Research Article

Optimizing Seed Cotton Yield: Exploring the Synergistic Effects of De-topping Stage and Plant Spacing

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Abstract | Cotton being an important cash crop of Pakistan contributing substantially to foreign exchange earnings and playing a crucial part in the industry, agricultural sector and overall economic development. Achieving a high cotton yield is closely linked to optimal plant population. However, many farmers adhere to traditional plant spacing practices, which often result in lower yields. Thus, standardizing plant spacing based on the crop's requirements is essential for maximizing yield. Moreover, excessive vegetative development has been observed a major factor limiting yield improvement in cotton cultivation. Excessive vegetative growth often occurs at the expense of reproductive growth. Hence de-topping, removal of apical shoot, inhibits excessive vegetative growth and redirects the resources for the improvement of lateral/reproductive growth which results in improvement in seed cotton yield. However, for lateral growth enhancement, plant needs wider plant spacing. Therefore, two years (2019 and 2020) field experiments were planned and executed to optimize plant spacing as well as time of de-topping to maximize cotton yield. Two factors were studied: plant spacing (30, 23 and 15 cm) and de-topping (performed at 90, 105, and 120 days after sowing (DAS)). Significant interactions were found between these factors for plant population, height, sympodial branches per plant, bolls per plant, boll weight, and seed cotton yield. Cotton sown at 15 cm spacing had the highest plant population and plant height, while 30 cm spacing resulted in the higher sympodial branches, bolls, and highest boll weight. De-topping at 90 DAS significantly improved the number of branches, bolls and yield, whereas 75 DAS had the lowest values. Higher seed cotton yield was observed with 30 cm spacing and de-topping at 90 DAS. Hence for optimal cotton yield and growth, the recommended treatment is sowing at 30 cm plant spacing with de-topping at 90 DAS that provides the best balance of plant population, height, number of sympodial branches, boll number, and seed cotton yield.

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Introduction

Cotton (*Gossypium hirsutum* L.) is a vital cash crop in Pakistan that provides fiber, oil, and fuel wood, and significantly contributing to farmers' incomes both locally and globally (Kashif *et al*., 2022). It performs crucial role in economy (Razzaq *et al*., 2021) and offers security of livelihood to masses of people across the country (Abbas and Waheed, 2017). Regardless of its importance, cotton production in Pakistan surfaces numerous challenges that hamper its growth and productivity (Razzaq *et al*., 2021). These challenges are conventional farming methods, pest and disease pressures, water insufficiency as well as climate change (Soomro *et al*., 2020). To address these concerns, farmers can employ advance farming techniques, integrated pest management practices, water conservation methods and climate-smart agriculture practices and can increase seed cotton yield and quality of produce (Siddiqua *et al*., 2021). Furthermore, crop yield at farm level is subjected to various aspects such as soil, climate and management practices (Dhaliwal *et al*., 2022). At farm level, it is vital to adopt amended management practices to boost yield potential of cotton (Ibrahim *et al*., 2022). One such practice is de-topping that involves removing terminal portion of plant from uppermost node to boost yield. De-topping improves yield by reducing undesired growth, minimizing mutual shading of leaves, increasing light capture, improving nutrient uptake and reducing competition amongst vegetative and reproductive development for nutrients (Dhaliwal *et al*., 2022). This practice also helps in readdressing plant nutrients to reproductive parts that improves source-sink relationship and promotes better boll development (Bhargavi *et al*., 2017; Esechie and Al-Alawi, 2002).

Cotton displays an indeterminate growth pattern and has prominent apical dominance (Wu *et al*., 2023). De-topping is a common practice in China and other cotton-producing regions (Dai and Dong, 2014). This practice disrupts apical dominance and allows a more provision of resources towards reproductive organs which results in increased squaring, flowering, boll formation and ultimately higher lint yield (Li *et al*., 2006). Additionally, de-topping can help in mitigating issues with sucking pests and bollworm infestations by eliminating fresh growth that might attract pests (Renou *et al*., 2011). Therefore, implementation of de-topping after plant has reached optimal vegetative growth can enhance cotton production. A study by Dai *et al*. (2022) has demonstrated that de-topping is an effective practice for improving cotton yield. In another study de-topping at plant height of 75 cm was found to improve yield contributing traits and seed cotton yield (Obasi and Msaakpa, 2005). Similarly, Kataria and Valu (2018) also reported 15 to 21% improvement in yield related parameters and yield of cotton.

Amongst various production factors, planting geometry plays a crucial role, particularly as a cost-effective input (Pinnamaneni *et al*., 2021). Achieving right plant density is essential for high yields, as insufficient plant density can lead to resource wastage, while excessive density can hinder growth of individual plant (Munir *et al*., 2015). Humidity, wind movement, moisture availability and radiation interception are affected by plant density (Heitholt *et al*., 1992). This change in crop microclimate further affects the height of canopy, branching of plant, behavior of fruiting, maturity of crop and ultimately yield (Heitholt *et al*., 1992). Proper density of plants also improves irrigation as well as fertilizers use efficiencies of crop (Abbas, 2000). Additionally, crop geometry influences yield by affecting rooting patterns and moisture extraction (Reddy and Reddy, 2011). The highest yields are achieved when plant populations enable individual plants to reach their full potential (Hussain *et al*., 2021). Plant geometry has been shown to significantly impact various growth characteristics, yield attributes and overall cotton yield (Ghule *et al*., 2013; Waghmare *et al*., 2018).

Despite lots of research conducted on de-topping and plant spacing in previous years, however optimal timing and plant spacing for de-topping in cotton remained unclear. Further research is needed to explore the interaction between de-topping stage and plant spacing to determine most effective combination for maximizing seed cotton yield. Therefore, this study aimed to optimize cotton production by examining the influences of de-topping and plant spacing on seed cotton yield. This study investigated how de-topping at various growth stages influenced yield and how this interacted with plant spacing. By identifying the optimal timing for de-topping and the most productive plant arrangement, this research was aimed to provide valuable recommendations for cotton farmers. These improved practices can empower them to maximize seed cotton yield and enhance their agricultural output.

Materials and Methods

Experimental site, design and treatments

This field study was executed at research area of Agronomic Research Station, Khanewal, Pakistan, situated at a latitude of 30°18' 35.95" N, a longitude of 71°59' 40.14" E, and an elevation of 454 m, for two years; 2019 and 2020. Climate of this region is arid with sandy loam soil. The chemical properties of the soils were as; a pH of 8.6, EC 4 ds cm^{-1}, nitrogen (N) content 0.06%, phosphorous (P) content 6.90 ppm and K content 206.70 ppm. Two factors were studied in this experiment i.e., plant spacing; 30, 23, 15 cm and de-topping; de-topping at 90, 105 and 120 DAS. The experiment was set up in the field using a net plot size of 8.0 × 3.5 m and three replications in accordance with randomized complete block design (RCBD).

Crop husbandry

Following wheat harvesting, land preparation involved two cultivations, followed by one planking. The entire crop received fertilization: 247 kg ha^{-1} N as urea, 99 kg ha^{-1} P as single superphosphate (SSP), 94 kg ha^{-1} K as sulfate of potash (SOP), 12 kg ha^{-1} zinc sulfate (33%), and 6 kg ha^{-1} boric acid (17%). During seed bed preparation, the entire amount of P, K, zinc sulfate, and boric acid was applied to the soil, whereas N was given in four equal splits (at sowing, squaring, flowering, and boll formation). Nitrogen was applied in furrows immediately after irrigation. Beds with dimensions of 75 cm on the bed top and 75 cm in the furrow were made using a tractor-drawn bed shaper. Cotton was planted at a seed rate of 15 kg ha^{-1} using test variety named; MNH-1050. Sowing was performed manually on both sides of the bed using dibbling method maintaining plant-to-plant distance as per treatment. To manage weeds, a pre-emergence herbicide, Pendimethylene (Stomp), was sprayed immediately after sowing at a rate of 2457 ml ha^{-1}. Crop was gap filled at six days after sowing (DAS) whereas thinning was performed at 25 DAS. A total of fourteen irrigations were scheduled, with the first irrigation applied at 4 DAS, followed by the 2nd, 3rd, and 4th irrigations at 7-day intervals. Subsequent irrigations were administered at 12-day intervals as per the crop's requirements, with irrigation applied in furrows. Three pickings were conducted during each growing season.

Observations

At maturity, twenty plants from each treatment were randomly labeled to record yield-related variables. Using the meter rod, the plant height was calculated in centimeters. Sympodial branches of these labelled plants were counted and noted. Likewise, bolls per plant of these labelled plants was counted and noted. For each replicate, 50 bolls from each treatment were taken, weighted using a weight balance, and then averaged to record the average boll weight. Whole plot was picked and weighted using weight balance (electric compact scale: GT-500) to record seed cotton yield of each treatment in kilogram, afterwards convert into kilogram per hectare by employing unit method and noted.

Weather conditions

Figure 1 is presenting the weather of the experimental area during both growing seasons; 2019 and 2020. In the year 2019, during growing period the maximum temperature noted was 47°C though in 2020 the maximum temperature noted was 45°C. Moreover, in the year 2019, during growing period the least temperature noted was 14°C whereas in 2020 it was 12°C. In case of rain fall, total rainfall noted in growing period of 2019 was 290 mm while it was 196 mm in 2020.

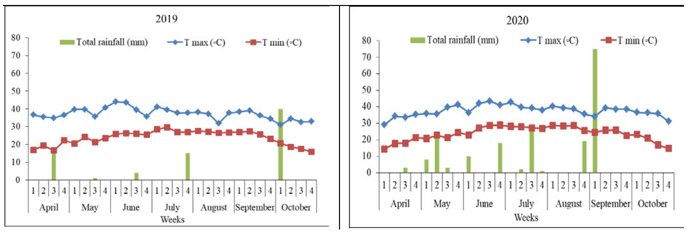

Figure 1: *Weather conditions of the experimental site during the course of study in years 2019 and 2020.*
T max= Average maximum temperature; T min= Average minimum temperature.

Statistical analysis

Fisher's analysis of variance was utilized to evaluate the data using STATISTIX 8.1 statistical software (Statistix, analytical software, Statistix; Tallahassee, FL, USA, 1985-2003) (Steel *et al.*, 1980). Means were compared using the Least Significance Difference (LSD) test at the 5% probability level.

Results and Discussion

The experiment results underscored the substantial effects of plant spacing, timing of de-topping, and their interaction on various yield contributing traits of cotton over two years. Plant spacing was identified as a critical factor for improving cotton canopy structure and enhancing photosynthetic efficiency (An *et al*., 2022) and it is also an integral component of production technology of cotton. Absorption of light, availability of moisture, and movement of wind are the factors which are effects by plant density which in turns affect structure and height of plant, development of bolls, maturity of crop and ultimately productivity of crop (Fahad *et al*., 2021). High plant populations reduce the space between plants within rows, potentially leading to crowding stress that can limit yield (Bernhard and Below, 2020). Increasing row spacings can alleviate crowding, improve plant-to-plant spacing, and reduce competition for light, water, and nutrients (Tollenaar and Wu, 1999; Bernhard and Below, 2020). Relationship among cotton productivity and plant density has been explored in numerous studies (Bondada and Oosterhuis, 2001; Wei *et al*., 2022). Additionally, de-topping cotton after a significant vegetative growth stage has been shown to promote the growth of existing sympodia and enhance the formation of new sympodia. This increase in sympodia and bolls is crucial for maximizing seed cotton yield. The significant differences observed in the study highlight the importance of optimizing these agronomic practices to improve cotton production.

Plant population (plants ha^{-1})

In both year, plant population was significantly ($P \leq 0.05$) affected by plant spacing however was non-significant for time of de-topping (Table 1). Higher plant population was noted when cotton was planted at 15 cm plant spacing whereas least was noted where cotton was planted at 30 cm plant spacing (Table 1).

Table 1: *Influence of plant spacing and De-topping on yield and yield components of cotton.*

Treatments		Plant population (ha^{-1})		Plant height (cm)		Sympodial branches per plant		Bolls per plant		Average boll weight (g)		Seed cotton yield (kg ha^{-1})	
		2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Plant spacing (cm)													
15		87178A	86385A	78A	85A	10C	11C	11C	11 C	2.35C	2.31 C	2111B	2200 C
23		57771B	57741B	68B	83B	13B	14B	15B	16 B	2.74B	2.73 B	2183A	2522 B
30		35536C	35150C	63C	81C	16A	16A	20A	23 A	3.52A	3.62 A	2214A	2965 A
LSD 0.05		216	127	1.8	0.2	0.06	0.5	0.07	0.3	0.07	0.08	68	91
Time of De-topping (Days after sowing)													
Control		60056	59855	88A	97A	11D	12C	14D	15 D	2.86C	2.77 C	1933D	2127 D
75		60154	59873	56E	67E	10E	12C	12E	14 E	3.02A	2.87 B	1821E	2082 D
90		60270	59712	63D	77D	16A	16A	20A	21 A	2.61D	2.89 AB	2559A	3165 A
105		60163	59699	68C	83C	14B	14B	16B	18 B	2.92BC	2.94 A	2335B	2813 B
120		60165	59656	73B	91B	13C	14B	15C	17 C	2.94B	2.95 A	2198C	2624 C
LSD 0.05		-	-	1.3	0.5	0.2	0.5	0.2	0.5	0.07	0.06	69	111
Plant spacing × Time of de-topping													
15	Control	86953a	86663 a	94a	103a	8j	9i	10j	10 k	2.27g	2.13 k	1702ij	1918 h
	75	87055a	86727 a	64f	68n	7k	9i	9k	8 l	2.40f	2.25 jk	1656j	1627 i
	90	87282a	86253 b	72e	76k	14e	13ef	15g	13 hi	2.20g	2.49 hi	2547b	2884 c
	105	87370a	86216 b	76d	83h	11h	12g	13h	12 j	2.43ef	2.27 j	2430bc	2378 ef
	120	87229a	86067 b	83c	95c	9i	10h	11i	11 k	2.47ef	2.39 i	2220def	2191 fg
23	Control	57926b	57738 c	88b	96b	12g	13f	15g	13 ij	2.77d	2.55 gh	2120fg	1867 h
	75	57935b	57750 c	54i	64o	10i	14e	13h	14 h	3.03c	2.63 fg	2003gh	2126 g
	90	57955b	57744 c	59g	79j	16c	16bc	18d	19 e	2.53e	2.98 d	2312cd	3273 ab
	105	57683bc	57739 c	66f	84g	14e	15d	17e	17 f	2.67d	2.79 e	2298d	2795 c
	120	57357c	57738 c	71e	92e	13f	15d	16f	16 g	2.70d	2.70 ef	2179ef	2546 de
30	Control	35289e	35164 d	81c	93d	15d	16cd	18d	20 d	3.53b	3.63 b	1975h	2597 d
	75	35472de	35142 d	49j	69m	13f	14ef	16f	19 e	3.63ab	3.73 ab	1805i	2493 de
	90	35575de	35139 d	57h	74l	19a	20a	28a	30 a	3.10c	3.20 c	2819a	3337 a
	105	35436e	35142 d	61g	82i	16b	17b	19b	25 b	3.67a	3.77 a	2276de	3265 ab
	120	35909d	35164 d	65f	86f	16c	17b	19c	24 c	3.67a	3.77 a	2196def	3134 b
LSD 0.05		461	295	2.2	0.9	0.4	0.8	0.4	0.9	10	0.1	119	191

Means sharing same case letter do not differ significantly at $p \leq 0.05$.

In case of interaction between plant spacing and time of de-topping, during 2019, higher plant population was noted in all those de-topping treatments where cotton was planted at 15 cm plant spacing although least was noted in the de-topping treatments where cotton was planted at 30 cm plant spacing (Table 1). However, during 2020, higher plant population was noted where cotton was planted at 15 cm plant spacing and de-topped at 75 DAS as well as in control treatment whereas least was noted in the treatments where cotton was planted at 30 cm plant spacing and de-topped at 75, 90, 105 DAS as well as in control.

Results of this study revealed that plant spacing significantly affected plant population in both years, with the highest plant population noted at the closest spacing of 15 cm and the lowest at 30 cm. This pattern is consistent across both years, indicating that closer plant spacing results in a denser plant population. Lesser plant population in wider row spacing as well as higher plant population in narrow row spacing has also been reported by many researchers (Zaman *et al*., 2021; Haarhoff and Swanepoel, 2022).

Plant height (cm)

In both years, plant height was significantly ($P \leq 0.05$) affected by plant spacing, time of de-topping and interaction between plant spacing and time of de-topping (Table 1). In case of plant spacing, higher plant height was noted when cotton was planted at 15 cm plant spacing whereas least was noted where cotton was planted at 30 cm plant spacing (Table 1). In case of time of de-topping, higher plant height was noted when cotton was not de-topped (control) whereas least was noted when de-topping was performed at 75 DAS (Table 1). Regarding interaction between plant spacing and time of de-topping, during 2019, higher plant height was noted in treatment where cotton was planted at 15 cm plant spacing and no de-topping was performed (control) whereas least was noted where cotton was planted at 30 cm plant spacing and de-topped at 75 DAS (Table 1). During 2020, higher plant height was noted in treatment where cotton was planted at 15 cm plant spacing and no de-topping was performed (control) whereas least was noted where cotton was planted at 23 cm plant spacing and de-topped at 75 DAS (Table 1).

The results demonstrated that both plant spacing and de-topping time significantly affected plant height. Plants sown at 15 cm spacing were consistently taller than those at wider spacing, indicating that closer spacing might promote vertical growth (Shrestha *et al*., 2021). The increased height in closer spaced plants can be attributed to competition for light, which encourages vertical growth as plants strive to outgrow their neighbors (Zaman *et al*., 2021). These findings align with those of Sharma and Kumar (1989), Sharma (1998), and Ali *et al*. (2009), who observed that closer plant spacing led to increased plant height. This height increase was attributed to the elongation of internodes as plants sought to access more solar energy at higher canopy levels. De-topping time also played a crucial role, with the tallest plants noted in the control (no de-topping), followed by later de-topping times (120 DAS and 105 DAS), while the shortest plants were noted with early de-topping (75 DAS). This trend was consistent across both years, suggesting that delaying de-topping allows for greater vertical growth (Nayak *et al*., 2023). The interaction effects further emphasized that the combination of 15 cm spacing and no de-topping resulted in the tallest plants, highlighting the combined influence of these factors on plant height (Khubna *et al*., 2021).

Sympodial branches per plant

In both years, sympodial branches per plant was significantly ($P \leq 0.05$) affected by plant spacing, time of de-topping and interaction between plant spacing and time of de-topping (Table 1). In case of plant spacing, higher sympodial branches per plant was noted when cotton was planted at 30 cm plant spacing whereas least was noted where cotton was planted at 15 cm plant spacing (Table 1). In case of time of de-topping, during 2019, higher sympodial branches per plant was noted when cotton was de-topped at 90 DAS whereas least was noted when de-topping was performed at 75 DAS (Table 1). During 2020, higher sympodial branches per plant was noted when cotton was de-topped at 90 DAS whereas least was noted when de-topping was performed at 75 DAS as well as in control (Table 1). Regarding interaction between plant spacing and time of de-topping, during 2019, higher sympodial branches per plant was noted in treatment where cotton was planted at 30 cm plant spacing and de-topped at 90 DAS whereas least was noted where cotton was planted at 23 cm plant spacing and de-topped at 75 DAS (Table 1). During 2020, higher sympodial branches per plant was noted in treatment where cotton was planted at 30 cm plant spacing and de-topped at 90 DAS whereas least was noted where cotton was planted at 15 cm plant spacing and de-topped at 75 DAS and control (Table 1).

The sympodial branches per plant was highest at the widest spacing (30 cm) and lowest at the narrowest spacing (15 cm), suggesting that wider spacing promotes the development of lateral branches. This increase in fruit branches per plant at lower planting densities (wider spacing) is likely owing to more space for growth of plant and reduced competition (Ibrahim *et al*., 2022). These findings are consistent with observations by Sharma (1994, 1998), Singh and Singh (1998), and Mukharjee (1999), who reported that wider plant spacing enhances branch development by improving photosynthetic efficiency. Additionally, de-topping at 90 DAS consistently gave in the highest number of sympodial branches across both years, with 105 DAS and 120 DAS showing intermediate results, and the lowest number of branches noted at 75 DAS. Since cotton has an indeterminate growth habit, de-topping after the appropriate vegetative stage encourages the growth of existing sympodial branches and the formation of new ones (Brar *et al*., 2000). Furthermore, de-topping inhibits vertical growth, which subsequently promotes lateral growth and branching (Alam *et al*., 2024). Rathore and Gumber (2015) also found that de-topping increases the number of sympodial branches by breaking apical dominance and promoting the development of lateral fruiting branches. The interaction effects showed that the combination of 30 cm spacing and 90 DAS de-topping yielded the highest number of branches as wider spacing enabled plant to grow better due to low plant to plant competition for resources and higher photosynthetic efficiency (Ibrahim *et al*., 2022) and de-topping after attaining suitable vegetative growth enabled plant to allocate the photosynthates for the development of sympodial branches instead of allocating resources on vertical growth (Alam *et al*., 2024).

Bolls per plant

In both years, bolls per plant was significantly (P≤0.05) affected by plant spacing, time of de-topping and interaction between plant spacing and time of de-topping (Table 1). In case of plant spacing, higher bolls per plant was noted when cotton was planted at 30 cm plant spacing whereas least was noted where cotton was planted at 15 cm plant spacing (Table 1). In case of time of de-topping, higher bolls per plant was noted when cotton was de-topped at 90 DAS whereas least was noted when de-topping was performed at 75 DAS (Table 1). Regarding interaction between plant spacing and time of de-topping, higher bolls per plant was noted in treatment where cotton was planted at 30 cm plant spacing and de-topped at 90 DAS whereas least was noted where cotton was planted at 15 cm plant spacing and de-topped at 75 DAS (Table 1).

The trend in the bolls per plant showed that of the sympodial branches, with the highest count at 30 cm spacing and the lowest at 15 cm. This pattern aligns with findings by Hussain *et al*. (2000) and Alfaqeih *et al*. (2002), who noted that an improvement in bolls per plant was directly related to a higher number of sympodial branches. Additionally, Iqbal *et al*. (2010) suggested that the increased number of bolls with wider plant spacing could be the result of lesser competition among plants, as wider spacing allows for better water and nutrient uptake, leading to more sympodial branches (Zaman *et al*., 2021). This, in turn, results in a higher bolls per plant. Furthermore, the increase in boll number could also be due to improved assimilation and translocation of photosynthates, facilitated by better light interception in plants with wider spacing (Iqbal *et al*., 2012). In addition to that in wider spaced plants the plant roots can grow better so that they can absorb nutrients better hence the plant grow's better (Khubna *et al*., 2021). Likewise de-topping at 90 DAS again resulted in the highest number of bolls, followed by 105 DAS and 120 DAS, with the fewest bolls at 75 DAS. Vekaria *et al*. (2020) also reported an increased boll per plant as a result of de-topping compared to no de-topping. Vani *et al*. (2021) observed that removing the shoot apex shifts growth from the vegetative stage to the reproductive stage and improves boll number by increasing nutrient availability. This is because the removal of the shoot apex alters the distribution of nutrients, enhancing uptake (Pandey *et al*., 2021). Therefore, nutrient availability significantly affects the bolls per plant in cotton (Vani *et al*., 2021). Additionally, removing the shoot apex reduces apical dominance and promotes the growth of lateral shoots, which increases boll number (Swapna and Singh, 2008). Ohta and Ikeda (2016) and Ohta (2017) found that after removing the shoot apex, the number of bolls increased significantly due to better availability of photosynthetic products and nutrients. These findings are consistent with Pandey *et al*. (2021), who reported the highest bolls per plant following shoot apex removal compared to plants without apex removal. The interaction effects highlighted that the combination of 30 cm spacing and 90 DAS de-topping was optimal for boll production. These findings suggest that wider spacing and appropriately timed de-topping can enhance boll development, potentially leading to higher yields.

Boll weight (g)

In both years, average boll weight was significantly (P≤0.05) affected by plant spacing, time of de-topping and interaction between plant spacing and time of de-topping (Table 1). In case of plant spacing, higher average boll weight was noted when cotton was planted at 30 cm plant spacing whereas least was noted where cotton was planted at 15 cm plant spacing (Table 1). In case of time of de-topping, during 2019, higher average boll weight was noted when cotton was de-topped at 75 DAS whereas least was noted when de-topping was performed at 90 DAS (Table 1). During 2020, higher average boll weight was noted when cotton was de-topped at 75, 90, 105 and 120 DAS as compared to control (Table 1). Regarding interaction between plant spacing and time of de-topping, higher average boll weight was noted in treatments where cotton was planted at 30 cm plant spacing and de-topped at 105 and 120 DAS whereas least was noted where cotton was planted at 15 cm plant spacing and no de-topping was performed (Table 1).

Plant spacing and de-topping time significantly influenced the average boll weight. The highest average boll weight was observed at 30 cm spacing, followed by 23 cm, and the lowest at 15 cm. The increased boll weight at wider spacings is likely due to reduced competition among plants, leading to more efficient resource use (Zaman *et al*., 2021). These results are consistent with findings by Alfaqeih *et al.* (2002) and Shah *et al.* (2017), who reported that wider spacing increased both the number of branches per plant and boll weight due to decreased competition. Additionally, lower plant density was associated with a higher number of heavier bolls per plant, while higher plant density led to a reduction in both boll quantity and weight (Bednarz *et al*., 2007). De-topping at 75 DAS yielded the highest average boll weight in 2021, while in 2022, the highest weights were observed at all de-topping times compared to the control. This because of the reason that due to de-topping the vertical growth is inhibited and photosynthates are mostly allocated to the developing bolls (Zaman *et al*., 2021). Studies have shown that increase in average boll weight owing to de-topping is because by removing the top portion of the plant, the plant's resources are concentrated on remaining bolls instead of producing more vegetative growth, allowing for larger and heavier bolls to develop (Dai *et al*., 2022). The interaction effects revealed that the combination of 30 cm spacing and de-topping at 105 and 120 DAS produced the heaviest bolls. These results indicate that wider spacing and delayed de-topping enhance boll weight, contributing to overall yield.

Seed cotton yield (Kg ha^{-1})

In both years, seed cotton yield was significantly (P≤0.05) affected by plant spacing, time of de-topping and interaction between plant spacing and time of de-topping (Table 1). In case of plant spacing, higher seed cotton yield was noted when cotton was planted at 30 and 23 cm plant spacing whereas least was noted where cotton was planted at 15 cm plant spacing (Table 1). In case of time of de-topping, during 2019, higher seed cotton yield was noted when cotton was de-topped at 90 DAS whereas least was noted when de-topping was performed at 75 DAS (Table 1). During 2020, higher seed cotton yield was noted when cotton was de-topped at 90 DAS whereas least was noted when de-topping was performed at 75 DAS and control (Table 1). Regarding interaction between plant spacing and time of de-topping, during 2019, higher seed cotton yield was noted in treatments where cotton was planted at 30 cm plant spacing and de-topped at 90 DAS whereas lowest was noted in treatment where cotton was planted at 15 cm plant spacing and de-topped 75 DAS (Table 1). During 2020, higher seed cotton yield was noted in treatments where cotton was planted at 30 cm plant spacing and de-topped at 90 DAS whereas lowest was noted in treatment where cotton was planted at 15 cm plant spacing and de-topped 75 DAS (Table 1).

Seed cotton yield was significantly affected by plant spacing and de-topping timing. The highest yields were achieved at 30 cm and 23 cm spacings, while the lowest yield was observed at 15 cm. According to Shrestha *et al.* (2021) and Khubna *et al.* (2021), higher plant densities led to increased plant competition, resulting in taller plants with fewer branches, more lodging, and reduced pod and seed production, ultimately decreasing seed yield compared to lower densities. Additionally, de-topping at 90 DAS consistently produced the highest yields, followed by 105 DAS and 120 DAS, with the lowest yield at 75 DAS. This is due to de-topping breaking apical dominance and redirecting resources to reproductive organs, resulting in more squares, flowers, bolls, and lint yield (Li *et al*., 2006; Dai *et al*., 2022). Similar increases in lint yield and yield components with de-topping have been observed in both full-season cotton under single cropping (Ren *et al*., 2013; Li *et al*., 2018) and short-season cotton under double cropping (Yu *et al*., 2022). The interaction effects showed that the combination of 30 cm spacing and 90 DAS de-topping produced the highest yields, particularly in 2022. These findings underscore the importance of optimizing both plant spacing and de-topping time to maximize cotton yield. These results showed that closer spacing supported higher plant density, which may influence other growth parameters and overall yield.

Conclusions and recommendations

The experiment demonstrated that both plant spacing and de-topping time are critical factors affecting cotton growth and yield. Closer plant spacing (15 cm) promoted higher plant population and plant height, while wider spacing (30 cm) enhanced the number of sympodial branches, bolls, and average boll weight, leading to higher seed cotton yield. The optimal de-topping time appeared to be 90 DAS, which consistently resulted in higher yield related parameters and yield. Hence it is concluded that to maximize the seed cotton yield the cotton plants should be planted at 30 cm plant spacing and de-topped at 90 DAS.

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Novelty Statement

This study addressed the gap in cotton agronomy by exploring the combined effects of de-topping and plant spacing on seed cotton yield. However de-topping has been known in some cotton-producing regions but its optimal timing and interaction with plant spacing was unclear. By systematically examining de-topping at various growth stages and different plant densities, this research identified the most effective combination for maximizing yield.

Author's Contribution

Muhammad Iqbal: Wrote the paper
Saba Iqbal: Handled experiment execution, data collection, analysis, and co-wrote the paper.
Arbab Jahangeer: Worked on proofreading, data tabulation, and graphs.
Muhammad Arshad: Removed plagiarism.
Naveed Akhtar, Ansar Hussain, Mussurrat Hussain, Muhammad Shahid and Qaisar Abbas: Contributed to proofreading and editing.

Conflict of interest
The authors have declared no conflict of interest.

References

Abbas, M.A., 2000. General agriculture. Publisher Emporium Urdu Bazar Lahore, Pakistan. pp. 120.

Abbas, S. and A. Waheed. 2017. Trade competitiveness of Pakistan: Evidence from the revealed comparative advantage approach. Comp. Rev., 27(5): 462–475. https://doi.org/10.1108/CR-12-2015-0092

Alam, J., M. Salim, N. Islam, A.K. Hasan and M.A. Kader. 2024. Detopping reduces field duration of cotton while increases the yield and quality of cotton fiber. J. Agric. Food Res., 16: 101135. https://doi.org/10.1016/j.jafr.2024.101135

Alfaqeih, F.M., A.M. Ali and A.S. Baswaid. 2002. Effect of plant density on growth and yield of cotton. J. Nat. Appl. Sci., 6: 279–285.

Ali, A., M. Tahir, M. Ayub, I. Ali, A. Wasaya and F. Khalid. 2009. Studies on the effect of plant spacing on the yield of recently approved varieties of cotton. Pak. J. Life Soc. Sci., 7(1): 25-30.

An, J., Z. Zhang, X. Li, F. Xing, Y. Lei and B. Yang. 2022. Loose and tower-type canopy structure can improve cotton yield in the Yellow River basin of China by increasing light interception. Arch. Agron. Soil Sci., pp. 1–14. https://doi.org/10.1080/03650340.2022.2045584

Bednarz, C.W., R.L. Nichols and S.M. Brown. 2007. Within-boll yield components of high yielding cotton cultivars. Crop Sci., 47: 2108–2112. https://doi.org/10.2135/cropsci2006.12.0827

Bernhard, B.J. and F.E. Below. 2020. Plant population and row spacing effects on corn: Plant growth, phenology, and grain yield. Agron.

J., 112(4): 2456–2465. https://doi.org/10.1002/agj2.20245

Bhargavi, B.M., B. Mukundam, M.M. Reddy and A. Sreenivas. 2017. Effect of de-topping practice on growth parameters and yield of rabi maize (*Zea mays* L.). Int. J. Curr. Microbiol. App. Sci., 6(8): 51–59. https://doi.org/10.20546/ijcmas.2017.608.008

Bondada, B.R. and D.M. Oosterhuis. 2001. Canopy photosynthesis, specific leaf weight, and yield components of cotton under varying nitrogen supply. J. Plant Nutr., 24: 469–477. https://doi.org/10.1081/PLN-100104973

Brar, A.S., A. Singh and T. Singh. 2000. Response of hybrid cotton (*Gossypium hirsutum*) to nitrogen and canopy modification practices. Indian J. Agron., 45(2): 395–400.

Dai, J., L. Tian, Y. Zhang, D. Zhang, S. Xu, Z. Cui, Z. Li, W. Li, L. Zhan, C. Li and H. Dong. 2022. Plant topping effects on growth, yield, and earliness of field-grown cotton as mediated by plant density and ecological conditions. Field Crops Res., 275: 108337. https://doi.org/10.1016/j.fcr.2021.108337

Dai, J.R. and H.Z. Dong. 2014. Intensive cotton farming technologies in China: Achievements, challenges and countermeasures. Field Crop Res., 155: 99–110. https://doi.org/10.1016/j.fcr.2013.09.017

Dhaliwal, J.K., D. Panday, D. Saha, J. Lee, S. Jagadamma, S.M. Schaeffer and A. Mengistu. 2022. Predicting and interpreting cotton yield and its determinants under long-term conservation management practices using machine learning. Comput. Electron. Agric., 199(2): 107107. https://doi.org/10.1016/j.compag.2022.107107

Esechie, H.A. and K. Al-Alawi. 2002. Effect of tassel removal on grain yield of maize (*Zea mays* L.) under saline conditions. Crop Res., 24: 96–101.

Fahad, S., O. Sonmez, S. Saud, D. Wang, C. Wu and M. Adnan. 2021. Sustainable soil and land management and climate change. Boca Raton, FL: CRC Press. https://doi.org/10.1201/9781003108894

Ghule, P.L., V.V. Dahiphale, J.D. Jadhav and D.K. Palve. 2013. Absolute growth rate, relative growth rate, net assimilation rate as influenced on dry matter weight of Bt cotton. Int. Res. J. Agric. Econ. Stat., 4(1): 42–46.

Haarhoff, S.J. and P.A. Swanepoel. 2022. Plant population and row spacing affects growth and yield of rainfed maize in semi-arid environments. Front. Plant Sci., 13: 761121. https://doi.org/10.3389/fpls.2022.761121

Heitholt, J.J., W.T. Pettigrew and W.R. Meredith. 1992. Light interception and lint yield of narrow row cotton. Crop Sci., 32: 728–733. https://doi.org/10.2135/cropsci1992.0011183X003200030030x

Hussain, N., A. Anwar, A. Yasmeen, M. Arif, S. Naz, M. Bibi, J. Iqbal, I. Qadir, M.N. Salim and S. Latif. 2021. Resource use efficiency of cotton in improved vs conventional planting geometry with exogenous application of bio-stimulant and synthetic growth retardant. Braz. J. Biol., 81(1): 18–26. https://doi.org/10.1590/1519-6984.213951

Hussain, S.Z., F. Sheraz, F., M. Anwar, M.I. Gill and M.D. Baugh. 2000. Effect of plant density and nitrogen on the yield of seed cotton-variety CIM-443. Sarhad J. Agric., 16: 143–147.

Ibrahim, A.E.I., W.M.B. Yehia, F.H. Saleh, S.F. Lamlom, R.Y. Ghareeb, A.A.A. El-Banna and N.R. Abdelsalam. 2022. Impact of plant spacing and nitrogen rates on growth characteristics and yield attributes of Egyptian cotton (*Gossypium barbadense* L.). Front. Plant Sci., 13: 916734. https://doi.org/10.3389/fpls.2022.916734

Iqbal, M. and M.A. Khan. 2010. Management of cotton leaf curl virus by planting time and plant spacing. Adv. Agric. Bot., 2: 25–33.

Iqbal, M., S. Ahmad, S., W. Nazeer, T. Muhammad, M.B. Khan, M. Hussain, A. Mehmood, M. Tauseef A. Hameed and A. Karim. 2012. High plant density by narrow plant spacing ensures cotton productivity in elite cotton (*Gossypium hirsutum* L.) genotypes under severe cotton leaf curl virus (CLCV) infestation. Afr. J. Biotechnol., 11: 2869–2878. https://doi.org/10.5897/AJB11.3259

Kashif, N., H.M.N. Cheema and A.A. Khan. 2022. Expression profiling of transgenes (Cry1Ac and Cry2A) in cotton genotypes under different genetic backgrounds. J. Integr. Agric. 21(10): 2818–2832.

Kataria, G.K. and M.G. Valu. 2018. Effect of de-topping and growth retardants on physiological parameters and yield of Bt cotton (*Gossypium hirsutum* L.). J. Cotton Res. Dev., 32(2): 226–230.

Khubna, M., S. Supriyono, S. Supriyono, S. Nyoto and M.T.S. Budiastuti. 2021. The growth and yield of hybrid corn on different plant spacing. IOP Conf. Ser. Earth Environ. Sci., 637(1): 012064. https://doi.org/10.1088/1755-1315/637/1/012064

Li, F., M. Du, D. Xu, J. Chen, X. Tian and Z. Li. 2018. Effects of chemical topping with fortified mepiquat chloride on cotton growth, yield and maturity under different plant densities and nitrogen rates in the Yellow River valley region of China. J. China Agric. Univ., 23: 10–22.

Li, L., Z.W. Huang, G.W. Chen, Z.Z, Lv and Z.J. Li. 2006. Study on the change of hormone and nutrient absorption of cotton after decapitation. Arid Zone Res., 23: 604–608.

Mukherjee, D., 1999. Annuals. In: (eds. T.K. Bose, R.G. Maiti, R.S. Dhua and P. Das), Floriculture and Landscaping. Pub. Naya Prokash, pp. 315-350.

Munir, M.K., M. Tahir, M.F. Saleem and M. Yaseen. 2015. Growth, yield and earliness response of cotton to row spacing and nitrogen management. J. Anim. Plant Sci., 25(3): 729–738.

Nayak, N., S.S. Angadi, D. Shivamurthy and N.S. Hebsur. 2023. Effect of various stages and levels of detopping on growth, fodder yield and quality of detopped Rabi maize (*Zea mays* L.). Curr. J. Appl. Sci. Technol., 42(30): 25–35. https://doi.org/10.9734/cjast/2023/v42i304209

Obasi, M.O. and T.S. Msaakpa. 2005. Influence of topping, side branch pruning and hill spacing on growth and development of cotton (*Gossypium barbadense* L.) in the southern Guinea Savanna location of Nigeria. J. Agric. Rural Dev. Trop. Subtrop., 106(2).

Ohta, K., 2017. Branch formation and yield by flower bud or shoot removal in tomato. In: Physical methods for stimulation of plant and mushroom development, pp. 35-51. https://doi.org/10.5772/intechopen.71519

Ohta, K. and D. Ikeda. 2016. Effects of pinching treatment on harvest term and plant growth in processing tomato. Can. J. Plant Sci., 97(1): 92–98. https://doi.org/10.1139/CJPS-2016-0127

Pandey, M., S. Subedi, P. Khanal, P. Chaudhary, A. Adhikari and T.P. Sharma. 2021. Effects of different rates of nitrogen and pinching on yield and yield attributes of African marigold (*Tagetes erecta* L.). J. Agric. Nat. Resour., 4(2): 21–28. https://doi.org/10.3126/janr.v4i2.33650

Pinnamaneni, S.R., S.S. Anapalli, R. Sui, N. Bellaloui and K.N. Reddy. 2021. Effects of irrigation and planting geometry on cotton (*Gossypium hirsutum* L.) fiber quality and seed composition. J. Cotton Res., 4(2). https://doi.org/10.1186/s42397-020-00078-w

Rathore, S.K.P. and R. Gumber. 2015. Effects of foliar application of nutrients on growth, maturity and yield parameters of Banana cv. Grand Naine. Bangladesh J. Bot., 44: 9–14. https://doi.org/10.3329/bjb.v44i1.22717

Razzaq, A., M.M. Zafar, A. Ali, A. Hafeez, W. Batool and Y. Shi. 2021. Cotton germplasm improvement and progress in Pakistan. J. Cotton Res., 4(1): 1–14. https://doi.org/10.1186/s42397-020-00077-x

Reddy, M.A. and S.B. Reddy. 2011. Effect of planting geometry and fertility level on growth and seed yield of cluster bean (*Cyamopsis tetragonoloba* (L)) under scarce rainfall zone of Andhra Pradesh. Legume Res., 34(2): 143–145.

Ren, X., L. Zhang, M. Du, J.B. Evers, W. van der Werf, X. Tian and Z. Li. 2013. Managing mepiquat chloride and plant density for optimal yield and quality of cotton. Field Crops Res., 149: 1–10. https://doi.org/10.1016/j.fcr.2013.04.014

Renou, A., I. Téréta and M. Togola. 2011. Manual topping decreases bollworm infestations in cotton cultivation in Mali. Crop Prot., 30(10): 1370–1375. https://doi.org/10.1016/j.cropro.2011.05.020

Shah, T., M. Kalsoom, K. Eifediye, H.A. Khan. 2017. Yield and quality characters of cotton varieties response to different plant spacing. Middle East J. Agric. Res., 6: 113–118.

Sharma, B.D., 1994. Performance of various cotton cultivars under different row and plant spacing. Maysoor J. Agric. Res., 12: 211–217.

Sharma, D.K. and A. Kumar. 1989. Effect of water stress on plant water relations and yield of varieties of Indian mustard (*Brassica juncea*). Indian J. Agric. Sci., 59: 281–285.

Sharma, V.P., 1998. Influence of intra row spacing on the performance of cotton varieties. Ind. J. Agric. Sci., 22: 310–316.

Shrestha, R., S.K. Das and R. Neupane. 2021. Effect of spacing and plant density on yield performance of determinate soybean variety Tarkari Bhatmas-1 under mid hill condition.

Agron. J. Nepal (Agron. J.), 5: 39–45. https://doi.org/10.3126/ajn.v5i01.44727

Siddiqua, A., A. Anwar, M.M. Anwar and J.U. Rehman. 2021. Cotton yield and climate change adaptation in Pakistan: Application of multinomial endogenous switching regression model. J. Bus. Soc. Rev. Emerg. Econ., 7(3): 491–502. https://doi.org/10.26710/jbsee.v7i3.1828

Singh, V.P. and R.K. Singh. 1998. Effect of different row and plant spacing on the growth and yield of cotton varieties. Indian J. Agron., 13: 150–155.

Soomro, A.R., M.H. Channa, G.H. Kalwar, G.N. Dayo and A.H. Memon. 2000. Yield response of three cotton cultivars under varying plant spacing at Ghotki, upper Sindh. Pak. Cottons, 44(1-2): 57–60.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics, a biological approach, 2nd ed. McGraw Hill, Inc. New York, Toronto, London.

Swapna, M. and P.K. Singh. 2008. Shoot apex development at various stages of flowering in sugarcane (*Saccharum* spp. hybrid). Cytologia, 73(2):173–177. https://doi.org/10.1508/cytologia.73.173

Tollenaar, M. and J. Wu. 1999. Yield improvement in temperate maize is attributable to greater stress tolerance. Crop Sci., 39: 1597–1604. https://doi.org/10.2135/cropsci1999.3961597x

Vani, K.P., B.K. Rekha and N. Nalini. 2021. Yield and nutrient uptake of Bt cotton as influenced by composted waste, organic and inorganic fertilizers. Chem. Sci. Rev. Lett., 9(34): 432–441.

Vekaria, G.B., M.L. Patel, D.S. Hirpara, M.M. Talpada, K.S. Jotangiya and T.J. Patel. 2020. Effect of growth regulators and detopping on reproductive growth parameters of Bt cotton (*Gossypium hirsutum* L.) under rainfed condition. J. Pharmacogn. Phytochem., 9(3): 377–381.

Waghmare, Y.M., D.N. Gokhale, P.N. Karanjikar and A.K. Gore. 2018. Effect of different plant geometries and irrigation schedules on growth and yield contributing characters of pigeon pea. Int. J. Curr. Microbiol. Appl. Sci., 6: 2480–2486.

Wei, K., J. Zhang, Q. Wang, Y. Guo and W. Mu. 2022. Irrigation with ionized brackish water affects cotton yield and water use efficiency. Ind. Crops Prod., 175: 114244. https://doi.org/10.1016/j.indcrop.2021.114244

Wu, Y., J. Tang, J. Tian, M. Du, L. Gou, Y. Zhang and W. Zhang. 2023. Different concentrations of chemical topping agents affect cotton yield and quality by regulating plant architecture. Agronomy, 13: 1741. https://doi.org/10.3390/agronomy13071741

Yu, T., L. Baopeng, H. Huanyong, W. Fangyong, D. Mingwei, T. Xiaoli and L. Zhaohu. 2022. The efficacy of chemical topping in field-grown cotton is mediated by drip irrigation amount in irrigated agricultural area. J. Cotton Res., 5: 16. https://doi.org/10.1186/s42397-022-00124-9

Zaman, I., M. Ali, K. Shahzad, M.S. Tahir, A. Matloob, W. Ahmad, S. Alamri, M.R. Khurshid, M.M. Qureshi and A. Wasaya. 2021. Effect of plant spacings on growth, physiology, yield and fiber quality attributes of cotton genotypes under nitrogen fertilization. Agronomy, 11: 2589. https://doi.org/10.3390/agronomy11122589