org/10.18016/ksudobil.349207

Hake, K., & Meredith, B. (1990). Cotton Physiology Today. Newsletter of the Cotton Physiology Education Program, National Cotton Council, 1-4.

Hu, W., Ma, Y., Lv, F., Liu, J., Zhao, W., Chen, B., Meng, Y., Wang, Y., & Zhou, Z. (2016). Effects of late planting and shading on sucrose metabolism in cotton fiber, Environmental and Experimental Botany, 131, 164-172. https://doi.org/10.1016/j.envexpbot.2016.08.001

Johnson, J. R., & Saunders, J. R. (2003). Evaluation of chlorophyll meter for nitrogen management in cotton. http://msucares.com/nmrec/reports/2002

Li, T., Dai, J., Zhang, Y., Kong, X., Li, C., & Dong, H. (2019). Topical shading substantially inhibits vegetative branching by altering leaf photosynthesis and hormone contents of cotton plants, Field Crops Research, 238, 18-26. https://doi.org/10.1016/j.fcr.2019.04.019

Liu, J., Meng, Y., Lv, F., Chen, J., Yina, M., Wang, Y, Chen, B., Zhang, L., & Zhou, Z. (2015). Photosynthetic characteristics of the subtending leaf of cotton boll at different fruiting branch nodes and their relationships with lint yield and fiber quality, Frontiers in Plant Science, 6. https://doi.org/10.3389/fpls.2015.00747

Liu, Z., Chen, Y., Li, Y., Chena, C., Ma, Y., Chen, Y., Chen, D., Zhang, X., & Zhou, M. (2020). Construction of optimum number of fruiting nodes benefit high yield in cotton population, Industrial Crops and Products, 158, 113020, 1-9. https://doi.org/10.1016/j.indcrop.2020.113020

Lv, F., Liu, J., Ma, Y., Chen, J., Abudou keyoumu, A., Wang, Y., Chen, B., Meng, Y., & Zhou, Z. (2013). Effect of shading on cotton yield and quality on different fruiting branches, Crop Science, 53, 2670-2678. https://doi.org/10.2135/cropsci2013.03.0170

Najeeb, U., Bange, M. P., & Tan, D. K. Y. (2015). Understanding of the interactive effect of waterlogging and shade on cotton (Gossypium hirsutum L.) growth and yield, Procedia Environmental Sciences, 29, 85-86. https://doi.org/10.1016/j.proenv.2015.07.171

Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives, Atmospheric Environment, 43, 37-50. https://doi.org/10.1016/j.atmosenv.2008.09.063

Raphael, J. P. A., Echer, F. R., & Rosolem, C. A. (2019). Shading and nitrogen effects on cotton earliness assessed by boll yield distribution, Crop Science, 59 (2), 697-707. https://doi.org/10.2135/cropsci2018.05.0343

Reddy, V. R., Baker, D. N., & Hodges, H. F. (1991). Temperature effect on cotton canopy growth, photosynthesis and respiration, Agronomy Journal, 83, 699-704. https://doi.org/10.2134/agronj1991.00021962008300040010x

Reddy, K. R., Hodges, H. F., McKinion, J. M., & Wall, G. A. (1992). Temperature effects on pima cotton growth and development, Agronomy Journal, 84, 237-243. https://doi.org/10.2134/agronj1992.00021962008400020022x

Reddy, K. R., Hodges, H. F., & McKinion. J. M. (1997). A comparison of scenarios for the effect of global climate change on cotton growth and yield, Australian Journal of Plant Physiology, 24, 707-713. https://doi.org/10.1071/PP96138

Saini, D. K., Impa, S. M., McCallister, D., Patil, G. B., Abidi, N., Ritchie, G., Jaconis, S. Y., & Jagadish, K. S. V. (2023). High day and night temperatures impact on cotton yield and quality current status and future research direction, Journal of Cotton Research, 6, 16, 1-17. https://doi.org/10.1186/s42397-023-00154-x

Shu, H. M., Zhou, Z. G., Xu, N. Y., Wang, Y. H., & Zheng, M. (2009). Sucrose metabolism in cotton (Gossypium hirsutum L.) fibre under low temperature during fibre development, European Journal of Agronomy, 31, 61-68. https://doi.org/10.1016/j.eja.2009.03.004

Singh, R. P., Prasad, P. V. V., Sunite, K., Giri, S. N., & Reddy, K. R. (2007). Influence of high temperature and breeding for heat tolerance in cotton: A review, Advances in Agronomy, 93, 313-385. https://doi.org/10.1016/S0065-2113(06)93006-5

Singhakumara, B. M. P., Gamage, H. K., & Ashton, M. S. (2003). Comparative growth of four Syzygium species within simulated shade environments of a Sri Lankan rain forest, Forest Ecology and Management, 174 (1-3), 511-520. https://doi.org/10.1016/S0378-1127(02)00071-3

Sorour, F. A., & Rassoul, S. F. A. (1974). Effect of shading at different stages of growth of the cotton plant on flowering and fruiting boll shedding yield of seed cotton and earliness, Libyan Journal of Agriculture, 3, 39-43.

Ünay, A., & Başal, H. (2005). Climatic Changes and Cotton. Journal of Adnan Menderes University Agricultural Faculty 2 (1), 11-16.

Wu, Y., Gong, W., & Yang, W. (2017). Shade inhibits leaf size by controlling cell proliferation and enlargement in soybean, Science Report, August 23, 7 (1), 9259. https://doi.org/10.1038/s41598-017-10026-5

Xue, G., Wu, J., Zhou, B., Zhu, X., Zeng, J., Ma, Y., Wang, Y., & Jia, H. (2023). Effects of shading on the growth and photosynthetic fluorescence characteristics of Castanopsis hystrix Seedlings of top community-building species in Southern Subtropical China, Forests, 14 (8), 1659. https://doi.org/10.3390/f14081659

Yan, H. S., Hu, J., Fan, K., & Zhang, Y. J. (2007). The analysis of relationship between the variation of westerly index in summer and precipitation during the flood period over China in the last 50 years, China Journal of Atmosferic Science, 31, 717-726. https://doi.org/10.3878/j.issn.1006-9895.2007.04.16

Zhao D., & Oosterhuis D. (1995). Effects of shading and PGR-IV on cotton photosynthesis, boll retention and components of yield, Arkansas Cotton Research.

Zhao, D., & Oosterhuis, D. (1998a). Physiological and yield responses of field-grown cotton to shade. Proceedings of the World Cotton Research Conference-2 Athens- Greece, September 6-12, 602-607.

Zhao, D., & Oosterhuis, D. (1998b). Physiological and yield responses of shaded cotton to the plant growth regülatör, PGR-IV, Journal of Plant Growth Regulator, 17, 47-52.

Zhao, W., Wu, Y., Rizwan, Z., Wang, Y., Yina, Y., Chen, B., Meng, Y., & Zhou, Z. (2018). Effects of planting dates and shading on carbohydrate content, yield, and fiber quality in cotton with respect to fruiting positions, Journal of Integrative Agriculture, 17 (5), 1106-1119. https://doi.org/10.1016/S2095-3119(17)61797-0

Zhao, D., & Oosterhuis, D. (2000). Cotton responses to shade at different growth stages: growth, lint yield and fibre quality, Experimental Agriculture, 36 (1), 27-39. https://doi.org/10.1017/S0014479700361014

Zhou, Z., Meng, Y., & Shi, P. (2002). Effect of seedling stage shading on cotton yield and its quality formation, Ying Yong Sheng Tai Xue Bao, 13(8), 997-1000. Chinese. PMID: 12418264.