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PLANT SPACING AND ITS EFFECT ON YIELD, FIBRE QUALITY AND PHYSIOLOGICAL PARAMETERS IN COTTON

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ABSTRACT. The purpose of this study was to see how changing plant spacings affected cotton yield, yield components, fibre quality traits, and physiological parameters. In this study, six plant spacings (no thinning, 5, 10, 15, 20, and 25 cm) were investigated. Plant density caused significant differences in the number of first fruiting branches, number of bolls, ginning percentage, seed cotton yield, fibre yield, and normalised difference vegetative index (NDVI). Plant height, the number of sympodial branches, number of monopodial branches, boll weight, seed cotton weight/boll, number of 100-seed weight, seeds/boll, canopy temperature, chlorophyll content, leaf area, and fibre quality properties (micronaire, length, strength, elongation, uniformity, short fibre index, reflectance, yellowness, and spinning consistency index [SCI] were non-significant. The highest values of seed cotton yield, fibre yield, ginning percentage, number of first fruiting branches, and NDVI were obtained in the no thinning and 5 cm plant spacing applications, while the highest boll number was obtained at 20 and 25 cm plant spacings. In this study, physiological parameters, such as canopy temperature, leaf area, chlorophyll content, and fibre technological traits, were not affected by plant spacing. The highest seed cotton yield, fibre yield, ginning percentage and NDVI were obtained from no thinning and 5 cm intra-row spacing, indicating their impact on examined characteristics. Therefore, a yield estimation can be made in the flowering period with the NDVI in different plant densities in cotton.

Keywords: cotton; plant spacing; yield; physiology; fibre quality.

INTRODUCTION

Although the cotton plant is mainly grown for its fibre, it is among the most important products in the food industry, with 17-24% oil content in its seeds. It is one of the most essential raw ingredients used in the

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feed manufacturing process, with a protein content of 35-45% in its meal after the oil is removed (Kaplan *et al*., 2017).

In general, cotton is a strategic industrial plant with serious economic importance and constitutes an important raw material for many sectors, such as textiles, oil, food, and animal feedstock (Tumer, 2010). As a result of the ever-increasing population change, the increasing interest in natural fibre, and the increase in living standards, the demand for cotton plants is rapidly increasing.

To increase the yield per unit area, the genetic potential of the variety to be cultivated, and the improvement of agricultural processes, such as irrigation, fertilisation, environmental conditions, plant protection, and cultural processes, can be used to affect the amount of the product.

Aside from these considerations, the optimal number of plants per unit area has a significant impact on yield (Khan *et al*., 2020). Plant density is an important agronomic factor in cotton, as in many plants. Planting in suitable climatic conditions has a positively impact on yield and quality (Liu *et al*., 2019).

In contrast, it has been stated that plants with genetic structures tolerant to climate changes will have a shorter stature and appearance in conditions that may change, such as temperature and CO_2 increase. In these cases, plants will be insufficient in weed competition due to plant growth in the early development period. To prevent or minimise, such negativities, increasing the plant density is recommended (Hall and Zıska, 2000).

In addition, in cotton cultivation areas, which are of great importance in Turkey, the sowing time is between mid-April and mid-May. In some years, due to the negative climate conditions, planting is late, leading to crop losses. To minimise crop loss in late-planted areas, changing the plants density has been demonstrated as a solution (Delaney *et al.,* 1999).

Many investigations have been conducted in order to establish the most suitable plant density for the varieties grown in cotton farming and the regions in which it is grown (Fang *et al*., 2014; Wang *et al*., 2016; Zhi *et al*., 2016; Liu *et al*., 2019; Ye *et al*., 2021). In a team study conducted in Alabama (USA), which is in an almost similar cotton belt, Delaney *et al.* (1999) stated that dense plant growth provides positive results for early plantings, and sparse planting gives positive results in late plantings.

Kerby *et al.* (1990) stated that the amount of dry matter in the plant during the first squaring, first flowering, peak flowering, and boll opening period increased in direct proportion with the increase in plant density. In addition, the number of bolls per unit area, leaf area index and plant dry matter accumulation increase inversely with the decrease in the distance between rows in the agricultural area (Samani *et al*., 1999).

As the number of plants increases, more squares, flowers, and bolls can be obtained from the unit area (Kaynak *et al.,* 1994). Thus, there is an increase in leaf area index (LAI) and light retention by the plant due to the increase in plant population density; however, the effect on yield is uncertain (Heitholt and Sassenrath-Cole, 2010).

Crop management practices have a significant impact on the photosynthetic capacity of the canopy. Plant population density affects the structural features of the canopy. For example, factors such as leaf area index, canopy opening, and light distribution significantly affect the photosynthetic capacity of the canopy (Yao *et al.,* 2016).

Although changes in plant spacing have important effects on plant physiology, morphology, canopy development, boll and fibre development, some physiological mechanisms are still not fully understood. As plant density increases, the light flux density in the middle and lower parts of the canopy changes drastically due to shading. This has a direct effect on carbohydrate mechanism.

Plant density is important for the height of the plant and the number of bolls per plant, which are important yield components affecting plant growth parameters, yield, and fibre quality criteria. These traits can be increased with an appropriate planting frequency, thus reducing seed usage costs and sustaining economical production (Bednarz *et al.,* 2000; Zhang *et al*., 2004; Awan *et al*., 2011).

Plant density is an important factor in cotton, as in many plants. To achieve high productivity, the optimum number of plants per unit area should be provided.

The purpose of this study was to determine the effects of different plant densities or plant spacings on yield, yield components, fibre quality, and physiological parameters in cotton.

MATERIALS AND METHODS

This research was carried out in the experimental area of the Faculty of Agriculture of Siirt University in 2017, according to a four-replication randomised block design. ‘BA-119’ an Upland variety was used as material, as it is preferred due to its adaptability and high yield.

The area where the experiment was carried out was processed deeply with a plough in the fall and outcovered with a cultivator in the spring, and it was made suitable for planting by using the cultivator three times. Soil samples were collected from the trial area for further analyses. The results obtained are listed in *Table 1*.

As shown in *Table 1*, the soil had a calcareous structure, with little organic matter; the pH was slightly alkaline, and the soil texture was clayey. The electrical conductivity was unsalted. The amount of nitrogen, zinc, manganese, and phosphorus in the soil was low, while the amount of copper and iron was sufficient, and the amount of potassium was high. A total of 140 kg · ha^{-1} N and 80 kg · ha^{-1} P_2O_5 were incorporated into the planting area. During planting, 80 kg · ha^{-1} N and 80 kg · ha^{-1} P_2O_5 20-20-0 fertiliser were applied to the band with a seeder and the remaining 60 kg · ha^{-1} N was in the form of 33% ammonium nitrate during the squaring period/before the first irrigation was applied.

Table 1 - Soil characteristics of the experimental area

Texture	Clay	
pH	7.98	Slightly alkaline
EC (mS/cm)	0.363	Unsalted
Clay (%$CaCO_3$)	13.02	Clayey
Organic matter (%)	1.31	Low
N (%)	0.082	Low
P (ppm)	7.47	Low
K (me/100g)	0.98	High
Fe (ppm)	5.70	Sufficient
Cu (ppm)	2.63	Sufficient
Zn (ppm)	0.23	Low
Mn (ppm)	6.04	Low

In the experiment, sowing occurred on May 4, 2017, with a seeder. At sowing, each plot was formed from 4 rows of 12 m in length. During sowing, the distance between rows was 0.70 m, and the distance between inter-rows was created by thinning with the help of a ruler at 5, 10, 15, 20, and 25 cm and no thinning. The applications were as follows:

1) No thinning (572,420 plants ha^{-1})
2) 5 cm (285,710 plants ha^{-1})
3) 10 cm (142,850 plants ha^{-1})
4) 15 cm (95,230 plants ha^{-1})
5) 20 cm (71,420 plants ha^{-1})
6) 25 cm (57,140 plants ha^{-1}).

All maintenance operations in the trial were carried out when necessary. When the height of the plants has reached 10-15 cm, the in-row plant density was created by thinning. During the experiment, hoeing was performed three times by hand and twice with a machine. Pest control occurred at regular intervals, and no pesticide was applied because it was not needed. The experiment was irrigated using the drip irrigation method. Irrigation was determined according to the plant's water demand. Irrigation was started before the flowering period and completed at the 10% boll opening period. Harvesting operations were done manually and completed twice. The first harvest was carried out during the 60% boll opening period, and the remaining cotton was collected at the second harvest.

Two rows in the centre of the plots were harvested during harvest.. The first harvest occurred on October 2, and the second harvest occurred on October 25, 2017. The climate data of the year in which the experiment was carried out are given in *Table 2*, in comparison with the long years. The average temperature 2017 was higher than that in other years, and the minimum and maximum temperature values were lower than in other years. In 2017, the highest precipitation in April was 132.8 mm, which was higher than in long years, and there was no precipitation between June and September.

Examined Properties and Determination Methods

Agronomic Traits. Plant height, monopodial branch count, fruiting branch count, nodes on first fruiting branches count and boll count were all recorded in ten randomly selected plants from each plot and 50 bolls were collected in the 1st position between the 1st and 5th fruit branches from each plot. The boll weight, boll seed cotton weight, 100-seed weight, number of seeds per boll, and ginning percentage were determined.

The weight of the boll, the weight of the boll seed cotton, 100-seed weight, the number of seeds per boll, and the ginning percentage were determined.

Seed cotton yield values were obtained by weighing the product obtained from each parcel and the yield of the parcel converted to kg ha^{-1}. Physiological observations were examined during the flowering period, and information about the physiological observations is given below.

Leaf/Canopy Temperature (°C). Leaf/canopy temperature was determined using a Spectrum Brand 2956 Model Infrared Thermometer (Pask *et al.*, 2012).

Chlorophyll Content (SPAD value). Chlorophyll content was determined with the Minolta SPAD 502 instrument in 10 randomly selected plants during the flowering period. The top five newly opened and fully grown leaves of the plant were used to record measurements (Johnson and Sounders, 2003).

Leaf Area. In one randomly selected plant from each plot, the top 5th newly opened and fully developed leaf was cut off and drawn on A4 paper. Then, the image was scanned, and the leaf area was determined using the AutoCAD program.

Normalised Difference Vegetative Index (NDVI). The NDVI was determined using a Trimble brand GreenSeeker instrument. Values were recorded by holding the sensor 76 to 91 cm above the plant canopy (Gwathmey *et al.,* 2010; Gwathmey *et al.,* 2011).

Laboratory Analyses. Fibre analyses were determined in the fibre quality laboratory of the GAP International Agricultural Research and Training Center with the help of the HVI 1000 instrument.

Statistical Analyses. The results were evaluated using the JMP 7.0 statistical program, and the LSD$_{(0.05)}$ test was used to compare the averages.

RESULTS AND DISCUSSION

Plant Height (cm) varied between 76.16 and 83.16 cm, but there were no statistically significant differences between the applications *(Table 3)*. The lowest plant height was obtained in the no thinning application at 76.16 cm, while the highest value was obtained from the application at a 20 cm plant density at 83.16 cm. The increase in plant density slightly decreased the plant height, but the differences were not significant.

Similar findings were reported by Wang *et al.* (2016). These findings differed from those that stated that plant height decreased with the increase in plant density (Kaynak, 1995) and that plant height was highest at a density of 7 m^2 (Stephenson *et al.* 2011). The differences between studies likely occurred because they were conducted in different climatic conditions, and the variety and cultural processes differed.

Number of Monopodial Branches (number plant^{-1}) varied between 0.89 and 1.91 per plant, but differences between applications were not statistically significant (*Table 3*). While the lowest value was obtained from 10 cm plant spacing (0.89), the highest number of monopodial branches was obtained at 20 cm plant spacing (1.91 plant^{-1}).

These results were consistent with those of Incekara and Turan (1997), who stated that the increasing number of plants per unit area did not cause any difference in the number of monopodial branches. These findings differed from those that reported an increase in the number of monopodial branches when the plant density decreased (Düven, 1992) and that the number of monopodial branches decreased as the distance between rows decreased (Kaynak, 1995; Azizpour *et al.*, 2005).

Table 2 - Climate data for the year 2017 and long-term periods

Month	Average Temperature (°C)		Min. Temperature (°C)		Max. Temperature (°C)		Rainfall (mm)		Relative Humidity (%)	
	2017	Long Term	2017	Long Term	2017	Long Term	2017	Long Term	2017	Long Term
April	14.0	13.8	4.3	8.9	25.9	19.1	132.8	105.1	59.5	57.5
May	19.5	19.2	10.1	9.0	32.0	36.1	74.6	66.8	51.7	50.1
June	26.9	25.9	12.8	17.8	39.8	40.2	0.0	9.3	29.5	34.1
July	32.3	30.5	22.1	23.4	41.2	44.4	0.0	1.6	19.0	26.6
August	32.0	30.0	21.5	27.0	42.9	46.0	0.4	0.9	19.0	25.7
September	28.4	25.0	17.2	14.7	39.5	39.9	0.0	5.2	19.1	30.9
October	18.4	17.9	9.8	12.7	28,4	36.6	5.2	48.8	34.6	46.5

General Directorate of Meteorology, Siirt Station, Average of long-term period: 1950–2015

Table 3 - Average values for the investigated agronomic properties and LSD test

Plant Spacing	PH	NMB	NSB	NNFFB	BN	BW	BSCW	NSPB
No thinning	76.16	1.08	8.41	7.41 a	8.74 bc	5.29	3.87	29.25
5 cm	77.41	1.16	7.66	7.66 a	6.74 c	5.55	3.99	27.70
10 cm	78.58	0.89	8.33	6.99 ab	8.74 bc	5.71	4.15	29.70
15 cm	78.99	0.91	9.83	5.57 c	10.58 ab	5.44	3.94	27.65
20 cm	83.16	1.91	10.49	7.08 a	11.58 a	5.61	4.04	28.60
25 cm	80.24	1.16	10.33	5.83 bc	11.41 a	5.61	4.06	27.45
Mean	**79.09**	**1.18**	**9.7**	**6.76**	**6.93**	**5.53**	**4.01**	**28.39**
CV (%)	**5.29**	**45.76**	**14.31**	**11.52**	**14.13**	**5.36**	**5.48**	**8.34**
LSD (0.05)	**ns**	**ns**	**ns**	**1.17****	**2.04****	**ns**	**ns**	**ns**

*, **; Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively; PH: Plant height (cm), NMB: Number of monopodial branches (number · plant^{-1}), NSB: Number of sympodial branches (number plant^{-1}), NNFFB: Number of nodes in first fruiting branches (number · plant^{-1}), BN: Boll number (number plant^{-1}), BW: Boll weight (g), BSCW: Boll seed cotton weight (g), NSPB: Number of seeds per boll (number plant^{-1})

Number of Fruiting Branches (number plant^{-1}) varied between 7.66 and 10.49 plant^{-1}, but the differences between applications were not statistically significant (*Table 3*). The lowest value was obtained at a 5 cm plant spacing, with 7.66 plant^{-1}, and the highest number of fruiting branches was obtained from at a 20 cm plant spacing, with 10.49 plant^{-1}. These results were compatible with those that demonstrated that an increasing plant number per unit area did not cause any change in the number of fruiting branches (Incekara and Turan, 1977; Kaynak, 1995).

The number of fruit branches has been reported to increase as plant density decreases (Düven, 1992; Kumar *et al.*, 2017), and the number of fruit branches decreases as the distance between the rows decreases (the plant density increases in a unit area) (Kaynak *et al.*, 1994; Azizpour *et al.*, 2005). However, the research findings differ, likely due to differences in climatic conditions and variety.

Number of Nodes in First Fruiting Branches (number plant^{-1}) varied between 5.57 and 7.66 plant^{-1}, and there were statistical differences between applications at the 1% significance level. The lowest number of nodes of the first fruiting branches was obtained at a 15 cm plant density, with 5.57 plant^{-1}, and the highest value was obtained at a 5 cm plant density, with 7.66 plant^{-1}.

The 5 cm plant density and the no thinning application were not significantly different. The number of nodes in the first fruiting branches was influenced by plant density. Similar findings have also been reported by Wang *et al.* (2016). However, Akbar *et al.* (2015) found that the number of nodes in first fruiting branches was not affected by a 10, 20, or 30 cm in-row distance.

Number of Bolls (number · plant^{-1}) ranged between 6.74 and 11.58 plant^{-1}. There were statistical differences between the applications at the 1% significance level, and the general average of the experiment was 6.93 plant^{-1}. The lowest number of bolls was obtained at a 5 cm plant density (6.74 plant^{-1}). The highest value was obtained at a 20 cm plant density (11.58 plant^{-1}), followed by 25 and 15 cm planting densities, and these applications were not significantly different. Plant density had a significant influence on the number of bolls and the number of bolls increased as the plant density decreased or the distance between rows increased.

As plant density decreases, the number of bolls increases (Düven, 1992; Stephenson *et al.* 2011; Silva *et al.* 2012; Sawan, 2016), and the number of bolls decreases as the distance between the rows decreases (as the plant density increases in a unit area). The findings of Kaynak *et al.* (1994) supported the results of this study. Different findings were obtained by Bednarz *et al.* (2000), who stated that a low plant density did not affect the number of bolls.

Boll Weight (g). varied between 5.29 and 5.71 g, but there were no statistically significant differences. The lowest boll weight was obtained in the no thinning treatment (5.29 g), while the highest boll weight was obtained at a 10 cm plant density (5.71 g). Plant density did not have a significant influence on boll weight. Similar findings were also reported by Iqbal *et al.* (2012) and McCarty *et al.* (2017). It has been reported that as the distance between rows decreases, the boll weight decreases (Kaynak *et al.* 1994; Zhi *et al.*, 2016; Darawsheh *et al.*, 2019), which differs from the present findings. These differences may be caused by the differences in climatic conditions, the variety used, and cultural processes used in the years the research was conducted.

Boll Seed Cotton Weight (g) varied between 3.87 and 4.15 g, but the differences between applications were not statistically significant. The lowest boll seed cotton weight was obtained in the no thinning treatment (3.87 g), while the highest value was obtained at a 10 cm plant density (4.15 g).

The findings showed that plant density had no effect on boll seed cotton weight (Incekara and Turan, 1977), which is similar to the results of Akçar and Gençer (1987). Different results were obtained in this study compared with those reporting that the boll seed cotton weight decreases as the distance between rows decreases (Düven, 1992; Kaynak, 1995; Kaynak *et al.*, 2014; Zhi *et al.*, 2016).

Number of Seeds in the Boll (number boll^{-1}). ranged between 27.45 and 29.70, but there were no statistically significant differences *(Table 3)*. The lowest value was obtained at a 25 cm plant density (27.45 boll^{-1}), while the highest value was obtained at a 10 cm plant density (29.70 boll^{-1}). Similar results were observed in Akbar *et al* (2015) and Mahil and Lokanadhan (2017), who reported that plant density did not affect the number of seeds in the boll. In contrast, Zhi *et al.* (2016) reported that the number of seeds in the boll increased as the plant density decreased.

100-Seed Weight (g). The weight of 100 seeds varied between 8.15 and 8.35 g, but the differences between applications were not statistically significant (*Table 4*). The lowest 100-seed weight was obtained in the no thinning application, at 8.15 g, and the highest value was obtained at a 25 cm plant density, at 8.35 g. Previous reports have stated that the effect of plant density on the weight of 100 seeds was not significant (Akçar and Gençer, 1987), that the weight of 100 seeds increases as the distance between the rows decreases (Kaynak *et al.*, 1994), and that the weight of 100 seeds decreases with the increase in plant density (Zhao *et al.,* 2019). These findings differed from those that reported no change in the weight of 100 seeds as the distance between rows decreased (the plant density increased in a unit area (Kaynak, 1995).

Ginning Percentage (%). As shown in *Table 4*, there were significant differences between applications at the 1% significance level in terms of ginning percentage. The average values of the ginning percentage ranged between 40.30 and 43.36%, and the general average of the trial was 42.41%. The lowest ginning percentage value was obtained at a 20 cm plant density, while the highest value was obtained at a 5 cm plant density, followed by the no thinning application (43.03%).

Plant density was found to have a significant effect on ginning percentage. Similar findings were reported by Awan *et al.* (2011). As the distance between the rows decreases (the plant density increases in the unit area), the ginning percentage decreases (Kaynak *et al.*, 1994). The ginning percentage is not affected by a narrow row planting method (Özdemir, 2007), and the decrease in the plant density does not have a significant effect on the ginning percentage (Akbar *et al.*, 2015; Sawan, 2016).

Table 4 - Average values for the investigated agronomic and physiological properties

Plant Spacing	100 SW	GP	SCY	FY	LT	CC	NDVI	LA
No thinning	8.15	43.03 ab	4583.30 a	1972.40 a	33.17	43.75	0.80 ab	66.60
5 cm	8.22	43.36 a	4165.40 ab	1809.20 ab	32.00	41.92	0.81 a	60.32
10 cm	8.18	42.67 ab	3825.00 bc	1630.30 bc	30.35	43.07	0.77 abc	63.34
15 cm	8.22	42.14 b	3528.50 bc	1488.60 c	33.02	41.25	0.74 c	60.07
20 cm	8.26	40.30 c	3588.90 bc	1450.50 c	32.32	42.45	0.74 c	58.51
25 cm	8.35	42.93 ab	3438.60 c	1476.40 c	31.25	42.65	0.76 bc	72.72
Mean	**8.23**	**42.41**	**3855.00**	**1637.90**	**32.02**	**42.51**	**0.77**	**63.60**
CV (%)	**4.49**	**1.61**	**11.31**	**10.77**	**10.43**	**10.45**	**4.15**	**10.82**
LSD (0.05)	**ns**	**1.02****	**657.25***	**265.73****	**ns**	**ns**	**0.04***	**ns**

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively; 100 SW: 100-seed weight (g), GP: Ginning percentage (%), SCY: Seed cotton yield (kg ha^{-1}), FY: Fibre yield (kg ha^{-1}), LT: Leaf temperature (ºC), CC: Chlorophyll content (SPAD value), NDVI: Normalised difference vegetative index, LA: Leaf area (cm^2)

Seed Cotton Yield (kg ha^{-1}) varied between 3438.60 and 4583.30 kg ha^{-1}; as seen in *Table 4*, there were statistical differences between applications at the 5% significance level, and the general average of the experiment was 3855.00 kg ha^{-1}. The lowest seed cotton yield was obtained at a 25 cm plant density (3438.60 kg ha^{-1}). The highest value was obtained in the no thinning application (4583.30 kg ha^{-1}), followed by a 5 cm plant density (4165.40 kg ha^{-1}) and these applications were not significantly different. In this study, the seed cotton yield decreased with the decrease in plant population.

The seed cotton yield increased with the increasing number of plants per unit area (Incekara and Turan, 1977; Azizpour *et al.,* 2005; Ali *et al.*, 2009; Chen *et al.*, 2019; Liu *et al.*, 2019). Darawsheh *et al.* (2009b) confirmed these research findings. Bednarz *et al.* (2000) found that the seed cotton yield was not affected by plant density, differing from the results of this study.

Fibre Yield (kg ha^{-1}) varied between 1450.50 and 1972.40 kg ha^{-1} and there were statistical differences between applications at the 1% significance level. The lowest value was obtained at a 20 cm plant spacing (1450.50 kg ha^{-1}). The highest value was obtained in the no thinning application (1972.40 kg ha^{-1}), followed by 5 cm plant spacing (1809.20 kg ha^{-1}). Plant spacing had a significant influence on fibre yield, and the highest fibre yield was obtained in the no thinning application.

Increasing plant density causes an increase in fibre yield (Unay and Inan, 1994; Mert *et al.,* 2005; Zhi *et al.*, 2016; Liu *et al.*, 2019), and narrow row planting has the potential to increase yield (Heitholt, 1995). However, these research findings differed from those that reported no differences between row spacings (Jost *et al.*, 1998) and that showed the highest fibre yield at a 7.5 plant m^2 spacing in late sowing (Dong *et al.*, 2005).

Leaf/Canopy Temperature (ºC) varied between 30.35 and 33.17ºC, but differences between applications were not significant. The lowest value was obtained at a 10 cm plant spacing, while the highest value was obtained in the no thinning application.

Xie *et al.* (2016) reported that canopy temperature decreased with increased plant density, which differed from the present findings. This may have been due to differences in climate, temperature, humidity, leaf/canopy temperature measurements and irrigation.

Leaf Chlorophyll Content (SPAD value) varied between 41.25 and 43.75, but no significant difference was observed between applications. The highest chlorophyll content was obtained in the no thinning application (43.75), and the lowest value was obtained at a 15 cm plant spacing (41.25). While the findings were in agreement with Janat and Khalout (2011), who reported that the chlorophyll content in the leaf was not influenced by plant density, Xie *et al.* (2016) obtained different results.

Normalised Difference Vegetative Index (NDVI). NDVI values ranged from 0.74 to 0.81, and there were differences between applications at the 5% significance level. The lowest NDVI was obtained at a 15 and 20 cm plant spacing (0.74). The highest NDVI was obtained at a 5 cm plant spacing (0.81), followed by the no thinning application (0.80), and the NDVI values for these applications were not significantly different. The NDVI was affected by plant density, which was confirmed by Ramirez *et al.* (2017).

Leaf Area (cm^2) varied between 58.51 and 72.72 cm^2, but the differences between applications were not statistically significant. The lowest value was obtained at a 20 cm plant spacing (58.51 cm^2), and the highest value was obtained at a 25 cm plant spacing (72.72 cm^2). Plant density applications did not cause a significant difference in leaf area. Similar findings were also reported by Janat and Khalout (2011). However, these results differed from other studies, which showed that an increase in plant density increased the leaf area (Darawsheh *et al.,* 2009a; Liu *et al.,* 2019).

Fibre Micronaire (mic) ranged from 3.78 to 4.30 mic. The differences between applications were not statistically significant (*Table 5*). The lowest value was obtained in the no thinning application (3.78 mic), while the highest value was obtained at a 25 cm plant spacing (4.30 mic).

Previous studies have reported that plant density does not have a significant effect on fibre micronaire (Bednarz *et al.*, 2005; Özdemir, 2007; Janat and Khalout, 2011; Stephenson *et al.*, 2011).

Fibre Length (mm) varied between 27.57 mm and 28.12 mm, and the differences between applications were not statistically significant. The lowest fibre length was obtained from at a 15 cm plant spacing (27.57 mm), and the highest value was obtained at a 25 cm plant spacing (28.12 mm). It has been reported that plant density does not affect fibre length (Hawkins and Peacock, 1971; Bridge *et al.*, 1972; Baker, 1976; Janat and Khalout, 2011; Stephenson *et al.*, 2011), which agrees with the present results.

Fibre Strength (g · tex^{-1}). As shown in *Table 5*, fibre strength varied between 29.47 and 31.05 g · tex^{-1}, and the differences between applications were not significant. The lowest value was obtained in the no thinning application, with 29.47 g · tex^{-1}, and the highest value was obtained at a 15 cm plant spacing (31.05 g · tex^{-1}).

It has been reported that plant density does not affect fibre strength (Bridge *et al.*, 1972; Stephenson *et al.*, 2011), which agrees with the present findings.

Fibre Elongation (%) values ranged between 6.15 and 6.57%. Although there was no significant difference between the applications, the lowest fibre elongation was obtained at a 10 cm plant spacing, while the highest fibre elongation was obtained at a 5 cm plant spacing. These results were supported by previous studies demonstrating that increasing plant density does not have a significant effect on fibre elongation (Bridge *et al.*, 1972; Stephenson *et al.*, 2011).

Fibre Uniformity Ratio (%) varied between 83.32 and 84.12%, but the differences were not statistically significant. The lowest fibre uniformity ratio was obtained at a 20 cm plant spacing, while the highest value was obtained at a 25 cm plant spacing. Similar results were reported by Stephenson *et al.* (2011) who reported that the fibre uniformity ratio was not affected by the increase in plant density.

Short Fibre Index (%) varied between 6.90 and 8.30%, but the differences between applications were not statistically significant. The lowest short fibre index was obtained at a 25 cm plant spacing (6.90%), while the highest value was obtained at a 20 cm plant spacing (8.30%). Plant density or plant spacing did not affect the short fibre index. Similar findings were also reported by Darawsheh *et al.* (2009b), Sawan (2016) and Afzal *et al.* (2018).

Fibre Reflectance (Rd) Fibre reflectance (Rd) varied between 79.07 and 79.45, but the differences between applications were not statistically significant. The lowest Rd value was obtained at a 15 cm plant spacing (79.07), and the highest Rd value was obtained at a 5 cm plant spacing (79.45). Fibre reflectance was not affected by plant density. Similar findings were also reported by (Darawsheh *et al.,* 2009b; Sawan 2016; Afzal *et al.,* 2018).

Fibre yellowness varied between 10.22 and 11.10, but the differences were not significant. The lowest fibre yellowness value was obtained in the no thinning application, while the highest value was obtained at a 20 cm plant spacing.

Table 5 - Average values for the investigated fibre quality traits

Plant Spacing	Mic	FL	FS	FE	FU	SFI	RD	%b	SCI
No thinning	3.78	27.65	29.47	6.40	83.57	7.37	79.22	10.22	140.25
5 cm	3.90	27.91	30.50	6.57	83.57	7.47	79.45	10.52	143.25
10 cm	4.16	27.62	30.52	6.15	83.95	7.17	79.42	10.60	141.75
15 cm	4.16	27.57	31.05	6.37	83.62	8.12	79.07	10.60	141.50
20 cm	4.12	27.86	29.65	6.32	83.32	8.30	79.27	11.10	137.50
25 cm	4.30	28.12	30.25	6.20	84.12	6.90	79.20	10.62	141.50
Mean	**4.07**	**27.79**	**30.24**	**6.33**	**83.69**	**7.55**	**79.27**	**10.61**	**140.95**
CV (%)	**7.12**	**2.51**	**8.59**	**4.64**	**1.37**	**12.71**	**0.85**	**3.91**	**8.41**
LSD (0.05)	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively; Mic: Fibre micronaire, FL: Fibre length (mm), FS: Fibre strength ($g \cdot tex^{-1}$), FE: Fibre elongation (%), FU: Fibre uniformity (%), SFI: Short fibre index (%), RD: Fibre reflectance, +b: Fibre yellowness, SCI: Spinning consistency index

Spinning Consistency Index (SCI) varied between 137.50 and 143.25, but the differences between the applications were not statistically significant. The lowest SCI index was obtained at a 20 cm plant spacing, while the highest value was obtained at a 5 cm plant spacing. Similar results were obtained by Mert *et al.* (2005), Darawsheh *et al.,* (2009b), Janat and Khalout (2011) and Sawan (2016).

CONCLUSIONS

In this study, different plant spacings (no thinning, 5, 10, 15, 20 and 25 cm) were compared. The highest values in terms of number of nodes of first fruiting branches, ginning percentage, seed cotton yield, fibre yield, and NDVI value were observed at a 5 cm plant spacing and in the no thinning application. The highest number of bolls per plant was obtained at 20 and 25 cm plant spacings. The leaf/canopy temperature, leaf area, and chlorophyll content in the leaves, which were among the physiological parameters examined in the study, were not affected by the plant spacing applications, but plant density affected the NDVI. As a result of this study, it was concluded that the cultivation of the BA 119 cotton variety at a 5 cm plant density or without thinning performs better than at a sparse plant density (20 or 25 cm) and should be preferred. Yield estimation could be made in the flowering period using the NDVI at different plant densities in cotton.

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