# SUITABILITY OF PLANT SPACINGS AGAINST MEPIQUAT CHLORIDE TREATED COTTON PLANT FOR IMPROVEMENT OF YIELD AND QUALITY

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Dedicated to my parents

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## *CERTIFICATE*

*This is to certify that the thesis entitled 'SUITABILITY OF PLANT SPACINGS AGAINST MEPIQUAT CHLORIDE TREATED COTTON PLANT FOR IMPROVEMENT OF YIELD AND QUALITY' submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirement for the degree of DOCTOR OF PHILOSOPHY IN AGRONOMY, embodies the result of a piece of bonafide research work carried out by* ***MD. SHAHEEN AHMED, REGISTRATION NO. 16-07523*** *under the supervisión and guidance of his Advisory Committee. No part of the thesis has been submitted for any other degree or diploma.*

*I further certily that any help or source of information as has been availed of during the course of this investigation has duly been acknowledged.*

*Dated :November,12, 2020*
*Place :Dhaka, Bangladesh*

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# SUITABILITY OF PLANT SPACINGS AGAINST MEPIQUAT CHLORIDE TREATED COTTON PLANT FOR IMPROVEMENT OF YIELD AND QUALITY


## ABSTRACT

Plant growth regulators (PGRs) are used in cotton production to optimize yield and quality and even suppressing excess growth whenever necessary. Experiments were conducted in three consecutive years (2016-17, 2017-18 and 2018-19) at Cotton Seed Multiplication, Training and Research Farm, Sreepur, Bangladesh to study the response of cotton yield and quality to different plant spacings, concentration and time of application of mepiquat chloride (MC) growth regulator. Plant spacings like 45 cm × 30 cm, 60 cm × 20 cm, 60 cm × 30 cm, 60 cm × 40 cm, 75 cm × 30 cm, 75 cm × 40 cm, 90 cm × 10 cm and 90 cm × 45 cm; MC spray @ 1.0 ml $L^{-1}$ water at 25, 50, 75, 100 and 125 DAE; MC spray @ 1.0, 2.0, 3.0 and 4.0 ml $L^{-1}$ water at 25, 50 and 75 DAE for each concentration; MC spray @ 2.0 and 4.0 ml $L^{-1}$ water at 25 DAE, 2.0 and 4.0 ml $L^{-1}$ water at 50 DAE, 2.0 ml $L^{-1}$ water at 25 & 50 DAE along with water spray as control, were the treatment variables. Plant spacing of 60 cm × 30 cm showed the highest values of different parameters of cotton across the years (2016, 2017 and 2018) as maximum seed cotton yield (4.20, 3.48 and 4.04 t $ha^{-1}$) and lint yield (9.08, 7.59 and 7.57 bales $ha^{-1}$); higher LAI (0.75 and 0.80) and boll weight (4.94 and 4.9 g) during 2016 and 2017, internode (4.46 and 4.16 cm) and leaf canopy size (0.29 and 0.33 $m^2$) during 2016 and 2017; maximum squares $plant^{-1}$ (10.21 and 12.67) and bolls $plant^{-1}$ (11.56 and 11.37) during 2017 and 2018 were evident. In case of MC application, maximum seed cotton (2.62 t $ha^{-1}$) and lint yield (6.79 bales $ha^{-1}$) were noted from 1.0 ml MC $L^{-1}$ water sprayed at 25 DAE during 2016. In 2017 and 2018, treatment 2 ml MC $L^{-1}$ water at 25 DAE gave higher squares $plant^{-1}$ (10.94 and 13.83), bolls $plant^{-1}$ (14.56 and 10.97), boll weight (4.98 and 5.00 g), seed cotton yield (3.96 and 4.03 t $ha^{-1}$) and lint yield (8.78 and 7.71 bales $ha^{-1}$), respectively. Plant spacing of 60 cm × 30 cm along with application of 2 ml MC $L^{-1}$ water at 25 DAE gave significantly higher values of squares $plant^{-1}$ (15.24 and 16.6), bolls $plant^{-1}$ (17.33 and 16.6), seed cotton yield (4.53 and 4.67 t $ha^{-1}$) and lint yield (9.43 and 10.06 bales $ha^{-1}$) as compared to control treatments (without MC and conventional wider spacing of 90 cm × 45 cm) in 2017 and 2018. So, cotton cultivation in Sreepur, Gazipur areas may be accelerated with foliar application of mepiquat chloride @ 2 ml $L^{-1}$ water at 25 DAE along with plant spacing of 60 cm x 30 cm for higher yield and quality.

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## LIST OF ABBREVIATIONS AND ACHRONYMS

| Abbreviation | Full Word |
|---|---|
| *Agric.* | Agriculture |
| *Agron.* | Agronomy |
| *Appl.* | Applied |
| *Biol.* | Biology |
| *+b* | Yellowness |
| *CDB* | Cotton Development Board |
| *cm* | Centimeter |
| CV | Coefficient of Variance |
| *DAE* | Days After Emergence |
| *e.g.* | Exempli gratia (for example) |
| *EI* | Elongation |
| *et al* | et alii, And Others |
| *g* | Gram |
| $g\ tex^{-1}$ | Gram per tex |
| *ha* | Hectare |
| *HQ* | Head quarters (Head Office) |
| *i.e.* | *id est* (L), that is |
| *J.* | Journal |
| *kg* | Kilogramme |
| *LI* | Lint Index |
| *LAI* | Leaf Area Index |

| | |
|---|---|
| *LSD* | Least Significant Difference |
| $m^2$ | Meter squares |
| *MC* | Mepiquat chloride |
| *Mic* | Micronaire |
| *ml* | Millilitre |
| *ML* | Mean Length |
| *mm* | Millimeter |
| *Moist* | Moisture Content |
| *MR* | Maturity Ratio |
| *%* | Percent |
| *Rd* | Reflectance |
| *RTSM* | Research Training and Seed Multiplication Farm |
| *Res.* | Research |
| *SAU* | Sher-e-Bangla Agriculture University |
| *SFI* | Short Fiber Index |
| *SI* | Seed Index |
| *Str* | Strength |
| $t\ ha^{-1}$ | Ton per hectare |
| *UHML* | Upper Half Mean Length |
| *UI* | Uniformity Index |
| *Viz* | *videlicet* (L.), namely |

# CHAPTER I

# INTRODUCTION

Upland cotton (*Gossypium hirsutum* L.) is a leading cash crop in many countries of the world. Bangladesh produces 156,509 bale or 28,328 ton lint and 28484 ton seed cotton from 43050 hectare of land per year (CDB, 2018). Production of cotton in Bangladesh is far behind to fulfill the demand (about 75-80 lac bales year$^{-1}$) of the 450 spinning mills at home when an amount of 30-35 thousand crore taka is spending annually to keep running our industries importing cotton from India, Uzbekistan, Kazakhsthan, Turkmenistan, Pakistan and many African countries (CDB, 2018). Our textile industries are facing serious problems for non-supply of raw cotton at the peak period of knitting. Cotton is not only used for fiber production but also for edible oil, dairy and fisheries feed and also as fertilizer in the form of oilcake.

Lower yield of cotton in Bangladesh is a cumulating effect of this long durated rain-fed crop exposed to biotic and abiotic stresses, lack of short durated high yielding varieties and inadequate agronomic practices. Long durated variety is no longer suitable to accommodate in cropping systems while improvement of our cropping intensity (CI) is mandatory. In these circumstances, the high demand of cotton could be met up by increasing per hectare yield following appropriate crop management techniques and using short durated varieties.

However, optimum plant population or spacing is important for crop production through efficient utilization of light, nutrients and water uptake by the plants. In some cases, higher plant populations adversely affect yield per unit area simultaneously vegetative and reproductive growth of plants but is important to compensate yield loss due to short canopy of plant (Wright *et al*., 2008; Silvertooth, 1999 and Hake *et al.*, 1991). Silva *et al.* (2012) opined that flower buds, bolls plant$^{-1}$ and yield were influenced by the spacing in cotton. Baumhardt *et al.* (2018) reported that plant height increased significantly with increased row spacing in cotton. While Jahedi *et al.* (2013) obtained reduced plant height, number sympodia and total bolls plant$^{-1}$ in cotton having narrow row spacing. Sowmiya and Sakthivel (2018) noted that sympodial branches plant$^{-1}$ and bolls plant$^{-1}$ were found significant in wider spacing (75 cm x 30 cm) in cotton. Xiao-yu *et al.* (2016) opined that the number of bolls increased while boll weight decreased as plant density rosed in cotton.

Sowmiya and Sakthivel (2018) reported that the closer plant spacing of 60 cm x 15 cm recorded significantly higher leaf area index in cotton. The highest leaf area index was found at 8 plants dripper$^{-1}$, while the lowest was found at 4 plants dripper$^{-1}$ in faba bean (Al-Suhaibani, 2013). Now-a-days high population density (closer spacing) has been emerged in USA, Argentina and small areas in Brazil as an alternate crop management for short structured crop canopy cotton plant for economic use of land and yield. Optimizing cotton yield through manipulation of plant spacing has been reported by many researchers that increasing plant population density (number of plants per unit ground area) consistently increases leaf area index (LAI) and light interception but its effects on yield have been inconsistent. Understanding how the arrangement of plants in the field affects cotton growth requires consideration of many interacting factors, such as genetics, physiology, and canopy structure (Heitholt and Sassenrath-Cole, 2010). Stewart *et al.* (1997) suggested that decreasing row spacing increased relative leaf area and light interception by the canopy in peanuts. Alterations in plant spacing through row spacing and plant population have a significant effect on canopy development and yield components.

Application of plant growth regulator (either auxin or retardant) can also lead to improve the growth, flowering and yield of many crops. Plant growth regulators are organic compounds, other than nutrients, that affect physiological processes of plants when applied in small concentrations. These compounds represent diverse chemistries and modes of action and provide numerous possibilities for altering crop growth and development. Their time of use extends from early season when they are applied in-furrow or as seed treatments at planting to late season in preparing the crop for harvest. Timing the first application of mepiquat chloride has caused concerns among cotton producers in that too much applied too soon can result in serious damage to plant structure and subsequent lint yields. However, too little material applied too late can increase production costs and still leave the grower with a rank plant and difficult harvest. Application timing and concentration that worked well in one production year may be useless or impractical in a subsequent year, for almost two decades the decision of when and how much mepiquat chloride to apply has been accomplished through the experienced eye of those who have worked extensively with the product and have come to understand the factors affecting its usage, a better understanding of the physiology of the cotton plant, its water requirements and the influence of its environment (temperature and rainfall) resulted in new capabilities to prescribe accurate mepiquat chloride doses for use in cotton grown in regions normally requiring plant height control (Livingston *et al.*, 1996). Overall benefits from plant growth regulator use in cotton include yield enhancement, improved fiber quality, and greater ease of harvest; more specific responses include alteration of C partitioning, greater root: shoot ratios, enhanced photosynthesis, altered nutrient uptake, improved water status, and altered crop canopy; these responses are a reflection of the interaction of heritable characteristics, cultural inputs, and environment (Cothren *et al.*, 1983). Copur *et al.* (2010) studied that the applied PGRs had significant positive effects on the seed cotton yield, plant height, average number of open bolls, number of sympodia, boll weight, lint percentage and seed index. Use of plant growth retardant is an eye-catching technology today which improves seed cotton yield through increased number of sympodia by controlling undesirable vegetative development of cotton plant thus giving a short statured plant canopy. Reema *et al.* (2017) obtained maximum bolls plant$^{-1}$ and seed cotton yield while using Pix at 1500 ml/500 litre water as foliar spray at bud initiation stage of cotton. Amit *et al.* (2015) revealed that foliar application of mepiquat chloride (MC) growth retardant @ 300 ppm yielded more seed cotton by improving the setting percentage and therefore, increased bolls plant$^{-1}$ without exhibiting any adverse effect on quality traits while plant was shortened. Kumar *et al.* (2005) had found reduced plant height (restructuring canopy size) with MC (50 ppm) sprayed at 90 DAS as compare to Chlormequat Chloride (CCC) application in cotton plant. Kataria and Khanpara (2012) reported that the applied Cycocel @ 40 ppm at 90 DAS had significantly increased squares, bolls, seed cotton yield, one week early 50% boll opening and crop mature with decreased the plant height in cotton. Raoofi *et al.* (2014) opined that NAA can increase fruit setting ratio, prevent fruit dropping, promotes flower sex ratio in leafy vegetabes and field crops. Planofix (Naphthalene Acetic Acid) had a significant effect on plant height, number of fruiting branches, volume of boll and yield in cotton (Abro *et al.*, 2004). Naphthalene Acetic Acid 20 ppm showed better performance in enhancing the straw and grain yields of wheat cultivars (Alam *et al.*, 2002). Chang-chi *et al.* (2019) observed that combinations of ethephon and thidiazuron or thidiazuron alone were more effective than ethephon alone for reducing late-season immature green bolls in cotton. Chaplot (2015) obtained that foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton, cotton seed and lint yield by 57.3, 53.3 and 67.6 percent, respectively over water spray which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation as evidenced by higher flowers plant$^{-1}$, bolls plant$^{-1}$, mature bolls plant$^{-1}$, per cent boll setting, seed cotton weight boll$^{-1}$ and cotton weight boll$^{-1}$. Spitzer *et al.* (2015) found that maize plant height could be reduced by as much as 125 cm (49% of control) using a double application of ethephon (576 g a.i. ha$^{-1}$) at growth stages BBCH 18–19 and BBCH 34–36.

Zhao *et al.* (2019) reported that application of MC reduced plant height, fruit branch length and fruiting branch under different plant densities, resulting in a lower and more compact plant canopy in cotton. Rademacher (2016) opined that growth retardants reduce shoot elongation, thereby lowering the risk of lodging in cereals, rice and oilseed rape, and making ornamentals more compact. Gu *et al.* (2014) narrated that canopy structure became more compact with the decrease of leaf area index and internode length due to the application of MC in cotton. The changes in plant structure and canopy development with altered plant spacing observed in cotton canopies result, at least in part, from photomorphogenetic responses to the altered light quality within the canopy, the photomorphogenetic responses are mediated via the phytochrome system which provides a mechanism for plants to sense and respond to the light environment of the canopy as suggested by Ballare *et al.* (1992) in cucumber. Edgerton (1983) observed that the application of BA (benzlaminopurine), or the BA + $GA_4$ + $A_7$ (gibberellins) formulation has also been beneficial in promoting a more desirable branching and canopy development in young spur type 'Delicious' and 'McIntosh' cultivars of apple tree. Ponnuswami and Rani (2019) obtained that the treatment combination of 40 cm x 20 cm with organic compound 20 kg ha$^{-1}$ recorded the better canopy size under high density planting system.

Systematic and comprehensive research effort on blending plant spacing, concentration and time of application of mepiquat chloride (MC) in order to increase yield of cotton are inadequate or absent at home or abroad.

Keeping these views in mind, the present research programme was undertaken with the following objectives:

i) To determine optimum plant density of cotton,

ii) To optimize time of application and concentration of mepiquat chloride (MC) as foliar spray on cotton to have a restructured plant,

iii) To assess the performance of yield and quality of cotton as affected by optimum plant spacing coupled with time of application and concentration of MC as foliar spray.

# CHAPTER II
# REVIEW OF LITERATURE

The results of different experiments on spacing and growth retardants have been reviewed and observed that the use of various levels of plant spacing and MC sprays at different rates at different growth stages have got positive or negative results. Some of the reviews regarding the present study are discussed under the following heads and subheads in this chapter as follows:

## 2.1 Concept of plant spacing

Heitholt and Sassenrath-Cole (2010) defined that plant density or row spacing is a management decision that determines the spatial arrangement of plants within a field. Plant spacing is related to the distance between plants within a row (intra-row) and between plants of two rows. Row spacing is the distance between rows. Altering plant density and row spacing changes the radiative transport within the canopy in cotton. Changes in radiative transport alter the interception of photosynthetically active radiation (PAR), and the distribution and quality of light within the canopy. Changes in plant spacing have a distinct impact on physiology, morphology, canopy development, boll and fiber growth of cotton and other crops although the specific physiological mechanisms are largely unknown.

## 2.2 Concept of phytohormone

According to Cothren *et al.* (1983), plant growth regulators are organic compounds, other than nutrients, that affect physiological processes of plants when applied in small concentrations. These compounds represent diverse chemistries and modes of action and provide numerous possibilities for altering crop growth and development. Their time of use extends from early season when they are applied in-furrow or as seed treatments at planting to late season in preparing the crop for harvest. Overall benefits from plant growth regulator use in cotton include yield enhancement, improved fiber quality, and greater ease of harvest. More specific responses include alteration of C partitioning, greater root: shoot ratios, enhanced photosynthesis, altered nutrient uptake, improved water status, and altered crop canopy. These responses are a reflection of the interaction of heritable characteristics, cultural inputs, and environment. Because of this complex interaction, crop response to PGRs is not always predictable. Techniques have been developed to monitor the growth and development of the crop, with specific emphasis on the fruiting characteristics. One such technique, plant mapping, provides detailed information on fruiting rates and potential, fruit retention, and distribution of fruit set relative to PGR treatment. Since over 80% of the yield is produced on first position fruiting sites, retention and maturation of these bolls is critical. Increased boll retention at the early fruiting sites enhances crop maturity, allowing quicker harvest and improved lint quality in cotton. Strategies for using PGRs in cotton production include numerous options for beneficially modifying crop response to improve yield and management of the crop. PGRs have two options; one synergistic, which is known as auxin, Gibberellin, Cytokinin (promoters), responsible for increasing crop growth and development eg. Napthalene acetic acid (NAA), Indole butyric acid (IBA), 2, 4-dichlorophenoxyacetic (2, 4-D) etc. The other antagonistic (inhibitor), which is Abscisic acid (ABA), Ethylene (retardant), responsible to check growth and development in general but restructuring crop canopy (controlling excessive vegetative growth) for increasing quality is particular eg. Chlormequat Chloride (CCC), mepiquat chloride (MC), TIBA etc.

Boquet and Coco (1993) opined that the effect of row spacing and mepiquat chloride treatment on earliness of eight cultivars was inconsistent in cotton. Earliness of Deltapine 20 was unaffected by row spacing without mepiquat chloride, but with mepiquat chloride, maturity was earlier at the 30 inch row spacing versus the 40 inch row spacing. Stoneville LA 887 was earlier maturing in 40 inch rows than in 30 inch rows when treated with mepiquat chloride.

### 2.1.1 Effect of plant spacing

#### 2.1.1.1 Plant height

Jahedi *et al.* (2013) investigated modern cotton (*Gossypium hirsutum* L.) cultivars with herbicide resistance have rejuvenated an interest in narrow row (30 cm) cotton production. Plant height was reduced in cotton grown in narrow row spacing.

Deotalu *et al.* (2013) observed a positive correlation of the plant height with spacing in cotton. The variety NDLH 1938 recorded maximum plant height (75.27 cm) followed by

AKH 9916 (74.71 cm) in wider spacing of 60 cm × 45 cm and minimum plant height was observed in BS 79 (62.78 cm) under closer spacing 60 cm × 30 cm.

Ganvir *et al.* (2013) narrated the effect of spacings on plant height with spacing in cotton. Maximum plant height of 96.45 cm was observed in 60 cm × 10 cm, medium plant height of 87.96 cm was observed in 60 cm × 105 cm spacing and minimum plant height of 79.22 cm was recorded in 60 cm × 30 cm as compared to narrow spacing of 60 cm × 15 cm (9.09) and in ultra narrow spacing of 60 × 10 cm (8.06).

Pendharkar *et al.* (2010) marked that plant height was positively correlated with the spacing in hybrid cotton. Maximum plant height of 130 cm was observed in 180 cm × 30 cm spacing while, minimum of 123 cm was observed in 90 cm × 60 cm spacing.

Balkcoma *et al.* (2010) conducted a study at the field crops unit, E.V.Smith Research Center, United States to compare cotton production across conventional, glyphosate-tolerant and glufosinate-tolerant varieties in both conventional and conservation tillage systems for standard row (102 cm) and narrow row (38 cm) cotton planting patterns. Plant heights were shorter for 38 cm cotton compared to 102 cm cotton, regardless of growth stage or tillage system.

Iqbal *et al*. (2005) opined that plant height should be kept less than 76 cm to avoid high humidity in very narrow cotton for efficient control of insect pest attack, good retention and to save boll from rottening.

Bairagi *et al.* (2015) reported on baby corn (Var. G-5414) with five dates of planting viz,October (D), 1November (D), December (D), January (D) and February (D) and three levels of plant population viz. 45 cm × 30 cm (S), 45 cm × 20 cm (S) and 45 cm × 10 cm (S). Plant height was higher when baby corn planted at wider spacing of 45 cm × 30 cm.

Baumhardt *et al.* (2018) conducted research in Texas Panhandle and southwestern Kansas, USA with dry land cotton on a nearly in a wheat (*Triticum aestivum* L.), cotton, fallow (W-Ctn-F) rotation. Field tests of row widths from 0.25 to 0.76 m and plant densities with in-row spacing ranging from 0.075 to 0.15 m. They repeated that plant height increased significantly with increased row spacing.

Ponnuswami and Rani (2019) studied on moringa tea at Tamil Nadu Agricultural University, India laid out with five main plot treatments (spacing) viz., $M_1$ = 10 cm × 15 cm (6.66 lakh plants $ha^{-1}$), $M_2$ = 15 cm × 15 cm (4.44 lakh plants $ha^{-1}$), $M_3$ = 0 cm × 10 cm (5 lakh plants $ha^{-1}$), $M_4$ = 20 cm × 20 cm (2.5 lakh plants $ha^{-1}$), $M_5$ = 40 cm × 20 cm (1.25 lakh plants $ha^{-1}$) and five subplot treatments (organics) $S_1$ = FYM 25 t $ha^{-1}$, $S_2$ = Vermicompost 12.5 t $ha^{-1}$, $S_3$ = Sheep manure 25 t $ha^{-1}$, $S_4$= Humic acid 20 kg $ha^{-1}$ and $S_5$ = Control. Among the different plant density, plant density of 40 cm × 20 cm (1.25 lakh plants $ha^{-1}$) resulted in increased plant height.

#### 2.1.1.2 Internode length

Baumhardt *et al.* (2018) observed that experimental and computer simulated internode increased significantly with increased row spacing and occasionally, in-row plant spacing (0.38 or 0.76 m row widths and plant spacing of 0.075, 0.10 and 0.15 m) in cotton.

Singh *et al.* (2017 a) conducted an experiment at Vegetable Research Farm, Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India with tomato (*Solanum lycopersicum* L.) grown under protected environment. Plants spaced at closer spacing 70 cm × 60 cm with 3 stems pruning had higher nodes $plant^{-1}$, and minimum internodal length.

#### 2.1.1.3 Canopy size

Stewart *et al.* (1997) experimented three row spacings and two planting dates for peanuts, (*Arachis hypogaea L.)* and observed that decreasing row spacing increased relative leaf area and light interception by the canopy.

Emilie and Kufimfutu (1995) conducted field studies on cultivated oats and wild oats, in part to test the assumption of radial plant canopy expansion. Individual plant canopies, photographed from above 31 days after emergence (DAE), were radial for wild oats in all crop planting patterns and for cultivated oats planted in triangular and square planting patterns. Canopy radius perpendicular to the crop row axis in rectangular patterns was similar to canopy radius along the same cardinal axis in equidistant patterns, but was reduced along the crop row axis, resulting in a rectangular canopy shape and decreased canopy area in rectangular compared to equidistant patterns.

Liu *et al.* (2011) studied that planting pattern affects canopy structure of crops and influences other physiological characteristics such as light interception and radiation use efficiency. The effects of planting patterns on the canopy structure, light interception, and photosynthetic characteristics at silking stage of two maize (*Zea mays* L.) cultivars (Beiyu 288 and Xianyu 335) were examined in three planting patterns narrow–wide rows of (1) 30 cm + 170 cm ($P_1$, 6.4 plants $m^{-2}$), and (2) 40 cm+90 cm ($P_2$, 6.4 plants $m^{-2}$) and uniform row of 65 cm (control, i.e. CK, 6.4 plants $m^{-2}$). The ratio of leaves perpendicular to rows was highest in $P_1$ and the leaf orientation value in $P_1$ was constant and slightly lower in P2 compared with that in CK. These results indicated that narrow-wide row planting patterns improved the canopy structure, allowed more IPAR to reach the middle–low strata of the canopy, and enhanced the leaf photosynthetic characteristics of maize crops at silking stage compared with CK.

Ponnuswami and Rani (2019) conducted experiment on moringa tea at Tamil Nadu Agricultural University, India with five main plot treatments (spacing) viz., $M_1$ = 10 × 15 cm (6.66 lakh plants $ha^{-1}$), $M_2$ = 15 × 15 cm (4.44 lakh plants $ha^{-1}$), $M_3$ = 20 cm x 10 cm (5 lakh plants $ha^{-1}$), $M_4$ = 20 cm × 20 cm (2.5 lakh plants $ha^{-1}$), $M_5$ = 40 cm × 20 cm (1.25 lakh plants $ha^{-1}$) and five subplot treatments (organics) $S_1$ = FYM 25 t $ha^{-1}$, $S_2$= Vermicompost 12.5 t $ha^{-1}$, $S_3$ = Sheep manure 25 t $ha^{-1}$, $S_4$ = Humic acid 20 kg $ha^{-1}$ and $S_5$ = Control. Among the different plant density, plant density of 40× 20 cm (1.25 lakh plants $ha^{-1}$) resulted in increased plant height, leaflets $plant^{-1}$, fresh leaf yield $plant^{-1}$ and leaf yield $plot^{-1}$. The treatment combination of 40 cm × 20 cm with humic acid 20 kg $ha^{-1}$ recorded the better canopy size under high density planting system.

**2.1.1.4 Leaf area index**

Sowmiya and Sakthivel (2018) carried out an experiment with seven spacing treatments *viz.*, 60 cm × 15 cm, 60 cm × 20 cm, 75 cm × 15 cm, 75 cm × 20 cm, 75 cm × 30 cm, 90 cm × 15 cm, 90 cm × 20 cm. Significant variation for plant spacing was observed for all the traits studied. The plant spacing of 60 cm × 15 cm recorded significantly higher leaf area index in cotton.

Pengcheng *et al.* (2015) conducted a field experiment in the farm of Institute of Cotton Research of Chinese Academy of Agricultural Sciences in Anyang City, Henan Province, China using transgenic *Bt+CpTI* cotton cultivar CCRI 79 and there were 3 treatments with

different planting density in main plot which were 3.00, 5.25, 7.50 plant $m^{-2}$ respectively, and 4 dosages of N fertilizer which were 0, 112.5, 225.0, 337.5 kg $h^{-1}$ respectively. The results showed that leaf area index of cotton at budding stage and flowering stage under the same N application rate significantly increased with the increase of planting density.
Darawsheh *et al.* (2009a) reported that increase of plant density with decreasing cotton row spacing has been an alternative strategy to optimize cotton profit. In this task, three cultivation systems were studied in terms of narrow row high plant density (NRHPD; 48 cm and 32 plants / m2), narrow row low plant density (NRLPD; 48 cm and 16 plants / $m^2$) and conventional row spacing (CR; 96 cm and 16 plants / $m^2$). Effects of these systems on the accumulation and allocation of dry mass as well as on leaf area index (LAI) were examined at critical growth stages during two growing seasons. Independently of row spacing, system with high plant density (NRHPD) produced significantly ($P \leq 0.001$) greater leaf area index (LAI) compared to lower plant density systems, i.e. CR and NRLPD. These differences became more significant at stage of maximum LAI.

Ricaurte *et al.* (2016) argued that sowing density is a major management factor that affects growth and development of grain crops by modifying the canopy light environment and interplant competition for water and nutrients in bean. In terms of leaf area development, analysis using a power function reflected large differences in the dynamics and final size of individual plant leaf area between the lower density (<15 plants $m^{-2}$) treatments and commonly used values (>20 plants $m^{-2}$) at the growth habit.

**2.1.1.5 Squares plant$^{-1}$**

Parekh *et al.* (2018) carried out an experiment at College Nursery, Department Of Horticulture, B.A. College of Agriculture, Anand Agricultural University, Anand, India on spider lily. Three different planting distance and foliar spray of two different plant growth regulators viz, gibberellic acid and napthalic acetic acid were used as treatment. Squares plant$^{-1}$ was increased as the plants were widely spaced, highest being recorded at 90 cm × 90 cm level.

**2.1.1.6 Bolls plant$^{-1}$**

Ali *et al.* (2009) conducted a field experiment at Sahiwal, Pakistan with plant spacing 15, 22.5 and 30 cm on the yield of three recently approved varieties of cotton CIM-496, CIM-

534 and MNH-786. Effect of cultivars and different plant spacing was significant in yield and yield components. Bolls plant$^{-1}$ was significantly highest in CIM-496.

Xiao-yu *et al.* (2016) arranged a field experiment at Anyang, Henan Province, China with transgenic insect resistant Bt (*Bacillus thuringiensis*) cotton hybrid cultivar CRI75 and conventional cultivar SCRC28 and three plant densities (15 000, 51 000 and 87 000 plants ha$^{-1}$) in 2012 and 2013. It was found that the bolls in upper nodes increased with decreasing plant density.

Sylla *et al.* (2013) reported that as the distance between the plants increased, the bolls plant$^{-1}$ also increased in cotton. Jahedi *et al.* (2013) observed that plant height, sympodia and total bolls plant$^{-1}$ were reduced in cotton grown in narrow row spacing. Sowmiya and Sakthivel (2018) noticed that the bolls plant$^{-1}$ was found significant in wider spacing of 75 cm × 30 cm in cotton.

Singh *et al.* (2017) reported that tomato (*Solanum lycopersicum* L.) grown under protected environment. Plants spaced at 70 cm × 60 cm with 3 stems pruning had higher fruits plant$^{-1}$ than 70 cm × 30 cm with 2 stems pruning.

Lima *et al* (2016) narrated that the mean values of fruits plant$^{-1}$ and fruits ha$^{-1}$ were significantly influenced by planting density in dense plantations in jatropha (*Physic nut* L).

Ahmad *et al.* (2008) conducted a field experiment to compare the seed cotton yield and its components in *Gossypium hirsutum* L. on inter-plant densities. Bolls plant$^{-1}$ increased with increasing plant spacing. Maximum bolls plant$^{-1}$ (47) was recorded in case of wider plant spacing of 60 cm against the minimum (14) in closer plant spacing of 15 cm of VH-306. Similarly, VH-311 recorded maximum bolls plant$^{-1}$ (43) in wider plant spacing of 60 cm.

Oad *et al*. (2002) observed that in a dense population stand of the cotton plants that were subjected to severe competition from an early stage due to which very few or no vegetative branches formed, fruiting on set delays, and reduced bolls plant$^{-1}$ than in widely spaced cotton. Bhalerao and Gaikwad (2010) conducted an experiment to find out the impact of plant geometry and levels of N, P and K fertilization on performance of *Bt* cotton. Wider spacing of plants had more bolls plant$^{-1}$ (23.1) than closer spaced (20.8 bolls plant$^{-1}$).

Kumara *et al.* (2014) reported that treatments consisted of four levels of spacing (120 cm × 120 cm, 120 cm × 90 cm, 90 cm × 60 cm and 90 cm × 45 cm) with two *Bt* cotton hybrids viz., Rasi-530 *Bt*(H x H) and MRC-6918 *Bt* (H x B). Maximum bolls plant$^{-1}$ was recorded (83.7) at wider spacing of 120 cm × 120 cm followed by 120 cm × 90 cm (76.0) and the minimum bolls (38.6) were recorded with closer spacing of 90 cm × 45 cm.

Singh *et al.* (2012) found that maximum bolls plant$^{-1}$ (55.5) was recorded at wider spacing of 67.5 cm x 90 cm in cotton. Rajakumar and Gurumurthy (2008) studied that lowest plant density of 9,259 plants ha$^{-1}$ recorded the maximum bolls plant$^{-1}$ (32.87) compared to high plant density of 13,888 plants ha$^{-1}$, which registered 30.78 bolls plant$^{-1}$ in cotton.
Liaqat *et al.* (2018) conducted experiment at Agronomy Research Farm of the University of Agriculture Peshawar, Pakistan with three cotton plant spacing (21 , 27 and 33 cm) and four nitrogen levels (0, 55, 110, and 165 kg ha$^{-1}$). Results showed a significant effect ($P \leq 0.05$) of both plant spacing and nitrogen rates on opened bolls plant$^{-1}$. Higher values for all the studied traits were recorded with 33 cm plant spacing.

Hake *et al*. (1991) opined that cotton plant spacing can alter plant architecture, boll distribution and crop maturity by manipulating soil water removal, radiation interception, humidity and wind movement. Jiang *et al.* (2017) argued that tomato plants in greenhouse production are often confronted with light insufficiency in the lower canopy, especially in the winter low irradiation season. Periodic alteration of plant density (PD) was proposed to improve plant growth and fruit development.

**2.1.1.7 Weight of boll plant$^{-1}$**

Jadhav *et al.* (2015) observed the influence of plant geometry on performance of cotton hybrid Bunny *Bt* (NCS-145 Bt) under irrigated condition. The treatments of plant geometry included $S_1$: 90 cm × 60 cm, $S_2$: 120 cm × 45 cm, $S_3$: 150 cm × 36 cm and $S_4$: 180 cm × 30 cm. Boll weight was significantly influenced by plant geometries. Maximum boll weight (3.48 g) was recorded in spacing of 150 cm × 36 cm followed by (3.28 g) in 120 cm × 45 cm and the minimum boll weight (3.10 g) was recorded in 180 cm × 30 cm.
Singh (2015) conducted an experiment with three *hirsutum* genotypes (Bihani251, CSH3129 and LH2076) in two plant geometries (67.5 cm × 60 cm and 67.5 cm × 75 cm) was evaluated. Maximum boll weight (3.17 g) was recorded at closer spacing of 67.5 cm × 60 cm and minimum boll weight (3.12 g) with wider spacing of 67.5 cm × 75 cm.

#### 2.1.1.8 Seed cotton yield

Kumar *et al.* (2017) conducted a field experiment in clay textured soil at Cotton Research Scheme, VNMKV, Parbhani, India laid out with four levels of plant densities *viz.*, 45 cm × 15 cm (148148 plants ha$^{-1}$), 45 cm × 22.5 cm (98765 plants ha$^{-1}$), 45 cm × 30 cm (74074 plants ha$^{-1}$) and 60 cm × 10 cm (166666 plants ha$^{-1}$) in main plots and three levels of *desi* cotton varieties *i.e.*, PA 08, PA 528 and PA 255 in sub plots. The result of experiment indicated that significantly higher seed cotton yield (2063 kg ha$^{-1}$) was recorded at plant spacing of 45 cm x 15 cm as compared to other spacing.

Sylla *et al.* (2013) conducted an experiment in Namialo village, Mozambique where the distance between the cotton plants within the rows (15, 20, 25, 30 cm) was assigned to main plot and distance between the rows (50, 75, 100 cm) as subplots making plant from 33000 to 133000 plants hectare$^{-1}$. Results of this experiment showed that the combination of 70 cm between the rows and 20 cm between the plants, with a total density of about 71400 plants hectare$^{-1}$ resulted in a highest yield.

Ali *et al.* (2009) conducted a field experiment at Sahiwal, Pakistan with plant spacing 15 cm, 22.5 cm and 30 cm on the yield of three recently approved varieties of cotton CIM-496, CIM-534 and MNH-786. Effect of cultivars and different plant spacing was significant in yield and yield components. Significantly maximum seed cotton yield was obtained when crop was sown at 22.5 cm plant spacing.

Sowmiya and Sakthivel (2018) reported that the narrow spacing of 60 cm × 15 cm registered highest seed cotton yield. Khan *et al.* (2002) concluded that plant spacing of 23 cm gave better yield than 30 and 38 cm spacing in cotton.

Keren *et al.* (1983) observed the response of the cotton plant (*Gossypium hirsutum* L.) to 9.0 and 12.5 cm intra-row and 75.0 and 96.5 cm inter-row spacing under irrigation with saline water (5.5 dS m$^{-1}$, SAR 18). In general, yield plant$^{-1}$ was affected significantly by intra-row spacing. Although the effect of intra-row spacing on yield for a unit area was found to be not significant, the effect of inter-row spacing was significant. Yield in plots with the conventional spacing (96.5 cm between rows and 12.5 cm between plants in the row) was 4863 kg ha$^{-1}$, whereas the yield in plots with 75 cm between rows was about 23% higher (5974 kg ha$^{-1}$).

Sher *et al.* (2017) observed that modern cropping is based on relatively high plant density. The improved grain yield per unit area of modern maize (*Zea mays* L.) hybrids was due to the increased optimum plant population rather than the improved grain yield per plant. High plant density has been widely used to enhance grain yield in maize.

Rao *et al.* (2015) conducted field experiment with Bt cotton (*Gossypium hirsutum* L.) to different planting geometry under irrigated condition. Significantly higher seed cotton yield was obtained from the transplanting seedlings with different plant densities (2.492 to 2,828 kg ha$^{-1}$) than the dibbled cotton at the spacings of 90 cm × 60 cm (2,238 kg ha$^{-1}$) and 120 cm × 45 cm (2095 kg ha$^{-1}$). Among different transplanting geometry, significantly higher seed cotton yield was obtained in the spacing of 90 cm × 60 cm (2,828 kg ha$^{-1}$) and it was at par with 90 cm × 45 cm (2,782 kg ha$^{-1}$) and 120 cm × 45 cm (2,674 kg ha$^{-1}$) spacings and significantly superior over 120 cm × 60 cm (2,563 kg ha$^{-1}$) and 90 cm × 90 cm spacings (2,492 kg ha$^{-1}$). Number of bolls plant$^{-1}$ and seed cotton yield plant$^{-1}$ were significantly higher with transplanted cotton at different plant geometries as compared to dibbled cotton at spacing of 120 cm × 45 cm.

Siebert *et al*. (2006) opined that as results of maximizing inputs for cotton production under optimum growing conditions plants in dense plant population often become excessively tall and vegetative as a larger fraction of photo-assimilates were directed to vegetative growth rather than reproductive growth and leading to reduced yield. Soomro *et al.* (2000a) reported that 23 and 30 cm plant spacings gave higher seed cotton yield than 38 cm distance between plants. Soomro *et al*. (2000b) conducted an experiment on cotton Cultivars CRIS-9, CRIS-19, CRIS-82 and CRIS-134 and found higher yield at 15 cm and 22 cm plant spacing than 30, 37 and 45 cm spacings.

Silvertooth (1999) argued that crop canopy can be manipulated by row spacing and population adjustment for improving cotton yields, production efficiencies and profits. Establishment of an acceptable population is significantly influenced by varied regions, agroclimatic conditions, genotype and grower preference. Erect type plants required less space to perform better at high density while cotton plants having bushy growth habits require more space and resultantly produced potential yield at low plant density. Maximum yield was obtained by maintaining optimum plant population according to plant morphological characteristics.

Wright *et al.* (2008) suggested that advantage of closer row spacing and elevated plant densities is more rapid canopy closure that in turn reduced the weed competition increased light interception in early season, decreased soil water evaporation and can potentially increase cotton yield.

Munir *et al.* (2015) carried out a field study at Post Graduate Agricultural Research Station, University of Agriculture, Faisalabad, Pakistan with three row spacing of 60, 75 and 90 cm as the whole plots and four nitrogen fertilizer rates of 0, 60,120 and 180 kg N $ha^{-1}$ applied as the split plots in successive 2 years. The maximum seed cotton yield (2106 and 1936 kg $ha^{-1}$ respectively) was recorded from 75 cm row spacing.

Hiwale *et al.* (2015) conducted field experiment with cotton at Agronomy Farm Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidypeeth, Akola, India laid out consisting three levels of plant densities viz., $S^1$ =1,66,666 plants $ha^{-1}$ (60 cm x 10 cm), $S^2$ = 1,11,111 plants $ha^{-1}$ (60 cm x 15 cm) and $S^3$ = 55,555 plants $ha^{-1}$ (60 cm x 30 cm) in main plots and three fertilizer doses i.e. $F^1$ = 100% RDF (50:25:25 N:P2O5:K2O kg $ha^{-1}$ ), $F^2$ = 150% RDF (75:37.5:37.5 N:P2O5:K2O kg $ha^{-1}$ ) and $F^3$ = 200% RDF (100:50:50 N:P2O5:K2O kg $ha^{-1}$ ) in sub plots. The results revealed that the plant density of 1,66,666 plants $ha^{-1}$ produced significantly superior seed cotton yield over plant density of 55,555 plants $ha^{-1}$ and it was at par with plant density of 1,11,111 plants $ha^{-1}$.

Udikeri and Shashidhara (2017) conducted a field experiments with cotton genotypes and plant spacing at the University of Agricultural Sciences, Dharwad, India. Genotypes, RAH-274, RAH-99 and DSC-1351 recorded significantly higher seed cotton yield (3,199, 3,156 and 3,134 kg $ha^{-1}$, respectively) than DHG-7-96. Closer spacing of 45 × 10 cm (2,22,222 plants $ha^{-1}$) recorded significantly higher seed cotton yield (3,372 kg $ha^{-1}$) over other wider spacing.

Ali *et al.* (2012 ) reported cotton genotype BH-160 in irrigated environment and found that the yield $plant^{-1}$ decreased with closer spacing but seed cotton yield $hectare^{-1}$ increased. The 15 cm plant to plant spacing produced more seed cotton yield due to more number of plants $hectare^{-1}$ which compensated the other yield components.

Mahi and Lokanadhan (2018) conducted a field experiment in cotton at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India laid out with two cotton genotypes Co 14 and TCH 1819 and seven spacing 90 cm × 45 cm, 60 cm × 30 cm, 90 cm × 45-10 cm, 60 cm × 30-10 cm, 80 cm × 10 cm, 90 cm × 10 cm and 100 cm × 10 cm. Seed cotton yield (2734 kg $ha^{-1}$) were higher in the Co 14 variety when compared to TCH 1819. In the study Co 14 with 80 cm × 10 cm spacing gave higher seed cotton yield.

Silva *et al.* (2006) reported row spacing (0.38, 0.76, 0.95 m) and plant densities (5,8,11 and 14 per meter) of the IAC 23 cultivar in cotton and found that production of seed cotton was 12% and 8.4% higher at spaced ultra-dense and high dense respectively compared to the conventional.

CDB (2018) narrated that the highest seed cotton yield (4.48 t $ha^{-1}$) was obtained from the lowest spacing i.e. 90 cm × 10 cm, where treatments were consisted of 4 levels of plant spacing 90 cm × 45 cm, 90 cm × 25 cm, 90 cm × 15 cm and 90 cm × 10 cm in hybrid cotton DM-3.

Firoz *et al.* (2007) conducted an experiment at the Hill Agricultural Research Station, Khagrachari, Bangladesh with planting time (1st week of June, July, August and September) and plant spacing (60 cm × 30 cm, 60 cm × 40 cm and 60 cm × 50 cm) of okra in hill slope condition during rainy season. In case of plant spacing, the highest yield (9.02 t $ha^{-1}$) was recorded from close spacing at 60 cm x 30 cm that was statistically different from other two spacing and the widest spacing of 60 cm x 50 cm produced the lowest yield (8.06 t $ha^{-1}$). The treatment combination July sowing with 60 cm x 30 cm plant spacing produced significantly highest yield (12.86 t $ha^{-1}$).

Awais *et al.* (2015) conducted a field experiment during spring seasons at agronomic research area, University of Agriculture, Faisalabad, Pakistan with different plant populations (83,333, 66,666 and 55,555 plants $ha^{-1}$ ) and N rates (90, 120 and 150 kg N $ha^{-1}$ ) on sunflower hybrid (Hysun-33). Results revealed that yield were highest in 55,555 plants $ha^{-1}$ treatment.

#### 2.1.1.9 Lint yield

Clawson *et al*. (2006) found that lint turn out was higher for narrow rows cotton or higher plant density. Singh *et al.* (2015) observed that maximum lint yield (777.8 kg $ha^{-1}$) was recorded at closer spacing of 67.5 × 60 cm and minimum lint yield (684.6 kg $ha^{-1}$) with wider spacing of 67.5 × 75 cm in cotton.

Shukla *et al.* (2013) conducted a field experiment with different plant spacing and NPK levels. Results indicated that maximum lint yield (345 kg $ha^{-1}$) was recorded in closer spacing of 60 cm × 60 cm, but in wider spacing of 90 cm × 60 cm lint yield was minimum (301 kg $ha^{-1}$) in cotton.

Xiao-yu *et al.* (2016) reported that plant densities of 51000 and 87000 plants $ha^{-1}$ increased lint yield by 61.3 and 65.3% in 2012 and 17.8 and 15.5% in 2013 relative to low plant density (15000 plants $ha^{-1}$) in cotton.

Richard (2006) conducted an experiment at Auscott Warren farm, Sydney, Australia with 1 m and 1.5 m row treatments in cotton. The paddock scale whole block was two large field blocks of 1 m and 1.5 m row treatments. The 1 m cotton yielded 1.8 bales $ha^{-1}$ and 3.6 bales $ha^{-1}$ higher than the 1.5 m cotton in the machine picked and handpicked experiment, respectively.

Manuel *et al.* (2019) conducted a field experiments with cotton during three consecutive years with four sowing density (62,500; 83,333; 100,000 and 142,857 plants $ha^{-1}$) and two cotton varieties, 'Delta Pine 160 and 'SN-2900 in Venezuela. High lint yield was found in 'SN-2900 (4216.2 kg $ha^{-1}$) at 100,000 plants $ha^{-1}$ and in 'Delta Pine 160 (3917.3 kg $ha^{-1}$) at 83,333 plants $ha^{-1}$. Results indicate that highest lint yields could be obtained with sowing densities between 83,333 and 100,000 plants $ha^{-1}$ depending upon varieties used across savannahs of Venezuela.

Jahedi *et al.* (2013) conducted an experiment in Gonabad, Iran using modern cotton cultivars in narrow rows for cotton production and to assess the effect of these various systems on cotton growth, lint yield, and fiber quality. Results indicated that cotton grown in narrow rows (30 cm) had lint yields equal to or higher than those attained in the 70 cm spacing.

Singh *et al.* (2014) reported that maximum lint yield (345 kg $ha^{-1}$) was recorded in closer pacing of 60 cm × 60 cm, but in wider spacing of 90 cm × 60 cm lint yield was minimum (301 kg $ha^{-1}$) in cotton.

Berry *et al.* (2008) conducted a field experiment with cotton in Virginia, North Carolina and Louisiana in USA. Plant populations of 4.9, 9.8, and 16.4 plants $m^{-2}$ and two planting dates ranging from 24 April to 5 May and 15 to 25 May were targeted. Actual plant populations achieved were 5.2, 9.2, and 11.2 plants $m^{-2}$ (Virginia 2005); 5.2, 9.2, and 15.4 plants $m^{-2}$ (North Carolina 2005); 5.6, 9.5, and 17.1 plants $m^{-2}$ (Louisiana 2005); 4.9, 6.6, and 12.8 plants $m^{-2}$ (Virginia 2006); 5.9, 8.9, and 12.8 plants $m^{-2}$ (North Carolina 2006). Lint yields were highest with populations of 8.9 and 12.8 plants $m^{-2}$ in Virginia and North Carolina compared to 5.3 plants $m^{-2}$.

**2.1.1.10 Seed number, Seed index, Lint index and Ginning out turn**

Omadewu *et al.* (2019) conducted a field experiment at two locations within the Research Farm, College of Agriculture, Jalingo in Nigeria to investigate the influence of four nitrogen rates (0, 120, 150, 200 kg $ha^{-1}$) and two plant densities (44,444 and 60,000 plants $ha^{-1}$) on yield components of three cotton varieties (Jalingo Local, Samcot-13, Sketch-8) and data were collected on cotton seeds $boll^{-1}$. Plant density and variety had a positive effect on number of seeds $boll^{-1}$.

Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

Pitombeira (1972) also reported that lint percent, lint index, seed index, seed $boll^{-1}$, were not significantly affected by plant population but seed index increased with plant population in cotton and sorghum.

Khalil *et al.* (2010) studied at New Developmental Farm, NWFP Agricultural University, Peshawar, Pakistan with Faba bean planted on eight dates from September 20 to December 27, 1999 with 14 days interval maintaining 4 density (150,000, 300,000, 450,000, 600,000 plants $ha^{-1}$). Plant density of 450,000 plants $ha^{-1}$ took more grain $pod^{-1}$ (3.2). Cao *et al.* (2016) reported that seeds were reduced under the highest density in ephemeral herb *Cardamine hirsuta*.

Zakaria (2016) carried out an experiment with foliar sprays of (PGR's) Cycocel and Alar that were applied at concentrations of 250, 500, and 750 ppm after 105 days after plantation (square and boll setting stage) to Egyptian cotton cultivar planted at three plant densities (166.000, 222.000, and 333.000 plants $ha^{-1}$). Both Cycocel and Alar increased opened seed and lint indices in cotton.

Edivaldo *et al.* (1996) conducted a study with cotton during four years in three localities of Sao Paulo State, Brazil with variety IAC 18 and the inter-row spacing 1.0 m with population density (4, 8 and 16 plants $meter^{-2}$) and chemical growth limitant chlorocholine chloride (CCC). The CCC used @ 50 g a.i. $ha^{-1}$, applied from 60 to 70 days after the emergence of the plants. The CCC increased weight of 100 seeds.

Copur *et al.* (2010) showed that the applied PGRs (except pix) had significant positive effects on seed index in cotton.

Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

#### 2.1.1.11 Upper half mean length, Mean length, Uniformity index, Soft fiber index Micronaire, Maturity ratio, Strength, Elongation, Reflectance and Yellowness of lint

Hasab and Al-Naqeeb *et al.* (2019) conducted a field experiment with cotton at the research station of Field Crop Department- College of Agricultural Engineering Sciences - University of Baghdad, Iraq with two factors. Treatment T4 (tip topping at the beginning of flower appearance) had the highest average in lint fineness. The one plant $hill^{-1}$ treatment was exceeded by producing the highest boll weight and open bolls which reflected on increasing lint fineness and micronnaire by (4.66 and 4.72) for both seasons respectively.

Feng *et al.* (2011) conducted field experiments with cotton during 2006 and 2007 using two contemporary cultivars of cotton (FM9063B2RF and ST4554B2RF) and two irrigation rates (6.33 and 4.32 mm $d^{-1}$), plant density (79, 071; 128, 490; 197, 677 plants $ha^{-1}$). Results indicated that increased irrigation generally increased fiber length and upper quartile length, and decreased fineness and maturity ratio. Irrigation effects were also greater on fiber length and maturity ratio at seed positions close to the apex of the locule. Increased plant density reduced both fineness and maturity ratio.

Darawsheh *et al*. (2009 b) reported that narrow or ultra narrow row production system has been suggested as an alternative strategy instead of conventional to increase yield and to reduce cotton input cost. This study was conducted to evaluate this prospect in a marginal cotton belt. In this task, three cropping systems were evaluated in terms of conventional row (CR; 96 cm 16 plants / m2), narrow row high plant density (NRHPD; 48 cm, 32 plants / m2) and narrow row low plant density (NRLPD; 16 plants / m2). Effects of these systems on lint quality parameters were studied during two growing seasons. From the examined lint properties, micronaire and 50% span length were negatively affected ($P \leq 0.05$) by high plant density in narrow row. The other lint quality parameters were not consistently affected by plant density and row spacing.

Of the fiber properties investigated, row spacing and irrigation regime influenced most the micronnaire readings and less the fiber elongation.

Nichols *et al*. (2003) studied that fiber length was increased as plant population increased in cotton. Nichols *et al*. (2004) found negative impact of increased plant density on lint uniformity in cotton. Valco *et al*. (2001) marked no differences in fibre uniformity due to varied row spacing or plant density in cotton.

Pitombeira (1972) conducted a field experiments at the University of Arizona Experiment Farm at Marana, Arizona, USA with cotton (*Gossypium hirsutum* L.) cultivar "Deltapine 16" and the grain sorghum [*Sorghum bicolor* (Linn.) Moench] hybrid "DeKalb A 25". Fiber length (upper half mean), fiber strength and fiber fineness were not significantly affected by plant population.

### 2.2.1Effect of MC growth regulator

#### 2.2.1.1 Plant height

Kumar *et al.* (2005) reported with Mepiquat Chloride (MC at 25, 37.5 and 50 ppm), Chlormequat Chloride (CCC at 375 and 500 ppm) at 45 and 90 DAS and NAA at 20 ppm at 90 DAS on hybrid cotton (DHH-11). Treatment 50 ppm MC sprayed at 90 DAS was found to be effective than CCC in reducing plant height.

Shahr *et al.* (2015) conducted an experiment in Parsabad, Moghan, Iran with cotton cultivars foliar sprayed by recommended doses of Pix in 15 and 30 days after flowering and topping at 30 days after flowering. Crop height in topping treatment of Mehr cultivar at 30 days after flowering reduced 19.5% compared to the control.

Niakan and Habibi (2013) carried out a research with pix effect as plant growth regulators on growth parameters of cotton plant were evaluated. Cotton seeds (*Gossypium hirsutum* L. cv Ci-Ocra) were planted under pots condition in photoperiods 20 ± 2 ºC and $14^{-h}$ light or $10^{-h}$ dark. After 80 days, pix was sprayed in different concentrations include 0 (control), 0.5,1, 1.5, 2 L $ha^{-1}$ twice within ten days on shoot of cotton plants. The results showed that pix at different treatments decreased stem length in comparison with control.

Eveleigh *et al.* (2010) opined that Pix belongs to a group of chemicals which reduce the production of the plant hormone gibberellic acid, which in turn slows cell expansion. All varieties have plant height reduced by Pix applications. The more Pix applied, the greater the reduction in height.

Amit *et al.* (2016) carried out an experiment involved three *Bt* cotton hybrids (MRC 7017, MRC 7031 and RCH 314) in main plots and growth regulation treatments (Mepiquat chloride (MC) @ 300 ppm, 2, 3, 5-tri iodo benzoic acid (TIBA) @ 100 ppm and Maelic hydrazide (MH) @ 250 ppm) in sub plots. Application of MC @ 300 ppm, TIBA @ 100 ppm and MH @ 250 ppm reduced plant height than control.

Almeida and Rosolem (2012) conducted a greenhouse experiment with Cotton seeds of the cultivar FM 993 sprayed with MC at five different doses of active ingredient (a.i.): 0, 3, 6, 9 and 12 g $kg^{-1}$ seed. Shoot length were evaluated 21 days after sowing. The application of MC to cotton seeds decreased the shoot length.

Reddy *et al.* (1990) conducted preliminary experiment and showed that mepiquat chloride (MC) caused a dramatic reduction in plant height and number of main-stem nodes in cotton.

Kirkland (1992) carried out a field experiment at the Scott Experimental Farm to determine the effect of the growth regulator, triapenthenol, on the growth and development of Argentine canola (*Brassica napus* L.). They reported that triapenthenol reduced plant height 25-45 cm of canola under optimal growing conditions. Application at the bud stage was more effective than earlier treatment in the rosette.

Setia *et al.* (1995) observed that foliar spraying on *Brassica carinata* (cv. PC 5) with paclobutrazol (PP 333) at 5, 10 and 20 µg $ml^{-1}$ concentrations, reduced plant height significantly.

Zhang *et al.* (2017) carried out an experiment set up in the greenhouse at the Ottawa Research and Development Centre (ORDC), Canada to study the effect of the selected PGRs (Manipulator, the active ingredient of which is chlormequat; and Palisade, the active ingredient of which is trinexapac-ethyl) on yield, stem height and morphological traits in six spring wheat cultivars (AC Carberry, AAC Scotia, Hoffman, Fuzion, FL62R1, and AW725). Results showed that the mixture of the two PGRs made the stem shorter. The application of PGRs significantly reduced lodging, increased stem diameter, thickness, filling degree and stem strength.

Baylis and Dickst (1983) conducted an experiment with oil-seed sunflower (cvs Flambeau and Luciole) and indicated that suitable growth regulators might improve sunflower husbandry principally by shortening the stem. A mixture of mepiquat chloride and ethephon (BAS 098 OOW) was the most effective stem shortener.

Spitzer *et al.* (2015) conducted a field experiment to evaluate the effect in reducing maize plant height using growth regulators ethephon, chlormequat chloride (CCC), CCC + ethephon, and mepiquat chloride + prohexadione-Ca. Research showed that maize plant height could be reduced by as much as 125 cm (49% of control) using a double application of ethephon (576 g a.i. $ha^{-1}$) at growth stages BBCH 18–19 and BBCH 34–36. An optimum level of shortening was achieved using ethephon (576 g a.i. $ha^{-1}$) at BBCH 34–36 (reducing plant height by 40–90 cm).

Butcher and Malik (2016) reported that applications of Moddus Evo significantly reduced the lodging and also significantly reduced the plant height in oats. On average, the height reduced from 108 cm (nil treatment) to 73 cm and 57 cm at Muradup and from 128 (nil treatment) to 102 and 80 cm with the application of 200 mL and 400 mL $ha^{-1}$ of Moddus Evo respectively over the untreated.

Yasmeen *et al.* (2016) conducted field experiments to optimize the effects of foliar application of natural plant growth promoter i.e., moringa leaf extract (MLE) and synthetic growth retardant mepiquate chloride (MC) alone and in combined form. The time of applications were beginning of bloom, 45 and 90 days after blooming on both the conventional (CIM 573) and Bt cotton (CIM 598) cultivars at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujabad, Pakistan. The combined application of MLE and MC at 45 days after blooming enhanced absolute growth rate. Application of MC alone reduced the plant growth without significantly increasing the yield.

#### 2.2.1.2 Internode length

Priyanka and Dalvi (2019) suggested that application of Mepiquat chloride @ 15ml and 10ml 10 $lit^{-1}$ of water at square and flowering stage in hybrid cotton (*Gossypium hirsutum* L.) was found significantly superior throughout all growth stages which is resulted in alteration of cotton plant growth and development like reduction in internode length. Application of mepiquat chloride (mc) at square and flower formation stage was found effective in reducing internode length.

Shahr *et al.* (2015) conducted the experiment on new released cotton cultivars and revealed that crop height in topping treatment of Mehr cultivar at 30 days after flowering reduced 19.5% compared to the control. Short intenodes of 5 to 6 cm observed in spraying of Pix and topping, while long internodes below 8 cm developed in control.

Gu *et al.* (2014) showed that good correspondence between simulated and observed values for leaf area index with an overall root-mean-square error of 0.50 $m^2$ $m^{-2}$, and with an overall prediction error of less than 10% for bolls, plant height and phytomers. Canopy structure became more compact with the decrease of leaf area index and internode length due to the application of MC in cotton.

Eveleigh *et al.* (2010) opined that Pix belongs to a group of chemicals which reduce the production of the plant hormone gibberellic acid, which in turn slows cell expansion. Internode elongation is reduced in cotton.

Volterrani *et al.* (2015) reported that Trinexapac-ethyl (TE), chlormequat chloride (CM), paclobutrazol (PB), propiconazole (PPC), diquat (DQ), flazasulfuron (FS), glyphosate (GP), ethephon (EP), and gibberellic acid (GA) applied to pot-grown 'Patriot' hybrid Bermuda grass turf in eight different application rates, ranging for each product from the minimum expected effective rate to a potentially harmful rate, of the tested treatments, TE applied at 2.0 kg·ha$^{-1}$ and PB applied at 1.0 kg·ha$^{-1}$ reduced internode length .

**2.2.1.3 Canopy size**

Gu *et al.* (2014) observed that Canopy structure became more compact with the decrease of leaf area index due to the application of MC in cotton.

Eveleigh *et al.* (2010) opined that Pix belongs to a group of chemicals which reduce the production of the plant hormone gibberellic acid, which in turn slows cell expansion. Leaf growth (canopy) is reduced in cotton.

Zhao *et al*. (2019) conducted a two year field experiment with cotton in Dafeng, Jiangsu Province, China with treatments of four plant densities (1.35, 2.55, 3.75 and 4.95 plants·m$^{-2}$) and two doses of MC (0 and 135 g·hm$^{-2}$). They found that plant density and mepiquat chloride (MC) are still uncertain and application of MCproduced more compact plant canopy in cotton.

Gollagi *et al.* (2019) reported that canopy management is one of the important tools to accommodate more number of plants per unit area or to adopt different planting systems such as high density planting and Meadow orcharding and these planting systems will helps to increase the productivity. Due to absence of dwarfing rootstocks in guava the pruning and use of growth regulators played vital role in management of canopy.

Singh and Chanana (2005) opined that guava tree responded well to canopy modification with respect to vegetative and reproductive growth and it produced fruits on current season shoots therefore, modification of canopy through pruning and use of certain growth regulators may be steps to enhance the production efficiency.

Edgerton (1983) had worked with several plant growth regulators including 6-benzlaminopurine (BA), gibberellins $A_4$+$A_7$ ($GA_4$+$A_7$), 2-chloroethylphosphonic acid (ethephon) and succinic acid-2–2-dimethyhydrazide (daminozide) used in studies on branching and canopy development to facilitate this objective on several apple cultivars. The application of BA or the BA+$GA_4$+$A_7$ formulation has also been beneficial in promoting a more desirable branching and canopy development in young spur type 'Delicious' and 'McIntosh' cultivars.

#### 2.2.1.4 Leaf area index

Kumar *et al.* (2005) conducted a field studies with application of 50 ppm MC sprayed at 90 DAS was found to be effective than CCC in reducing leaf area and showed higher photosynthesis which resulted in higher yield in cotton.

Amit *et al.* (2016) carried out a field experiment to characterize the growth and development of *Bt* cotton hybrids by detopping and use of plant growth retardants. The experiment involved three *Bt* cotton hybrids (MRC 7017, MRC 7031 and RCH 314) in main plots and growth regulation treatments (Mepiquat chloride (MC) @ 300 ppm, 2, 3, 5-tri iodo benzoic acid (TIBA) @ 100 ppm and Maelic hydrazide (MH) @ 250 ppm) in sub plots. Application of MC @ 300 ppm, TIBA @ 100 ppm and MH @ 250 ppm reduced leaf area index than control.

#### 2.2.1.5 Squares plant$^{-1}$

Kataria and Khanpara (2012) conducted an experiment at Cotton Research Station, JAU, Junagadh, India that comprised of total nine treatments with control (water spray). Cotton plants were sprayed with the growth regulator MC @ 50 and 70 ppm, once at 60 days after planting (DAP) or 90 DAS and CCC @ 40 and 80 ppm once at 60 DAP or 90 DAS. The results revealed that the applied Cycocel @ 40 ppm at 90 DAS had significantly increased the squares (108) with decreasing the plant height.

Sabale *et al.* (2018) conducted a field study with eighteen treatment combinations comprised of the foliar spray of growth regulators and nutrients viz. 30 ppm NAA, 50 ppm GA3, 200 ppm Mepiquat chloride, 2 % Urea and control applied at 60 and 80 days after sowing. Foliar application of NAA @ 30 ppm significantly gave early and higher number of squares / flowers compared to other treatments. The application of NAA increased the flowering percentage, reduced the abscission and increased the flower retention percentage in cotton.

Chaplot **(**2015) conducted a field studies in Rajasthan with plant growth regulators viz GA, NAA, Cycocel,ethephon and TIBA at 100 ppm and benzyladenine at 0.5 ppm with cotton cultivar RST-9. The chemicals were foliar sprayed at square formation stage and 20 days after first spray. Results showed that the foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton, cotton seed and lint yield by 57.3, 53.3 and 67.6 per cent respectively over water spray which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation as evidenced by higher number of squares plant$^{-1}$ (76.9).

Jamil *et al.* (2015) conducted a research at the Horticultural research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh with *Hippeastrum*. There were ten treatments comprising of three concentrations of three growth regulators viz., IAA (20, 60 and 100 ppm), ethrel (100, 300 and 500 ppm) and GA3 (100, 300 and 500 ppm) along with control (soaked in water). Application of Ethrel at a concentration of 100 ppm increased squares (4) scape$^{-1}$.

Raoofi *et al.* (2014) opined that plant growth regulators are one of the most important factors for increasing higher yield in leafy vegetables. Application of growth regulators (NAA) can increase fruit setting ratio, prevent fruit dropping, promote flower sex ratio in cotton.

Pal (2019) reported that plant growth regulators were being used by the commercial growers of ornamental plants as a part of cultural practice. Plant growth regulators have quicker impact on vegetative as well as square yield of flowering crops.

Koley and Maitra (2015) conducted an experiment at the instructional field of the Department of Floriculture, Medicinal and Aromatic Plants, Faculty of Horticulture, UBKV, W.B., India in 2013-2014 with Gladiolus (*Gladiolus grandiflorus*) cv. American Beauty. Three different plant growth regulators viz., Gibberellic acid (GA3), N-6 Benzyladenine (BA) and Triacontanol each at 3 different levels (25 ppm, 50 ppm and 100 ppm) were applied on Gladiolus and the effect was compared with control (distilled water) plants. Application of GA3 @ 50 ppm increased the production of floret spikes$^{-1}$ (13.00). BA @ 100 ppm induced earliness in square or flower bud development (7.74 days).

Parmar *et al.* (2015) carried out the experiment at Hi-Tech Horticulture Park, Department of Horticulture, College of Agriculture, Junagadh Agricultural University, Junagadh, India laid out nine treatments comprising of four levels each of GA3 (50, 100, 150 and 200 ppm) and CCC (1000, 2000, 3000 and 4000 ppm) along with control (Water spray) in protected condition. Among all treatments, an application of GA3 @ 200 ppm is most effective treatment for increasing square plant$^{-1}$ of rose flowers.

Yasmeen *et al.* (2016) conducted field experiments to optimize the effects of foliar application of natural plant growth promoter i.e., moringa leaf extract (MLE) and synthetic growth retardant mepiquate chloride (MC) alone and in combined form. The time of applications were beginning of bloom, 45 and 90 days after blooming on both the conventional (CIM 573) and Bt cotton (CIM 598) cultivars at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujabad, Pakistan. The combined application of MLE and MC at 45 days after blooming enhanced squares plant$^{-1}$ in Bt.

**2.2.1.6 Bolls plant$^{-1}$**

Reema *et al.* (2017) carried out a field studies conducted the experiment at the experimental fields of Cotton Section, Agriculture Research Institute, Tandojam, India. The treatments were comprised such as control (un-treated plots), Planofix at 50 ml/500 litres of water at bud formation, Planofix at 100 ml/500 litres of water at bud formation, Planofix at 150 ml/500 litres of water at bud formation, Pix at 500 ml / 500 litres of water at bud formation, Pix at 1000 ml/500 litres of water at bud formation, Pix at 1500 ml / 500 litres of water at bud formation. All the growth and yield character of cotton variety of sindh-1 was significantly at ($P<0.05$) affected by various plant growth regulators. The maximum opened bolls plant$^{-1}$ (30.1) and un-opened bolls plant$^{-1}$ (4.0) were observed under Pix at 1000 ml/500 litres of water at bud formation. Pix at 1500 ml / 500 litres of water at bud formation were more effective for obtaining more bolls plant$^{-1}$.

Arif and Yasmeen (2016) studied an experiment on cotton performed at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujaabad, Pakistan in 2012. Application of moringa leaf extract alone and moringa leaf extract + mepiquate chloride at 45 and 90 days after blooming showed the promoting effect on bolls plant$^{-1}$ leading to improvement in yield.

Chaplot (2015) reported that the foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton, cotton seed and lint yield by 57.3, 53.3 and 67.6 per cent respectively over water spray which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation as evidenced by higher number of bolls plant$^{-1}$ (49.3), mature bolls plant$^{-1}$ (24.5) and per cent boll setting (49.8%).

Ali *et al.* (2012) studied with seven treatments including control (check). Mepiquate chloride, Acetyl salicylic acid and Naphthalene acetic acid (plant growth regulators) were applied on 10th, 25th August and 9th September. The results indicated that there was significantly effect on volume of bolls and yield in comparison to control in cotton.

Amit *et al.* (2016) studied that MRC 7017 produced significantly higher (p<0.01) seed cotton yield which was attributed to the maximum picked bolls plant$^{-1}$. The results revealed that foliar application of MC @ 300 ppm yielded more seed cotton by improving the setting percentage and therefore, increased number of picked (open) bolls plant$^{-1}$.

Gumber *et al.* (2005) suggested that the application of granular Biovita @ 20 kg ha$^{-1}$ followed by foliar application of liquid Biovita @ 750 ml ha$^{-1}$ at boll development stage only were effective for enhancing boll number in cotton. Kataria *et al.* (2012) revealed that the applied Cycocel @ 40 ppm at 90 DAS had significantly increased the bolls (58) in cotton.

Bons *et al.* (2015) suggested that the use of plant growth regulators has become an important component in the field of citriculture because of the wide range of potential roles they play in increasing the productivity of crop per unit area. The plant growth regulating compounds actively regulate the growth and development by regulation of the endogenous processes and there exogenous applications have been exploited for modifying the growth response. Plant growth regulators have been used in citrus fruit production for influencing fruit set and fruit drop and play a major role in fruit growth and abscission.

Yasmeen *et al.* (2016) conducted field experiments to optimize the effects of foliar application of natural plant growth promoter i.e., moringa leaf extract (MLE) and synthetic growth retardant mepiquate chloride (MC) alone and in combined form. The time of applications were beginning of bloom, 45 and 90 days after blooming on both the conventional (CIM 573) and Bt cotton (CIM 598) cultivars at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujabad, Pakistan. The combined application of MLE and MC at 90 days after blooming improved the number of bolls plant$^{-1}$.

#### 2.2.1.7 Weight of single boll

Echer and Rosolem (2017) stated that the bolls in cotton plants treated with mepiquat chloride was lower than in non-treated plants, for the IMA5672B2RF and IMA5675B2RF cultivars, but a higher average weight of bolls was observed for these genotypes.

Kumar *et al.* (2005) recorded that 50 ppm MC sprayed at 90 DAS was found to be effective than CCC in reducing plant height, leaf area and showed higher photosynthesis which resulted in higher yield and boll weight in cotton.

Copur *et al.* (2010) showed that the applied PGRs (except pix) had significant positive effects on the seed cotton yield and boll weight.

Evangelos *et al.* (2004) conducted a field experiment with cotton at a spacing of 90 cm x 60 cm. The growth regulator treatments, Chamatkar (N, N-dimethyl piperidinium chloride) contains 5% mepiquat chloride (500, 750 and 1000 ppm), Lihocin (2-chloroethyl trimethyl ammonium chloride) contains 50% chlormequat chloride (750 and 1000 ppm) and NAA (naphthalene acetic acid) (20 ppm) were given as foliar spray at two stages i.e., 45 DAS and 90 DAS. Higher yield was obtained in the treatments sprayed with NAA @ 20ppm followed by chamatkar 1000 and 750 ppm sprayed at 90 DAS as compared to control due to more bolls and higher boll weight.

Boshra (2013) conducted a study on "Langra Cv." mango trees growing in a private orchard, Tema, Sohag governorate, Egypt during the "On" and "Off" years. The result showed that paclobutrazol (PBZ) application at 30 or 40 gm tree$^{-1}$ as a soil drench increased the fruit weight and yield in both "On" and "Off" years.

Choudhury *et al.* (2017) carried out a field experiment at Horticulture Farm of Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh on tomato during summer season 2011 with different plant growth regulators (PGR) viz. PGR = Control, PGR = 4-CPA (4-chloro phenoxy01acetic acid) @ 20 ppm, PGR = GA (Gibberellic Acid) @ 20 ppm and PGR = 4-CPA + GA3 @ 20 ppm. The maximum single fruit weight (74.01 g) and yield (28.40 t $ha^{-1}$) were found in PGR and the minimum for all the parameters were found in control (without PGR ) treatment.

Thakur *et al.* (2017) conducted a field trial on strawberry cv. Chandler. The 16 treatments viz. CPPU at 1, 2 and 4 ppm, GA3 at 25, 50 and 75 ppm, Promalin at 2, 4 and 6 ppm, GA4+7 at 5, 10 and 15 ppm, NAA at 10, 20 and 30 ppm and control (water spray). The results revealed that the plants sprayed with 15 ppm GA4+7 two weeks before flowering significantly reported highest fruit length (53.63 mm), fruit diameter (37.19 mm) and fruit weight (23.70 g) as compared to control. This treatment resulted in 56.22 % increase in fruit weight over control. Plants sprayed with 6 ppm Promalin also showed significant improvement in fruit size, yield and fruit quality, which resulted in 51.81 % increase in fruit weight over control.

**2.2.1.8 Yield of seed cotton**

Kataria and Khanpara (2012) conducted an experiment at Cotton Research Station, JAU, Junagadh, India on *Bt* cotton during Kharif season with the application of varying doses of Mepiquat Chloride (MC) and Cycocel (CCC), comprised of total nine treatments with control (water spray). Cotton plants were sprayed with the growth regulator MC @ 50 and 70 ppm, once at 60 days after planting (DAP) or 90 DAS and CCC @ 40 and 80 ppm once at 60 DAP or 90 DAS. The results revealed that the applied Cycocel @ 40 ppm at 90 DAS had significantly increased seed cotton yield (3091 kg $ha^{-1}$).

Reema *et al.* (2017) conducted an experiment at the experimental fields of Cotton Section, Agriculture Research Institute, Tandojam, Pakistan, comprised such as control or un-treated plots, Planofix at 50 ml/500 litres of water at bud formation, Planofix at 100 ml/500 litres of water at bud formation, Planofix at 150 ml / 500 litres of water at bud formation, Pix at 500 ml/500 litres of water at bud formation, Pix at 1000 ml/500 litres of water at bud formation, Pix at 1500 ml / 500 litres of water at bud formation. The maximum seed cotton yield $plant^{-1}$ (97.4 g) and seed cotton yield (3074.0 kg $ha^{-1}$) were observed under Pix at 1000 ml/500 litres of water at bud formation. Pix at 1500 ml / 500 litres of water at bud formation was more effective for obtaining maximum seed cotton yield $ha^{-1}$.

Sabale *et al.* (2018) conducted a field studies on cotton with eighteen treatment combinations comprised of the foliar spray of growth regulators and nutrients viz. 30 ppm NAA, 50 ppm GA3, 200 ppm mepiquat chloride, 2 % urea and control applied at 60 and 80 days after sowing. They reported that higher seed cotton yield (1213.27 kg $ha^{-1}$) and biological yield (241.66 gm) was obtained with application of 30 ppm NAA.

Amit *et al.* (2016) carried out a field experiment with three *Bt* cotton hybrids (MRC 7017, MRC 7031 and RCH 314) in main plots and three growth regulators (Mepiquat chloride (MC) @ 300 ppm, 2, 3, 5-tri iodo benzoic acid (TIBA) @ 100 ppm and Maelic hydrazide (MH) @ 250 ppm) in sub plots. MC @ 300 ppm, TIBA @ 100 ppm and MH @ 250 ppm at 80 days after sowing had beneficial effect on seed cotton yield. The results revealed that foliar application of MC @ 300 ppm yielded more seed cotton by improving the setting percentage.

Fang *et al.* (2019) conducted a 2-year experiment with gibberellic acid (GA3), N6-benzyladenine (6-BA) and N, N-dimethyl piperidinium chloride (DPC) with two application methods [(A) seed soaking and (B) foliar spraying at squaring stage] on cotton floral bud development, yield and yield components compared with the control (water application). The results showed that seed cotton yield increased by 6.3%–7.5% and 12.1%–13.3% respectively in GA3 and 6-BA seed soaking treatments, and by 7.7%–8.5% and 8.2%–11.0% after foliar application compared to control .

Chang-chi *et al.* (2019) reported that Combinations of ethephon and thidiazuron or thidiazuron alone were more effective than ethephon alone for reducing late-season immature green bolls. None of the PGR's alone or in combination affected cotton yields.

Chaplot (2015) conducted a field studies in Rajasthan, India with plant growth regulators viz GA, NAA, Cycocel, ethephon and TIBA at 100 ppm and benzyladenine at 0.5 ppm foliar sprayed at square formation stage and 20 days after first spray. Results showed that the foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton and cotton seed by 57.3 and 53.3 per cent respectively over water spray in cotton.

Arif and Yasmeen (2016) studied an experiment performed at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujaabad, Pakistan. Foliar spray of growth regulators improved the growth and yield parameters of cotton in both locations. However, application of moringa leaf extract alone and moringa leaf extract + mepiquate chloride at 45 and 90 days after blooming showed the promoting effect on improvement in yield.

Pan *et al.* (2013) reported that gibberellic acid (GA3), paclobutrazol (PBZ), 6-Benzylaminopurine (6-BA) treatments and distilled water (control) were sprayed to two hybrid rice cultivars (*Peizataifeng* and *Huayou 86*) at the heading stage in the field experiments. Subplot treatments included plots sprayed with distilled water (CK) and plots sprayed with 20 mg $L^{-1}$ GA3 prepared using 95% ethanol as surfactant (GA3), plots sprayed with 50 mg $L^{-1}$ PBZ and plots sprayed with 30 mg $L^{-1}$ 6-BA. Spraying PBZ with 50 mg $L^{-1}$ or 6-BA with 30 mg $L^{-1}$ at the heading stage could increase the grain yields in *Peizataifeng* and *Huayou86*.

Kamran *et al.* (2017) conducted a field experiment on maize crop with Seed-soaking at rate of 0 (CK1), 200 (S1), 300 (S2), and 400 (S3) mg $L^{-1}$, and seed-dressing at rate of 0 (CK2), 1.5 (D1), 2.5 (D2), and 3.5 (D3) g $kg^{-1}$. Paclobutrazol improved the ear characteristics and grain yield, and were consistently higher than control. The average grain yield of S1, S2 and S3 were 18.9%, 61.3%, and 45.9% higher, while for D1, D2 and D3 were 20.2%, 33.3%, and 45.2%, compared to CK, respectively. Paclobutrazol could efficiently be used to enhance root-physiological and morphological characteristics, resulting in higher grain yield.

Rao *et al.* (2002) conducted a field trial using five varieties of sugarcane with each variety planted in six rows of 5 meter length with a spacing of 1.3 m. The growth regulator was sprayed during the fifth month. The results of the field trial indicated that in the cane plant Ethephon at 400 ppm increased the yield marginally in all the varieties with maximum yield of 13.29 ton $rai^{-1}$ in K 88-92.

Sarwar *et al.* (2017) studied that highest maize crop yield was recorded with gibberellic acid application under optimum irrigation level, while its application under drought stress improved crop tolerance and resulted in better crop yield, similar to optimum irrigation level. Exogenous application of gibberellic acid not only improved the drought tolerance in maize, but also increased the crop yield under normal condition.

Ghosh *et al.* (2009) taken up research on a 6-year-old *Banarasi Karka* cultivar of ber raised through in situ budding on 2 year old rootstock with the spacing of 3.5 m (row to row) and 4.5 m (plant to plant). There were seven treatments with two growth regulators viz., NAA at 25, 50 and 100 mg $L^{-1}$; GA at 10, 20 and 40 mg $L^{-1}$ and control (water spray) that were thoroughly sprayed three times just after fruit set at 21 days interval. Results of two years of investigation revealed that application of NAA at 25 mg $L^{-1}$ gave significantly highest fruit retention (75%) which resulted in highest fruit yield of 120.5 quintals as against 64.7 quintals $ha^{-1}$ in control.

Maity *et al.* (2016) conducted a field experiment on okra (*Abelmoschus esculentus* L. Moench) cv. Arka Abhay with four treatments each of GA3 @ $T_3$ = 25, $T_4$ = 50, $T_5$ = 100 and $T_6$ = 150 (ppm) and IBA @ $T_7$ = 25, $T_8$ = 50, $T_9$ = 100 and $T_{10}$ = 150 (ppm) besides controls i.e. $T_1$ = without spray and $T_2$ = with water spray. The results revealed that highest yield was recorded from $T_6$ (324.87 g $plant^{-1}$) followed by $T_7$ (314.17 g $plant^{-1}$). All the growth and yield parameters of okra were more positively influenced by GA3 as compared to IBA under respective treatment.

Khan *et al.* (2002) reported that application of gibberellic acid at $10^{-5}$ M with nitrogen at 80 kg $ha^{-1}$ could increase growth and development of mustard plants leading to highest yield in the field.

Nasir (2019) conducted various filed experiments on wheat crop with concentrations and formulations of three PGR salts (ortho-nitrophenolate, para-nitrophenolate and Sodium-5-Nitroguaiacolate) applied as foliar application during different stages of plant growth. The results indicate that the PGR concentrations of 100 ppm and 150 ppm were found to give the best results. Dose concentration ranging from100 ppm to 150 ppm has momentous potential on plant growth and yield of wheat crop.

Sebastian *et al.* (2019) opined that Plant hormones are signal molecules produced within the plant, and occur in extremely low concentrations. Phytohormones determine the formation of flowers, stems, leaves, shedding of leaves, and development and ripening of fruits in pomegranate. They shape the plant, affecting seed growth, time of flowering, sex of flowers, senescence of leaves and fruits. Hormones are vital for plant growth and lacking them, plants would be mostly a mass of undifferentiated cells. Plant growth regulators include auxins, gibberellins, cytokinins, ethylene, growth retardants and growth inhibitors. The production of poor quality fruits is a matter of common experience. It would be therefore worthwhile to improve the yield and quality of fruit crops by foliar application of plant growth regulators. The use of growth regulators has become an important component of agro-technical procedures for most of the cultivated plants and especially for fruit plants.

Kumar *et al.* (2012) established a field-based micro-trial setup with five different PBZ treatments (Control: $T_0$; 25 mg $l^{-1}$: $T_1$; 50 mg $l^{-1}$: $T_2$; 75 mg $l^{-1}$: $T_3$; 100 mg $l^{-1}$: $T_4$; 125 mg $l^{-1}$: $T_5$) applied (soil application) at the time of initiation of flowering in Camelina *(Camelina sativa* L. Crantz), non-food oilseed crop. PBZ at 100 mg $l^{-1}$ concentration ($T_4$) resulted in highest seed yield by 80% and 15%, respectively.

Fahad *et al.* (2016) conducted a 2-year experiment with two rice cultivars (IR-64 and Huanghuazhan) subjected to temperature treatments in controlled growth chambers and four different combinations of ascorbic acid (Vc), alpha-tocopherol (Ve), brassinosteroids (Br), methyl jasmonates (MeJA), and triazoles (Tr). The Huanghuazhan performed better than IR-64 under high temperature stress with better growth and higher grain yield. The highest grain production by Vc+Ve+MejA+Br treated plants was due to enhanced grain filling.

Gadade *et al.* (2017) conducted a field experiment on field of Department of Argil. Botany, College of Agriculture, Parbhani (M.S.), India during kharif season with okra (*Abelmoschus esculentus*L.). The treatments consisted of two growth regulators viz., gibberrllic acid (50, 100, 150 and 200 ppm) and naphthalene acetic acid (50, 100, 150 and 200 ppm). Results revealed that the application of plant growth regulators significantly increased yield plant$^{-1}$ and plot$^{-1}$ as compared to control.

Rademacher (2016) opined that the gibberellins GA3, GA4 and GA7 are primarily used to increase fruit yield and quality in fruit trees and table and wine grapes. Distinct steps of the gibberellin biosynthetic pathway can be inhibited by growth retardants: chlormequat and mepiquat chloride, ancymidol, flurprimidol, paclobutrazol, uniconazole, and the fungicides tebuconazole and metconazole and daminozide, trinexapac-ethyl and prohexadione-calcium used in crop production. In fruit and nut trees, less pruning is required and increases in crop yield were obtained.

Yasmeen *et al.* (2016) conducted field experiments to optimize the effects of foliar application of natural plant growth promoter i.e., moringa leaf extract (MLE) and synthetic growth retardant mepiquate chloride (MC) alone and in combined form. The time of applications were beginning of bloom, 45 and 90 days after blooming on both the conventional (CIM 573) and Bt cotton (CIM 598) cultivars at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujabad, Pakistan. The combined application of MLE and MC 90 days after blooming improved the seed cotton yield in Bt cotton.

Cimen *et al.* (2004) studied with Paclobutrazol (PBZ), is a growth retardant through inhibiting or declining *Verticillium* wilt of cotton, aimed to increase crop yield. The dose and time of application of PBZ were determined at Nazilli 87 and Sur-Grow SG 501 cotton varieties. He reported that the application of Paclobutrazol at a dose of 0.05 g $m^{-2}$ was considered suitable after the second irrigation without decreasing the density (20 plant $m^{-2}$), when the plant height reaches 40-50 cm.

#### 2.2.1.9 Yield of lint

Chaplot **(**2015) showed that the foliar application of NAA at 100 ppm brought about significantly higher lint yield by 67.6 per cent over water spray which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation in cotton.

McCarty *et al.* (2017) observed that various plant growth hormones and regulators have been increased the yield of cotton (*Gossypium hirsutum* L.) lint when applied to foliage in field tests.

Yasmeen *et al.* (2016) conducted field experiments to optimize the effects of foliar application of natural plant growth promoter i.e., moringa leaf extract (MLE) and synthetic growth retardant mepiquate chloride (MC) alone and in combined form. The time of applications were beginning of bloom, 45 and 90 days after blooming on both the conventional (CIM 573) and Bt cotton (CIM 598) cultivars at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujabad, Pakistan. The combined application of MLE and MC at 90 days after blooming improved lint yield in Bt cotton.

Robertson and Cothren (1993) reported that at least two-thirds of the total lint produced comes from the first two fruiting positions following treatment.

**2.2.1.10 Seed number, Seed weight, Lint weight, Seed index, Lint index and Ginning out turn**

Ernst *et al.* (2016) conducted an experiment during two growing seasons with biological material (hybrids) and foliar application of two different PGR (Terra-Sorb Foliar–containing free amino acids and Unicum–containingAbiestins) on the yield-forming parameters, seed yield and the oil content in seeds of three selected hybrids of sunflower (NK Brio, NKNeoma, NK Ferti). The results showed that the application of selected PGR has contributed to an increase of sunflower seed yield, mainly through increase the weight of thousand seeds.

Baylis and Dickst (1983) studied that Daminozide gave variable effects on yield of two cultivars of oil-seed sunflower (cvs Flambeau and Luciole) depending on the rate and time of treatment. The seeds $m^{-2}$ was the major determinant of yield and 1000-seed weights were similar for all treatments.

Cao *et al.* (2016) reported that seeds were reduced under the highest density in ephemeral herb *Cardamine hirsuta*.

Zakaria (2016) carried out an experiment with foliar sprays of (PGR's) Cycocel and Alar that were applied at concentrations of 250, 500, and 750 ppm after 105 days after plantation (square and boll setting stage) to Egyptian cotton cultivar planted at three plant densities (166.000, 222.000, and 333.000 plants $ha^{-1}$). Both Cycocel and Alar increased opened seed and lint indices in cotton.

Edivaldo *et al.* (1996) conducted a study with cotton during four years in three localities of Sao Paulo State, Brazil with variety IAC 18 and the inter-row spacing 1.0 m with population density (4, 8 and 16 plants $meter^{-2}$) and chemical growth limitant chlorocholine chloride (CCC). The CCC used @ 50 g a.i. $ha^{-1}$, applied from 60 to 70 days after the emergence of the plants. The CCC increased weight of 100 seeds.

Copur *et al.* (2010) showed that the applied PGRs (except pix) had significant positive effects on seed index in cotton.

Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

Manenji *et al.* (2016) conducted a trial at Gwebi Agricultural College Farm in Mashonaland West Province of Zimbabwe, winter wheat season (May to August) with Tianda 2116 plant growth regulator on the growth and yield of wheat (variety SC Sekuru). The treatments were: Tianda 2116 applied at the following weeks after planting (WAP): 2 WAP, 3 WAP, 4 WAP, 5 WAP, 6 WAP, 14 WAP and no Tianda 2116 applied (control). Early application of Tianda 2116 increased the thousand grain weight.

Yasmeen *et al.* (2016) conducted field experiments to optimize the effects of foliar application of natural plant growth promoter i.e., moringa leaf extract (MLE) and synthetic growth retardant mepiquate chloride (MC) alone and in combined form. The time of applications were beginning of bloom, 45 and 90 days after blooming on both the conventional (CIM 573) and Bt cotton (CIM 598) cultivars at agronomic research area, Bahauddin Zakariya University, Multan and Usmania Agricultural Farm, Shujabad, Pakistan. The combined application of MLE and MC at 90 days after blooming improved cotton seed yield and lint index in Bt cotton.

#### 2.2.1.11 Upper half mean length, Mean length, Uniformity index, Short fiber index, Micronaire, Maturity ratio, Strength, Elongation, Reflectance and Yellowness of lint

Edivaldo *et al.* (1996) carried out an experiment with cotton in three localities of Sao Paulo State, Brazil with variety IAC 18 and the inter-row spacing 1.0 m with population density (4, 8 and 16 plants meter$^{-2}$) and chemical growth limitant chlorocholine chloride (CCC). The CCC used @ 50 g a.i. ha$^{-1}$, applied from 60 to 70 days after the emergence of the plants. The CCC increased fiber length and maturity.

Copur *et al.* (2010) reported that fiber length, fiber fineness, fiber strength and fiber uniformity were not affected by the treatments PGRs (except pix) in cotton.

Silva *et al.* (2016) conducted a study at the Alvorada farm research field, in Luis Eduardo Magalhães municipality-BA, Brazil with biostimulants used in cotton (*Gossypium hirsutum* L.) with five treatments (control group, untreated group, Booster, Stimulate, Improver and Biozyme). The results showed that application of biostimulants caused changes in the fiber characteristics, related to length uniformity, micronaire, length and strength of the fiber.

Hasab and Al-Naqeeb (2019) conducted a field experiment with cotton at the research station of Field Crop Department-College of Agricultural Engineering Sciences-University of Baghdad, Iraq with two factors. Treatment $T_4$ (tip topping at the beginning of flower appearance) had the highest average in lint fineness. The one plant hill$^{-1}$ treatment was exceeded by producing the highest boll weight and open bolls which reflected on increasing lint fineness and micronnaire by (4.66 and 4.72) for both seasons respectively.

## 2.3 Combined effect of plant spacing and time of application and concentratin of MC growth regulator

### 2.3.1 Plant height

Zhao *et al.* (2019) conducted a two year field experiment on cotton in Dafeng, Jiangsu Province, chaina. The treatments were four plant densities (1.35, 2.55, 3.75 and 4.95 plants m$^{-2}$) and two doses of MC (0 and 135 g hm$^{-2}$). The application of MC reduced plant height under different plant densities.

Lucieli *et al.* (2017) carried out a field experiment on maize carried out in the municipality of Lages, state of Santa Catarina, Brazil with two sowing dates (10/15 - preferential, and 12/5 - late), four plant densities (5, 7, 9, and 11 plants m$^{-2}$) and with and without Trinexapac-ethyl application. The growth regulator was sprayed at a rate of 150 g a.i. ha$^{-1}$, when hybrid P30F53YH was at the V5 and V10 growth stages. The spraying of Trinexapac-ethyl decreased the stem length above the ear insertion node.

### 2.3.2 Internode length

Iqbal *et al.* (2007) conducted a field experiment on cotton (*Gossypium hirsutum* L.) var. MNH789 with three plants spacing (15, 23 and 30 cm), four nitrogen fertilizer level (0, 50, 100 and 150 kg ha$^{-1}$) with two rates of Mepiquat chloride (2 × 100, 2 × 200 mL ha$^{-1}$).

Results showed that cotton grown in narrow plant spacing (15 and 23 cm) had increased the total main stem nodes while the internodal length decreased.

### 2.3.3 Canopy size

Zhao *et al*. (2019) carried out a two year field experiment with cotton in Dafeng, Jiangsu Province, China with treatments of four plant densities (1.35, 2.55, 3.75 and 4.95 plants·m$^{-2}$) and two doses of MC (0 and 135 g·hm$^{-2}$). They found that plant density and mepiquat chloride (MC) are still uncertain and application of MC produced more compact plant canopy in cotton.

### 2.3.4 Square plant$^{-1}$

Parekh *et al.* (2018) studied an experiment at College Nursery, Department Of Horticulture, B.A. College of Agriculture, Anand Agricultural University, Anand, India on spider lily. Three different planting distance (90 cm × 45 cm, 60 cm × 45 cm, 60 cm × 60 cm) and foliar spray of two different plant growth regulators viz, gibberellic acid and napthalic acetic acid were used as treatment. Squares plant$^{-1}$ was increasing as the plants were widely spaced, highest being recorded at 60 cm × 60 cm level. Studies on evaluation of growth regulators on this crop showed that there was an increase in the growth and flower yield plant$^{-1}$ by foliar application of gibberellic acid at 250, 200 and 150 ppm and NAA at 200 and 150 ppm.

### 2.3.5 Boll plant$^{-1}$

Iqbal *et al.* (2007) conducted a field experiment on cotton (*Gossypium hirsutum* L.) var. MNH789 with three plants spacing (15, 23 and 30 cm), four nitrogen fertilizer level (0, 50, 100 and 150 kg ha$^{-1}$) with two rates of Mepiquat chloride (2 × 100, 2 × 200 mL ha$^{-1}$). Results showed that cotton grown in narrow plant spacing (15 and 23 cm) had increased bolls plant$^{-1}$.

Chormule and Patel (2017) observed that okra seeds treated with GA3 150 ppm (T3) recorded significantly the maximum values for fruits plant$^{-1}$ and fruit thickness. A combination of wider plant spacing 60 cm x 45 cm and seed treatment of GA3 @ 150 ppm before sowing (S3T3) was found best suited combination, as it has good field emergence and produced significantly or comparatively the maximum fruits plant$^{-1}$, fruit length and fruit thickness.

### 2.3.6 Weight of single boll

Singh *et al.* (2012) reported that cotton yields in upland, rainfed regions can be increased by higher plant populations that optimize boll weight. Zakaria (2016) studied with foliar sprays of (PGR's) Cycocel and Alar applied at concentrations of 250, 500, and 750 ppm after 105 days after plantation (square and boll setting stage) to Egyptian cotton cultivar planted at three plant densities (166000, 222000, and 333000 plant ha$^{-1}$). Both Cycocel and Alar increased boll weight.

Edivaldo *et al.* (1996) carried out a study with cotton during four years (from 1976/77 to 1979/80) in three localities of Sao Paulo State, Brazil with variety IAC 18 and the inter-row spacing 1.0 m with population density (4, 8 and 16 plants meter$^{-2}$) and chemical growth limitant chlorocholine chloride (CCC). The CCC used @ 50 g a.i. ha$^{-1}$, applied from 60 to 70 days after the emergence of the plants. The CCC increased weight of singlle boll.

### 2.3.7 Yield of seed cotton

Zhao *et al.* (2019) conducted a two year field experiment on cotton in Dafeng, Jiangsu Province, china. The treatments were four plant densities (1.35, 2.55, 3.75 and 4.95 plants m$^{-2}$) and two doses of MC (0 and 135 g m$^{-2}$). Cotton seed yield showed a nonlinear increase as plant density increasing and achieved the highest value at 3.75 plants m$^{-2}$, regardless of MC application. Thus plant density of 3.75 plants m$^{-2}$ combined with 135 g m$^{-2}$ of MC applying is optimal for high cotton yield.

Copur *et al.* (2010) conducted a field experiments at Harran University Agricultural Research and Application Center located in Şanlıurfa, Turkey using cotton cv. 'Stoneville 453' and seven commercial PGRs (Pix, Bigtonik, Biozyme TF, K-Humate, Maxicrop and Biogibb) sprayed at recommended doses and application time during the study with six rows (0.70 m row spacing and 0.20 m plant-spacing on row). The results showed that the applied PGRs (except pix) had significant positive effects on the seed cotton yield. Higher yields were obtained in Maxicrop, Biozyme TF and Biogibb treated plots.

Evangelos *et al.* (2004) carried out a field experiment at a spacing of 90 cm x 60 cm in cotton. The growth regulator treatments, Chamatkar (N, N-dimethyl piperidinium chloride) contains 5% mepiquat chloride (500, 750 and 1000 ppm), Lihocin (2-chloroethyl trimethyl ammonium chloride) contains 50% chlormequat chloride (750 and 1000 ppm) and NAA (naphthalene acetic acid) (20 ppm) were given as foliar spray at two stages i.e., 45 DAS and 90 DAS and water treated as control. Higher yield was obtained in the treatments sprayed with NAA (20ppm) followed by chamatkar 1000 and 750 ppm sprayed at 90 DAS as compared to control. Application of NAA increased the boll retention percentage, which in turn helped in getting higher seed cotton yield.

Zakaria (2016) conducted an experiment with foliar sprays of (PGR's) Cycocel and Alar applied at concentrations of 250, 500, and 750 ppm after 105 days after plantation (square and boll setting stage) to Egyptian cotton cultivar planted at three plant densities (166000, 222000, and 333000 plant $ha^{-1}$). He reported that the intermediate plant density gave highest yields. Both Cycocel and Alar increased seed-cotton yield $plant^{-1}$.

Iqbal *et al.* (2007) showed that seed cotton yield were different among plant spacing. Cotton grown in narrow plant spacing (15 and 23 cm) had higher seed cotton yield (4218 and 4171 kg $ha^{-1}$) at high dose of fertilizer (150 kg $ha^{-1}$) with low dose of pix (2 × 100 mL $ha^{-1}$).

Golada *et al.* (2018) conducted an experiment at Rajasthan College of Agriculture Udaipur, India with spacing (45cm × 20cm, 60cm × 15cm and 90cm × 10cm), nitrogen levels (60, 90 and 120 kg $ha^{-1}$) and plant growth regulators (control, NAA @) 40 ppm and Mepiquat chloride @ 200 ppm) on baby corn. The higher green cob yield, baby corn yield and green fodder yield was significantly recorded at 60 cm × 15 cm spacing over 90 cm × 10 cm. The crop sprayed with Mepiquat chloride @ 200ppm produced the highest green cob yield (5903.03 kg $ha^{-1}$) and baby corn yield (2082.64 kg $ha^{-1}$).

### 2.3.8 Seed number, Seed weight, Lint weight, Seed index, Lint index and Ginning out turn

Omadewu *et al.* (2019) conducted a field experiment at two locations within the Research Farm, College of Agriculture, Jalingo in Nigeria to investigate the influence of nitrogen rates and plant density on yield components of cotton cultivars. Four nitrogen (N) rates (0, 120, 150, 200 kg $ha^{-1}$), three cotton varieties (Jalingo Local, Samcot-13, Sketch-8) and two plant densities (44,444 and 60,000 plants $ha^{-1}$) They reported that nitrogen rate, plant density and variety had a positive effect on number of seeds $boll^{-1}$.

Zakaria (2016) carried out an experiment with foliar sprays of (PGR's) Cycocel and Alar that were applied at concentrations of 250, 500, and 750 ppm after 105 days after plantation (square and boll setting stage) to Egyptian cotton cultivar planted at three plant densities (166.000, 222.000, and 333.000 plants $ha^{-1}$). Both Cycocel and Alar increased opened seed and lint indices in cotton.

Edivaldo *et al.* (1996) conducted a study with cotton during four years in three localities of Sao Paulo State, Brazil with variety IAC 18 and the inter-row spacing 1.0 m with population density (4, 8 and 16 plants $meter^{-2}$) and chemical growth limitant chlorocholine chloride (CCC). The CCC used @ 50 g a.i. $ha^{-1}$, applied from 60 to 70 days after the emergence of the plants. The CCC increased weight of 100 seeds.

Copur *et al.* (2010) showed that the applied PGRs (except pix) had significant positive effects on seed index in cotton.

Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

Pitombeira (1972) also reported that lint percent, lint index and seed index were not significantly affected by plant population but seed index increased with plant population in cotton and sorghum.

Khalil *et al.* (2010) studied at New Developmental Farm, NWFP Agricultural University, Peshawar, Pakistan with Faba bean planted on eight dates from September 20 to December 27, 1999 with 14 days interval maintaining 4 density (150,000, 300,000, 450,000, 600,000 plants $ha^{-1}$). Plant density of 450,000 plants $ha^{-1}$ took more grain $pod^{-1}$ (3.2).

Ernst *et al.* (2016) conducted an experiment during two growing seasons with biological material (hybrids) and foliar application of two different PGR (Terra-Sorb Foliar–containing free amino acids and Unicum–containingAbiestins) on the yield-forming parameters, seed yield and the oil content in seeds of three selected hybrids of sunflower (NK Brio, NKNeoma, NK Ferti). The results showed that the application of selected PGR has contributed to an increase of sunflower seed yield, mainly through increase the weight of thousand seeds.

Baylis and Dickst (1983) studied that Daminozide gave variable effects on yield of two cultivars of oil-seed sunflower (cvs Flambeau and Luciole) depending on the rate and time of treatment. The seeds $m^{-2}$ was the major determinant of yield and 1000-seed weights were similar for all treatments.

Manenji *et al.* (2016) conducted a trial at Gwebi Agricultural College Farm in Mashonaland West Province of Zimbabwe, during the 2012 winter wheat season (May to August) with Tianda 2116 plant growth regulator on the growth and yield of wheat (variety SC Sekuru). The treatments were: Tianda 2116 applied at the following weeks after planting (WAP): 2 WAP, 3 WAP, 4 WAP, 5 WAP, 6 WAP, 14 WAP and no Tianda 2116 applied (control). Early application of Tianda 2116 increased the thousand grain weight.

Cao *et al.* (2016) reported that seeds were reduced under the highest density in ephemeral herb *Cardamine hirsuta*.

### 2.3.9 Upper half mean length, Mean length, Uniformity index, Soft fiber index, Micronaire, Maturity ratio, Strength, Elongation, Reflectance and Yellowness of lint

Edivaldo *et al.* (1996) carried out an experiment with cotton in three localities of Sao Paulo State, Brazil with variety IAC 18 and the inter-row spacing 1.0 m with population density (4, 8 and 16 plants $meter^{-2}$) and chemical growth limitant chlorocholine chloride (CCC). The CCC used @ 50 g a.i. $ha^{-1}$, applied from 60 to 70 days after the emergence of the plants. The CCC increased fiber length and maturity.

Copur *et al.* (2010) showed that the applied PGRs (except pix) had significant positive effects on lint percentage and seed index. Fiber length, fiber fineness, fiber strength and fiber uniformity were not affected by the treatments in cotton.

Silva *et al.* (2016) conducted a study at the Alvorada farm research field, in Luis Eduardo Magalhães municipality – BA, Brazil with biostimulants used in cotton (*Gossypium hirsutum* L.) with five treatments (control group, untreated group, Booster, Stimulate, Improver and Biozyme). The results showed that application of biostimulants caused changes in the fiber characteristics, related to length uniformity, micronaire, length and strength of the fiber.

Hasab and Al-Naqeeb (2019) conducted a field experiment with cotton at the research station of Field Crop Department- College of Agricultural Engineering Sciences - University of Baghdad, Iraq with two factors. Treatment T4 (tip topping at the beginning of flower appearance) had the highest average in lint fineness. The one plant hill$^{-1}$ treatment was exceeded by producing the highest boll weight and open bolls which reflected on increasing lint fineness and micronnaire by (4.66 and 4.72) for both seasons respectively.

Feng *et al.* (2011) conducted a field experiments with cotton during 2006 and 2007 using two contemporary cultivars of cotton (FM9063B2RF and ST4554B2RF) and two irrigation rates (6.33 and 4.32 mm d$^{-1}$), plant density (79, 071; 128, 490; 197, 677 plants ha$^{-1}$). Results indicated that increased irrigation generally increased fiber length and upper quartile length, and decreased fineness and maturity ratio. Irrigation effects were also greater on fiber length and maturity ratio at seed positions close to the apex of the locule. Increased plant density reduced both fineness and maturity ratio.

Darawsheh (2009 b) conducted a field study with three row spacings, conventional (CR), narrow (NR) and ultra narrow (UNR) and eight fiber properties were studied under limited and normal irrigation regimes during two growing seasons in cotton. The decrease of row spacing significantly decreased some fiber quality parameters but differed between normal and limited irrigation regimes. Of the fiber properties investigated, row spacing and irrigation regime influenced most the micronnaire readings and less the fiber elongation.

Nichols *et al*. (2003) studied that fiber length was increased as plant population increased in cotton. Nichols *et al*. (2004) found negative impact of increased plant density on lint uniformity in cotton. Valco *et al*. (2001) marked no differences in fibre uniformity due to varied row spacing or plant density in cotton.

Pitombeira (1972) conducted a field experiments at the University of Arizona Experiment Farm at Marana, Arizona, USA with cotton (*Gossypium hirsutum* L.) cultivar "Deltapine 16" and the grain sorghum [*Sorghum bicolor* (Linn.) Moench] hybrid "DeKalb A 25". Fiber length (upper half mean), fiber strength and fiber fineness were not significantly affected by plant population.

From the above study of reviews it may be concluded that increased plant density increases LAI, boll weight, seed cotton and lint yields but decreases the plant height, internode length, plant canopy size and squares and bolls plant$^{-1}$. Application of growth regulator reduces the plant height, internode length and leaf areas but increases squares and bolls plant$^{-1}$, boll weight, seed cotton and lint yield. Combined effect of both of plant spacing and growth regulator of any kind eventually improved seed cotton and lint yields. Research has shown that at least two-thirds of the total lint produced comes from the first two fruiting positions. Thus growth regulator off course growth retardant proved them to restructuring cotton plant canopy for its early maturity with increased yield. The other advantage could be assumed that accommodation of another crop in cropping system of Bangladesh may help to improve cropping intensity of the country from using short durated cotton plant's space by other crops.

# CHAPTER III
# MATERIALS AND METHODS

Cotton plants were given different plant spacings, time of application and concentration of growth regulator (mepiquat chloride, MC) during three years (August, 2016 to January, 2019) of study in different treatment combinations under three experiments to evaluate the response of growth, yield and quality of cotton. The experimental field belongs to the agro-ecological zone of Modhupur Tract (AEZ-28).

The titles of three experiments are as follows:

EXPERIMENT 01: Influence of different plant spacing and time of foliar applications of growth regulator (mepiquat chloride) on the growth, yield and quality of cotton (August 5, 2016 to February 24, 2017).

EXPERIMENT 02: Response of cotton to different plant spacing along with concentrations of growth regulator (mepiquat chloride) and time of foliar application (August 21, 2017 to February 29, 2018).

EXPERIMENT 03: Yield and quality assessment of cotton plant spacing coupled with mepiquat chloride foliar spray management (July 17, 2018 to January 18, 2019).

## 3.1 Sites of the experiment

The experiment was carried out at research, training and seed multiplication Farm, Sreepur, Gazipur, Bangladesh. The experimental site is located at $24^0$ $39^/$ N Latitude and of $90^0$ $26^/$E longitude with an elevation of 8.4 m from the mean sea level (CDB, 2018).

## 3.2 Climate

The experimental site is sub-tropical in nature. Usually the rainfall is heavy during kharif (April to September) season and scanty in rabi (October to March) season. The weather data of last twenty years before experiment set up indicates that nearly 80% of the annual average rainfall (1200 mm) occurs during monsoon and the rest of the rainfall during other seasons. Total annual rainfall was ≤ 2000 mm with an average relative humidity, 78-90%. The mean maximum temperature was $34.53^0$ C and minimum temperature was $10.68^0$ C. The day length on an average was 12 hours in kharif season and 11 hours in rabi season.

The soil status of Sreepur farm was shallow red-brown terrace type belongs to salna series under the order of inceptisols of soil taxonomy, clay loam in texture. The initial soil status was pH 5.3-5.9, organic matter content 0.81-0.87%, total Nitrogen 0.041-0.044%, Potassium 0.20-0.21 meq 100g$^{-1}$ of soil, Magnesium 0.72-0.98 meq 100g$^{-1}$ of soil, Phosphorus 1.67-1.95 µg g$^{-1}$ or ppm, Sulphur 13.08-30.70 µg g$^{-1}$, Boron 0.15-0.18 µg g$^{-1}$, Zinc 1.12-1.82 µg g$^{-1}$ . The soil analysis was done in Soil Resource Development Institute (SRDI), Farmgate, Dhaka, Bangladesh.

### 3.3 Cropping history of the site

The crops that were grown in the experimental field before conducting experiment are given in Appendix I. Before initiation experiment the field was green manured with 50kg ha$^{-1}$ green manure (*Sesbania aculeata*) seed in the month of June. After 45-50 days all green manure plant ploughed down into soil to improve soil moisture and organic matter status.

### 3.4 EXPERIMENT 01: Influence of different plant spacings and time of foliar applications of growth regulator (mepiquat chloride) on the growth, yield and quality of cotton.

#### 3.4.1 Objectives

i) To determine optimum plant spacing for higher cotton yield.

ii) To select appropriate time of foliar application of growth regulator (mepiquat chloride, MC) determining the restructured plant canopy for higher yield and quality of cotton.

iii) To study the combined effect of plant spacing and time of growth regulator (MC) foliar spray on the yield and quality of cotton.

#### 3.4.2 Materials

##### 3.4.2.1 Characteristics of test variety

Cotton inbred cultivar CB 14 was selected as it is early maturing (short duration) and high yielding cultivar. A single plant of CB 14 cotton cultivar yields 9-10 matured medium sized bolls with an average weight 4.8 g, cotton lint 36.6% and seed weight 10.5 g. This cultivar possesses the ability to open broadly, which makes it easy to pick. The cultivar is known for high yielding with an estimated yield to be 3 t ha$^{-1}$ for gin cotton (seed cotton), an increase of 20% compared with a locally cultivated variety. The fibre of CB 14 tested by Cotton Quality Testing Centre, HQ, CDB analysed by HVI showed that upper half mean fibre length is 30 mm, mean length is 25 mm, strength is 31.11 gftex$^{-1}$ (gram-force per texture) with a thickness value of 4.4 micron. A single plant of CB 14 maintains 18-20 fruiting branches, the boll is ovoid shape, the single boll weighs around 5.13 g and the cotton is pure white. It has a lint weight of 8 g, lint of 40-41% and seed weight of 9.2 g. Lint cotton yield is 905 kg ha$^{-1}$.

### 3.4.3 Methods

#### 3.4.3.1 Treatments

A factorial experiment was conducted with five levels of plant spacing and six times of Mepiquat Chloride (MC) @ 1.0 ml L$^{-1}$ water foliar application. The experimental variables are as follows:

**Factor A: Level of plant spacings (5)**

(i) $S_0$= 90 cm × 45 cm (24, 691 plants ha$^{-1}$) (control CDB recommendation)
(ii) $S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
(iii) $S_2$ = 60 cm × 40 cm (41,666 plants ha$^{-1}$)
(iv) $S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
(v) $S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Factor B: Foliar application times of MC (6)**

(i) $G_0$= water spray (control)
(ii) $G_1$= Foliar spray at 25 days after emergence (DAE)
(iii) $G_2$= Foliar spray at 50 DAE
(iv) $G_3$= Foliar spray at 75 DAE
(v) $G_4$= Foliar spray at 100 DAE
(vi) $G_5$= Foliar spray at 125 DAE

The treatment combinations are as follows:

| | | | | |
|---|---|---|---|---|
| $S_0G_0$ | $S_1G_0$ | $S_2G_0$ | $S_3G_0$ | $S_4G_0$ |
| $S_0G_1$ | $S_1G_1$ | $S_2G_1$ | $S_3G_1$ | $S_4G_1$ |
| $S_0G_2$ | $S_1G_2$ | $S_2G_2$ | $S_3G_2$ | $S_4G_2$ |
| $S_0G_3$ | $S_1G_3$ | $S_2G_3$ | $S_3G_3$ | $S_4G_3$ |
| $S_0G_4$ | $S_1G_4$ | $S_2G_4$ | $S_3G_4$ | $S_4G_4$ |
| $S_0G_5$ | $S_1G_5$ | $S_2G_5$ | $S_3G_5$ | $S_4G_5$ |

#### 3.4.3.2 Experimental design and plot size

The experiment was laid out in a split plot design with three replications. Spacing or plant density was assigned to the main plots and growth regulators in the subplots. The size of each plot was 3.6 m × 4.5 m and the distance between replication to replication was 2.0 m. The distance between intra-plot and main plot were maintained 1.0 m.

#### 3.4.3.3 Crop management

##### 3.4.3.3.1 Preparation of experimental land

The experimental field was three times ploughed started from 25 July, 2016 with a disc plough followed by cultivator; rotavator was used to break the clods subsequently leveled by laddering and then furrows followed by ridges were formed. All weeds and other plant residues were removed from the field. 2.5 t $ha^{-1}$ cowdung and 1.5 t $ha^{-1}$ lime were applied before ploughing. Immediately after land preparation, the field lay out was done on 5 August, 2016 maintaining spacing as per treatments.

##### 3.4.3.3.2 Defuzzing

The cotton seeds were to be defuzzed by physical method for easy sowing and better germination. Seeds were kept in water for 3-4 hours and then were rubbed with dry soil or sand or cowdung to clear the fuzzes that were attached to the seed coat.

##### 3.4.3.3.3 Seed sowing

After land preparation the defuzzed seeds were sown in the field directly on 5 August, 2016. Five cotton seeds were sown in a same pit $hill^{-1}$ in line as per treatments.

##### 3.4.3.3.4 Fertilizer application

The crop was fertilized @ cowdung 2.5 t $ha^{-1}$ and cotton development board recommended N P K S Zn B and Mg @ 200-250-250-50-45-7.5-7.5 kg $ha^{-1}$ respectively (CDB, 2018). The entire amount of recommended nutrients were applied in the form of cowdung, TSP, gypsum, zinc sulphate, borax, magnesium sulphate and one fourth of urea and MoP were incorporated into soil before sowing as basal. The rest of urea and muriate of potash were top dressed in three equal splits on 30 August (20 DAE), 24 September (45 DAE) and 19 October (70 DAE), 2016.

##### 3.4.3.3.5 Foliar spray

Growth regulator, Mepiquat Chloride (MC) was sprayed on the crop canopy @ 1.0 ml $L^{-1}$ water following time of spray in treatment variables on 4 September (25 DAE), 29

September (50 DAE) and 24 October (75 DAE), 18 November (100 DAE) and13 December (125 DAE) 2016.

#### 3.4.3.3.6 Intercultural operations

##### 3.4.3.3.6.1 Gap filling

After 8-10 days of germination, as some hills had no seedling, gap filling was done with healthy seedlings on 20 August, 2016.

##### 3.4.3.3.6.2 Thinning

Thinning was done at 10 DAE to keep two healthy plants hill$^{-1}$. After that final thinning was done on 30 August, 2016 (20 DAE) keeping one healthy plant hill$^{-1}$ maintaining the spacing following treatment variables.

##### 3.4.3.3.6.3 Weed control

The cotton field was kept cleaned from weeds having three times weeding on 30 August (20 DAE), 24 September (45 DAE) and 19 October (70 DAE), 2016.

##### 3.4.3.3.6.4 Earthing up

Earthing up was done on 24 September (45 DAE) and 19 October (70 DAE), 2016.

##### 3.4.3.3.6.5 Irrigation

Cotton in Bangladesh is generally grown under rain-fed condition. As the land became dry during boll formation stage 2 irrigations were given 45 DAE (24 September, 2016) and 70 DAE (19 October, 2016) for optimum yield.

#### 3.4.3.3.7 Crop protection measures

The crop field was infested with aphids, jassids, white fly and spotted bollworm but the infestation was kept under injury level applying insecticides, imitaf (imidachloropid @ 1 ml L$^{-1}$ water and proclaim (emamectin benzoid) @ 1 gm L$^{-1}$ water on 31 August (21 DAE), 25 September (46 DAE) and 20 October (71 DAE), 2016. Hand picking and pheromone traps were also used to keep the pests below economic injury level.

#### 3.4.3.3.7 Harvesting

Flowering starts at 40-60 DAS in cotton. Boll maturity and bursting comes 50-60 days after flowering. Bursted bolls are harvested at three times. First harvest was done at 130 DAE when 40-50% bolls were bursted. The second picking was done at 145 DAE when 20-30% bolls were bursted. The third harvest was done at 194 DAE when the rest bolls were bursted. Then bolls were sun dried to keep the moisture content at the lowest level

(8-10 % moisture) and then kept under shadow for attaining normal temperature to obtain proper seed cotton weight. The total harvest (final) was completed by 24-02-2017. At harvest, data on different plant parameters were recorded that are given below:

### 3.4.3.4 Recording of data

Random selection of ten cotton plants from each treatment plot replicated three times resulting in 900 (30 × 3 × 10) plants were used to study the increasing or decreasing trend with time of different growth, yield components and yield parameters under different treatment combinations.

#### 3.4.3.4.1.1 Phenological data

#### 3.4.3.4.1.1.1Plant height (cm)

The graduated ruler was used to measure plant height at the time of final cotton harvest from the ground to the top of the main shoot of the plant. The mean plant height was recorded and expressed in cm.

#### 3.4.3.4.1.1.2 Internode length (cm)

The graduated ruler was used to measure internode length at the time of final cotton harvest and it was taken from distances between the 4th and 5th leaf from the terminal. The mean plant internode length was recorded and expressed in cm.

#### 3.4.3.4.1.1.3 Plant canopy size ($m^2$)

The graduated ruler was used to measure plant canopy area at the time of cotton harvest as it remains green. A number of leaves were counted from different position of each cotton plant. The mean canopy size was measured from each plant and expressed in $m^2$. Restructured plant canopy size was measured (assuming) as,

$$\text{Plant canopy size (CS)} = \pi r^2$$

Here, $\pi = 3.14$ (assume value), and r =probable radius of cotton leaf (m)

#### 3.4.3.4.1.1.4 Leaf area index

The graduated ruler was used to measure plant leaf area at the time of cotton harvest as it remains green. All the green leaves were measured by counting from different position of each cotton plant and then a mean leaf area (average length and width)
was determined from each plant. Leaf area index was determined using the following formula derived by Montgomery (1911) as:

$$\text{LAI} = \sum_{i=1}^{n} \text{Li} \times \text{Wi} \times \text{k}$$

Here, L = length of leaf from collar to tip of blade, W = maximum width of the leaf blade, n = number of leaves plant$^{-1}$ and k is constant; whose value is 0.771 for cotton (*Gossypium hirsutum* L.) reported by Ghule *et al*. (2013).

**3.4.3.4.1.2 Yield attributes and yield analysis**

**3.4.3.4.1.2.1 Data collection at harvest**

Random selection of ten cotton plants from each treatment plot replicated three times resulting in 900 (30 × 3 × 10) plants were used to keep record on yield attributes and yield.

**3.4.3.4.1.2.1 Squares plant$^{-1}$ (no.)**

A number of squares were enumerated from different position of each cotton plant after first 50% squares has been developed and calculated mean square number plant$^{-1}$.

**3.4.3.4.1.2.2 Bolls plant$^{-1}$ (no.)**

A total number of bursted and unbursted matured bolls were enumerated from different position of each cotton plant and then enumerated mean boll plant$^{-1}$.

**3.4.3.4.1.2.3 Weight of bolls plant$^{-1}$ (g)**

Ten bolls were taken from each plant and sundried. Ten plants were used from each plot resulted 9000 (10 × 10 × 30 × 3) bolls that were used to record mean boll weight plant$^{-1}$ and it was expressed in gramme (g).

**3.4.3.4.1.2.4 Seed cotton yield (t ha$^{-1}$)**

Obtained yield plot$^{-1}$ has been converted into yield (t hectare$^{-1}$) as per following formula (CDB) and mean seed cotton yield was calculated from collected data of 90 (30 × 3) plots and expressed in t ha$^{-1}$ as,

$$\text{Yield plot}^{-1} = \text{Seed cotton yield (kg plot}^{-1})$$

$$\text{Seed cotton yield (t ha}^{-1}) = \frac{\text{Yield /plot (ton)}}{\text{Plot area (m2)}} \times 10000$$

**3.4.3.1.4.2.5 Lint yield (bales ha$^{-1}$)**

Lints with seeds harvested from a number of mature and bursted bolls from different position. Then the lints were ginned out by the existing roller ginning machine and the out ginned seedless only lints of each plot was bagged, tagged, sundried and weighed with the help of electrical balance. Lint yield plot$^{-1}$ has been converted into yield (bale ha$^{-1}$) as per following formula used by CDB and mean lint yield was calculated from 90 (30 × 3) samples and expressed in bales ha$^{-1}$ as,

$$\text{Yield plot}^{-1} = \text{lint yield (kg plot}^{-1})$$

$$\text{Lint yield (bales ha}^{-1}) = \frac{\text{Yield / plot (bale)}}{\text{Plot area (m2)}} \times 10000$$

**3.4.3.4.1.3 Seed quality**

Total 9000 (10 × 10 × 30 × 3) bolls were used to study the seed quality as follows.

**3.4.3.4.1.3.1 Seed number**

The seeds were counted from each boll manually to get seed number.

**3.4.3.4.1.3.2 Seed index (SI)**

SI was calculated from sundried seed samples as (CDB),

Seed index = Weight of 100 seeds.

**3.4.3.4.1.3.3 Lint index (LI)**

Lint index was measured using the following formula (Ghule *et al.*, 2013):

$$\text{Lint index} = \frac{\text{weight of 100 seeds (g)}}{100 - \text{ginning percent}} \times \text{ginning percent}$$

**3.4.3.4.1.3.4 Ginnng out turn (GOT) or lint percentage**

Ginning out turn was calculated from the samples collected from 90 (30 × 3) plots as per formula given below and expressed in percentages ((Ghule *et al.*, 2013)) as,

$$\text{Ginning out turn} = \frac{\text{weight of lint (g)}}{\text{weight of seed cotton (g)}} \times 100$$

**3.4.3.4.1.4 Lint quality**

Two hundred and fifty gramme of sundried samples were taken from the out ginned lints of each plot randomly and then they were bagged and tagged and analyzed by the HVT expert 1401 MAG version7.0.1 machine at Cotton Development Board, Head Quarter, Dhaka and the following qualities were estimated:

Upper half medium length of fiber (UHML), Medium length of fiber (ML), Uniformity index of fiber length (UI), Short fiber index (SFI), Fiber thickness (micronaire), Maturity ratio (MR), Strength, Elongation, Reflectance (Rd) and Yellowness of lint (+b).

**3.4.3.5 Statistical analysis**

Data thus collected were subjected to analysis of variance (ANOVA) with the help of computer package MSTAT-C. Least Significant Difference (LSD) was used for mean separation at 5% level of probability (Gomez and Gomez, 1984).

**3.5. 3.2 EXPERIMENT 02: Response of cotton to different plant spacing along with concentrations of growth regulator (mepiquat chloride) and time of foliar application**

### 3.5.1 Objectives

i) To determine suitable plant spacing for cotton plant.

ii) To determine optimum dose of mepiquat chloride along with time of foliar application for higher yield and quality of cotton.

iii) To study the combined effect of plant spacing and time of MC application along with concentrations towards higher yield and quality performance of cotton

### 3.5.2 Materials

#### 3.5.2.1 Characteristics of test variety

The inbred variety CB 14 was again used in the second year experiment as described under section 3.4.2.1.

### 3.5.3 Methods

#### 3.5.3.1 Treatments

A factorial experiment with three levels of plant spacing and thirteen different concentrated MC foliar applications along with time of spraying was as follows:

**Factor A: Plant spacings (3):**

i) $S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from first year experiment as promising treatment

ii) $S_1$ = 45 cm × 30 cm (74,074 plants $ha^{-1}$)

iii) $S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

**Factor B: MC concentrations along with time of spraying (13)**

i) $G_0$ = Water spray (control)

ii) $G_1$ = Mepiquat Chloride spray @ 1.0 ml $L^{-1}$ water at 25 DAE

iii) $G_2$ = Mepiquat Chloride spray @ 2.0 ml $L^{-1}$ water at 25 DAE

iv) $G_3$ = Mepiquat Chloride spray @ 3.0 ml $L^{-1}$ water at 25 DAE

v) $G_4$ = Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 25 DAE

vi) $G_5$ = Mepiquat Chloride spray @ 1.0 ml $L^{-1}$ water at 50 DAE

vii) $G_6$ = Mepiquat Chloride spray @ 2.0 ml $L^{-1}$ water at 50 DAE

viii) $G_7$ = Mepiquat Chloride spray @ 3.0 ml $L^{-1}$ water at 50 DAE

ix) $G_8$ = Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 50 DAE

x) $G_9$ = Mepiquat Chloride spray @ 1.0 ml $L^{-1}$ water at 75 DAE

xi) $G_{10}$ = Mepiquat Chloride spray @ 2.0 ml $L^{-1}$ water at 75 DAE

xii) $G_{11}$ = Mepiquat Chloride spray @ 3.0 ml $L^{-1}$ water at 75 DAE

Xiii ) $G_{12}$ = Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 75 DAE

Treatment combinations are as follows:

| | | |
|---|---|---|
| $S_0G_0$ | $S_1G_0$ | $S_2G_0$ |
| $S_0G_1$ | $S_1G_1$ | $S_2G_1$ |
| $S_0G_2$ | $S_1G_2$ | $S_2G_2$ |
| $S_0G_3$ | $S_1G_3$ | $S_2G_3$ |
| $S_0G_4$ | $S_1G_4$ | $S_2G_4$ |
| $S_0G_5$ | $S_1G_5$ | $S_2G_5$ |
| $S_0G_6$ | $S_1G_6$ | $S_2G_6$ |
| $S_0G_7$ | $S_1G_7$ | $S_2G_7$ |
| $S_0G_8$ | $S_1G_8$ | $S_2G_8$ |
| $S_0G_9$ | $S_1G_9$ | $S_2G_9$ |
| $S_0G_{10}$ | $S_1G_{10}$ | $S_2G_{10}$ |
| $S_0G_{11}$ | $S_1G_{11}$ | $S_2G_{11}$ |
| $S_0G_{12}$ | $S_1G_{12}$ | $S_2G_{12}$ |

### 3.5.3.2 Experimental design and plot size

The experiment was laid out in a split plot design with three replications. Spacing was considered in the main plots and growth regulators in the subplots. The size of each plot was 3.6 m × 4.5 m and the distance between replication to replication was 2.0 m. The distance between intra-plot and main plot were maintained 1.0 m.

### 3.5.3.3 Crop management

Defuzzing, preparation of experimental land, sowing of seeds, green manure and fertilizer application, thinning and intercultural operations were carried out in the same manner as experiment 01. Delinted or defuzzed seeds were sown on 21 August, 2017 maintaining spacing as per treatments. Gap filling completed within 5 September, 2017 10 DAE and final thinning was done on 15 September, 2017 (20 DAE). Top dressing and weeding were done on 15 September (20 DAE), 10 October (45 DAE) and 4 November, 2017 (70 DAE); earthing up were done on 10 October (45 DAE) and 4 November, 2017 (70 DAE). As the land became dry during boll formation stage 2 irrigations were given on 10 October (45 DAE) and 4 November, 2017 (70 DAE) for higher yield.

#### 3.5.3.3.1 Foliar spray

Growth regulator, Mepiquat Chloride (MC) was sprayed on the crop canopy following time of spray in treatment variables as per treatment 3.5.3.1.

#### 3.5.3.3.2 Crop protection measures

The crop field was infested with aphids, jassids, white fly and spotted bollworm but the attack was kept under injury level providing insecticides imitaf (imidachloropid @ 1 ml $L^{-1}$ water and proclaim (emamectin benzoid) @ 1 gm $L^{-1}$ water on 16 September, 11 October and 5 November, 2017. Other protective measures were followed as per experiment 01.

#### 3.5.3.3.3 Harvesting

The crop was finally harvested on 28 February, 2018. Same harvesting procedure was followed as was done for the experiment 01.

#### 3.5.3.4. Recording of data

#### 3.5.3.4.1 Crop phenological parameter analysis

Randomly data were collected from ten cotton plants from each treatment plot replicated three times resulting in 1170 (30×13×3 ) plants in 2017 to measure physiological parameters. Same methods were done as those of experiment 01 to collect physiological data.

#### 3.5.3.4.2 Yield attributes and yield analysis

Randomly data were collected from ten cotton plants from each treatment plot replicated three times resulting in total 117 (3 × 13 × 3) plots to measure yield parameters. Same methods were done as those of experiment 01 to collect and calculate.

#### 3.5.3.4.2.1 Weight of bolls plant$^{-1}$ (g)

Random selection of ten bolls from each cotton plant and ten plants from each treatment plot replicated three times resulting in total 11700 (10 ×10×13×3 ×3) bolls were used to measure mean boll weight plant$^{-1}$. Same methods were done as those of experiment 01 to collect and calculate.

#### 3.5.3.4.3 Seed quality

Seed quality mean was calculated following the same method as those of experiment 01. 11700 (10 ×10×13×3 ×3) bolls were used to measure mean values.

#### 3.5.3.4.3.1 Seed index, lint index and ginning out turn

Seed index, lint index and ginning out turn were measured from the samples collected from 117 (39 × 3) plots following same methods as those of experiment 01.

**3.5.3.4.4 Lint quality**

Qualitative analyses were done following same procedures of experiment 01.

**3.5.3.5 Statistical analysis**

The collected data were analysed with the help of computer package MSTAT-C. Least Significant Difference (LSD) was used for mean separation at 5% level of probability (Gomez and Gomez, 1984).

## 3.6 EXPERIMENT 03: Yield and quality assessment of cotton under a package of optimum planting spacing coupled with mepiquat chloride foliar spray management.

### 3.6.1 Objectives:

i) To find out suitable spacing for cotton cultivar.

ii) To determine optimum dose of mepiquat chloride along with time of foliar application

iii) To assess yield performance of cotton in relation to plant spacing and management of mepiquat chloride.

iv) To study the compensating mechanism of short structured with closer plant spacing towards higher yield and quality of cotton.

### 3.6.2 Materials

#### 3.6.2.1 Characteristics of test crop

Cotton variety CB 14 was selected for the third year experiment.

#### 3.6.3 Methods

##### 3.6.3.1 Treatments

**Factor A: Plant spacings (3)**

(i) $S_0$= 60 cm × 30 cm ( 55,555 plants $ha^{-1}$) as check, selected from 1st and 2nd year's experiment

(ii) $S_1$= 90 cm × 10 cm ( 1,11,111 plants $ha^{-1}$)

(iii) $S_2$= 60 cm × 20 cm ( 83,333 plants $ha^{-1}$)

**Factor B: Application time and concentration of Mepiquat Chloride (9)**

i) $\mathbf{G_0}$ = Water spray as control at 25 DAE

ii) $\mathbf{G_1}$ = Mepiquat Chloride spray @ 2.0ml $L^{-1}$ water at 25 DAE

iii) $\mathbf{G_2}$ = Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 25 DAE

iv) $\mathbf{G_{3\ (0)}}$ = Water spray as control at 50 DAE

v) $\mathbf{G_4}$ = Mepiquat Chloride spray @ 2.0ml $L^{-1}$ water at 50 DAE

vi) $\mathbf{G_5}$ = Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 50 DAE

vii) $\mathbf{G_{6(0)}}$ = Water spray as control at 25 and 50 DAE

viii) $\mathbf{G_7}$ = Mepiquat Chloride spray @ 2.0ml $L^{-1}$ water at 25 and 50 DAE

ix) $\mathbf{G_8}$ = Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 25 and 50 DAE

The treatment combinations are as follows:

| | | |
|---|---|---|
| $S_0G_0$ | $S_1G_0$ | $S_2G_0$ |
| $S_0G_1$ | $S_1G_1$ | $S_2G_1$ |
| $S_0G_2$ | $S_1G_2$ | $S_2G_2$ |
| $S_0G_{3(0)}$ | $S_1G_{3(0)}$ | $S_2G_{3(0)}$ |
| $S_0G_4$ | $S_1G_4$ | $S_2G_4$ |
| $S_0G_5$ | $S_1G_5$ | $S_2G_5$ |
| $S_0G_{6(0)}$ | $S_1G_{6(0)}$ | $S_2G_{6(0)}$ |
| $S_0G_7$ | $S_1G_7$ | $S_2G_7$ |
| $S_0G_8$ | $S_1G_8$ | $S_2G_8$ |

##### 3.6.3.2 Experimental design and plot size

The experiment was laid out in a split plot design with three replications. Spacing or plant density was assigned to the main plots and growth regulators in the subplots. The size of each plot was 3.6 m × 4.5 m and the distance between replication to replication was 2.0 m. The distance between intra-plot and main plot were maintained 1.0 m.

#### 3.6.3.3 Crop management

Defuzzing, preparation of experimental land, sowing of seeds, green manure and fertilizer application, thinning and intercultural operations were carried out in the same manner as experiment 01. Delinted or defuzzed seeds were sown on 17 July, 2018 maintaining spacing as per treatments. Gap filling completed within 27 July, 2018 (10 DAE) and final thinning was done on 27 July, 2018 (10 DAE). Top dressing and weeding were done on 6 August (20 DAE), 31 August (45 DAE) and 25 September, 2018 (70 DAE). Earthing up were done on 31 August (45 DAE) and 25 September, 2018 (70 DAE).

##### 3.6.3.3.1 Foliar spray

Three plant spacings according to the experimental treatment were applied as 1st year's experiment. Nine concentrations of mepiquat chloride with time of application according to the experimental treatment were maintained as 1st year's experiment.

##### 3.6.3.3.2 Crop protection measures

The crop field was infested with aphids, jassids, white fly and spotted bollworm but the attack was kept under injury level providing insecticides imitaf (imidachloropid @ 1 ml $L^{-1}$ water and proclaim (emamectin benzoid) @ 1 gm $L^{-1}$ water on 16 August, 5 September and 25 September, 2018. Other protective measures were followed as per experiment 01.

##### 3.6.3.3.3 Harvesting

The crop was finally harvested on 18 January, 2019. Same harvesting method was followed as of the experiment 01.

##### 3.6.3.3.4 General observation of the experimental field

Observations were made regularly and the field was looked nice with normal green plants.

#### 3.6.3.4 Recording of data

##### 3.6.3.4.1 Crop phenological parameter analysis

Data were collected randomly from ten cotton plants from each treatment plot replicated three times resulting in 810 (30×9×3 ) plants in 2018 to measure physiological parameters. Same methods were done as those of experiment 01 to collect physiological data.

#### 3.6.3.4.2 Yield attributes and yield analysis

Data were collected randomly from ten cotton plants per treatment plot replicated three times from total 81(3 × 9 × 3) plots to measure yield parameters. Same processes were done as aforesaid experiment 01 to collect and calculate.

#### 3.6.3.4.2.1 Weight of bolls plant$^{-1}$ (g)

Random selection of ten bolls from each cotton plant and ten plants from each treatment plot replicated three times. Mean boll weight plant$^{-1}$ was measured from total 8100 (10 ×10×9×3 ×3) collected bolls. Same methods were done as those of experiment 01 to collect and calculate.

#### 3.6.3.4.3 Seed quality

Mean seed quality was calculated following the same way of experiment 01. Totally 8100 (10 ×10×9×3 ×3) bolls were used to measure mean values.

#### 3.6.3.4.3.1 Seed index, lint index and ginning out turn

Seed index, lint index and ginning out turn were calculated from the samples collected from 81 (27 × 3) plots following same procedure done in the experiment 01.

#### 3.6.3.4.4 Lint quality

The qualitative analyses were done following the procedures applied in experiment 01.

#### 3.6.3.5 Statistical analysis

The analysis was done with the help of computer package MSTAT-C. Least Significant Difference (LSD) was used for mean separation at 5% level of probability (Gomez and Gomez, 1984).

# CHAPTER IV
# RESULTS AND DISCUSSION

The results obtained from consecutive three years experiments have been discussed in this chapter under the captions of phenological observation, yield contributing characteristics, seed attributes and lint quality parameters. The outcomes of the experiments have been reviewed as best as possible with the results of other researchers who carried out experiments with plant spacing and phytohormones all over the world.

## 4.1 EXPERIMENT 01

**Influence of different plant spacings and time of foliar applications of growth regulator (mepiquat chloride) on the growth, yield and quality of cotton.**

The experiment was conducted in Kharif II, 2016 to Rabi 2017 with five levels of plant spacings and six times foliar application of mepiquat chloride (MC) @ 1.0 ml $L^{-1}$ water at different growth stages which are given in the chapter 3 (sub-title 3.1.3). The tested variety was CB 14.

The results obtained in the study have been presented either in table or figure which are followed by discussion.

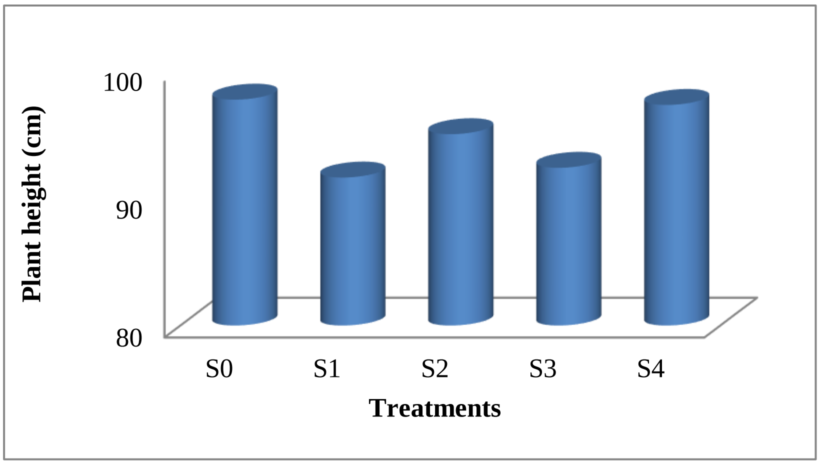
### 4.1.1 Phenological characters of cotton

#### 4.1.1.1 Plant height

**Effect of plant spacing**

No significant variation of plant height was found due to plant spacing treatments. Numerically plant height varied with different plant density ranged from 91.59 to 97.66 cm (Fig. 1). The tallest plant (97.66 cm) was obtained from 90 cm × 45 cm spacing ($S_0$, control) and the shortest plant (91.59 cm) was recorded from 60 cm × 30 cm spacing ($S_1$).

Baumhardt *et al.* (2018), Deotalu *et al.* (2013) and Jahedi *et al.* (2013) reported that plant height increased significantly with wider row spacing in cotton while Ponnuswami and Rani (2019) had similar observation as working with moringa.




Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)

$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

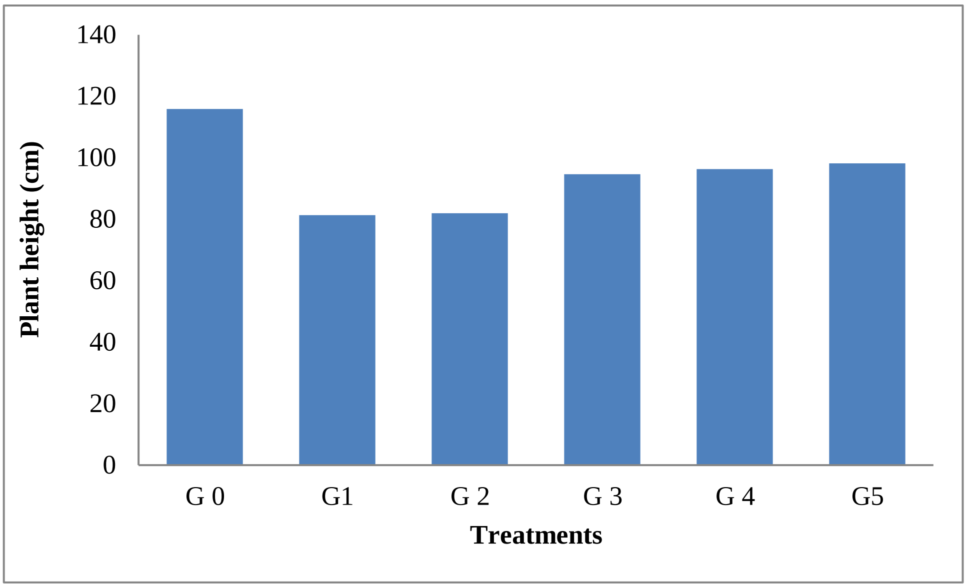
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 1. Plant height of cotton as affected by different plant spacing (LSD $_{(0.05)}$ = 6.729).**

**Effect of time of application of MC growth regulator**

Plant height varied significantly from 81.41 to 115.87 cm across the treatment variables (Fig. 2). Plants grown without added growth regulator ($G_0$) produced significantly tallest plant (115.87 cm) and the shortest (81.41 cm) from foliar sprayed at 25 DAE ($G_1$). Intermediate plant height was recorded when MC sprayed at early (50 DAE) or late (100 and 125 DAE).

Kumar *et al.* (2005) reported that 50 ppm MC sprayed at 90 DAS was found to be effective than CCC in reducing cotton plant height. Shahr *et al.* (2015) noted reduced plant height of cotton by 19.5% than control using Pix regulator at 30 days after flowering. Some other scientists observed reduced plant height of different crops with different growth retardants (Amit *et al.*, 2016 in cotton; Niakan and Habibi, 2013 in cotton; Reddy *et al.*, 1990 in cotton; Zhang *et al.*, 2017 in spring wheat; Butcher and Malik, 2016 in oats; Spitzer *et al.*, 2015 in maize; Lucieli *et al.*, 2017 in maize; Kirkland, 1992 in canola; Setia *et al.*, 1995 in *Brassica carinata* ; Baylis and Dickst, 1983 in sunflower). Eveleigh *et al.* (2010) opined that any growth retardant reduces the production of plant hormone gibberellic acid, which in turn slows cell expansion and elongation thus both leaf growth and internode elongation is ceased down to reduce cotton plant height.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 2. Influence of time of application of mepiquat chloride on plant height of cotton ($LSD_{(0.05)}$ = 8.365).**

**Combined effect of plant spacing and time of application of MC growth regulator**

The combined effect of plant spacing and time of application of growth regulator on plant height was significant (Table 1). Plant height increased with the increase of plant spacing irrespective of growth regulator application time. Irrespective of plant population, gradual shorter plants were observed when plants sprayed with MC compared to control which indicated that MC reduces plant height. Significantly the highest plant height (127.48 cm) was recorded at 90 cm × 45 cm spacing coupled without MC, control ($S_0G_0$) and the lowest (86.64 cm) at 25 DAE foliar spray and 60 cm × 30 cm spacing ($S_1G_1$) which was followed by $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 25 to 125 DAE, respectively with 60 cm × 30 cm spacing), $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$ (foliar sprayed from 25 to 100 DAE, respectively with 60 cm × 40 cm spacing), $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$ and $S_3G_5$ (foliar sprayed from 25 to 125 DAE, respectively with 75 cm × 30 cm spacing), $S_4G_1$, $S_4G_2$, $S_4G_3$ $S_4G_4$ and $S_4G_5$ (foliar sprayed from 25 to 125 DAE, respectively with 75 cm × 40 cm spacing) treatment combinations.

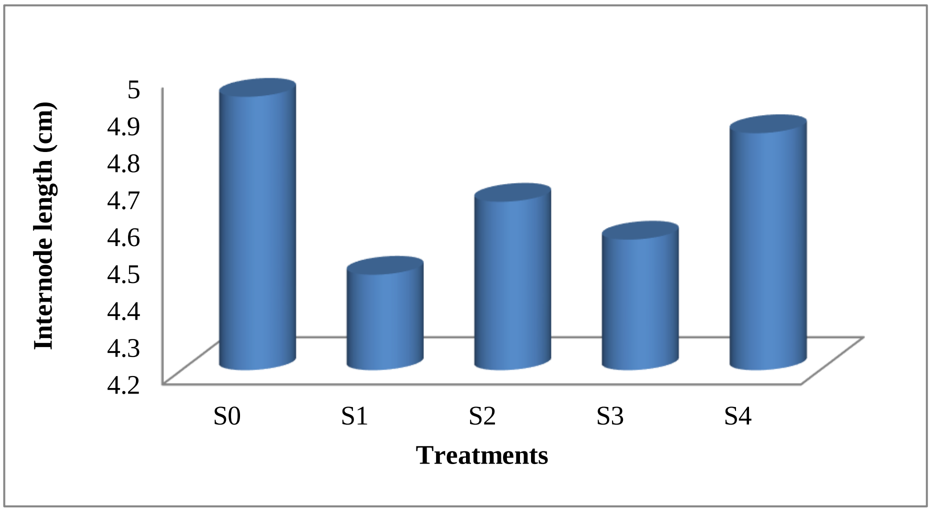
The findings are corroborated to Zhao *et al.* (2019) who stated that application of MC reduced plant height under different plant densities in cotton. Similar result was reported by Lucieli *et al.* (2017) in maize.

#### 4.1.1.2 Internodal length

**Effect of plant spacing**

Variation in internodal length due to different Plant spacing was statistically significant. Internodal length ranged between 4.46 and 4.94 cm (Fig. 3), plant spacing 90 cm x 45 cm ($S_0$) had the highest internodal length. The lowest being recorded for spacing 60 cm × 30 cm ($S_1$) which was at par with 75 cm × 30 cm spacing ($S_3$).

Baumhardt *et al.* (2018) narrated that internode increased significantly with increased row spacing in cotton (Singh *et al.*, 2017a in tomato).



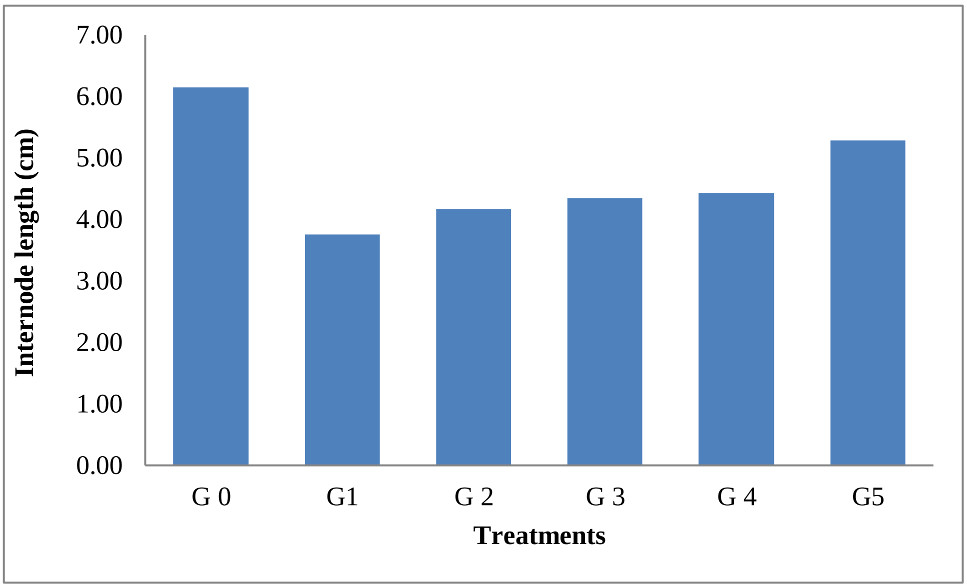

Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 3. Internode length of cotton as affected by different plant spacing (LSD $_{(0.05)}$ = 0.325).**

**Effect of time of application of MC growth regulator**

Application time of growth regulator had significantly influenced the internodal length (Fig. 4). Internodal length was maximum (6.14 cm) in plants grown in control ($G_0$) and the lowest (3.76 cm) was obtained from 25 DAE spray ($G_1$). Intermediate internode length was recorded when MC sprayed from 50 to 125 DAE.

Priyanka and Dalvi (2019) reported that internodal length reduced as MC sprayed compared to control. Application of mepiquat chloride (MC @ 15ml and 10 ml 10 $L^{-1}$ of water) at square and flower formation stage was found effective in reducing internode length in cotton. Some others also observed the same result (Shahr *et al.*, 2015 in cotton; Gu *et al.*, 2014 in cotton; Eveleigh *et al.*, 2010 in cotton; Volterrani *et al.*, 2015 in bermuda grass).




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 4. Influence of time of application of mepiquat chloride on internode length of cotton (LSD $_{(0.05)}$ = 0.569).**

**Combined effect of plant spacing and time of application of MC growth regulator**

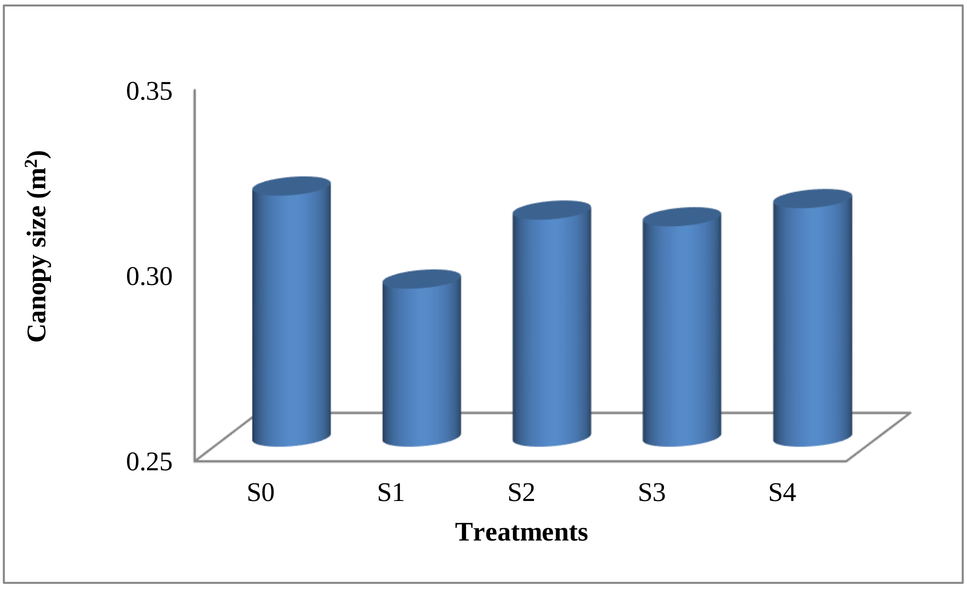
Plant spacing and application time of growth regulator significantly affected internodal length (Table 1). Internode of cotton plant became highest (6.67 cm) from water sprayed (control) with 90 cm × 45 cm spacing ($S_0G_0$) which was followed by $S_2G_0$ and $S_2G_5$ (foliar sprayed at 125 DAE with water spray + 60 cm × 40 cm spacing), $S_3G_0$ (foliar sprayed with water in 75 cm × 30 cm spacing) treatment combinations and it was marked lowest (3 cm) at 25 DAE foliar sprayed with 60 cm × 30 cm spacing ($S_1G_1$) which was statistically at par with $S_0G_1$, $S_0G_2$ and $S_0G_3$ (foliar sprayed from 25 to 75 DAE with 90 cm × 45 cm spacing); $S_1G_2$ and $S_1G_3$ (foliar sprayed from 50 to 75 DAE with 60 cm × 30 cm spacing); $S_2G_1$, $S_2G_2$ and $S_2G_3$ (foliar sprayed from 25 to 75 DAE with 60 cm × 40 cm spacing); $S_3G_1$, $S_3G_2$ and $S_3G_3$ (foliar sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing); $S_4G_1$, $S_4G_2$ and $S_4G_3$ (foliar sprayed from 25 to 75 DAE with 75 cm × 40 cm spacing) treatment combinations. Iqbal *et al.* (2007) suggested that internodal length decreased in narrow plant spacing with MC sprayed in cotton.

**4.1.1.3 Leaf canopy size**

**Effect of plant spacing**

Leaf canopy size of cotton was not significantly affected due to plant spacing (Fig. 5). Numerically the maximum leaf canopy size (0.32 $m^2$) was recorded from 90 cm × 45 cm spacing ($S_0$). The minimum leaf canopy size (0.29 $m^2$) was obtained from 60 cm × 30 cm spacing ($S_1$). Intermediate leaf canopy size was recorded from 60 cm × 40 cm ($S_2$), 75 cm × 30 cm ($S_3$) and 75 cm × 40 cm spacing ($S_4$) which were statistically similar.

Stewart *et al.* (1997) reported that leaf canopy size in peanuts increased as plant density decreased compared to control. The results are also in agreed with that of Emilie and Kufimfutu, 1995 in oats; Liu *et al.*, 2011 in maize; Ponnuswami and Rani, 2019 in moringa.



Here,

$S_0$ = 90 cm × 45 cm (24,691 plants $ha^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants $ha^{-1}$)

$S_3$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

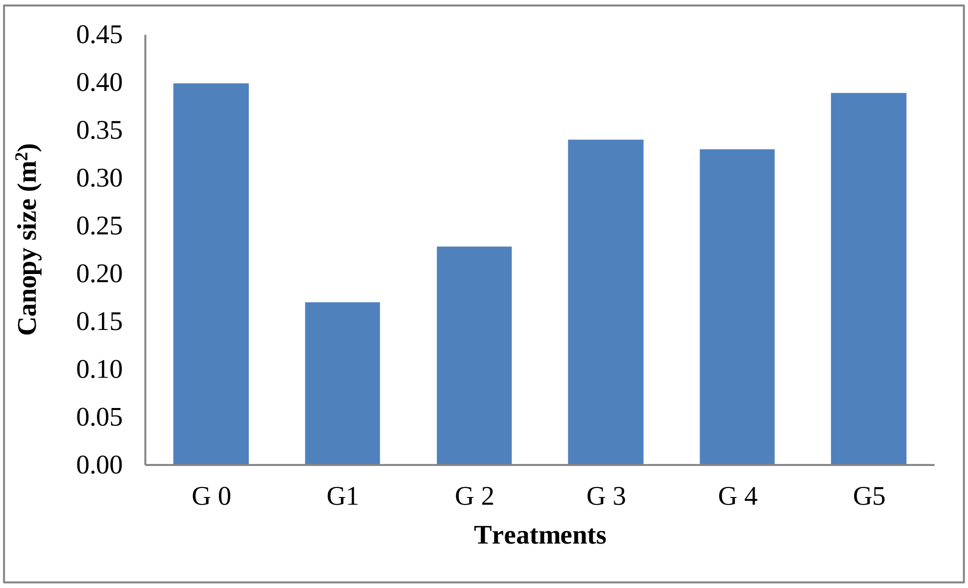
$S_4$ = 75 cm × 40 cm (33,333 plants $ha^{-1}$)

**Figure 5. Canopy size of cotton as affected by different plant spacing (LSD $_{(0.05)}$ = 0.033).**

**Effect of time of application of MC growth regulator**

A significant variation in leaf canopy size of cotton was observed due to the effect of foliar application of MC growth regulator (Fig. 6). Plant growth with water spray ($G_0$) showed the maximum leaf canopy size (0.40 $m^2$) followed by foliar sprayed at 125 DAE ($G_5$) and minimum leaf canopy size (0.17 $m^2$) at 25 DAE ($G_1$). Intermediate plant canopy size was recorded when MC sprayed at early (50 DAE) or late (75, 100 and 125 DAE).

Gu *et al.* (2014) reported that canopy structure became more compact with the decrease of leaf area index due to the application of MC in cotton. Zhao *et al.* (2019) found that leaf canopy size was decreased as MC sprayed compared to control in cotton. Similar finding was reported by Gollagi *et al.*, 2019 in guava; Singh and Chanana, 2005 in guava; Edgerton, 1983 in apple. Eveleigh *et al.* (2010) opined that plant hormone reduced the production of the gibberellic acid, which in turn slowed cell expansion resulting in reduced canopy (leaf growth) in cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 6. Influence of time of application of MC on canopy size of cotton (LSD ($_{0.05}$) = 0.031).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of Plant spacing and time of MC application on leaf canopy size was observed significant (Table 1). Cotton leaf canopy size became highest (0.45 $m^2$) from control with 90 cm × 45 cm spacing ($S_0G_0$) which was followed by $S_0G_4$ and $S_0G_5$ (foliar sprayed at 100 and 125 DAE, respectively with the same spacing) while the lowest (0.16 $m^2$) was recorded from foliar sprayed at 75 DAE with 60 cm × 30 cm spacing ($S_0G_3$) and it was statistically identical with $S_1G_4$ (foliar sprayed at 100 DAE with same spacing) and at par with $S_1G_1$, $S_1G_2$ (foliar sprayed at 25 and 50 100 DAE, respectively with same spacing); $S_3G_1$ and $S_3G_4$ (foliar sprayed at 25 and 100 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations. Zhao *et al*. (2019) reported that application of MC resulting in a lower and more compact plant canopy in cotton.

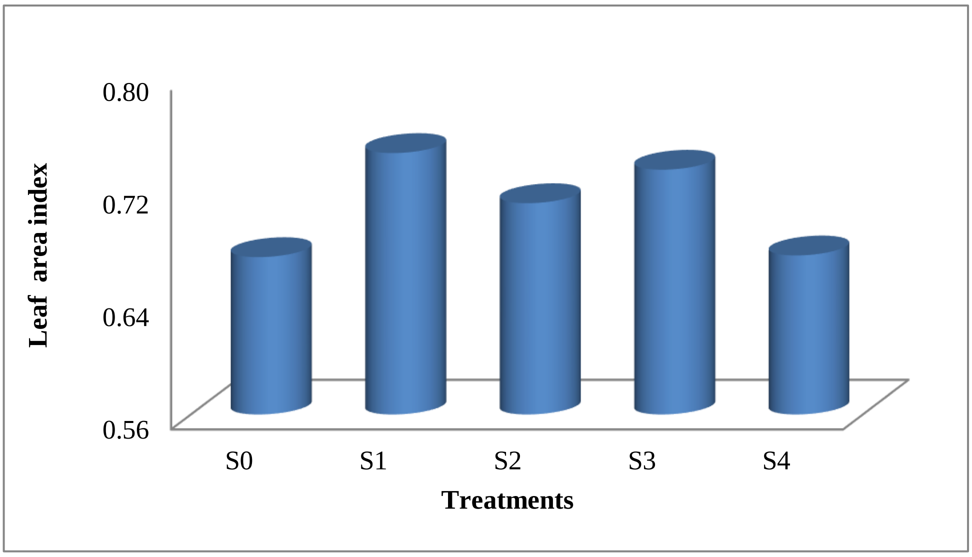
**4.1.1.4 Leaf area index (LAI)**

**Effect of plant spacing**

Leaf area index as influenced insignificantly by plant spacing (Fig. 7). Leaf area index increased as plant spacing decreased. The maximum LAI (0.75) was obtained from 60 cm

× 30 cm spacing ($S_1$) and it was followed by 75 cm × 30 cm spacing ($S_3$). The minimum LAI (0.67) was recorded at wider spacing 90 cm × 45 cm ($S_0$) which was statistically at par with 75 cm × 40 cm spacing ($S_4$).

Sowmiya and Sakthivel (2018) reported that the narrow plant spacing of 60 cm x 15 cm had significantly higher leaf area index in cotton (Pengcheng *et al.*, 2015 in cotton; Darawsheh and Aivalakis, 2007 in cotton). Ricaurte *et al.* (2016) argued that sowing density is a major management factor that affects growth and development of crops by modifying the canopy light environment and interplant competition for water and nutrients in bean.



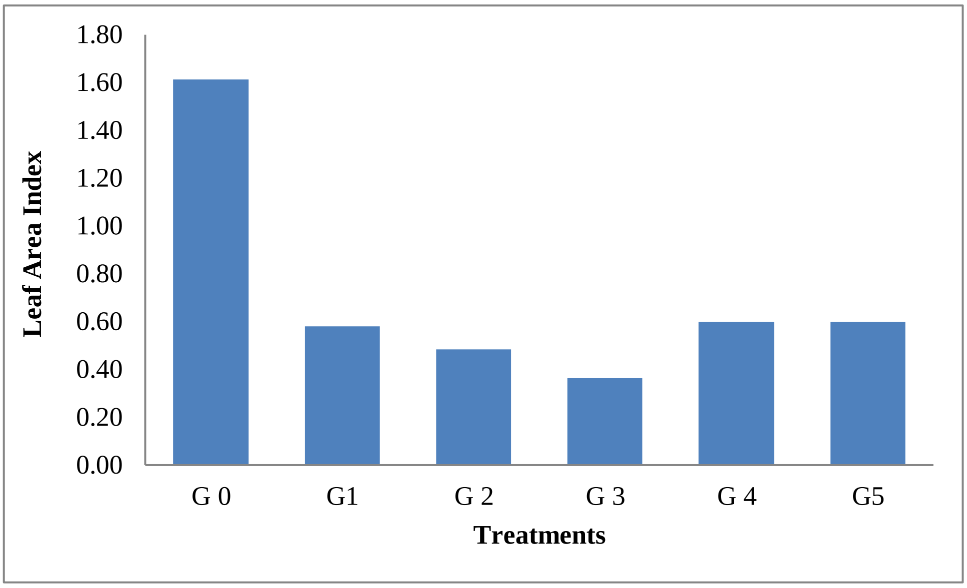

Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 7. Leaf area index of cotton as affected by different plant spacing (LSD $_{(0.05)}$ = 0.107).**

**Effect of time of application of MC growth regulator**

Time of application exerted significant variation in LAI (Fig. 8). The maximum value (1.61) for LAI was obtained from plants grown without MC (i.e. control plants) and the minimum (0.36) from MC treated at 75 DAE ($G_3$). Intermediate leaf area was recorded when MC sprayed at 25 DAE (early) or at 100 and 125 DAE (late). Amit *et al.* (2016)

reported that application of MC @ 300 ppm, TIBA @ 100 ppm and MH @ 250 ppm reduced leaf area index than control in cotton. Leaf area index of cotton was decreased as MC sprayed compared to control (Kumar *et al.*, 2005).




Here,

$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 8. Influence of time of application of mepiquat chloride on leaf area index of cotton (LSD $_{(0.05)}$ = 0.082).**

**Combined effect of plant spacing and time of application of MC growth regulator**

The combined effect of Plant spacing and time of MC application was found significant on LAI (Table 1). Leaf area index of cotton was found to be increased with increasing plant density but decreased as MC sprayed compared to control. Leaf area index was highest (1.72) at 75 DAE sprayed with 90 cm × 45 cm spacing ($S_0G_3$) which was statistically at par with $S_0G_2$, $S_0G_4$ and $S_0G_5$ (with 90 cm × 45 cm spacing and MC foliar sprayed at 50, 100 and 125 DAE, respectively) and the lowest (0.26) at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) followed by $S_1G_2$, $S_1G_3$ (MC foliar sprayed at 50 and 75 DAE, respectively with same spacing); $S_3G_3$ and $S_3G_5$ (with 75 cm × 30 cm spacing and MC foliar sprayed at 75 and 125 DAE); $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ treatment combinations (with 75 cm × 40 cm spacing and MC foliar sprayed from 25 to 125 DAE with water spray, respectively).

**Table 1. Combined influence of plant spacing and time of application of MC growth regulator on plant height, internode length, canopy size and leaf area index of cotton**

| Treatment combinations | Plant height (cm) | Internode length (cm) | Canopy size ($m^2$) | Leaf area index |
|---|---|---|---|---|
| $S_0G_0$ | 127.48 a | 6.67 a | 0.45 a | 0.72 c |
| $S_0G_1$ | 98.13 b-d | 4.21 d-j | 0.34 cd | 1.47 b |
| $S_0G_2$ | 98.00 b-d | 4.22 d-i | 0.36 b-d | 1.71 a |
| $S_0G_3$ | 98.00 b-d | 4.00 e-j | 0.16 i | 1.72 a |
| $S_0G_4$ | 99.10 b-d | 4.78 c-e | 0.42 ab | 1.64 ab |
| $S_0G_5$ | 99.00 b-d | 4.61 c-f | 0.42 ab | 1.52 ab |
| $S_1G_0$ | 105.43 bc | 4.94 b-e | 0.25 e-g | 0.60 cd |
| $S_1G_1$ | 86.64 d | 3.00 j | 0.17 hi | 0.26 f |
| $S_1G_2$ | 86.74 d | 3.06 ij | 0.17 hi | 0.40 d-f |
| $S_1G_3$ | 86.74 d | 4.19 d-j | 0.36 b-d | 0.33 ef |
| $S_1G_4$ | 97.45 b-d | 4.28 d-h | 0.16 i | 0.49 de |
| $S_1G_5$ | 90.78 cd | 4.72 c-e | 0.24 f-h | 0.59 cd |
| $S_2G_0$ | 107.46 b | 5.50 a-c | 0.34 cd | 0.72 c |
| $S_2G_1$ | 87.89 d | 4.01 e-j | 0.29 d-f | 0.58 cd |
| $S_2G_2$ | 87.78 d | 4.00 e-j | 0.25 e-g | 0.59 cd |
| $S_2G_3$ | 87.75 d | 4.00 e-j | 0.34 cd | 0.58 cd |
| $S_2G_4$ | 99.33 b-d | 4.44 c-g | 0.33 cd | 0.59 cd |
| $S_2G_5$ | 104.78 bc | 6.11 ab | 0.33 cd | 0.60 cd |
| $S_3G_0$ | 109.44 b | 6.06 ab | 0.33 cd | 0.60 cd |
| $S_3G_1$ | 89.56 cd | 3.47 f-j | 0.18 g-i | 0.59 cd |
| $S_3G_2$ | 89.53 cd | 3.23 g-j | 0.17 hi | 0.52 c-e |
| $S_3G_3$ | 89.45 cd | 3.22 h-j | 0.20 g-i | 0.46 d-f |
| $S_3G_4$ | 98.22 b-d | 4.33 c-h | 0.20 g-i | 0.50 de |
| $S_3G_5$ | 90.89 cd | 5.11 b-e | 0.33 cd | 0.35 ef |
| $S_4G_0$ | 105.56 bc | 5.34 b-d | 0.37 bc | 0.48 de |
| $S_4G_1$ | 94.93 b-d | 4.03 e-j | 0.34 cd | 0.34 ef |
| $S_4G_2$ | 94.64 b-d | 4.08 e-j | 0.34 cd | 0.27 f |
| $S_4G_3$ | 94.46 b-d | 4.06 e-j | 0.34 cd | 0.35 ef |
| $S_4G_4$ | 97. 78 b-d | 4.50 c-f | 0.32 c-e | 0.33 ef |
| $S_4G_5$ | 97.89 b-d | 5.11 b-e | 0.34 cd | 0.35 ef |
| **$LSD_{(0.05)}$** | **16.423** | **1.205** | **0.071** | **0.198** |
| **CV (%)** | **8.89** | **9.23** | **10.73** | **16.5** |

Means having same letters in the same column indicates no significant difference at $P \leq 0.05$.

Here,

$S_0$ = 90 cm × 45 cm (24,691 plants $ha^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm× 30 cm (55,555 plants $ha^{-1}$)

$S_2$ = 60 cm × 40 cm (41,666 plants $ha^{-1}$)

$S_3$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

$S_4$ = 75 cm × 40 cm (33,333 plants $ha^{-1}$)

$G_0$ = Water spray (control)

$G_1$= Foliar spray at 25 days after emergence (DAE)

$G_2$ = Foliar spray at 50 DAE

$G_3$ = Foliar spray at 75 DAE

$G_4$ = Foliar spray at 100 DAE

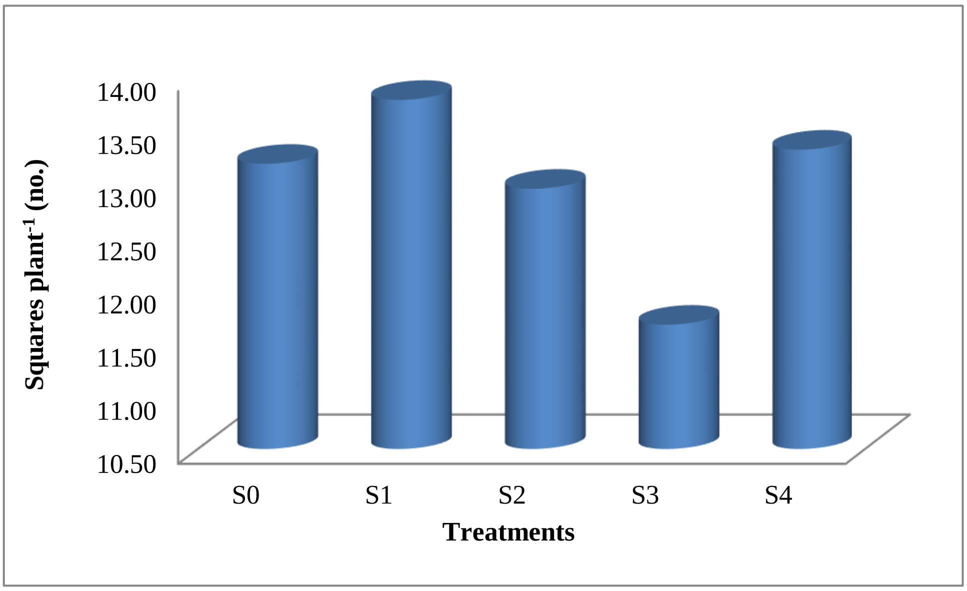
$G_5$ = Foliar spray at 125 DAE

### 4.1.2 Effect on yield attributes and yield of cotton.

#### 4.1.2.1 Squares plant$^{-1}$

**Effect of plant spacing**

The number of squares plant$^{-1}$ was significantly affected by plant population (Fig. 9). The highest squares plant$^{-1}$ (13.78) was produced from 60 cm × 30 cm spacing ($S_1$) which was statistically similar with 75 cm × 40 cm spacing ($S_4$). Plant spacing of $S_3$ i.e. 75 cm × 30 cm produced the minimum squares plant$^{-1}$ (11.67) and it was significantly different from all other spacing. The higher number of squares could have produced due to more photosynthates as partitioned to the flowers. Parekh *et al.* (2018) and Yagia *et al.* (2014) reported that there was a trend to decrease squares plant$^{-1}$ with the decrease in plant spacing in spider lily crop.

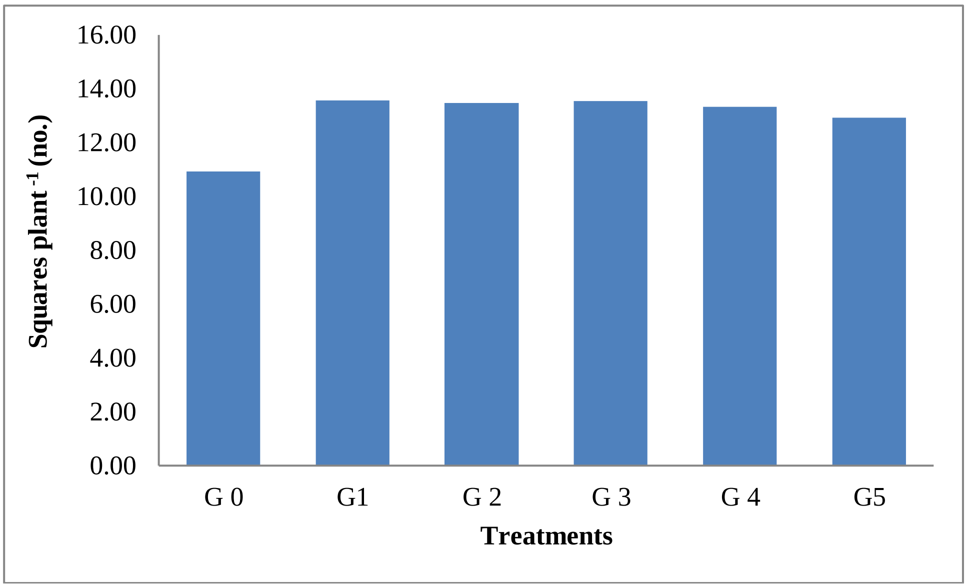



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 9. Influence of different plant spacing on squares plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.446).**

**Effect of time of application of MC growth regulator**

Variation in number of squares plant$^{-1}$ among the MC sprayed at different times was significant (Fig. 10). Squares plant$^{-1}$ were highest (13.57) from foliar sprayed at 25 DAE ($G_1$) which was statistically similar with $G_2$, $G_3$ and $G_4$ treatments (foliar sprayed from 50 to 100 DAE, respectively) and the lowest (10.93) at control ($G_0$). Chaplot **(**2015) and Sabale *et al.* (2018) reported maximum number of squares per plant in early spraying in cotton which is corroborating to the present findings. Kataria and Khanpara (2012) obtained significantly increased squares (108) with decreasing plant height in cotton with Cycocel foliar spray @ 40 ppm at 90 DAS. Similar observations were also reported with different crops i.e. Koley and Maitra, 2015 in gladiolus; Parmar *et al.*, 2015 in rose flowers; Jamil *et al.*, 2015 in *Hippeastrum*; Pal, 2019 in ornamental plants. Yasmeen *et al.* (2016) reported that combined application of MLE and MC at 45 days after blooming enhanced squares plant$^{-1}$ in Bt cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 10. Influence of time of application of mepiquat chloride on squares plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.63).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of plant density and time of application of MC showed significant influence on squares plant$^{-1}$ (Table 2). The squares plant$^{-1}$ increased as plant population decreased and MC sprayed compared to control. Squares plant$^{-1}$ marked highest (16.5) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) which was statistically at par with treatment combinations of $S_0G_2$, $S_0G_4$, $S_0G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with 90 cm × 45 cm spacing); $S_1G_4$ (foliar sprayed at 100 DAE with 60 cm × 30 cm spacing); $S_2G_2$, $S_2G_3$ (foliar sprayed at 50 and 75 DAE, respectively with 60 cm × 40 cm spacing); $S_4G_2$, $S_4G_3$ and $S_4G_4$ (foliar sprayed from 50 to 100 DAE, respectively with 75 cm × 40 cm spacing) and it became lowest (11) at water sprayed with 60 cm × 30 cm spacing ($S_1G_0$).

Cothren *et al.* (1983) opined that MC decreased plant height, intermodal length, increased leaf area but wider spacing increased final leaf size and number of shoots including fruiting branch number resulted in higher retention capacity of square plant$^{-1}$ in cotton. Parekh *et al.* (2018) reported that squares plant$^{-1}$ was increasing as the plants were widely spaced, highest being recorded at 90 x 90 cm level with foliar spray gibberellic acid at 250, 200 and 150 ppm and NAA at 200 and 150 ppm.

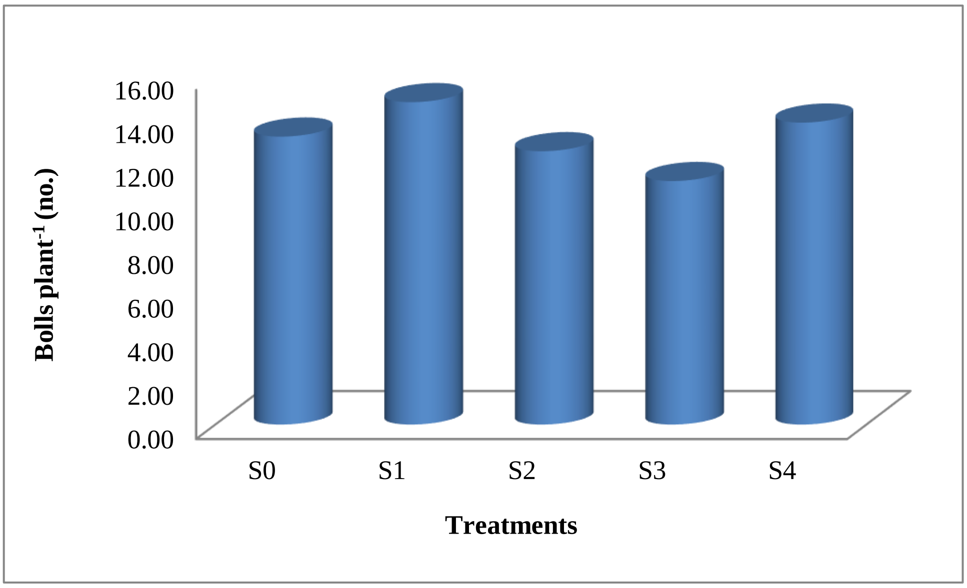
#### 4.1.2.2 Bolls plant$^{-1}$

**Effect of plant spacing**

Bolls plant$^{-1}$ was significantly affected by plant spacing (Fig. 11). Bolls plant$^{-1}$ decreased as plant spacing decreased compared to control. Numerically higher bolls plant$^{-1}$ (14.78) was counted from 60 cm × 30 cm spacing ($S_1$) followed by $S_0$ (90 cm × 45 cm) and $S_4$ (75 cm × 40 cm) treatments and the lowest (11.17) from $S_3$ (75 cm × 30 cm).

CDB (2018) reported that maximum bolls plant$^{-1}$ (19.3) was recorded in case of wider plant spacing of 90 cm × 45 cm against the minimum (12.0) in closer plant spacing of 90 cm × 10 cm of hybrid variety DM-3 in cotton. The results were also in line with the findings of Ahmad *et al.* (2008), Bhalerao and Gaikwad (2010), Kumara *et al.* (2014), Singh *et al.* (2012), Rajakumar and Gurumurthy (2008), Xiao-yu *et al.* (2016), Sowmiya and Sakthivel (2018), Sylla *et al.* (2013) and Jahedi *et al.* (2013) while they had experiments on cotton.

Oad *et al*. (2002) opined that in a dense population stand, the plants were subjected to severe competition from an early stage due to which very few or no vegetative branches formed, fruiting onset delays, and reduced bolls plant$^{-1}$ than in widely spaced cotton. While, widely spaced plants do not compete severely with each other in early stages of growth and relatively large vegetative branches were formed. Hake *et al.* (1991) suggested that plant spacing can alter boll distribution and crop maturity by manipulating soil water removal, radiation interception, humidity and wind movement in cotton. Jiang *et al. (*2017) opined that periodic alteration of plant density (PD) proposed to improve the light environment of plants' lower canopies and leaf photosynthesis thus produces more photosynthates to give support plant growth and fruit development.




Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)

$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

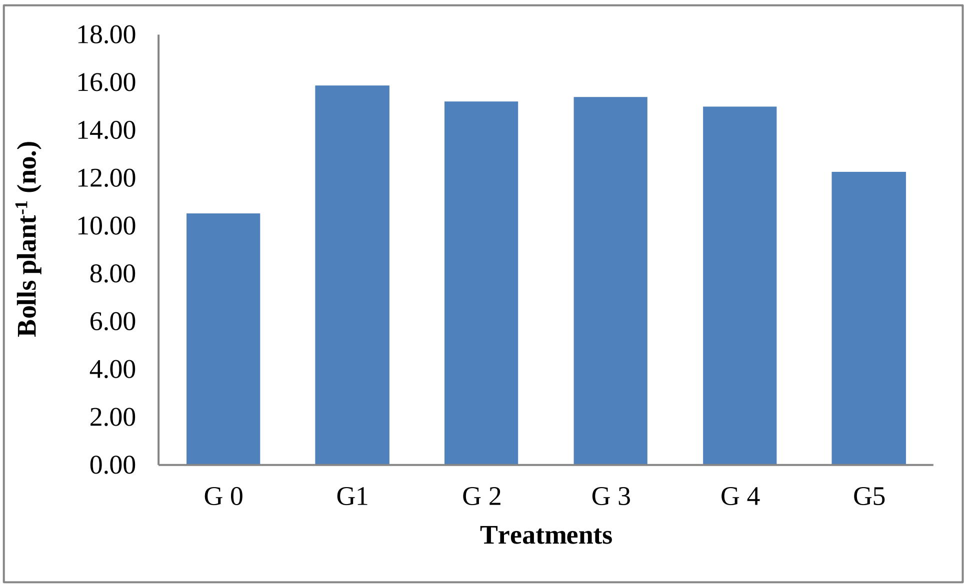
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 11. Influence of different plant spacing on bolls plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 2.22).**

**Effect of time of application of MC growth regulator**

Growth regulator MC showed significant influence on bolls plant$^{-1}$ (Fig. 12). Bolls plant$^{-1}$ increased as MC sprayed at different times compared to control. Bolls plant$^{-1}$ were recorded the highest (15.87) from foliar sprayed at 25 DAE ($G_1$) and the lowest (10.53) at control ($G_0$). Intermediate bolls plant$^{-1}$ was observed when MC sprayed at early (25 and 50 DAE) or late (100 DAE).

Reema *et al.* (2017) reported that the maximum opened bolls plant$^{-1}$ (30.1) and un-opened bolls plant$^{-1}$ (4.0) were observed under Pix at 1000 ml/500 litres of water at bud formation in cotton. Similar results obtained in cotton that was in conformity with Gumber *et al.*, 2005; Kataria and Khanpara 2012; Amit *et al.*, 2016; Arif and Yasmeen, 2016; Chaplot**,** 2015; Ali *et al.*, 2012; Ali *et al.*, 2009. Bons *et al.* (2015) opined that the plant growth regulating compounds actively regulate the growth and development by regulation of the endogenous processes and there exogenous applications have been exploited for modifying the growth response in citrus fruit. Yasmeen *et al.* (2016) reported that combined application of MLE and MC at 90 days after blooming improved the number of bolls plant$^{-1}$ in Bt cotton.




Here,

$G_0$ = Water spray (control)

$G_1$ =Foliar spray at 25 days after emergence (DAE)

$G_2$ = Foliar spray at 50 DAE

$G_3$ = Foliar spray at 75 DAE

$G_4$ = Foliar spray at 100 DAE

$G_5$ = Foliar spray at 125 DAE

**Figure 12. Influence of time of application of mepiquat chloride on bolls plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 1.678).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of plant spacing and time of application of MC showed significant influence on bolls plant$^{-1}$ (Table 2). The highest bolls plant$^{-1}$ (16.0) was achieved with the combined effect of MC sprayed at 25 DAE with 60 cm × 30 cm ($S_1G_1$) which was statistically at par with treatment combinations of $S_0G_2$, $S_0G_4$, $S_0G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with 90 cm × 45 cm spacing); $S_1G_3$, $S_1G_4$ (foliar sprayed from 75 to 100 DAE, respectively with 60 cm × 30 cm spacing); $S_2G_2$, $S_2G_3$, $S_2G_4$ (foliar sprayed from 50 to 100 DAE, respectively with 60 cm × 40 cm spacing); $S_3G_2$, $S_3G_3$, $S_3G_4$ (foliar sprayed from 50 to 100 DAE, respectively with 75 cm × 30 cm spacing); $S_4G_2$, $S_4G_3$ and $S_4G_4$ (foliar sprayed from 50 to 100 DAE, respectively with 75 cm × 40 cm spacing). Plants grown without MC with 60 cm × 30 cm spacing ($S_1G_0$) gave the lowest bolls plant$^{-1}$ (10.0) which was followed by $S_1G_0$ treatment combinations (foliar sprayed with water in 60 cm × 30 cm spacing).

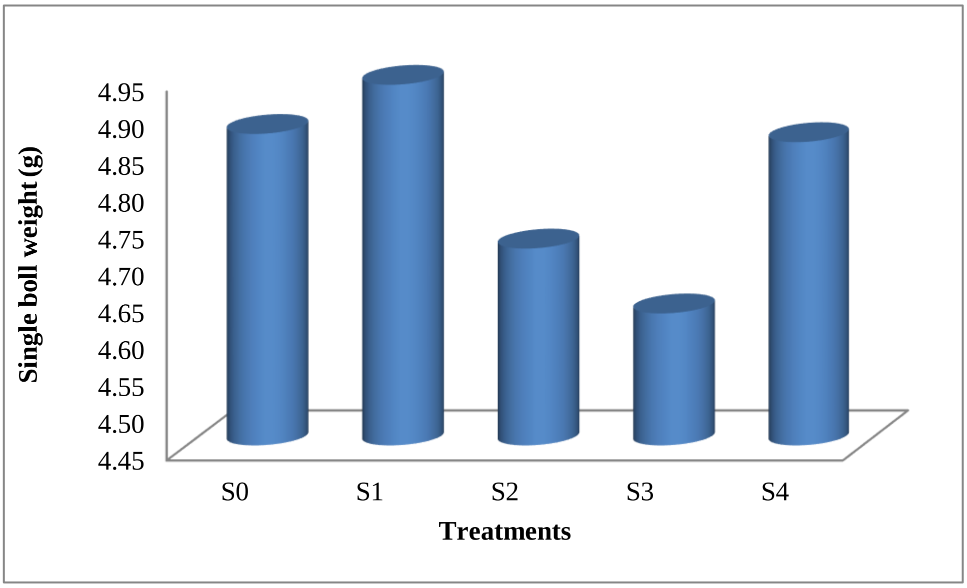
Oad *et al*. (2002) and Hake *et al*. (1991) reported that MC coupled with wider spacing enhanced better vegetative growth and flowering for better photosynthesis, water, nutrient, air, light and space sharing and consequently enhanced higher bolls plant$^{-1}$ in cotton. On the contrary, Iqbal *et al.* (2007) narrated that cotton grown in narrow plant spacing (15 and 23 cm) at high dose of fertilizer (150 kg ha$^{-1}$) with low dose of pix (2 x 100 ml ha$^{-1}$) increased the bolls plant$^{-1}$ in cotton. Chormule and Patel (2017) reported that combination of wider plant spacing 60 cm x 45 cm and seed treatment of GA3 @ 150 ppm before sowing was found best suited combination, as it has good field emergence and produced significantly and comparatively the maximum fruits plant$^{-1}$ in okra.

#### 4.1.2.3 Weight of boll

**Effect** of **plant spacing**

Plant spacing had a significant effect on weight of single boll (Fig. 13). Single boll weight was found to be increased with increased plant population. The highest boll weight (4.94 g) was obtained from closer 60 cm × 30 cm (55555 plants ha$^{-1}$) spacing ($S_1$) followed by $S_4$ (75 cm × 40 cm) and $S_0$ (90 cm × 45 cm) spacing. Treatment $S_3$ (75 cm × 30 cm) gave the lowest boll weight (4.63 g) followed by $S_2$ (60 cm × 40 cm) spacing.

Singh (2015) obtained maximum boll weight (3.17 g) at closer spacing of 67.5 × 60 cm and minimum boll weight (3.12 g) with wider spacing of 67.5 × 75 cm in cotton. Jadhav *et al.* (2015) had similar observations in cotton experiment.




Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)

$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

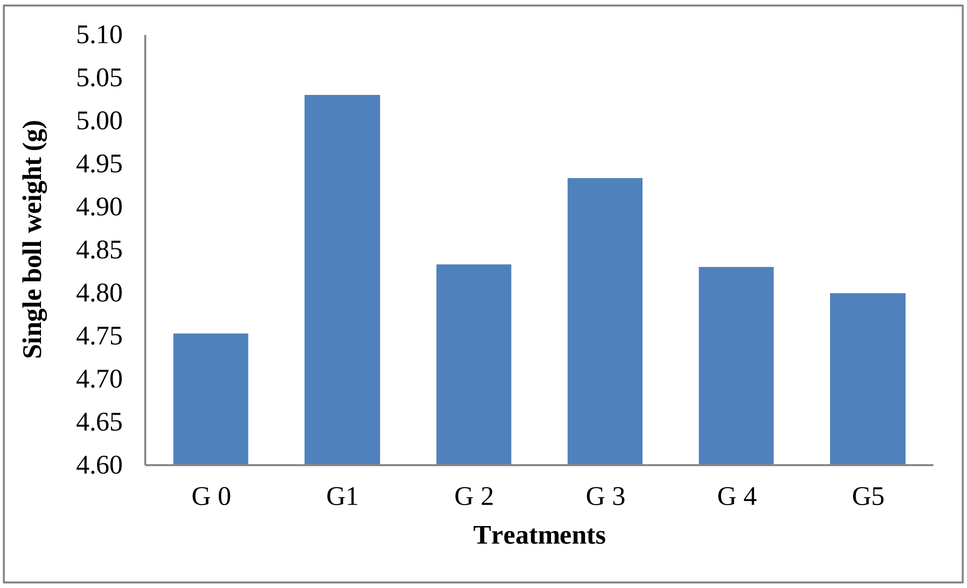
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 13. Influence of different plant spacing on boll weight plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.157).**

## Effect of time of application of MC growth regulator

MC application at different times exerted significant influence on weight of single boll (Fig. 14). Weight of boll plant$^{-1}$ increased with MC application up to 25 DAE and then decreased. The maximum weight of boll (5.03 g) was obtained from the treatment $G_1$ foliar sprayed at 25 DAE and the minimum (4.75 g) at $G_0$ treatment (control). Intermediate boll weight was recorded when MC sprayed at 50 to 100 DAE or water spray.

Zakaria (2016) reported that Cycocel and Alar increased opened boll weight. Echer and Rosolem (2017), Kumar *et al.* (2005), Copur *et al.* (2010) and Evangelos *et al.* (2004) reported similar observation while spraying different growth regulators on cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 14. Influence of time of application of mepiquat chloride on boll weight plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.165).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of plant spacing and time of MC spray was significant in respect of weight of single boll (Table 2). Weight of boll increased as plant population increased along with MC sprayed at different times over control. Single boll weight was highest (5.14 g) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) which was statistically at par with treatment combinations of $S_0G_1$, $S_0G_4$, $S_0G_5$ (foliar sprayed at 25, 100 and 125 DAE, respectively with 90 cm × 45 cm spacing), $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 50 to 125 DAE, respectively with water in 60 cm × 30 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 60 cm × 40 cm spacing), $S_3G_1$, $S_3G_2$, $S_3G_3$ $S_3G_4$, $S_3G_5$ (foliar sprayed from 25 to 125 DAE, respectively with 75 cm × 30 cm spacing), $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 75 cm × 40 cm spacing) while the lowest (4.57 g) was obtained for water sprayed at 25 DAE with 90 cm × 45 cm spacing ($S_0G_0$) which was followed by $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$ (foliar sprayed from 25 to 125 DAE, respectively with 90 cm × 45 cm spacing), $S_1G_0$ (foliar sprayed with water in 60 cm × 30 cm spacing), $S_2G_0$, $S_2G_5$ (foliar sprayed at 125 DAE with water in 60 cm × 40 cm spacing), $S_3G_0$, $S_3G_5$ (foliar sprayed at 125 DAE with water in 75 cm × 30 cm spacing) and $S_4G_0$, $S_4G_1$ and $S_4G_5$ treatment combinations (foliar sprayed at 25 and 125 DAE with water in 75 cm × 40 cm spacing).

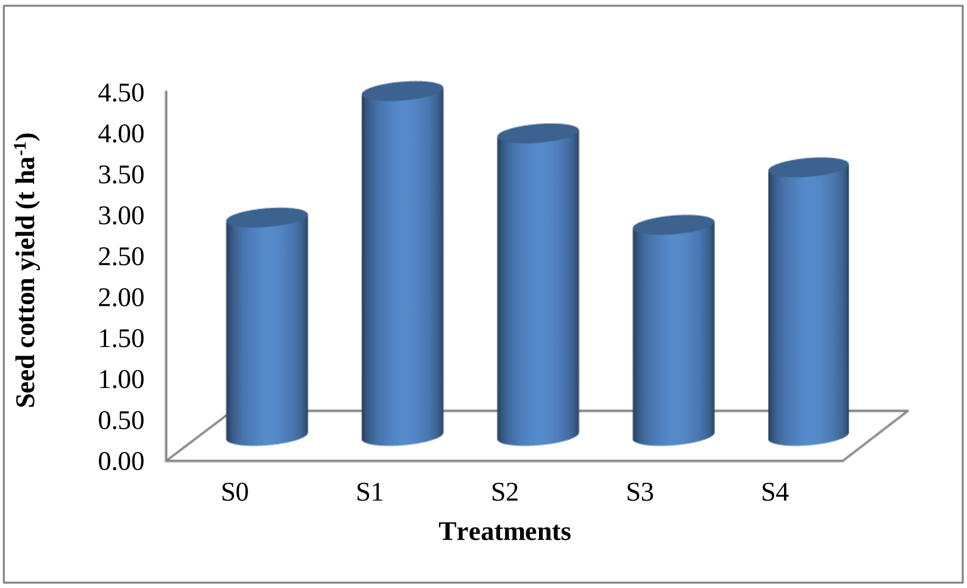
Oad *et al*. (2002) and Hake *et al.* (1991) opined that the lesser in vegetative growth of cotton at closer spacing (60 cm × 30 cm) might be due to higher competition for nutrient, light and space. MC treated plants produced short plants thus which partitioned more photosynthates towards lesser number of bolls which resulted in more boll weight.

#### 4.1.2.4 Seed cotton yield

**Effect of plant spacing**

Seed cotton yield was significantly affected by plant spacing and each treatment was varied markedly with others (Fig. 15). Seed cotton yield decreased gradually with wider spacing. The highest seed cotton yield (4.2 t $ha^{-1}$) was obtained from 60 cm × 30 cm spacing ($S_1$). Treatment $S_2$ (60 cm × 40 cm spacing) showed the second highest yield (3.69 t $ha^{-1}$) and gradually yield decreased with wider spacing. The lowest yield (2.57 t $ha^{-1}$) was obtained from 75 cm × 30 cm spacing ($S_3$). Treatment $S_1$ (close spacing) out yielded control ($S_0$, wider spacing) by 92.8% more yield as the increased yield was added with greater plant population per unit area. Yield was highest in 55,555 plants $ha^{-1}$ treatment confirmed by Awais *et al.* (2015). Firoz *et al.* (2007) also reported that sowing with 60 x 30 cm plant spacing produced significantly highest yield (12.86 t $ha^{-1}$). The result was also in conformity with the findings in cotton of CDB (2018), Sowmiya and Sukthivel (2018), Mahi and Lokanadhan (2018), Kumar *et al.*, (2017), Udikeri and Shashidhara (2017), Rao *et al.* (2015), Hiwale *et al.* (2015), Munir *et al.* (2015), Sylla *et al.* (2013), Ali *et al.* (2012), Sher *et al.* (2017), Ali *et al.* (2009), Khan *et al.* (2002), Soomro *et al.*, 2000a, Soomro *et al*. (2000b), Silva *et al.* (2006), Silvertooth (1999), Keren *et al.*(1983), Siebert *et al.* (2006) and Wright *et al*. (2008). Liu *et al.* (2011) studied that planting pattern affects canopy structure of crops and influences other physiological characteristics such as light interception and radiation use efficiency. These results indicated that narrow-wide row planting patterns improved the canopy structure, allowed more IPAR to reach the middle–

low strata of the canopy and enhanced the leaf photosynthetic characteristics of maize crops at silking stage compared with control resulting in higher yield.




Here,

$S_0$ = 90 cm × 45 cm (24,691 plants $ha^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants $ha^{-1}$)

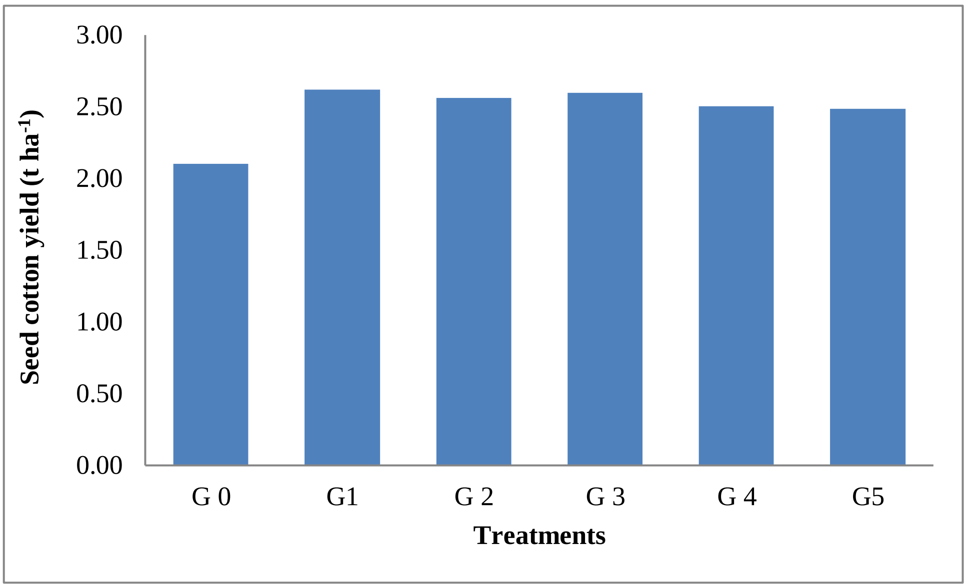
$S_3$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

$S_4$ = 75 cm × 40 cm (33,333 plants $ha^{-1}$)

**Figure 15. Influence of different plant spacing on seed cotton yield of cotton ($LSD_{(0.05)}$ = 0.079).**

### Effect of time of application of MC growth regulator

MC sprayed from 25 to 125 DAE had significant effect on seed cotton yield over without growth regulator treatment (control). It was apparent that there is an insignificant decrease trend in seed cotton yield with delaying MC spray time (Fig. 16). The seed cotton yield was recorded highest (2.62 t $ha^{-1}$) from MC sprayed at 25 DAE ($G_1$) and the lowest (2.1 t $ha^{-1}$) at control ($G_0$). Use of growth regulator at 25 DAE had 91.43 % more yield over no growth regulator use. Sabale *et al.* (2018) reported that higher seed cotton yield (1213.27 kg $ha^{-1}$) was obtained with application of NAA @ 30 ppm. The similar results of cotton yields under different growth regulator application were recorded in different experiments elsewhere (Fang *et al.*, 2019; Chang-chi *et al.*, 2019; Reema *et al.*, 2017; Arif and Yasmeen (2016); Amit *et al.*, 2016; Chaplot, 2015; Kataria and Khanpara (2012); Evangelos *et al.*, 2004) and also by Kamran *et al.*, 2017 in maize. Sebastian *et al.* (2019) argued that phytohormones determine the formation of flowers and its retention when shedding of leaves are minimum which enhances the development and ripening of fruits (pomegranate). Yasmeen *et al.* (2016) reported that the combined application of MLE and MC at 90 days after blooming improved seed cotton yield in Bt cotton. Application of MC alone reduced the plant growth without significantly increasing the yield.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 16. Influence of time of application of mepiquat chloride on seed cotton yield of cotton (LSD $_{0.05}$ = 0.145).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of plant spacing and time of MC spray on seed cotton yield was statistically significant (Table 2). Combination treatment 60 cm × 30 cm along with growth regulator sprayed at 25, 75 and 100 DAE; $S_1G_1$, $S_1G_3$ and $S_1G_4$, respectively showed statistically identical highest seed cotton yield (4.06 t $ha^{-1}$). Plants grown without MC sprayed with spacing of 90 cm × 45 cm ($S_0G_0$) treatment combination gave the lowest seed cotton yield (1.20 t $ha^{-1}$) which was statistically at par with $S_0G_1$ (MC foliar sprayed at 25 DAE with the same spacing) treatment combination.

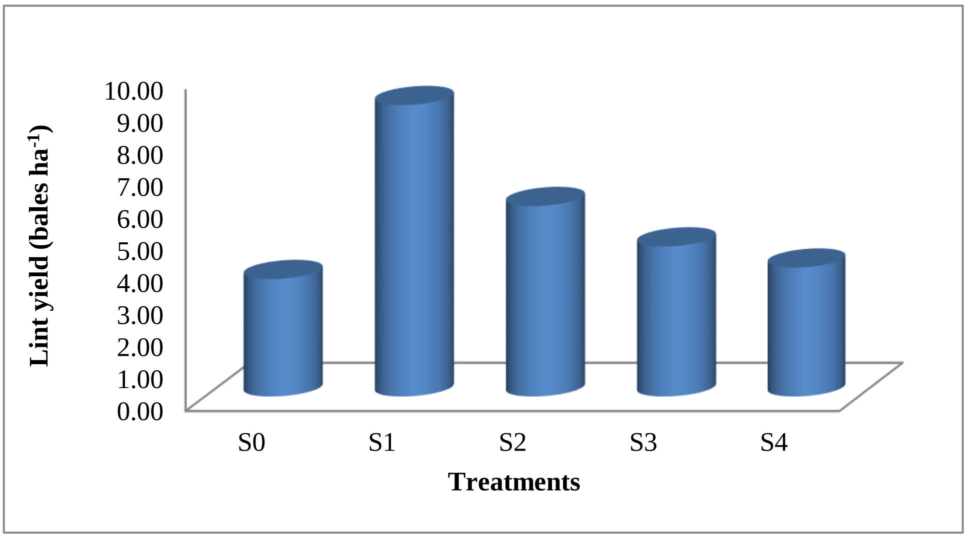
Zakaria (2016) reported that the intermediate plant density (222000 plants $ha^{-1}$) gave highest yields. Both Cycocel and Alar increased the seed-cotton yield $plant^{-1}$. Seed cotton yield increased as plant population increased as MC sprayed compared to control in cotton

(Zhao *et al.*, 2019; Iqbal *et al.*, 2007; Copur *et al.*, 2010; Evangelos *et al.*, 2004; Golada *et al.* (2018) noted the same observation in baby corn.

### 4.1.2.5 Lint yield

#### Effect of plant spacing

Lint yield of cotton showed considerable variation among the plant spacing. The maximum lint yield (9.08 bales ha$^{-1}$) was recorded at closer spacing (60 cm × 30 cm) ($S_1$) and it was significantly different from all other spacing (Fig. 17). It was indicated that lint yield decreased significantly with gradual plant population per unit area decreased. The widest spacing (90 cm × 45 cm i.e. $S_0$) gave the lowest lint yield (3.66 bales ha$^{-1}$). Singh (2015) observed that maximum lint yield (777.8 kg ha$^{-1}$) was recorded at closer spacing of 67.5 × 60 cm and minimum lint yield (684.6 kg ha$^{-1}$) with wider spacing of 67.5 × 75 cm. Yield of lint was increased as plant population increased at closer spacing in cotton (Clawson *et al.*, 2006; Shukla *et al.*, 2013; Xiao-yu *et al.*, 2016; Richard, 2006; Manuel *et al.*, 2019; Jahedi *et al.*, 2013; Singh *et al.*, 2014; Berry *et al.*, 2008).

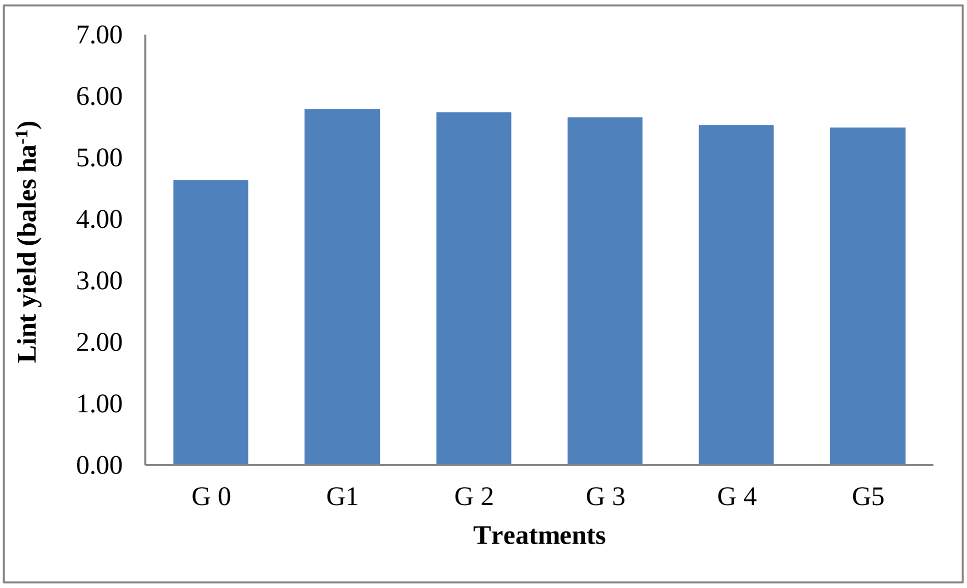



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 17. Influence of different plant spacing on lint yield of cotton (LSD $_{(0.05)}$ = 0.174).**

**Effect of time of application of MC growth regulator**

MC sprayed from 25 to 125 days after emergence had significant effect on lint yield of cotton over no growth regulator (Fig. 18). Lint yield decreased progressively over time of MC sprayed attaining the highest at 25 DAE. The maximum cotton lint yield (5.79 bales $ha^{-1}$) was obtained from foliar sprayed at 25 DAE ($G_1$) followed by $G_2$ (at 50 DAE) and $G_3$ (at 75 DAE) treatment. The minimum lint yield (4.64 bales $ha^{-1}$) was observed in control ($G_0$) which was at par with $G_4$ (at 100 DAE) and $G_5$ (at 125 DAE). Chaplot (2015) reported that the foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton by 57.3 per cent over water spray in cotton. McCarty *et al.* (2017) argued that various plant growth hormones and regulators have been increased the yield of cotton (*Gossypium hirsutum* L.) lint when applied to foliage in field tests which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation. Yasmeen *et al.* (2016) reported that the combined application of MLE and MC at 90 days after blooming improved lint yield in Bt cotton.




Here,

$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 18. Influence of time of application of mepiquat chloride on lint yield of cotton (LSD $_{(0.05)}$ = 0.32).**

### Combined effect of plant spacing and time of application of MC growth regulator

Combined effect of plant density and time of MC spray levels was found to be significant for lint yield of cotton (Table 2). Lint yield increased as plant population increased with MC sprayed compared to control. Likewise statistically identical lint yield was marked highest (8.97 bales ha$^{-1}$) from spacing 60 cm × 30 cm along with growth regulator sprayed at 25, 75 and 100 DAE; $S_1G_1$, $S_1G_3$ and $S_1G_4$, respectively. Lowest (2.66 bales ha$^{-1}$) lint yield was recorded from control plot, $S_0G_0$ (90 cm × 45 cm + Water spray) which was statistically similar with $S_0G_1$ (MC foliar sprayed at 25 DAE with same spacing).

**Table 2. Combined effect of plant spacing and time of application of MC growth regulator on yield and yield attributes of cotton**

| Treatments | Squares plant$^{-1}$ (no.) | Bolls plant$^{-1}$ (no.) | Boll weight (g) | Seed cotton yield (t ha$^{-1}$) | Lint yield (bales ha$^{-1}$) |
|---|---|---|---|---|---|
| **$S_0G_0$** | 13.67 ef | 12.67 fg | 4.57 e | 1.20 n | 2.66 i |
| **$S_0G_1$** | 13.00 f | 14.33 b-e | 4.83 a-e | 1.26 n | 2.67 i |
| **$S_0G_2$** | 16.00 ab | 15.00 a-c | 4.63 de | 2.72 h-j | 6.01 d |
| **$S_0G_3$** | 15.00 b-d | 14.00 c-f | 4.73 b-e | 2.74 g-i | 6.06 d |
| **$S_0G_4$** | 16.00 ab | 15.00 a-c | 4.77 a-e | 2.77 f-i | 6.20 d |
| **$S_0G_5$** | 16.00 ab | 15.00 a-c | 4.87 a-e | 2.29 kl | 5.06 fg |
| **$S_1G_0$** | 11.00 g | 10.00 h | 4.88 a-e | 2.56 i-k | 5.66 d-f |
| **$S_1G_1$** | 16.50 a | 16.00 a | 5.14 a | 4.06 a | 8.97 a |
| **$S_1G_2$** | 14.00 d-f | 13.00 e-g | 5.03 a-c | 3.36 bc | 7.42 bc |
| **$S_1G_3$** | 14.67 b-e | 15.00 a-c | 5.13 a | 4.06 a | 8.97 a |
| **$S_1G_4$** | 15.67 a-c | 15.00 a-c | 5.13 a | 4.06 a | 8.97 a |
| **$S_1G_5$** | 14.00 d-f | 13.00 e-g | 5.03 a-c | 3.36 bc | 7.42 bc |
| **$S_2G_0$** | 13.67 ef | 12.67 fg | 4.77 a-e | 1.75 m | 3.59 h |
| **$S_2G_1$** | 15.43 a-c | 14.43 b-d | 4.97 a-d | 2.41 j-l | 5.32 e-g |
| **$S_2G_2$** | 15.67 a-c | 15.00 a-c | 5.03 a-c | 3.06 c-f | 6.00 de |
| **$S_2G_3$** | 15.67 a-c | 15.33 a-c | 5.03 a-c | 3.09 c-e | 6.06 d |
| **$S_2G_4$** | 14.33 c-f | 15.67 ab | 5.07 ab | 3.36 bc | 7.42 bc |
| **$S_2G_5$** | 14.00 d-f | 13.00 e-g | 4.87 a-e | 2.77 f-i | 6.12 d |
| **$S_3G_0$** | 13.00 f | 12.00 g | 4.67 c-e | 1.68 m | 3.71 h |
| **$S_3G_1$** | 15.33 a-d | 14.33 b-e | 5.07 ab | 2.56 i-k | 5.66 d-f |
| **$S_3G_2$** | 14.00 d-f | 15.00 a-c | 5.10 ab | 3.05 c-g | 6.12 d |
| **$S_3G_3$** | 15.33 a-d | 15.67 ab | 5.03 a-c | 3.07 c-f | 6.17 d |
| **$S_3G_4$** | 15.33a-d | 15.00 a-c | 5.10 ab | 3.65 b | 8.07 b |
| **$S_3G_5$** | 13.67 ef | 12.67 fg | 4.83 a-e | 3.02 d-h | 4.75 g |
| **$S_4G_0$** | 13.67 ef | 12.67 fg | 4.87 a-e | 2.15 l | 4.78 g |
| **$S_4G_1$** | 15.33 a-d | 14.33 b-e | 4.93 a-e | 2.16 l | 4.85 g |
| **$S_4G_2$** | 16.00 ab | 15.00 a-c | 4.96 a-d | 2.20 l | 6.00 de |
| **$S_4G_3$** | 16.00 ab | 15.67 ab | 4.97 a-d | 3.02 d-h | 6.06 d |
| **$S_4G_4$** | 16.00 ab | 15.00 a-c | 4.98 a-d | 3.25 cd | 7.19 c |
| **$S_4G_5$** | 14.33 c-f | 13.33 d-g | 4.93 a-e | 2.79 e-i | 6.17 d |
| **LSD $_{(0.05)}$** | **1.360** | **1.360** | **0.372** | **0.306** | **0.67 5** |
| **CV (%)** | **4.48** | **4.48** | **4.20** | **4.13** | **4.13** |

Means having same letters in the same column indicates no significant difference at $P \leq 0.05$.

Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) ( check, CDB recommendation)

$S_1$ = 60 cm× 30 cm (55,555 plants ha$^{-1}$)

$S_2$ = 60 cm × 40 cm (41,666 plants ha$^{-1}$)

$G_0$ = Water spray (control)

$G_1$= Foliar spray at 25 days after emergence (DAE)

$G_2$ = Foliar spray at 50 DAE

$G_3$ = Foliar spray at 75 DAE

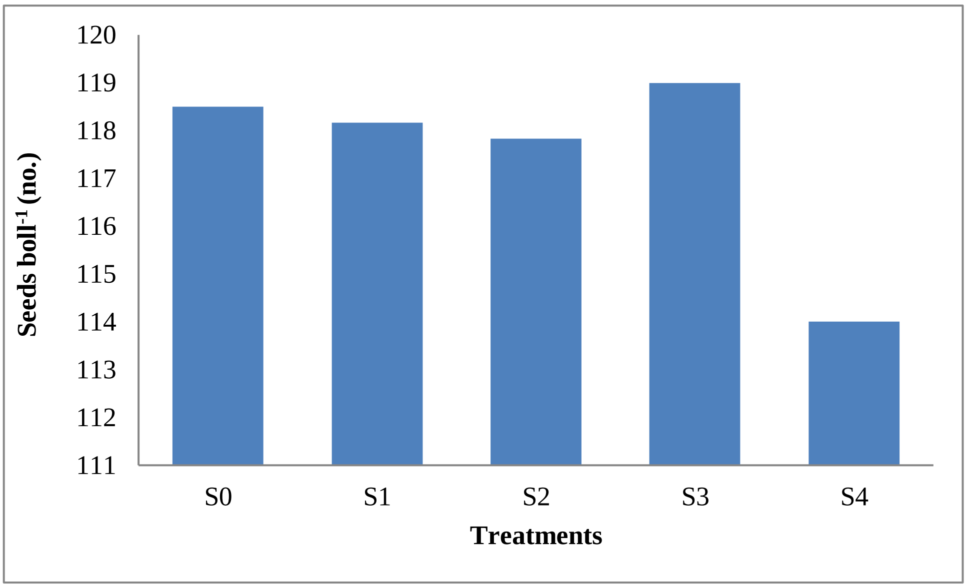
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)  G$_4$ = Foliar spray at 100 DAE
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)  G$_5$ = Foliar spray at 125 DAE

### 4.1.3 Effect of plant spacing and time of application of MC growth regulator on seed characters of cotton

#### 4.1.3.1 Seeds boll$^{-1}$

**Effect of plant spacing**

Seeds boll$^{-1}$ of cotton had considerable variations under different plant spacing (Fig. 19). The maximum seeds boll$^{-1}$ (119.00) was recorded at spacing 75 cm × 30 cm ($S_3$) and it was statistically at par with $S_0$ (90 cm × 45 cm), $S_1$ (60 cm × 30 cm) and $S_2$ (60 cm × 40 cm). The lowest seeds boll$^{-1}$ (114.00) was obtained from spacing 75 cm × 40 cm ($S_4$). Omadewu *et al.* (2019) reported that plant density had a positive effect on number of seeds boll$^{-1}$ in cotton. Khalil *et al.* (2010) reported that seeds pod$^{-1}$ in faba bean change with different plant spacings. On the contrary, Pitombeira (1972) reported that seeds fruit$^{-1}$ was not significantly affected by plant population in cotton and sorghum.

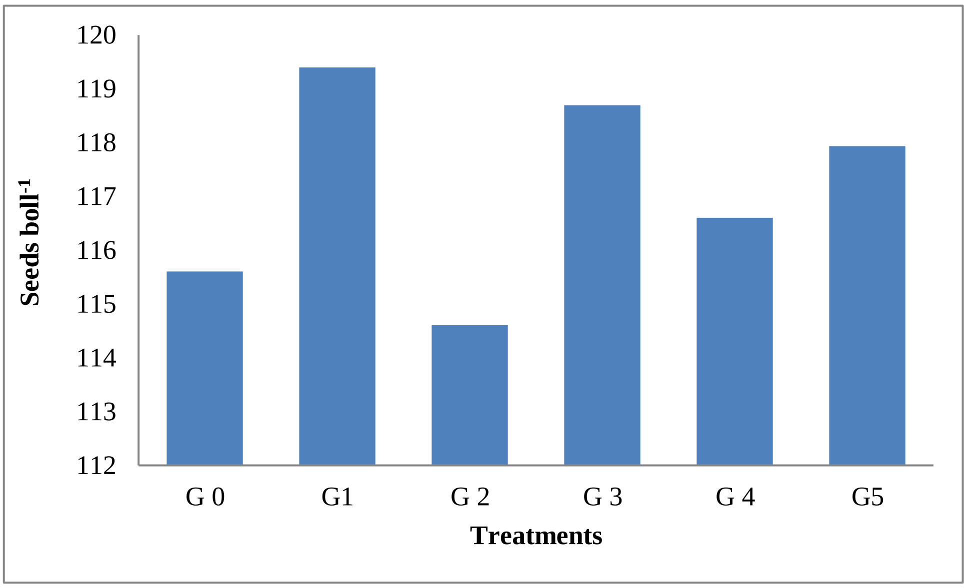


Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 19. Influence of different plant spacing on seeds boll$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.296).**

### Effect of time of application of MC growth regulator

MC sprayed had significant effect on seeds boll$^{-1}$ of cotton over no growth regulator (Fig. 20). Seeds boll$^{-1}$ increased progressively over time of MC sprayed attaining the highest at 25 DAE. The highest seeds boll$^{-1}$ (119.4) was obtained from foliar sprayed at 25 DAE ($G_1$) which was statistically similar with $G_3$ (at 75 DAE) and $G_5$ (at 125 DAE) and the lowest (114.6) at 50 DAE ($G_2$) which was statistically similar with $G_0$ (at control) and $G_4$ (at 100 DAE).




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 20. Influence of time of application of mepiquat chloride on seeds boll$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.769).**

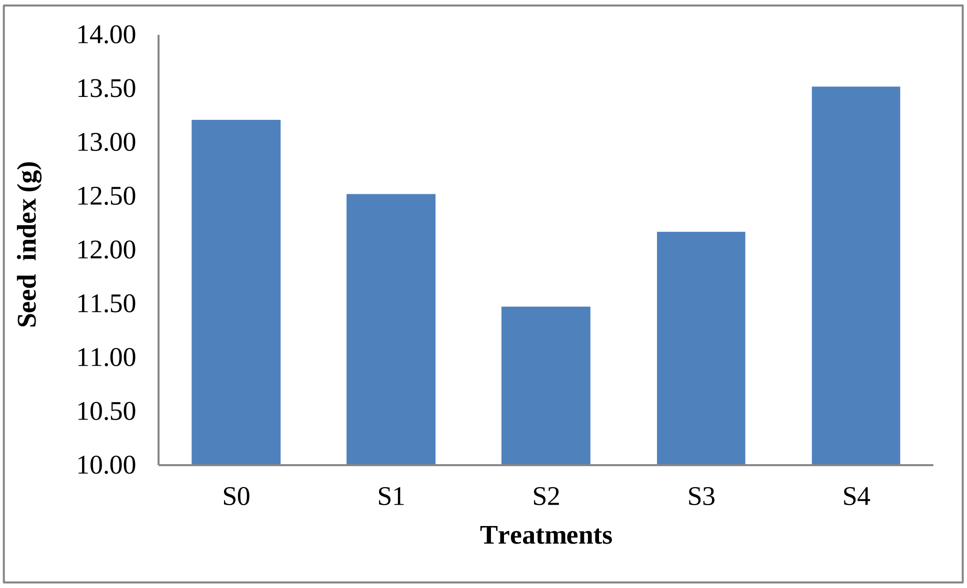
**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of plant density and time of application of growth regulator was significant in respect of seeds $boll^{-1}$ of cotton (Table 3). The highest Seeds $boll^{-1}$ (121.67) was obtained from and it was identical due to $S_1G_5$ (60 cm × 30 cm + foliar sprayed at 125 DAE), $S_3G_2$ (75 cm × 30 cm + foliar sprayed at 50 DAE) and $S_4G_1$ treatment combinations (75 cm × 40 cm spacing + foliar sprayed at 25 DAE) and it was statistically similar with $S_0G_4$ (foliar sprayed at 100 DAE under 90 cm × 45 cm spacing); $S_1G_2$ (foliar sprayed at 50 DAE with 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_3$, $S_2G_4$ (foliar sprayed at 75 and 100 DAE with water under 60 cm × 40 cm spacing); $S_3G_3$, $S_3G_4$ (foliar sprayed at 75 and 100 DAE with 75 cm × 30 cm spacing); and $S_4G_3$ (foliar sprayed at 75 DAE with 75 cm × 40 cm spacing) treatment combinations. The lowest (100.33) was obtained when MC foliar sprayed at 75 DAE with 90 cm × 45 cm spacing ($S_0G_3$ treatment combinations).

#### 4.1.3.2 Seed index

**Effect of plant spacing**

Seed index of cotton had considerable variation among the plant spacings. The maximum seed index (13.52 g) was recorded at spacing 75 cm × 40 cm ($S_4$) and it was statistically similar with spacing 60 cm × 30 cm (Fig. 21). The lowest seed index (11.47 g) was marked from spacing 60 cm × 40 cm ($S_2$). Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased.

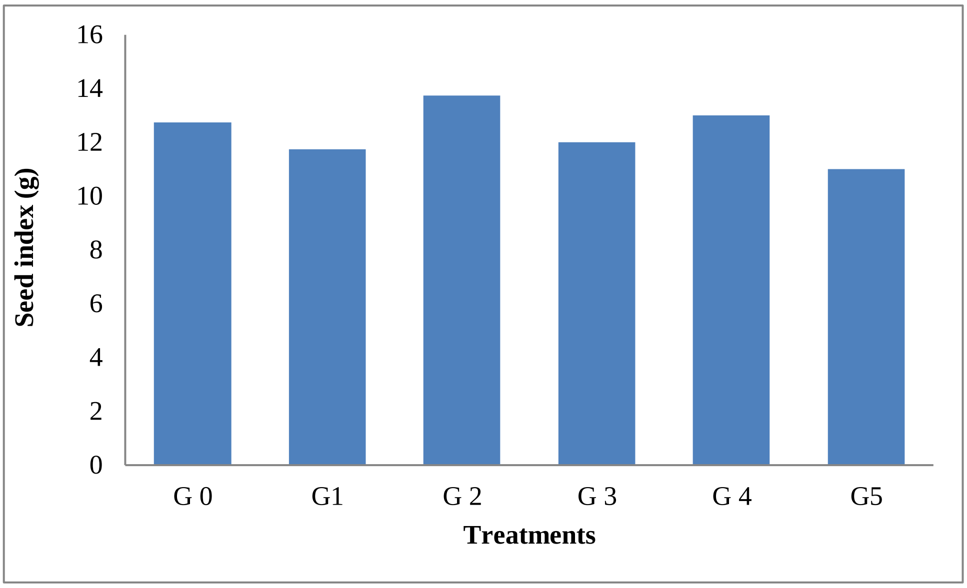



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$)
( check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 21. Influence of different plant spacing on seed index of cotton (LSD $_{(0.05)}$ = 0.156).**

### Effect of time of application of MC growth regulator

MC had significant effect on seed index of cotton (Fig. 22). Seed index increased progressively over time of MC sprayed attaining the highest at 50 DAE. The higher seed index (13.74 g) was obtained from foliar sprayed at 50 DAE ($G_2$) and and the lowest (11.01 g) at $G_5$ (at 125 DAE). Zhao *et al.* (2019) studied that the 100-seed weight significantly increased with MC applying under different plant densities in cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 22. Influence of time of application of mepiquat chloride on seed index of cotton (LSD $_{(0.05)}$ = 0.396).**

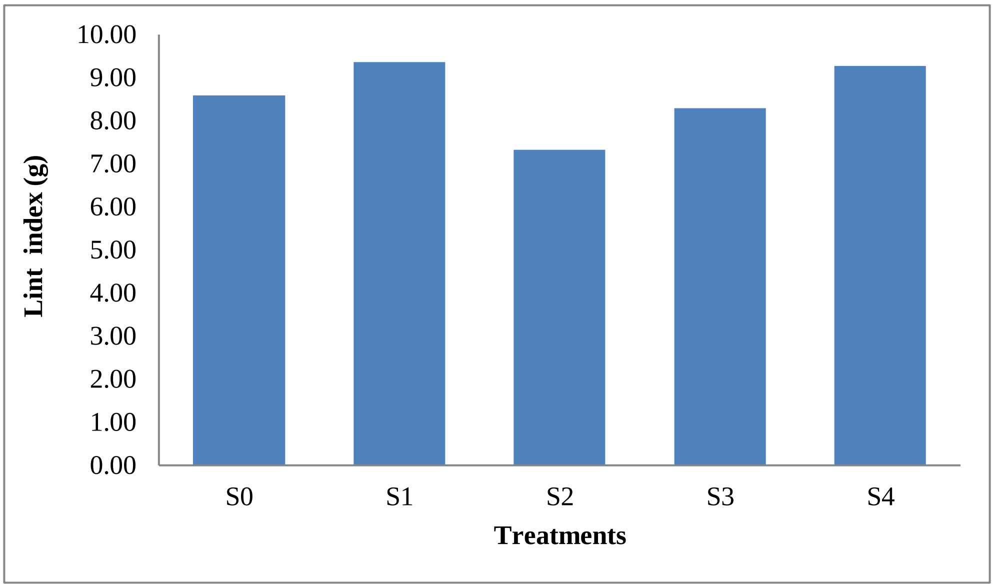
## Combined effect of plant spacing and time of application of MC growth regulator

Combined effect of plant density and time of application of growth regulator was significant in respect of seed index of cotton (Table 3). Maximum seed index (15 g) of cotton was marked from 90 cm × 45 cm spacing with foliar sprayed at 100 DAE ($S_0G_4$) which was statistically similar with $S_0G_0$, $S_0G_2$ (foliar sprayed at 50 DAE with water under 90 cm × 45 cm spacing); $S_3G_0$ and $S_3G_4$ (foliar sprayed at 100 DAE with water in 75 cm × 30 cm spacing) treatment combinations while the lowest (10.12 g) from 75 cm × 30 cm spacing as foliar sprayed at 75 DAE ($S_3G_3$) which was statistically similar with $S_0G_1$ (foliar sprayed at 25 DAE under 90 cm × 45 cm spacing); $S_1G_1$ (foliar sprayed at 25 DAE under 60 cm × 30 cm spacing); $S_3G_5$ (foliar sprayed at 125 DAE with 75 cm × 30 cm spacing); $S_4G_1$ and $S_4G_4$ (foliar sprayed at 25 and 125 DAE in 75 cm × 40 cm spacing) treatment combinations. Zakaria (2016) reported that both Cycocel and Alar increased opened seed indices in cotton. Zhao *et al.* (2019) also reported that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

#### 4.1.3.3 Lint index

**Effect of plant spacing**

Lint index of cotton had considerable variation among the plant spacings (Fig. 23). The maximum lint index (9.36 g) was recorded at spacing 90 cm × 45 cm ($S_1$) followed by 75 cm × 40 cm spacing. The lowest lint index (7.33 g) was recorded from spacing 60 cm × 40 cm ($S_2$).

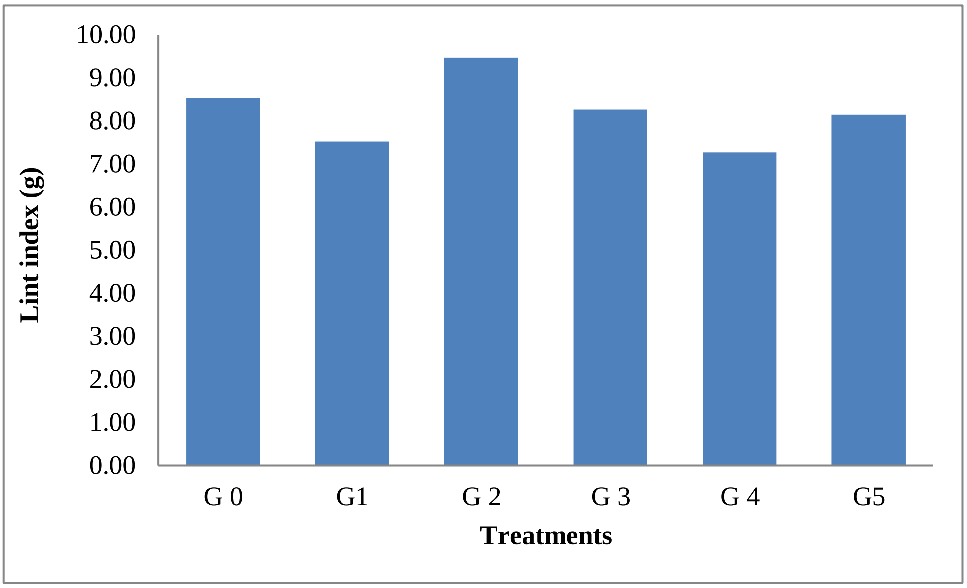



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 23. Influence of different plant spacing on lint index of cotton (LSD $_{(0.05)}$ = 0.071).**

**Effect of time of application of MC growth regulator**

MC had significant effect on lint index of cotton (Fig. 24). The highest lint index (9.47 g) was obtained from foliar sprayed at 50 DAE (early). The lowest (7.27 g) was at 100 DAE ($G_4$) which was statistically similar with $G_1$ (at 25 DAE) treatment. Zakaria (2016) also observed that both Cycocel and Alar increased lint indices in cotton. Yasmeen *et al.* (2016) reported that the combined application of MLE and MC at 90 days after blooming improved lint index in Bt cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 24. Influence of time of application of mepiquat chloride on lint index of cotton (LSD $_{(0.05)}$ = 0.285).**

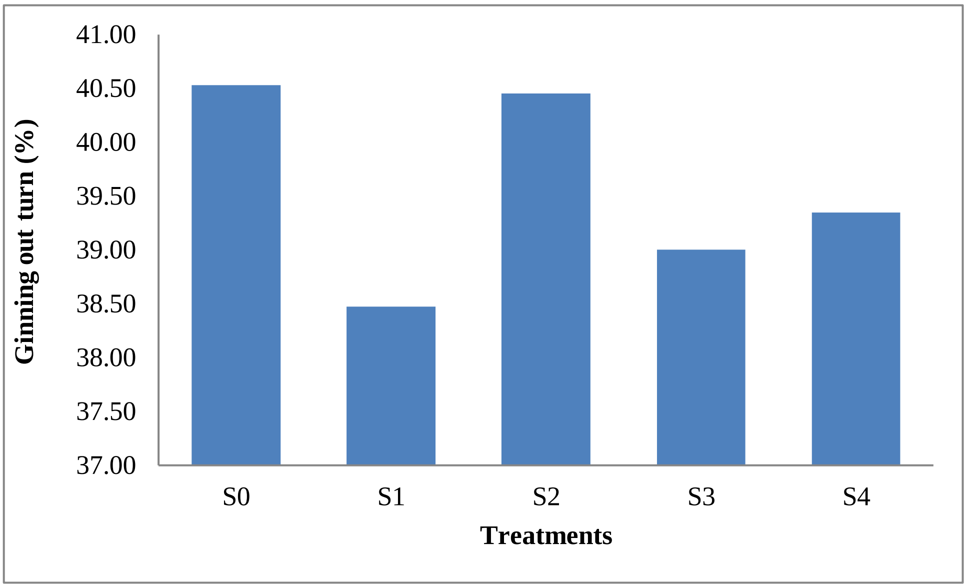
**Combined effect of plant spacing and time of application of MC growth regulator**

Combined effect of plant density and time of application of growth regulator was significant in respect of lint index of cotton (Table 3). Lint index was marked highest (10 g) from 90 cm × 45 cm spacing as foliar sprayed at 100 DAE with ($S_0G_4$) which was statistically similar with $S_0G_0$, $S_0G_2$ (foliar sprayed at 50 DAE with water under 90 cm × 45 cm spacing); $S_3G_0$ and $S_3G_4$ (foliar sprayed at 100 DAE with water in 75 cm × 30 cm spacing and lowest (6.44 g) from 60 cm × 30 cm spacing under water sprayed at 25 DAE ($S_1G_1$) which was statistically similar with $S_0G_1$ (foliar sprayed at 25 DAE with 90 cm × 45 cm spacing); $S_3G_3$, $S_3G_5$ (foliar sprayed at 75 and 125 DAE with 75 cm × 30 cm spacing) and $S_4G_4$ (foliar sprayed at 100 DAE with 75 cm × 40 cm spacing). Zakaria (2016) carried out experiment with foliar sprays of Cycocel and Alar at concentrations of 250, 500, and 750 ppm in cotton with three plant densities (166.000, 222.000, and 333.000 plants $ha^{-1}$) and reported that both Cycocel and Alar increased opened lint indices in cotton.

#### 4.1.3.4 Ginning out turn

**Effect of plant spacing**

Ginning out turn (GOT) of cotton had considerable variation among the plant spacing (Fig. 25). Numerically the maximum GOT (40.53%) was recorded at spacing 90 cm × 45 cm ($S_0$) which was statistically similar with $S_2$ (60 cm × 30 cm) and minimum GOT (38.47%) was obtained from spacing 60 cm × 30 cm ($S_1$).

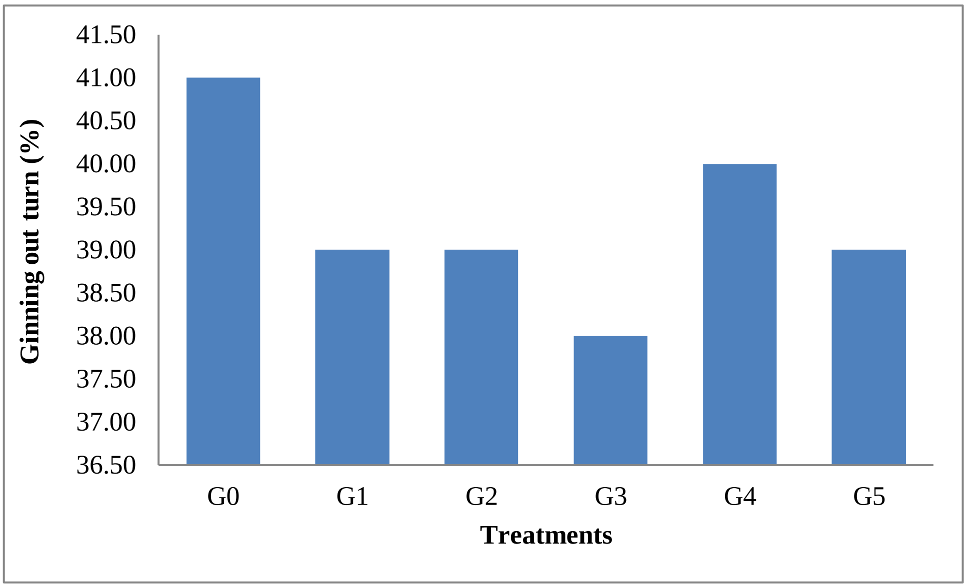



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$)
(check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 25. Influence of different plant spacing on ginning out turn of cotton (LSD $_{(0.05)}$ = 0.141).**

**Effect of time of application of MC growth regulator**

MC had significant effect on ginning out turn of cotton (Fig. 26). The maximum ginning out turn (41%) was obtained from control followed by $G_4$ (at 100 DAE) treatment. and the lowest (38%) at 75 DAE ($G_3$ treatment). Treatments $G_1$, $G_3$ and $G_5$ (foliar sprayed at 25, 75 and 125 DAE) were statistically identical.




Here,

$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 26. Influence of time of application of mepiquat chloride on ginning out turn of cotton (LSD $_{(0.05)}$ = 0.303).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Ginning out turn of cotton was noticed as significant due to combined effect of plant spacing and time of application of growth regulator (Table 3). Ginning out turn or lint percentages was found greater (40.80 %) from 60 cm × 30 cm spacing with foliar sprayed at 75 DAE ($S_1G_3$) which was statistically similar with $S_0G_1$, $S_0G_2$ (foliar sprayed at 25 and 50 DAE with 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_5$ (foliar sprayed at 125 DAE with water in 60 cm × 30 cm spacing); $S_2G_1$, $S_2G_3$, $S_2G_5$ (foliar sprayed at 25, 75 and 125 DAE with 60 cm × 40 cm spacing); $S_3G_1$, $S_3G_3$, $S_3G_5$ (foliar sprayed at 25, 75 and 125 DAE with 75 cm × 30 cm spacing) $S_4G_1$, $S_4G_3$ and $S_4G_5$ (foliar sprayed at 25, 75 and 125 DAE with 75 cm × 40 cm spacing) and lowest (38.27%) from foliar sprayed at 25 DAE under 60 cm × 30 cm spacing ($S_1G_1$) which was statistically similar with $S_4G_4$ (foliar sprayed at 100 DAE with 75 cm × 40 cm spacing).

**Table 3. Combined effect of plant spacing and time of application of MC growth regulator on seed characteristics of cotton**

| Treatment combination | Seeds boll$^{-1}$ (no.) | Seed index (g) | Lint index (g) | Ginning out turn (%) |
|---|---|---|---|---|
| $S_0G_0$ | 119.67 c-f | 14.78 ab | 9.74 ab | 39.73 d-h |
| $S_0G_1$ | 119.33 d-f | 10.31 kl | 6.94 lm | 40.23 a-e |
| $S_0G_2$ | 115.00 h-j | 14.33 a-c | 9.62 ab | 40.17 a-f |
| $S_0G_3$ | 100.33 l | 13.92 c-e | 9.29 bc | 39.03 ij |
| $S_0G_4$ | 121.33 ab | 15 a | 10.00 a | 40.00 g |
| $S_0G_5$ | 106.33 k | 14 b-e | 9.32 bc | 39.97 cg |
| $S_1G_0$ | 120.00 b-f | 13.65 c-f | 9.34 bc | 40.63 ab |
| $S_1G_1$ | 113.67 j | 10.39 kl | 6.44 m | 38.27 k |
| $S_1G_2$ | 120.67 a-d | 11.68 ij | 7.53 i-k | 39.20 hi |
| $S_1G_3$ | 116.00 gh | 12.59 gh | 8.68 d-f | 40.80 a |
| $S_1G_4$ | 119.00 ef | 11.05 jk | 7.57 ij | 39.60 e-i |
| $S_1G_5$ | 121.67 a | 12.20 hi | 8.36 e-g | 40.67 a |
| $S_2G_0$ | 121.33 ab | 13.22 e-g | 8.89 c-e | 39.20 hi |
| $S_2G_1$ | 107.67 k | 12.05 hi | 8.16 f-h | 40.37 a-c |
| $S_2G_2$ | 120.00 b-f | 11.97 hi | 8.07 g-i | 39.27 hi |
| $S_2G_3$ | 121.00 a-c | 13.08 fg | 8.82 c-e | 40.27 a-d |
| $S_2G_4$ | 120.33 a-e | 11.44 ij | 7.75 hi | 39.40 g-i |
| $S_2G_5$ | 118.67 f | 13.43 d-f | 9.17 b-d | 40.57 a-c |
| $S_3G_0$ | 114.33 ij | 14.76 ab | 9.93 a | 39.23 hi |
| $S_3G_1$ | 115.67 g-i | 11.93 hi | 8.18 f-h | 40.63 ab |
| $S_3G_2$ | 121.67 a | 11.65 ij | 7.90 g-i | 39.40 g-i |
| $S_3G_3$ | 120.33 a-e | 10.12 l | 6.89 lm | 40.50 a-c |
| $S_3G_4$ | 120.67 a-d | 14.22 a-d | 9.71 ab | 39.57 f-i |
| $S_3G_5$ | 114.33 ij | 10.39 kl | 6.98 k-m | 40.57 a-c |
| $S_4G_0$ | 119.67 c-f | 11.94 hi | 8.03 g-i | 39.23 hi |
| $S_4G_1$ | 121.67 a | 10.27 kl | 7.04 j-l | 40.64 a |
| $S_4G_2$ | 119.67 c-f | 11.39 ij | 7.70 hi | 39.33 i |
| $S_4G_3$ | 120.33 a-e | 13.65 c-f | 9.29 bc | 40.50 a-c |
| $S_4G_4$ | 115.67 g-i | 10.23 kl | 6.94 lm | 38.43 jk |
| $S_4G_5$ | 117.00 g | 11.68 ij | 7.94 g-i | 40.47 a-c |
| **LSD $_{(0.05)}$** | **1.554** | **0.8162** | **0.568** | **0.626** |
| **CV (%)** | **6.86** | **0.86** | **1.26** | **1.26** |

Means having same letters in the same column indicates no significant difference at $P \leq 0.05$.

Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (control, CDB recommendation)
$S_1$ = 60 cm× 30 cm (55,555 plants ha$^{-1}$)
$S_2$ = 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

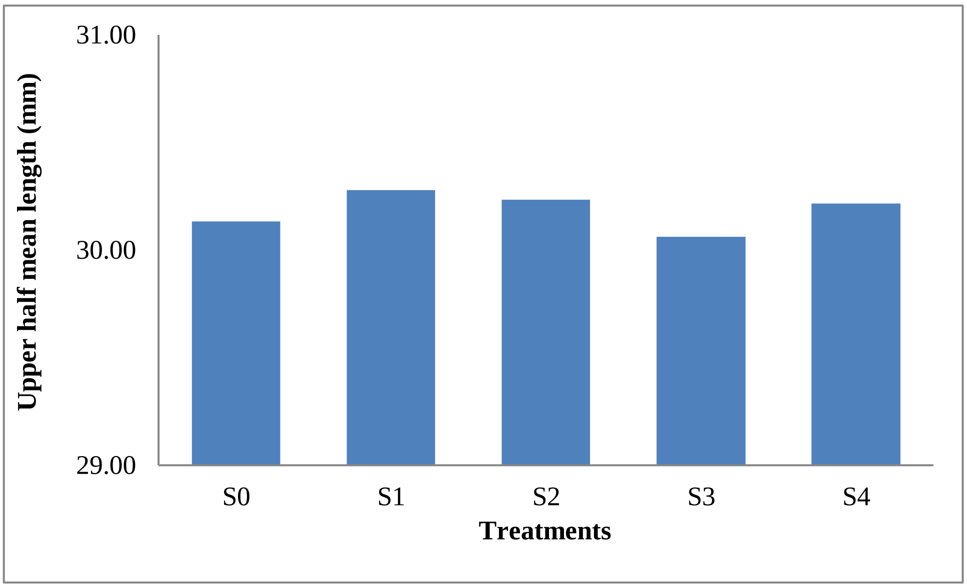
$G_0$ = Water spray (control)
$G_1$= Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

### 4.1.4 Effect of plant spacing and time of application of MC growth regulator on lint characteristics of cotton

#### 4.1.4.1 Upper half mean length (UHML)

**Effect of plant spacing**

Upper half mean length (UHML) of cotton had no considerable variation among the plant spacings (Fig. 27). The maximum UHML (30.28 mm) was recorded at spacing 60 cm × 30 cm ($S_1$). The lowest UHML (30.06 mm) was marked from spacing 75 cm × 30 cm i.e. $S_3$. Nichols *et al*. (2003) observed that fiber length was increased as plant population increased in cotton. Darawsheh *et al*. (2009 b) reported that 50% span length of lint was negatively affected ($P \leq 0.05$) by high plant density in narrow row. On the contrary, Pitombeira (1972) reported that fiber length (upper half mean) was not significantly affected by plant population.

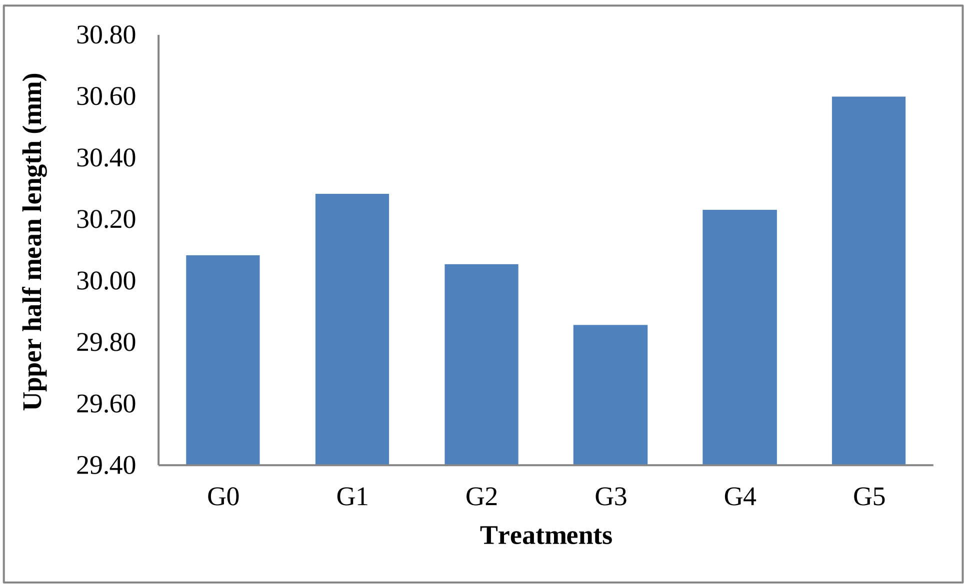



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 27. Influence of different plant spacing on upper half mean length of cotton (LSD $_{(0.05)}$ = 0.436).**

### Effect of time of application of MC growth regulator

MC had significant effect on UHML of cotton (Fig. 28). The highest UHML (30.60 mm) was obtained from foliar sprayed at $G_5$ (at 125 DAE) and the lowest (29.86 mm) at $G_3$ (at 75 DAE). Silva *et al.* (2016) and Edivaldo *et al.* (1996) reported that CCC @ 50 g a.i. ha$^{-1}$ applied from 60 to 70 days after the emergence increased fiber length in cotton. On the contrary, Copur *et al.* (2010) reported that fiber length was not affected by the PGRs (except pix) treatments in cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 28. Influence of time of application of mepiquat chloride on upper half mean length of cotton (LSD $_{(0.05)}$ = 0.302).**

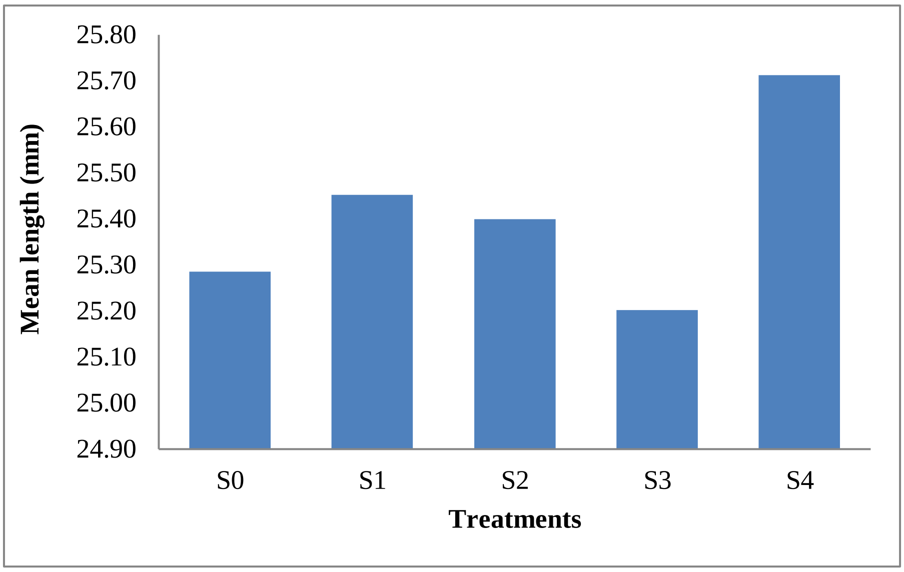
### Combined effect of plant spacing and time of application of MC growth regulator

Combined effect of MC and plant population had significant effect on upper half mean length (UHML) of lint but UHML increased on MC sprayed than control (Table 4). UHML of lint was maximum (30.78 mm) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) which was statistically similar with $S_0G_1$, $S_0G_2$, $S_0G_4$, $S_0G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE with 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_4$, $S_1G_5$ (foliar sprayed at 50, 100 and 125 DAE with water in 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_5$ (foliar sprayed at 25, 100 and 125 DAE with water under 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_4$, $S_3G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE with water for 75 cm × 30 cm spacing) $S_4G_0$, $S_4G_1$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed at 25, 75, 100 and 125 DAE with water in 75 cm × 40 cm spacing) and it was lowest (29.56 mm) at water sprayed with 90 cm × 45 cm spacing ($S_0G_0$) which was statistically at par with $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$ (foliar sprayed from 25 to 100 DAE with 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 50 to 125 DAE with water in 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$ (foliar sprayed from 25 to 125 DAE with water under 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$, $S_3G_5$ (foliar sprayed from 25 to 125 DAE with water for 75 cm × 30 cm spacing) $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_4$ and $S_4G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE with water in 75 cm × 40 cm spacing).

#### 4.1.4.2 Mean length (ML of lint)

**Effect of plant spacing**

Mean length (ML) of cotton had significant variation among the plant spacings (Fig. 29). The maximum ML (25.71 mm) was recorded at spacing 75 cm × 40 cm ($S_4$) which was statistically at par with $S_1$ (60 cm × 30 cm). The lowest ML (25.20 mm) was marked from spacing 75 cm × 30 cm ($S_3$) which was statistically at par with other spacings. Darawsheh *et al*. (2009 b) reported that 50% span length of lint was negatively affected ($P \leq 0.05$) by high plant density in narrow row. On the contrary, Pitombeira (1972) reported that fiber length was not significantly affected by plant population.

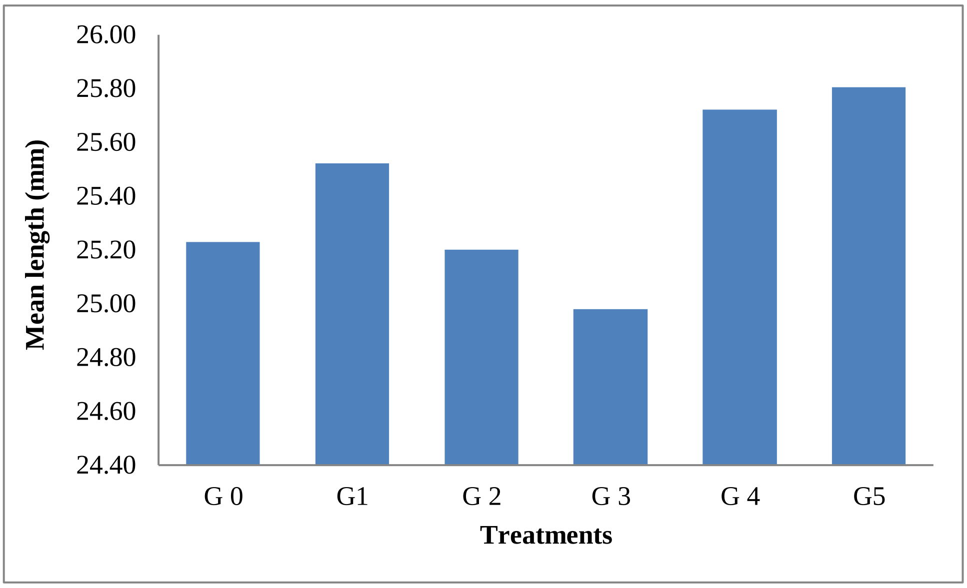



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 29. Influence of different plant spacing on mean length of cotton (LSD $_{(0.05)}$ = 0.413).**

**Effect of time of application of MC growth regulator**

MC had significant effect on ML of cotton (Fig. 30). The highest ML (25.81 mm) was obtained from foliar sprayed at $G_5$ (at 125 DAE) which was statistically similar with $G_1$ and $G_4$. The lowest ML (24.98 mm) was recorded at $G_3$ (at 75 DAE) which was at par with $G_2$ and $G_0$ treatments Silva *et al.* (2016) and Edivaldo *et al.* (1996) reported that CCC @ 50 g a.i. ha$^{-1}$ applied from 60 to 70 days after the emergence increased fiber length in cotton. On the contrary, Copur *et al.* (2010) reported that fiber length was not affected by the PGRs (except pix) treatments in cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 30. Influence of time of application of mepiquat chloride on mean length of cotton (LSD $_{(0.05)}$ = 0.496).**

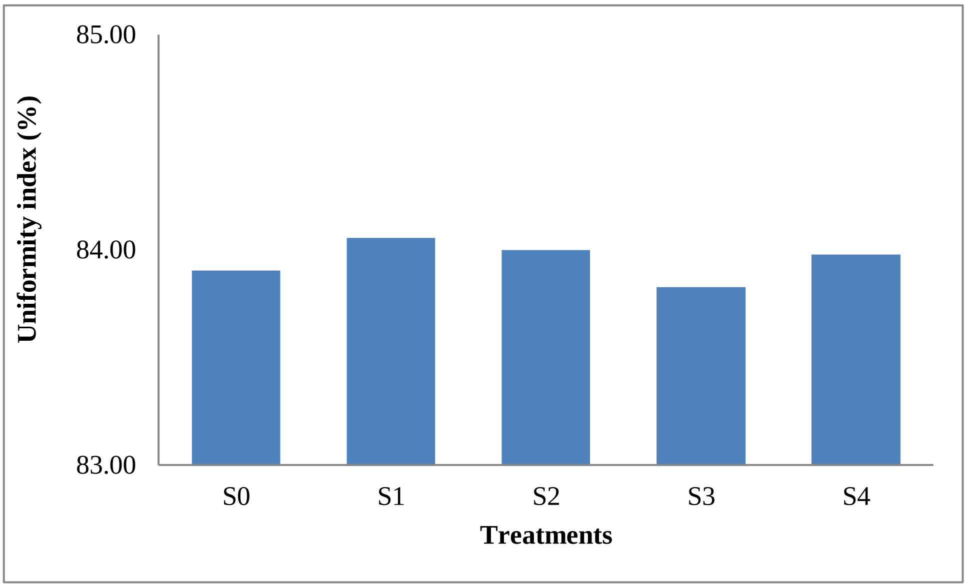
### Combined effect of plant spacing and time of application of MC growth regulator

Mean length (ML) of lint was remarkably affected by plant spacing and MC spray at different times (Table 4). Regardless of treatments, plants treated with MC at different times produced higher ML. ML of lint marked highest (27.01 mm) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) which was statistically similar with $S_0G_5$ (foliar sprayed at 125 DAE with 90 cm × 45 cm spacing); $S_2G_5$ (foliar sprayed at 125 DAE with 60 cm × 40 cm spacing); $S_4G_1$ and $S_4G_3$ (foliar sprayed at 25 and 75 DAE with 75 cm × 40 cm spacing) and it became lowest (24.68 mm) at foliar sprayed with 90 cm × 45 cm spacing ($S_3G_3$) which was statistically similar with $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$ (foliar sprayed from 25 to 125 DAE with 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 50 to 125 DAE with water in 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$ (foliar sprayed from 25 to 100 DAE with water under 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$, $S_3G_5$ (foliar sprayed from 25 to 125 DAE with water for 75 cm × 30 cm spacing); $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 25 to 125 DAE with water in 75 cm × 40 cm spacing).

### 4.1.4.3 Uniformity index (UI) of lint

**Effect of plant spacing**

Uniformity index (UI) of lint of cotton had no significant variation among the plant spacings (Fig. 31). The highest UI (84.05%) was recorded at spacing 60 cm × 30 cm ($S_1$). The lowest UI (83.83%) was marked from spacing 75 cm × 30 cm ($S_3$). Nichols *et al.* (2004) reported negative impact of increased plant density on lint uniformity in cotton (Feng *et al.*, 2011; Valco *et al.*, 2001 and Pitombeira, 1972).

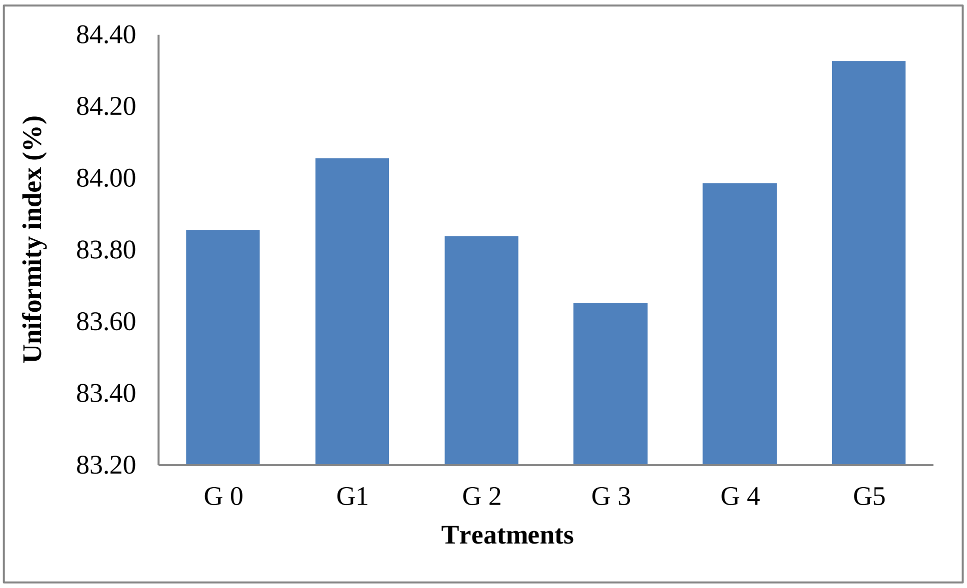



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 31. Influence of different plant spacing on uniformity index of cotton (LSD $_{(0.05)}$ = 0.392).**

**Effect of time of application of MC growth regulator**

MC had significant effect on UI of cotton (Fig. 32). The maximum UI (84.33%) was obtained from foliar sprayed at $G_5$ (at 125 DAE) and the lowest (83.65%) at 75 DAE ($G_3$). Copur *et al.* (2010) reported that fiber uniformity was not affected by the PGRs (except pix) treatments in cotton.




Here,

$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 32. Influence of time of application of mepiquat chloride on uniformity index of cotton (LSD $_{(0.05)}$ = 0.285).**

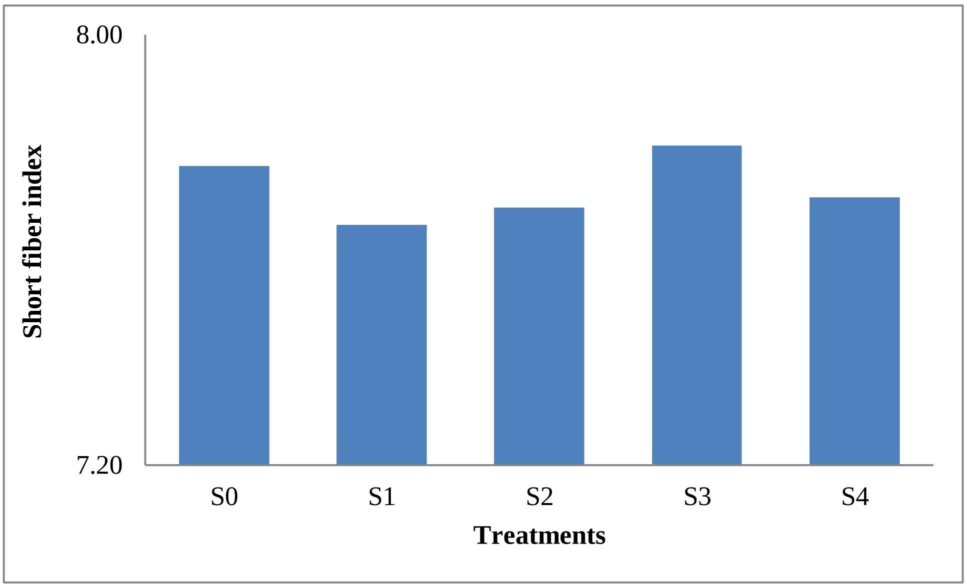
**Combined effect of plant spacing and time of application of MC growth regulator**

Uniformity index (UI) of lint was significantly affected by plant spacing and time of MC spray (Table 4). The highest UI of lint (84.63%) was obtained from $S_1G_1$ i.e. foliar sprayed at 25 DAE with 60 cm × 30 cm which was statistically at par with $S_0G_1$, $S_0G_2$, $S_0G_4$, $S_0G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE, respectively under 90 cm × 45 cm spacing), $S_1G_0$, $S_1G_2$, $S_1G_4$, $S_1G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with water under 60 cm × 30 cm spacing), $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_5$ (foliar sprayed from 25, 50, 100 and 125 DAE, respectively under 60 cm × 40 cm spacing), $S_3G_0$, $S_3G_4$, $S_3G_5$ (foliar sprayed from 100 to 125 DAE, respectively with water in 75 cm × 30 cm spacing), $S_4G_1$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed at 25 and from 75 to 125 DAE, respectively under 75 cm × 40 cm spacing) treatment combinations and the lowest (83.42%) from $S_3G_3$ i.e. foliar sprayed at 75 DAE with 75 cm × 30 cm spacing followed by $S_0G_0$, $S_0G_2$, $S_0G_3$, $S_0G_4$ (foliar sprayed from 50 to 100 DAE, respectively with water + 90 cm × 45 cm spacing), $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$ (foliar sprayed from 50 to 100 DAE, respectively with water + 60 cm × 30 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water in 60 cm × 40 cm spacing), $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water in 75 cm × 30 cm spacing), $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations.

#### 4.1.4.4 Short fiber index (SFI) of lint

**Effect of plant spacing**

Short fiber index (SFI) of lint of cotton had no significant variation among the plant spacings (Fig. 33). The maximum SFI (7.79) was recorded at spacing 75 cm × 30 cm ($S_3$). The lowest SFI (7.65) was obtained from 60 cm × 30 cm spacing ($S_1$).




Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) ( check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)

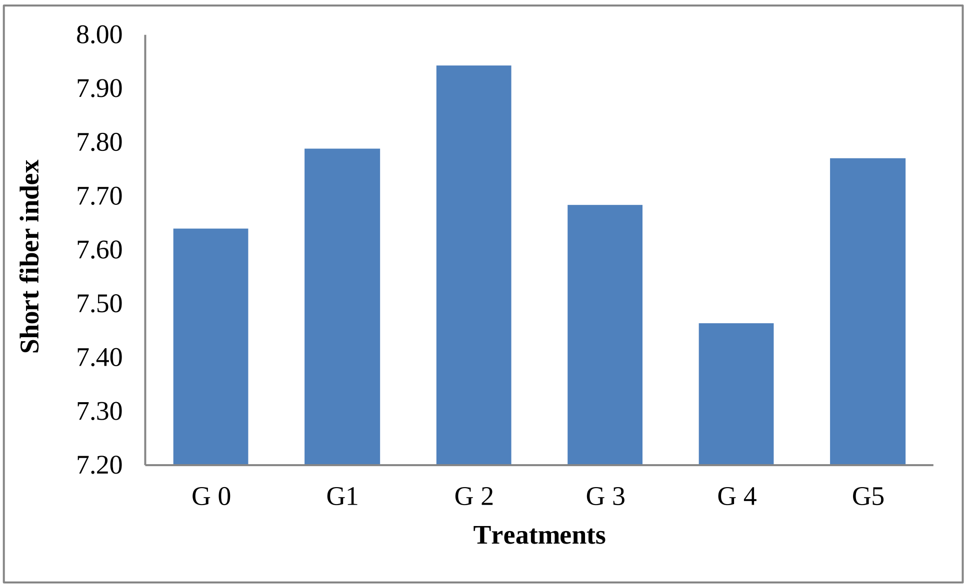
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 33. Influence of different plant spacing on short fiber index of cotton (LSD $_{(0.05)}$ = 0.261).**

**Effect of time of application of MC growth regulator**

MC had significant effect on SFI of cotton (Fig. 34). The highest SFI (7.94) was obtained from foliar sprayed at $G_2$ (at 50 DAE) and the lowest (7.46) at 100 DAE ($G_4$).




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 34. Influence of time of application of mepiquat chloride on short fiber index of cotton (LSD $_{(0.05)}$ = 0.179).**

**Combined effect of plant spacing and time of application of MC growth regulator**

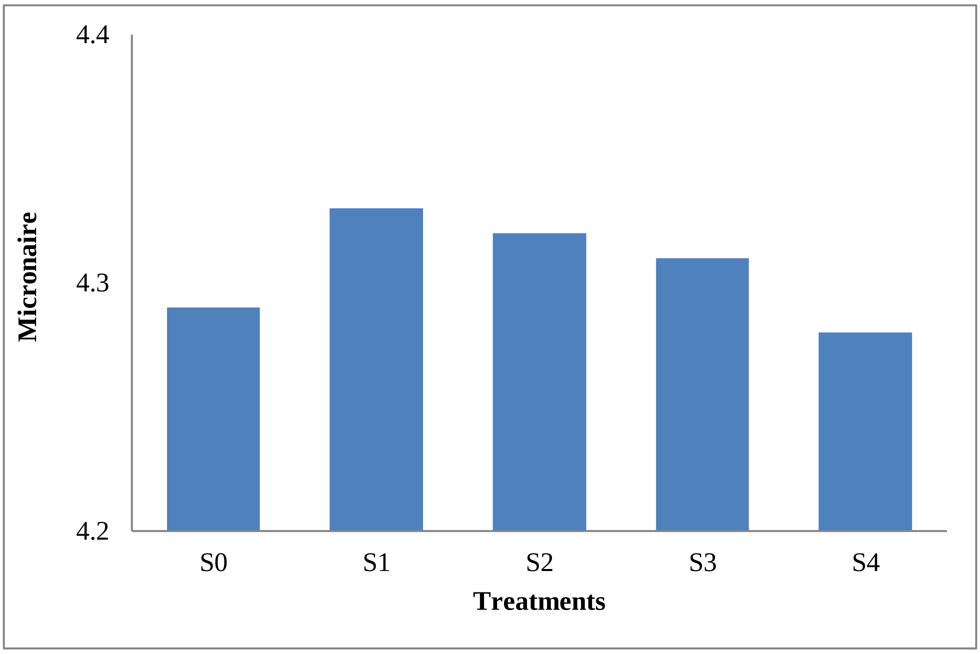
Short fiber index (SFI) of lint was significantly affected by plant spacing and MC sprays combinations (Table 4). SFI of lint was highest (8.1) from foliar sprayed at 75 DAE with 75 cm × 30 cm ($S_3G_3$) followed by $S_0G_0$, $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_3$ (foliar sprayed from 50 to 75 DAE, respectively with water + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations; and the lowest (7.3) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) followed by $S_0G_1$, $S_0G_2$, $S_0G_4$, $S_0G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE, respectively + 90 cm × 45 cm spacing), $S_1G_0$, $S_1G_2$, $S_1G_4$, $S_1G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with water + 60 cm × 30 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE, respectively with water in 60 cm × 40 cm spacing), $S_3G_0$, $S_3G_1$, $S_3G_4$, $S_3G_5$ (foliar sprayed at 25, 100 and

125 DAE, respectively with water in 75 cm × 30 cm spacing), $S_4G_0$, $S_4G_1$, $S_4G_4$ and $S_4G_5$ (foliar sprayed at 25, 100 and 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations.

#### 4.1.4.5 Micronaire (Mic.) of lint

**Effect of plant spacing**

Micronaire of lint of cotton had no significant variation among the plant spacings (Fig. 35). Numerically maximum micronaire (4.33) was recorded at 60 cm × 30 cm spacing ($S_1$). The lowest micronaire (4.28) was marked from spacing 75 cm × 40 cm ($S_4$). Darawsheh *et al*. (2009 b) reported that lint quality micronaire was negatively affected ($P \leq 0.05$) by high plant density in narrow row.

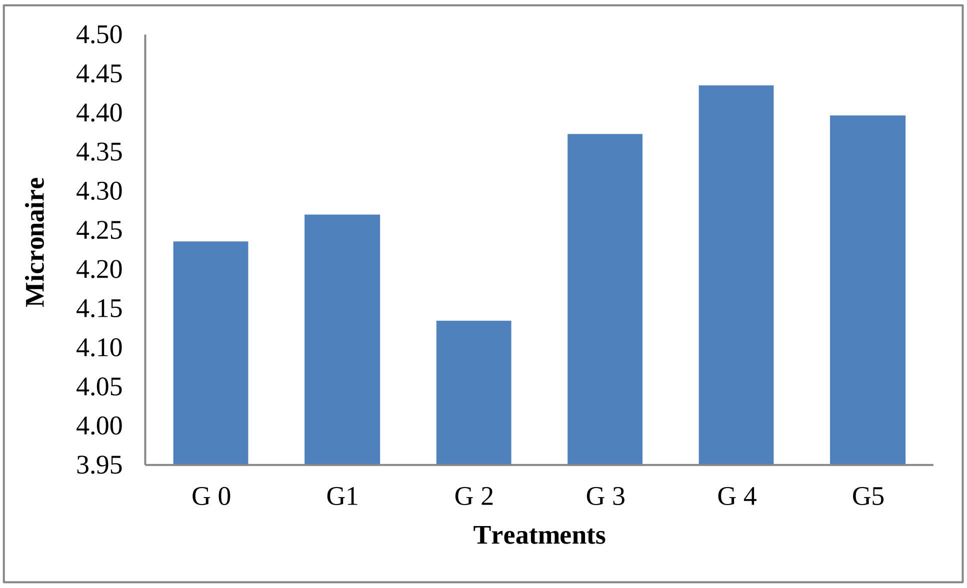



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 35. Influence of different plant spacing on micronaire of cotton (LSD $_{(0.05)}$ = 0.206).**

**Effect of time of application of MC growth regulator**

MC had significant effect on micronaire of cotton (Fig. 36). The highest micronaire (4.44) was obtained from foliar sprayed at 100 DAE ($G_4$) followed by 125 and 75 DAE and the lowest (4.13) at $G_2$ (at 50 DAE) which was at par with 25 DAE and control. Silva *et al.* (2016) observed that application of biostimulants caused changes in the fiber characteristics, related to micronaire of the fiber (Hasab *et al.*, 2019). On the contrary, Copur *et al.* (2010) reported that fiber fineness was not affected by the PGRs (except pix) treatments.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 36. Influence of time of application of mepiquat chloride on micronaire of cotton (LSD $_{(0.05)}$ = 0.142).**

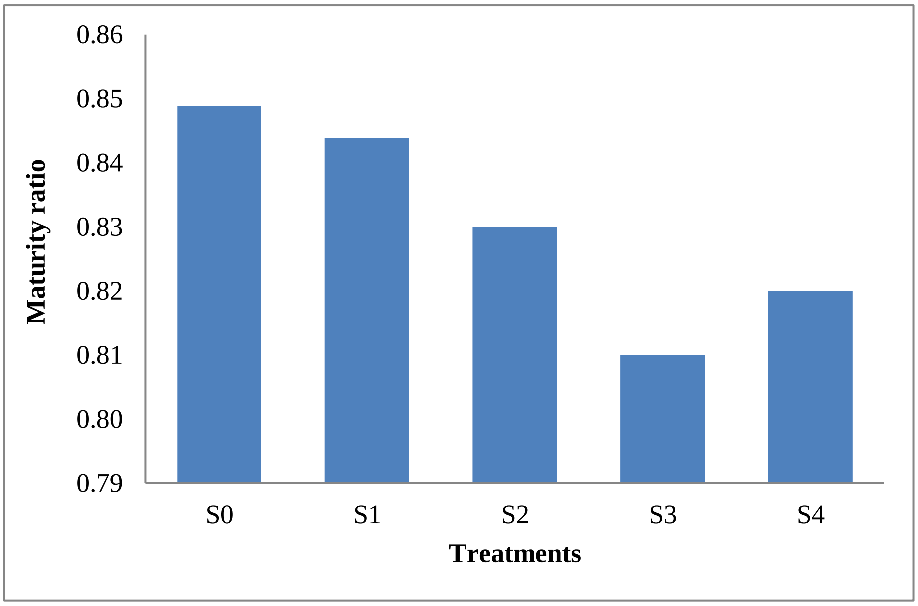
**Combined effect of plant spacing and time of application of MC growth regulator**

Micronaire had significantly affected by plant population and time of MC spray combinations (Table 4). Micronaire of lint was found highest (4.61) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) followed by $S_0G_0$, $S_0G_3$, $S_0G_4$, $S_0G_5$ (foliar sprayed from 75 to 125 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_5$ (foliar sprayed at 50 and 125 DAE, respectively with water + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_4$, $S_2G_5$ (foliar sprayed at 25, 100 and 125 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$, $S_3G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_0$, $S_4G_2$, $S_4G_4$ and $S_4G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations; and it was observed lowest (3.92) from foliar sprayed at 75 DAE with 75 cm × 40 cm spacing ($S_4G_3$) which was followed by $S_0G_0$, $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 50 to 125 DAE, respectively + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$ (foliar sprayed from 25 to 75 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_3$, $S_3G_4$ (foliar sprayed at 25, 75 and 100 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_1$, $S_4G_2$, $S_4G_3$ and $S_4G_4$ (foliar sprayed from 25 to 100 DAE, respectively in 75 cm × 40 cm spacing).

### 4.1.4.6 Maturity ratio (MR)

**Effect of plant spacing**

Maturity ratio of lint of cotton had considerable variation among the plant spacings (Fig. 37). The highest maturity ratio (0.85) was recorded at 90 cm × 45 cm spacing ($S_0$) and the lowest maturity ratio (0.81) was marked from 75 cm × 30 cm spacing ($S_3$). Feng *et al.* (2011) observed that increased plant density reduced maturity ratio.

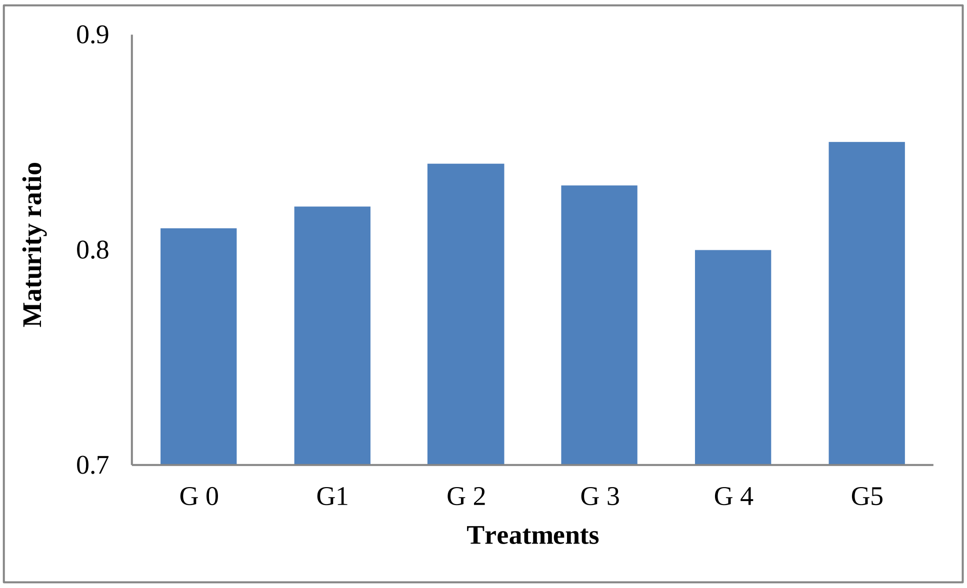


Here,
$S_0$ = 90 cm × 45 cm (24,691 plants $ha^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants $ha^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants $ha^{-1}$)

**Figure 37. Influence of different plant spacing on maturity ratio of cotton (LSD $_{(0.05)}$ = 0.026).**

## Effect of time of application of MC growth regulator

MC had no significant effect on maturity ratio of cotton (Fig. 38). The higher maturity ratio (0.85) was obtained from foliar sprayed at 125 DAE ($G_5$) which was statistically identical with 75 DAE and the lower (0.80) from foliar sprayed at 100 DAE ($G_4$). Edivaldo *et al*. (1996) reported that CCC @ 50 g a.i. $ha^{-1}$ applied from 60 to 70 days after the emergence increased fiber maturity in cotton.




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 38. Influence of time of application of mepiquat chloride on maturity ratio of cotton (LSD $_{(0.05)}$ = 0.049).**

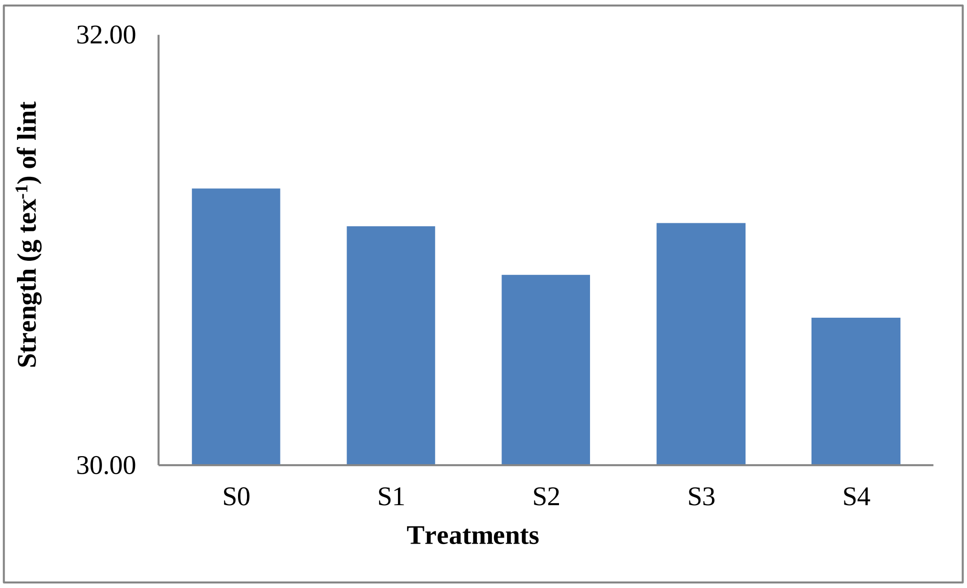
## Combined effect of plant spacing and time of application of MC growth regulator

Maturity ratio (MR) of lint had significantly affected by the combined effect of plant spacing and time of MC spray (Table 4). The maximum MR value (0.89) was obtained from $S_4G_4$ i.e. MC sprayed at 100 DAE with 75 cm × 40 cm spacing, which was statistically similar with $S_4G_1$ and $S_4G_3$ (MC sprayed at 25 and 75 DAE, respectively under the same spacing) treatment combinations and the minimum MR (0.83) was recorded from control with 60 cm × 30 cm spacing ($S_1G_0$) which was statistically similar with $S_0G_0$, $S_0G_2$, $S_0G_4$ (foliar sprayed at 25 and 100 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_3$, $S_1G_5$ (foliar sprayed at 75 and 125 DAE, respectively with water + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_2$, $S_2G_4$ (foliar sprayed at 50 and 100 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_4$, $S_3G_5$ (foliar sprayed at 25, 100 and 125 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_0$, $S_4G_2$ and $S_4G_5$ (foliar sprayed at 50 and 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations.

#### 4.1.4.7 Strength of lint

**Effect of plant spacing**

Strength of lint of cotton had no significant variation among the plant spacings (Fig. 39). The maximum strength (31.29 g $tex^{-1}$) was recorded at 90 cm × 45 cm spacing ($S_0$). The lowest strength of lint (30.69 g $tex^{-1}$) was noticed from 75 cm × 40 cm spacing ($S_4$).



Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)

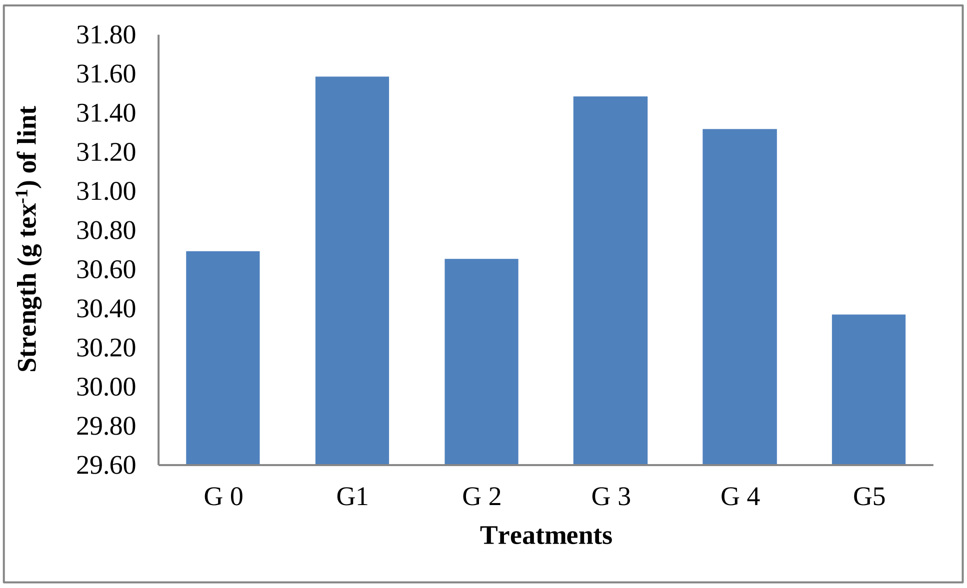
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 39. Influence of different plant spacing on strength of lint of cotton (LSD $_{(0.05)}$ = 0.626).**

### Effect of time of application of MC growth regulator

MC had significant effect on strength of lint of cotton (Fig. 40). The highest strength of lint (31.59 g tex$^{-1}$) was obtained from foliar sprayed at 25 DAE ($G_1$) which was followed by $G_3$ (75 DAE) and $G_4$ (100 DAE). The lowest (30.17 g tex$^{-1}$) was recorded at $G_5$ (125 DAE) and it was similar with $G_0$ (control) and $G_2$ (50 DAE). Silva *et al.* (2016) observed that application of bio-stimulants caused changes in the fiber characteristics related to strength of the fiber in cotton. On the contrary, Copur *et al.* (2010) reported that fiber strength was not affected by the PGRs (except pix) treatments (Pitombeira, 1972).




Here,

$G_0$ = Water spray (control)

$G_1$ =Foliar spray at 25 days after emergence (DAE)

$G_2$ = Foliar spray at 50 DAE

$G_3$ = Foliar spray at 75 DAE

$G_4$ = Foliar spray at 100 DAE

$G_5$ = Foliar spray at 125 DAE

**Figure 40. Influence of time of application of mepiquat chloride on strength of lint of cotton (LSD $_{(0.05)}$ = 0.752).**

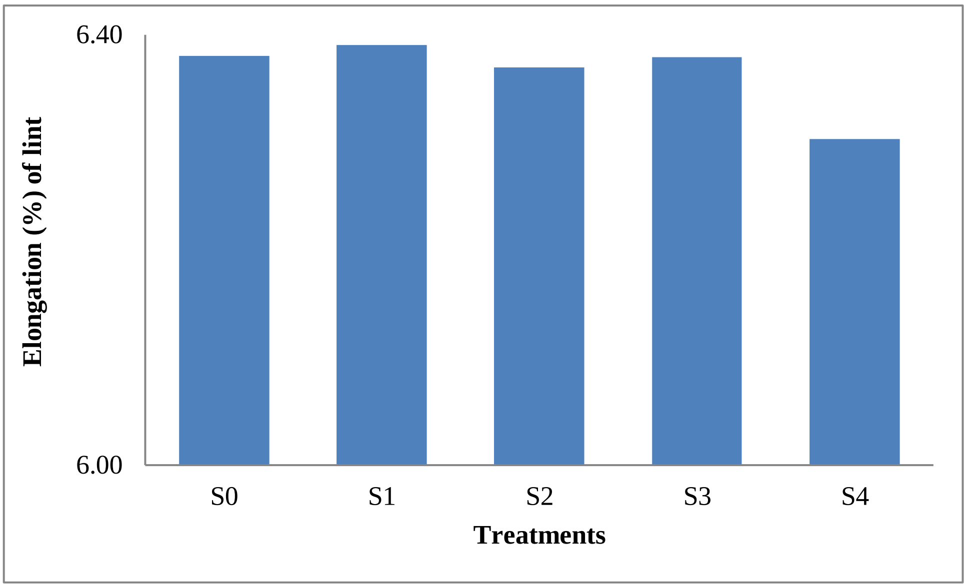
**Combined effect of plant spacing and time of application of MC growth regulator**

Strength of lint had significantly affected by plant spacing and MC spray (Table 4). Strength of lint was maximum (33.08 g tex$^{-1}$) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$) followed by $S_0G_4$ (foliar sprayed at 100 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_2$, $S_1G_4$, $S_1G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with 60 cm × 30 cm spacing); $S_2G_2$, $S_2G_4$, $S_2G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with 60 cm × 40 cm spacing); $S_3G_2$, $S_3G_4$, $S_3G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with 75 cm × 30 cm spacing); $S_4G_2$, $S_4G_3$ and $S_4G_4$ (foliar sprayed at 50 to 100 DAE, respectively with 75 cm × 40 cm spacing) treatment combinations; and it became lowest (29.91 g tex$^{-1}$) from water sprayed with 60 cm × 40 cm spacing ($S_2G_0$) followed by $S_0G_0$, $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 50 to 125 DAE, respectively with water + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$ (foliar sprayed from 25 to 75 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$, $S_3G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_0$, $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 25 to 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations.

**4.1.4.8 Elongation of lint**

**Effect of plant spacing**

Elongation of lint of cotton was not varied significantly across the plant spacings (Fig. 41). The maximum elongation of lint (6.39 %) was recorded at 60 cm × 30 cm spacing ($S_1$). The lowest elongation of lint (6.30 %) was marked from 75 cm × 40 cm spacing ($S_4$). Darawsheh (2009b) reported that row spacing influenced less the fiber elongation.




Here,

$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)

$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)

$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)

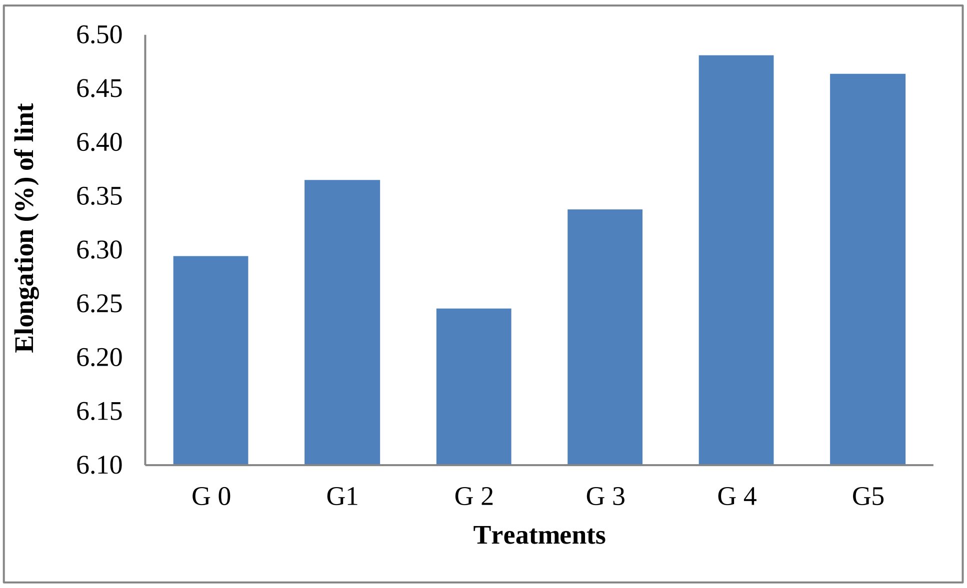
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 41. Influence of different plant spacing on elongation of lint of cotton ($LSD_{(0.05)}$ = 0.158).**

### Effect of time of application of MC growth regulator

MC showed significant effect on elongation of lint of cotton (Fig. 42). The highest elongation of lint (6.48 %) was obtained from foliar sprayed at 100 DAE ($G_4$) which was statistically similar with $G_1$ (25 DAE) and $G_5$ (125 DAE) and the lowest (6.25 %) was recorded at $G_2$ (50 DAE) which was statistically similar with $G_3$ (75 DAE) and without MC ($G_0$).




Here,

$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 42. Influence of time of application of mepiquat chloride on elongation of lint of cotton (LSD $_{(0.05)}$ = 0.128).**

**Combined effect of plant spacing and time of application of MC growth regulator**

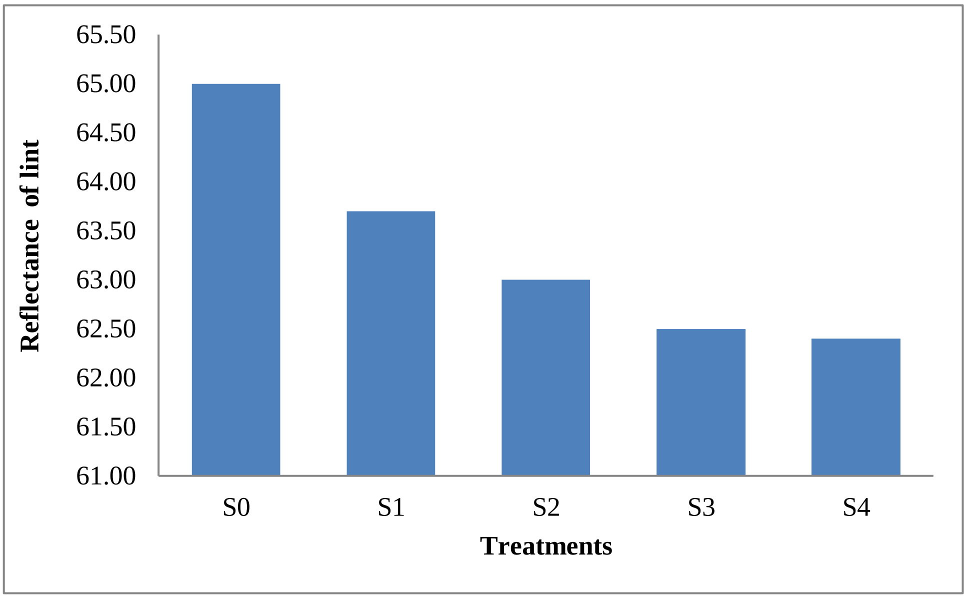
Elongation of lint had significantly affected by the interaction of plant spacing and time of MC spraying (Table 4). Elongation of lint was marked highest (6.62 %) from foliar sprayed at 125 DAE with 60 cm × 40 cm spacing ($S_2G_5$) which was followed by $S_0G_0$, $S_0G_5$ (foliar sprayed from 75 to 125 DAE, respectively with water + 90 cm × 45 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_5$ (foliar sprayed at 50 and 125 DAE, respectively with water + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$ (foliar sprayed at 25 and 50 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_2$, $S_3G_4$, $S_3G_5$ (foliar sprayed at 50, 100 and 125 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_0$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed at 75, 100 and 125 DAE, respectively with water in 75 cm × 40 cm spacing) treatment combinations; and it became lowest (6.15 %) from foliar sprayed at 75 DAE with 60 cm × 40 cm spacing ($S_2G_3$) which was followed by $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$ (foliar sprayed from 25 to 125 DAE, respectively + 90 cm × 45 cm spacing); $S_1G_1$, $S_1G_3$, $S_1G_4$ (foliar sprayed at 25, 50 and 100 DAE, respectively + 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_4$ (foliar sprayed at 25, 50 and 100 DAE, respectively with water in 60 cm × 40 cm spacing); $S_3G_0$, $S_3G_1$, $S_3G_2$, $S_3G_3$, $S_3G_4$ (foliar sprayed from 25 to 100 DAE, respectively with water in 75 cm × 30 cm spacing); $S_4G_1$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$

(foliar sprayed from 25 to 125 DAE, respectively in 75 cm × 40 cm spacing) treatment combinations.

### 4.1.4.9 Reflectance (Rd) of lint

#### Effect of plant spacing

Reflectance of lint of cotton showed significant variation among the plant spacings (Fig. 43). The maximum reflectance of lint (65) was recorded at $S_0$ (90 cm × 45 cm). The minimum reflectance of lint (62.4) was marked from 75 cm × 40 cm spacing ($S_4$).

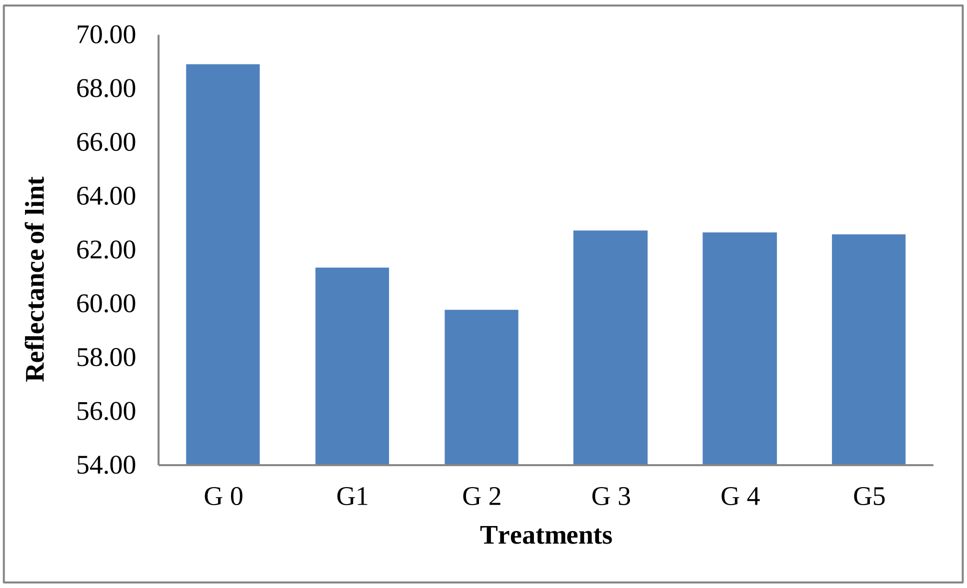



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants $ha^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants $ha^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants $ha^{-1}$)

**Figure 43. Influence of different plant spacing on reflectance of lint of cotton (LSD $_{(0.05)}$ = 1.305).**

#### Effect of time of application of MC growth regulator

MC had significant effect on reflectance of lint of cotton (Fig. 44). The highest reflectance of lint (71.1) was obtained from without MC ($G_0$) and the lowest (52.7) at $G_2$ (at 50 DAE).




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 44. Influence of time of application of mepiquat chloride on reflectance of lint of cotton (LSD $_{(0.05)}$ = 1.279).**

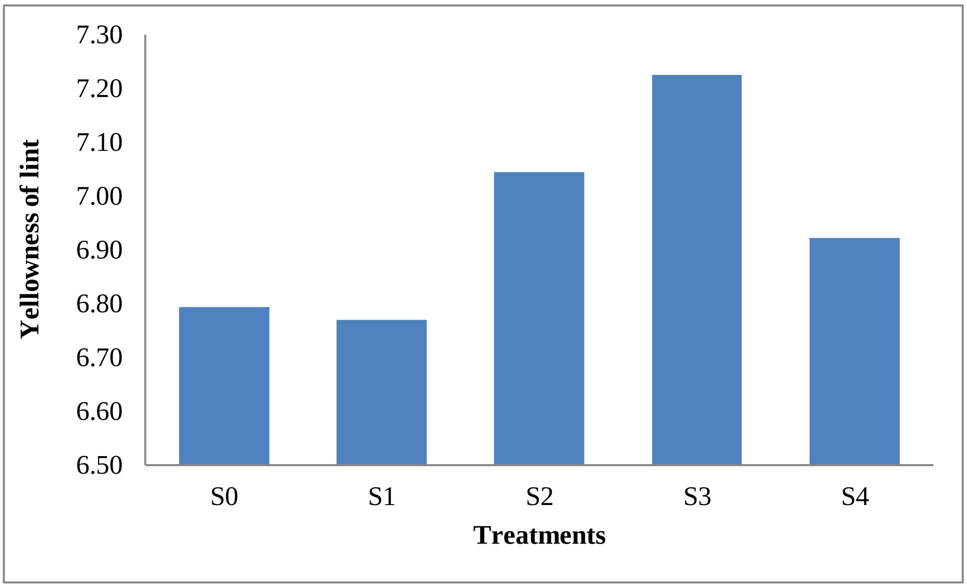
## Combined effect of plant spacing and time of application of MC growth regulator

Reflectance (Rd) of lint significantly affected by plant spacing and time of MC application (Table 4). Rd of cotton lint varied from 58.7 to 79.1. Rd was observed highest (79.1) from foliar sprayed at 25 DAE with 75 cm × 40 cm spacing ($S_4G_1$ treatment combination) and it became lowest (58.7) from foliar sprayed at 75 DAE with 60 cm × 30 cm spacing ($S_1G_3$) which was statistically at par with $S_0G_0$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$ (foliar sprayed from 50 to 125 DAE, respectively with water under 90 cm × 45 cm spacing), $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$ (foliar sprayed from 50 to 125 DAE, respectively under water in 60 cm × 30 cm spacing), $S_2G_0$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$ (foliar sprayed from 50 to 125 DAE, respectively with water under 60 cm × 40 cm spacing), $S_3G_0$, $S_3G_2$, $S_3G_3$, $S_3G_4$, $S_3G_5$ (foliar sprayed from 50 to 125 DAE, respectively with water under 75 cm × 30 cm spacing), $S_4G_0$, $S_4G_2$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 50 to 125 DAE, respectively with water + 75 cm × 40 cm spacing) treatment combinations.

#### 4.1.4.10 Yellowness (+b) of lint

**Effect of plant spacing**

Significant variation in yellowness of lint of cotton was evident among the plant spacings (Fig. 45). The highest yellowness of lint (7.22) was recorded at 75 cm × 30 cm ($S_3$) spacing which was statistically similar with $S_2$ (90 cm × 45 cm) and $S_4$ (75 cm × 40 cm) and the lowest yellowness of lint (6.77) was noted from 60 cm × 30 cm spacing ($S_1$) which was statistically similar with control $S_0$ (90 cm × 45 cm).

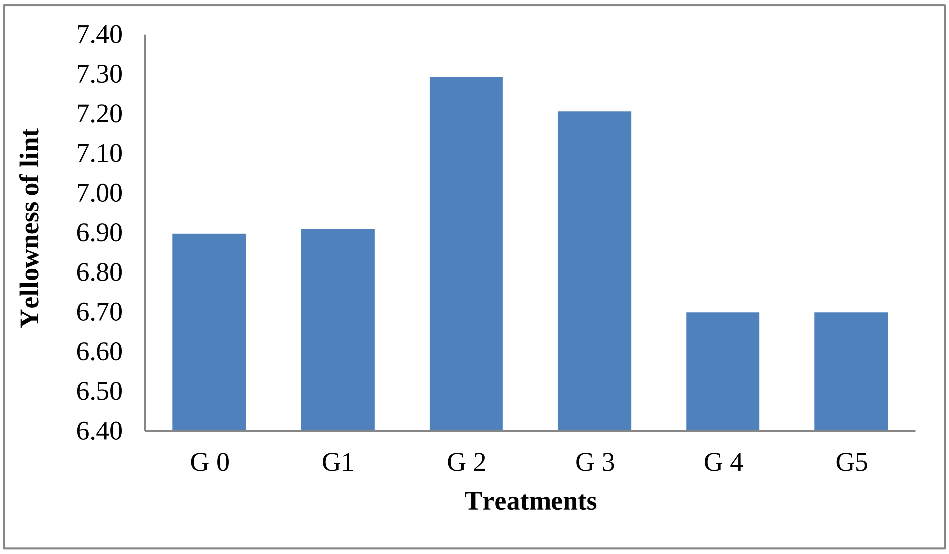



Here,
$S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (check, CDB recommendation)
$S_1$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$S_2$= 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)

**Figure 45. Influence of different plant spacing on yellowness of lint of cotton (LSD $_{(0.05)}$ = 0.338).**

**Effect of time of application of MC growth regulator**

MC had significant effect on yellowness of lint of cotton (Fig. 46). The highest yellowness of lint (7.29) was obtained from foliar sprayed at $G_2$ (at 50 DAE) which was statistically similar with $G_3$ (75 DAE). Treatment $G_1$ (25 DAE) and control are statistically similar. The lowest (6.7) was recorded at 100 DAE ($G_4$) which was statistically identical with 125 DAE ($G_5$).




Here,
$G_0$ = Water spray (control)
$G_1$ =Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

**Figure 46. Influence of time of application of mepiquat chloride on yellowness of lint of cotton (LSD $_{(0.05)}$ = 0.435).**

**Combined effect of plant spacing and time of application of MC growth regulator**

Yellowness (+b) of lint was significantly affected by plant spacing and time of MC application which was between 6.33 to 7.67 (Table 4). The highest +b (7.67) of lint obtained from ($S_4G_4$) foliar sprayed at 100 DAE with 75 cm × 40 cm spacing which was statistically at par with $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$ (foliar sprayed from 25 to 100 DAE, respectively under 90 cm × 45 cm spacing), $S_1G_3$, $S_1G_5$ (foliar sprayed at 75 and 125 DAE, respectively under 60 cm × 30 cm spacing), $S_2G_2$, $S_2G_3$ (foliar sprayed at 50 and 75 DAE, respectively under 60 cm × 40 cm spacing), $S_3G_1$, $S_3G_3$, $S_3G_4$ (foliar sprayed at 25, 75 and 100 DAE, respectively under 75 cm × 30 cm spacing), $S_4G_0$, $S_4G_3$, $S_4G_4$ and $S_4G_5$ (foliar sprayed from 75 to 125 DAE with water + 75 cm × 40 cm spacing) treatment combinations. The lowest (6.33) was observed from ($S_0G_0$) water sprayed with 90 cm × 45 cm spacing followed by $S_0G_1$, $S_0G_2$, $S_0G_5$ (foliar sprayed at 25, 50 and 125 DAE with 90 cm × 45 cm spacing), $S_1G_0$, $S_1G_1$, $S_1G_2$, $S_1G_4$, $S_1G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE, respectively with water + 60 cm × 30 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_5$ (foliar sprayed at 25, 50, 100 and 125 DAE, respectively with water + 60 cm × 40 cm spacing), $S_3G_0$, $S_3G_2$, $S_3G_5$ (foliar sprayed at 50 and 125 DAE, respectively with water +

75 cm × 30 cm spacing), $S_4G_0$, $S_4G_1$ and $S_4G_5$ (foliar sprayed at 25 and 125 DAE with water in 75 cm × 40 cm spacing) treatment combinations.

**Table 4. Combined effect of plant spacing and time of application of MC growth regulator on lint characteristics of cotton**

| Treatments | Upper half mean length (mm) | Mean length (mm) | Uniformity index (%) | Short fiber index | Micronaire | Maturity ratio | Strength (g tex$^{-1}$) | Elonga-tion (%) | Reflec-tance | Yellow-ness (+b) |
|---|---|---|---|---|---|---|---|---|---|---|
| $S_0G_0$ | 29.56 d | 24.71 c | 83.66 c-e | 7.93 ab | 4.29 a-d | 0.84 cd | 30.51 b-d | 6.47 a-e | 63.6 e | 6.33 f |
| $S_0G_1$ | 30.43 a-d | 25.62 bc | 84.18 a-d | 7.56 a-c | 4.19 b-d | 0.85 bc | 30.48 b-d | 6.17 ef | 70.2 b | 6.87 a-f |
| $S_0G_2$ | 30.12 a-d | 25.28 bc | 83.92 a-e | 7.76 a-c | 4.20 b-d | 0.84 cd | 30.70 b-d | 6.28 b-f | 62.1 jk | 6.97 a-f |
| $S_0G_3$ | 29.74 b-d | 24.86 bc | 83.55 c-e | 8.01 ab | 4.23 a-d | 0.86 b | 30.37 b-d | 6.29 b-f | 60.5 l | 7.27 a-e |
| $S_0G_4$ | 30.14 a-d | 25.29 bc | 89.30 a-e | 7.71 a-c | 4.27 a-d | 0.84 cd | 31.37 a-d | 6.20 d-f | 63 fg | 7.57 ab |
| $S_0G_5$ | 30.49 a-c | 25.68 a-c | 84.22 a-c | 7.53 bc | 4.46 c | 0.85 bc | 30.68 b-d | 6.40 a-f | 62.7 g-i | 6.53 f |
| $S_1G_0$ | 30.26 a-d | 25.42 bc | 84.01 a-e | 7.65 a-c | 4.53 ab | 0.83 d | 30.09 cd | 6.50 a-d | 62.4 h-j | 6.80 b-f |
| $S_1G_1$ | 30.78 a | 27.01 a | 84.63 a | 7.33 c | 4.61a | 0.85 bc | 33.08 a | 6.40 a-f | 69.1 c | 6.70 d-f |
| $S_1G_2$ | 30.25 a-d | 25.41 bc | 84.02 a-e | 7.67 a-c | 4.32 a-d | 0.85 bc | 31.23 a-d | 6.47 a-e | 60.2 lm | 6.43 ef |
| $S_1G_3$ | 29.84 b-d | 24.96 bc | 83.66 c-e | 7.95 ab | 4.15 b-d | 0.84 cd | 30.53 b-d | 6.20 d-f | 58.7 p | 7.20 a-e |
| $S_1G_4$ | 30.12 a-d | 25.27 bc | 83.90 a-e | 7.53 bc | 4.16 b-d | 0.85 bc | 31.16 a-d | 6.22 d-f | 61.7 k | 6.80 b-f |
| $S_1G_5$ | 30.43 a-d | 25.63 bc | 84.50 ab | 7.53 bc | 4.32 a-d | 0.84 cd | 31.62 a-d | 6.49 a-d | 62.9 gh | 6.83 a-f |
| $S_2G_0$ | 30.02 a-d | 25.16 bc | 83.81 b-e | 7.80 a-c | 4.25 a-d | 0.84 cd | 29.91 d | 6.39 a-f | 62.3 ij | 6.80 b-f |
| $S_2G_1$ | 30.29 a-d | 25.50 bc | 84.4 a-e | 7.63 a-c | 4.22 a-d | 0.85 bc | 30.00 b-d | 6.35 a-f | 67.3 d | 6.50 d-f |
| $S_2G_2$ | 30.17 a-d | 25.32 bc | 83.94 a-e | 7.69 a-c | 4.10 cd | 0.84 cd | 31.00 a-d | 6.39 a-f | 60.6 l | 6.92 a-f |
| $S_2G_3$ | 29.61 b-d | 24.71 c | 83.45 de | 8.06 ab | 4.09 cd | 0.85 bc | 30.55 b-d | 6.15 f | 59.9 mn | 7.23 a-e |
| $S_2G_4$ | 30.38 a-d | 25.56 bc | 84.15 a-e | 7.58 a-c | 4.52 ab | 0.84 cd | 32.22 ab | 6.44 a-f | 61.7 k | 6.70 d-f |
| $S_2G_5$ | 30.38 a-d | 26.18 b | 84.24 a-c | 7.30 c | 4.45 a-c | 0.85 bc | 32.08 a-c | 6.62 a | 62.6 g-j | 6.47 d-f |
| $S_3G_0$ | 30.17 a-d | 25.32 bc | 83.92 a-e | 7.70 a-c | 4.16 b-d | 0.84 cd | 30.57 b-d | 6.40 a-f | 62.4 h-j | 6.63 c-f |
| $S_3G_1$ | 30.01 a-d | 25.14 bc | 83.78 b-e | 7.81 a-c | 4.32 a-d | 0.84 cd | 30.49 b-d | 6.24 c-f | 69.9 b | 7.31 a-d |
| $S_3G_2$ | 29.89 a-d | 25.01 bc | 83.69 c-e | 7.89 ab | 4.44 a-c | 0.85 bc | 31.24 a-d | 6.41 a-f | 59.2 op | 6.76 b-f |
| $S_3G_3$ | 29.59 cd | 24.68 c | 83.42 e | 8.10 a | 4.28 a-d | 0.85 bc | 30.33 b-d | 6.25 b-f | 60.4 lm | 7.57 ab |
| $S_3G_4$ | 30.26 a-d | 25.41 bc | 83.96 a-e | 7.71 a-c | 4.30 a-d | 0.83 d | 31.30 a-d | 6.37 a-f | 63.6 e | 7.30 a-d |
| $S_3G_5$ | 30.46 a-d | 25.65 bc | 84.19 a-c | 7.55 bc | 4.49 a-c | 0.84 cd | 31.7 a-d | 6.54 a-c | 62.3 ij | 6.70 d-f |
| $S_4G_0$ | 30.11 a-d | 25.27 bc | 83.88 b-e | 7.76 a-c | 4.45 a-c | 0.84 cd | 30.76 b-d | 6.56 ab | 62.6 g-j | 6.9 a-f |
| $S_4G_1$ | 30.25 a-d | 25.76 a-c | 84.04 a-e | 7.65 a-c | 4.19 b-d | 0.88 a | 30.98 b-d | 6.30 b-f | 79.1 a | 7.12 a-f |
| $S_4G_2$ | 29.85 b-d | 24.97 bc | 83.64 c-e | 7.91 ab | 4.27 a-d | 0.84 cd | 31.32 a-d | 6.27 b-f | 62.6 g-j | 7.47 a-c |
| $S_4G_3$ | 30.50 ab | 25.69 a-c | 84.19 a-c | 7.98 ab | 3.92 d | 0.88 a | 31.49 a-d | 6.33 a-f | 59.5 no | 7.20 a-e |
| $S_4G_4$ | 30.25 a-d | 25.08 bc | 84.00 a-e | 7.66 a-c | 4.26 a-d | 0.89 a | 31.37 a-d | 6.45 a-f | 63.5 ef | 7.67 a |
| $S_4G_5$ | 30.33 a-d | 25.51 bc | 84.11 a-e | 7.60 a-c | 4.45 a-c | 0.84 cd | 30.83 b-d | 6.36 a-f | 62.5 g-j | 6.97 a-f |
| **LSD $_{(0.05)}$** | **0.895** | **1.35** | **0.73** | **0.539** | **0.401** | **0.010** | **1.999** | **0.314** | **0.587** | **0.855** |
| **CV (%)** | **1.89** | **2.13** | **0.61** | **4.43** | **6.27** | **0.40** | **2.64** | **3.26** | **5.76** | **6.37** |

Means having same letters in the same column indicates no significant difference at $P \leq 0.05$.

Here, $S_0$ = 90 cm × 45 cm (24,691 plants ha$^{-1}$) (control, CDB recommendation)
$S_1$ = 60 cm× 30 cm (55,555 plants ha$^{-1}$)
$S_2$ = 60 cm × 40 cm (41,666 plants ha$^{-1}$)
$S_3$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)
$S_4$ = 75 cm × 40 cm (33,333 plants ha$^{-1}$)
$G_0$ = Water spray (control)
$G_1$= Foliar spray at 25 days after emergence (DAE)
$G_2$ = Foliar spray at 50 DAE
$G_3$ = Foliar spray at 75 DAE
$G_4$ = Foliar spray at 100 DAE
$G_5$ = Foliar spray at 125 DAE

## 4.2 EXPERIMENT 02

**Response of cotton to different plant spacing along with concentrations of growth regulator (mepiquat chloride) and time of foliar application**

The experiment was conducted in the field during 2017-18 with three levels of spacing (selected from previous experiment) and thirteen levels of MC sprays at different growth stages which are given in the chapter 3 (sub-title 3.1.3). The tested variety was CB 14.

The results obtained in the study have been presented either in table or figure which are followed by discussion.

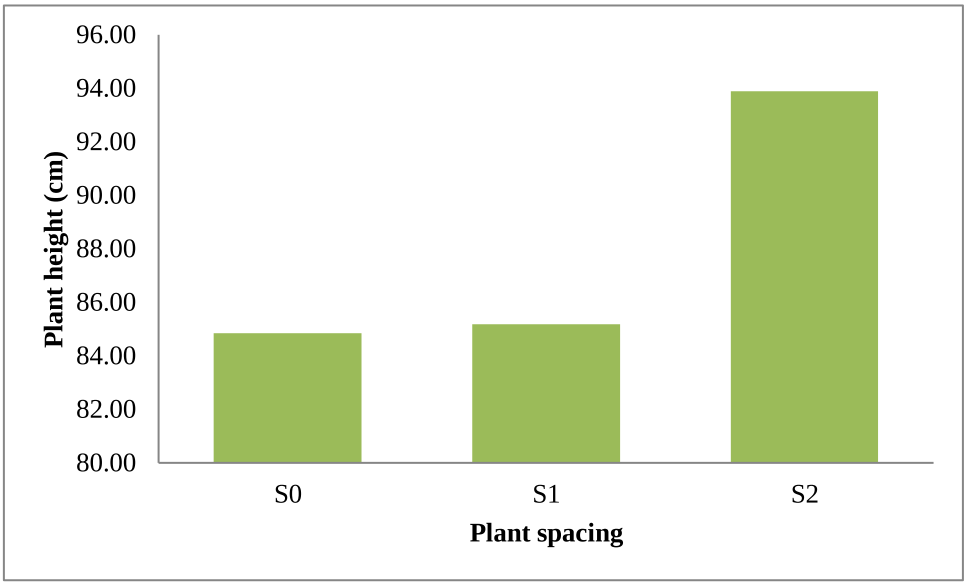
### 4.2.1 Effect of plant spacing and management of growth regulator on phenological parameters of cotton

#### 4.2.1.1 Plant height

**Effect of plant spacing**

Plant height was significantly affected by plant density (Fig. 47). Plant height varied with different plant density ranged from 84.84 to 93.89 cm. Tallest plant (93.89 cm) was produced in the crop raised from 75cm × 30 cm spacing ($S_2$) and the shortest plant (84.84 cm) was recorded from 60 cm × 30 cm spacing ($S_0$) and it was statistically at par with 45 cm × 30 cm spacing ($S_1$).

Baumhardt *et al.* (2018), Deotalu *et al.* (2013) and Jahedi *et al.* (2013) reported that plant height increased significantly with wider row spacing in cotton. Ponnuswami *et al.* (2019) also expressed the similar opinion in moringa.



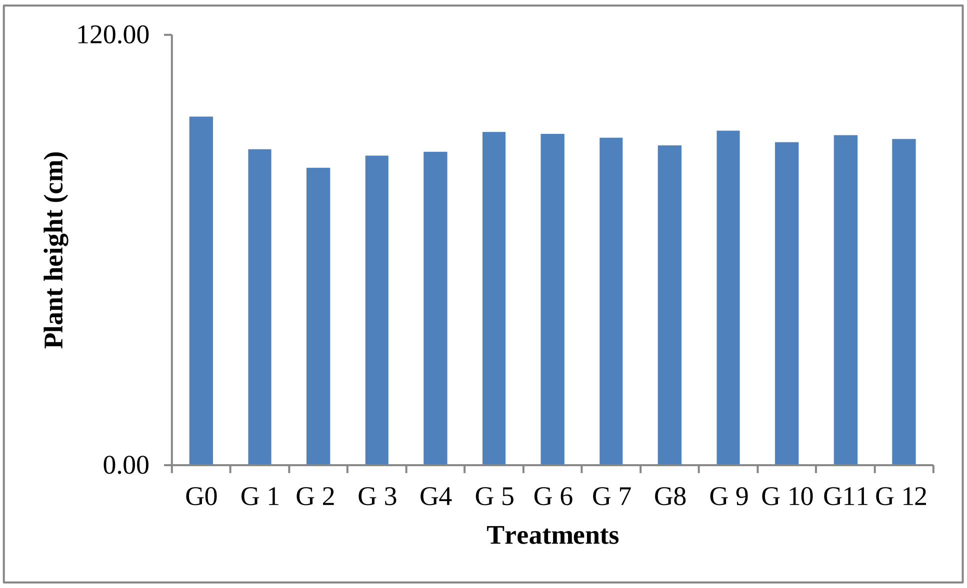

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

**Figure 47. Response of different plant spacing on plant height of cotton (LSD $_{(0.05)}$ = 4.832).**

**Effect of different times of application and concentrations of MC growth regulator**

Variable rates of MC at different time of application were not significant on plant height (Fig. 48). Plant height varied from 82.92 to 97.22 cm giving the mean 90.30 cm. The tallest plant (97.22 cm) was recorded from control ($G_0$) and the shortest (82.92 cm) from 2 ml MC $L^{-1}$ water at 25 DAE ($G_2$). Intermediate plant heights were recorded when MC sprayed at early (25 and 50 DAE) or late (75 DAE).

Kumar *et al.* (2005) reported that 50 ppm MC sprayed at 90 DAS was found to be effective than CCC in reducing cotton plant height. Shahr *et al.* (2015) noted reduced plant height of cotton by 19.5% than control using Pix regulator at 30 days after flowering. Some other scientists observed reduced plant height of different crops with different growth retardants (Amit *et al.*, 2016 in cotton; Niakan and Habibi, 2013 in cotton; Reddy *et al.*, 1990 in cotton; Zhang *et al.*, 2017 in spring wheat; Butcher and Malik, 2016 in oats; Spitzer *et al.*, 2015 in maize; Lucieli *et al.*, 2017 in maize; Kirkland, 1992 in canola; Setia *et al.*, 1995 in *Brassica carinata* ; Baylis and Dickst, 1983 in sunflower). Eveleigh *et al.* (2010) opined that any growth retardant reduces the production of plant hormone gibberellic acid, which in turn slows cell expansion and elongation thus both leaf growth and internode elongation is ceased down to reduce cotton plant height.




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 48. Effect of different times and concentrations of MC on plant height of cotton (LSD $_{(0.05)}$ = 15.76).**

**The Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Combined effect of plant density and MC levels at different times of application on plant height was found significant (Table 5). Plant height increased with the increase of plant spacing (lower plant density) irrespective of growth regulator application time. Irrespective of plant population, gradual shorter plants were observed when plants sprayed with MC at later stages compared to control which indicated that MC reduces plant height. Numerically the tallest Plant (108.75 cm) was recorded from spacing coupled without MC, (control) with 75 cm × 30 cm spacing ($S_2G_0$**)** followed by $S_0G_0$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_8$,

$S_0G_9$, $S_0G_{10}$, $S_0G_{11}$, $S_0G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray under 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE and 1 to 2 ml MC $L^{-1}$ water sprayed at 75 DAE, under 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_3$, $S_2G_5$, $S_2G_7$ and $S_2G_9$ (1 to 4 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE, respectively with water under 75 cm × 30 cm spacing) treatment combination and the shortest plant (67.92 cm) from 2 ml MC $L^{-1}$ water sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$) followed by $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_7$, $S_0G_{11}$ (1, 3 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_{10}$, $S_1G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 and 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$, $S_2G_8$, $S_2G_{10}$ and $S_2G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE, respectively with water under 75 cm × 30 cm spacing) treatment combination. The findings are corroborated to Zhao *et al.* (2019) who stated that application of MC reduced plant height under different plant densities in cotton. Similar result was reported by Lucieli *et al.* (2017) in maize.

#### 4.2.1.2 Internodal length

**Effect of plant spacing**

Variation in internodal length due to different plant spacing was statistically significant (Fig. 49). Internodal length ranged between 4.16 and 4.88 cm. Plant spacing 75 cm × 30 cm ($S_2$) showed maximum internodal length (4.88 cm) while the internodal length was minimum (4.16 cm) in 60 cm × 30 cm spacing ($S_0$) followed by 45 cm × 30 cm plant spacing ($S_1$). Baumhardt *et al.* (2018) narrated that internode increased significantly with increased row spacing in cotton. Similar result was reported by Singh *et al.* (2017a) in tomato.

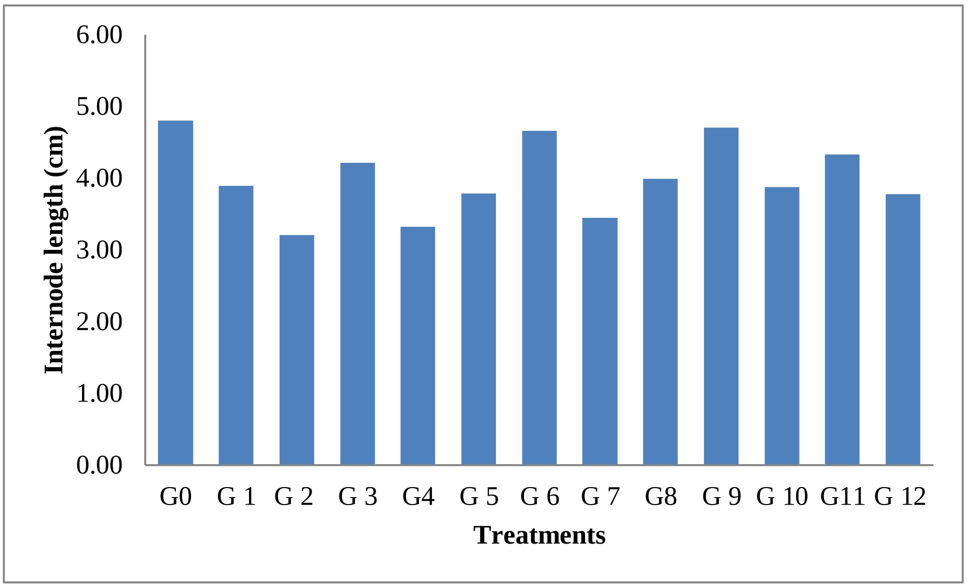

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

**Figure 49. Influence of plant spacing on internode length of cotton (LSD $_{(0.05)}$ = 0.668).**

**Effect of different times of application and concentrations of MC growth regulator**

Significant Variation in internodal length was also observed due to different times and concentrations of MC application (Fig. 50). Internodal length was maximum (4.8 cm) in plants grown in control ($G_0$**)** and the minimum (3.21cm) was from 2 ml MC L$^{-1}$ water sprayed at 25 DAE ($G_2$**)**. Intermediate internodal length was recorded when MC sprayed at early (25 and 50 DAE) or late (75 DAE).

Priyanka and Dalvi (2019) reported that internodal length reduced as MC sprayed compared to control. Application of mepiquat chloride (mc @ 15ml and 10 ml 10 L$^{-1}$ of water) at square and flower formation stage was found effective in reducing internode length in cotton. Some others also observed the same result (Shahr *et al.*, 2015 in cotton; Gu *et al.*, 2014 in cotton; Eveleigh *et al.*, 2010 in cotton; Volterrani *et al.*, 2015 in bermuda grass).




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 50. Effect of different times of application and concentrations of MC on internode length of cotton (LSD $_{(0.05)}$ = 0.673).**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Combined effect of Plant spacing and MC levels at different time of application of growth regulator significantly affected internodal length (Table 5). Internode of cotton plant noticed highest (5.50 cm) from water sprayed with 75 cm × 30 cm spacing ($S_2G_0$) which was statistically at par with $S_0G_0$, $S_0G_4$, $S_0G_5$, $S_0G_7$, $S_0G_{11}$ (4, 1 and 3 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray under 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_{12}$ (1, 3, 4, 1 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray under 45 cm × 30 cm spacing) and $S_2G_1$, $S_2G_5$, $S_2G_7$, $S_2G_9$ (1, 3 and 1 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE, respectively under 75 cm × 30 cm spacing) treatment combination and it was marked lowest (3.33 cm) at 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$) followed by $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_6$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE and 1 to 2 ml MC $L^{-1}$ water sprayed at 75 DAE, under 45 cm × 30 cm spacing); $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_6$, $S_2G_8$, $S_2G_{10}$ $S_2G_{11}$ and $S_2G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE, respectively with water under 75 cm × 30 cm spacing) treatment combination. Iqbal *et al.* (2007) suggested that internodal length decreased in narrow plant spacing with MC sprayed in cotton.

#### 4.2.1.3 Leaf canopy size

**Effect of plant spacing**

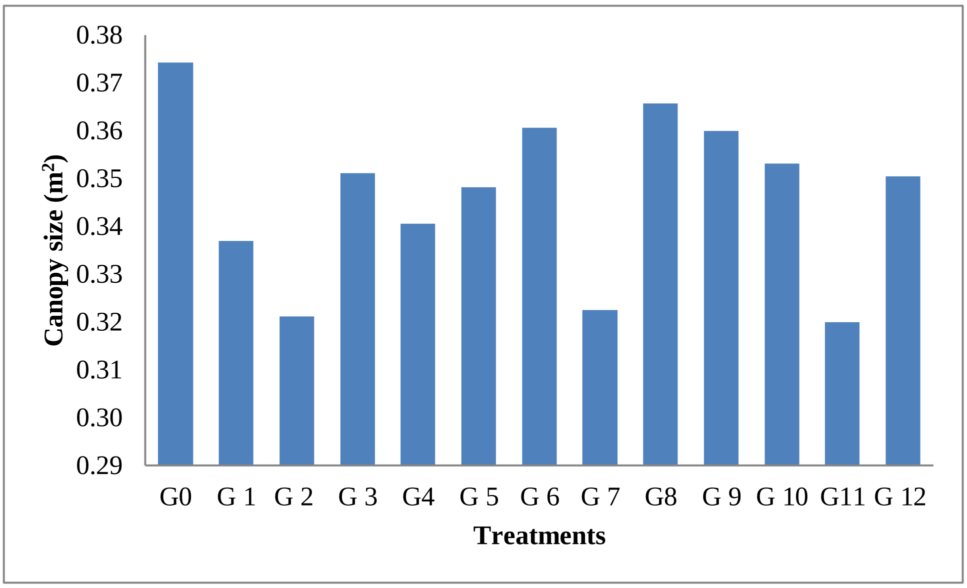
Leaf canopy size of cotton was not significantly affected due to plant spacing (Fig. 51). The maximum leaf canopy size (0.39 $m^2$) was recorded at wider spacing $S_2$ (75 cm × 30 cm). The minimum (0.33$m^2$) was from 60 cm × 30 cm spacing ($S_0$**)** followed by (45m × 30 cm) spacing ($S_1$**)**. Stewart *et al.* (1997) reported that leaf canopy size in peanuts increased as plant density decreased compared to control (Emilie and Kufimfutu, 1995 in oats; Liu *et al.*, 2011 in maize; Ponnuswami and Rani, 2019 in moringa).


Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

**Figure 51. Influence of plant spacing on canopy size of cotton (LSD $_{(0.05)}$ = 0.056).**

**Effect of different times of application and concentrations of MC growth regulator**

A significant variation in leaf canopy size of cotton was observed due to the effect of MC application at different growth periods ranges between 0.32 to 0.37 $m^2$ which was also not significant (Fig. 52). The maximum value for leaf canopy size (0.37 $m^2$) was obtained from water spray ($G_0$**)** and the minimum (0.32 $m^2$) from 2 ml MC $L^{-1}$ water at 25 DAE ($G_2$**)**. Intermediate plant canopy size was recorded when MC sprayed at early (25 and 50 DAE) or late (75 DAE). Gu *et al.* (2014) reported that canopy structure became more compact with the decrease of leaf area index due to the application of MC in cotton. Zhao *et al*. (2019) found that leaf canopy size was decreased as MC sprayed compared to control in cotton (Gollagi *et al.*, 2019 in guava; Singh and Chanana, 2005 in guava; Edgerton, 1983 in apple). Eveleigh *et al.* (2010) opined that Plant hormone reduced the production of the gibberellic acid, which in turn slowed cell expansion resulting in reduced canopy (leaf growth) in cotton.




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 52. Effect of different time of application and concentration of MC on canopy size of cotton (LSD $_{(0.05)}$ = 0.112).**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

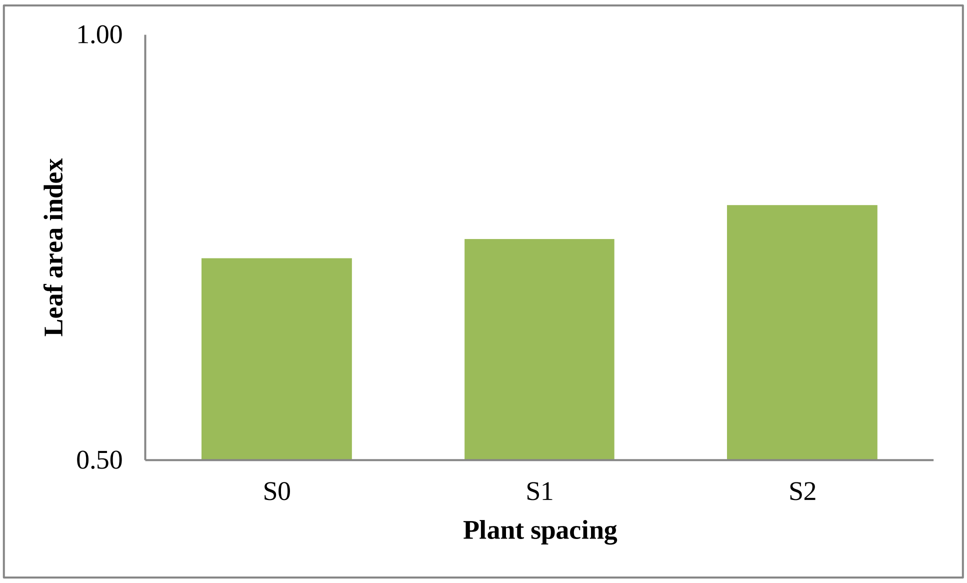
Leaf canopy was significantly affected by combined effect of plant density and MC concentration and application time (Table 5). Leaf canopy size was found to be increased with decreasing plant density. The wider spacing (75 cm × 30 cm) accompanied with plants grown without MC spray ($S_2G_0$**)** gave the highest leaf canopy size (0.46 $m^2$) which was followed by $S_0G_0$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$, $S_0G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water under 60 cm × 30 cm spacing) $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 50 to 75 DAE, under 45 cm × 30 cm spacing) and $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$, $S_2G_8$, $S_2G_9$, $S_2G_{10}$ $S_2G_{11}$, $S_2G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE, with water under 75 cm × 30 cm spacing) treatment combinations. The relatively closer spacing (60m × 30 cm) accompanied with 2 ml MC $L^{-1}$ water at 25 DAE ($S_0G_2$**)** gave the lowest (0.16 $m^2$) canopy size which was statistically at par with $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$, $S_0G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, with water under 60 cm × 30 cm spacing), $S_1G_0$, $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, with water + 45 cm × 30 cm spacing) and $S_2G_1$, $S_2G_2$, $S_2G_3$ (1 to 3 ml MC $L^{-1}$ water sprayed at 25 DAE, + 75 cm × 30 cm spacing), $S_2G_7$, $S_2G_8$ (3 to 4 ml MC $L^{-1}$ water sprayed at 50 DAE, with water + 75 cm × 30 cm spacing), $S_2G_9$, $S_2G_{10}$ and $S_2G_{12}$ (1, 2 and 4 ml MC $L^{-1}$ water sprayed at 75 DAE, + 75 cm × 30 cm spacing) treatment combinations. Zhao *et al*. (2019) reported that application of MC resulting in a lower and more compact plant canopy in cotton.

**4.2.1.4 Leaf area index**

**Effect of plant spacing**

Influence on leaf area index was not found significant by plant density (Fig. 53). LAI was increased with the increase of plant density and the maximum LAI (0.80) was obtained from ($S_2$**)** 75 cm × 30 cm spacing and the minimum LAI (0.74) was from 60 cm x 30 cm spacing ($S_0$**)** which was at par with wider spacing ($S_1$**)** 45 cm × 30 cm.

Sowmiya and Sakthivel (2018) reported that the narrow plant spacing of 60 cm x 15 cm had significantly higher leaf area index in cotton (Pengcheng *et al.*, 2015 in cotton; Darawsheh and Aivalakis, 2009a in cotton). Ricaurte *et al.* (2016) argued that sowing density is a major management factor that affects growth and development of crops by modifying the canopy light environment and interplant competition for water and nutrients in bean.



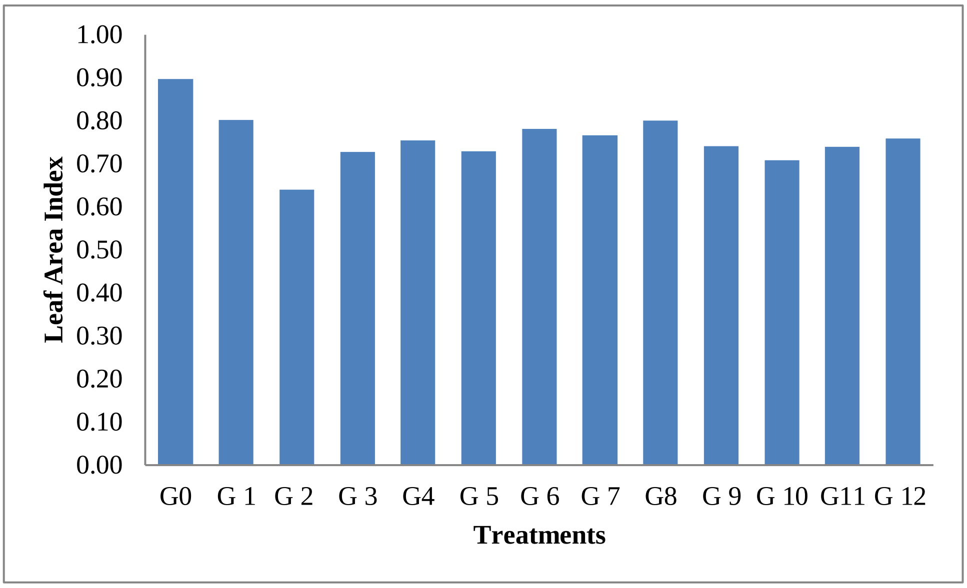

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

**Figure 53. Influence of plant spacing on LAI of cotton (LSD $_{(0.05)}$ = 0.101).**

**Effect of different times of application and concentrations of MC growth regulator**

Application time and concentration of MC had a significant influence on LAI (Fig. 54). LAI was maximum (0.90) for $G_0$ i.e. plants grown without MC (control plants) and ranged between 0.64 to 0.90 across the treatments. Plants grown with application of MC 2 ml L$^{-1}$ water at 25 DAE ($G_2$) produced the minimum (0.64) LAI. Intermediate leaf area was recorded when MC sprayed at early (25 and 50 DAE) or late (75 DAE).

Amit *et al.* (2016) reported that application of MC @ 300 ppm, TIBA @ 100 ppm and MH @ 250 ppm reduced leaf area index than control in cotton. Leaf area index of cotton was decreased as MC sprayed compared to control (Kumar *et al.*, 2005).




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 54. Effect of different times of application and concentrations of MC on LAI of cotton ($LSD_{(0.05)}$ = 0.21).**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Leaf area index was significantly affected by the combined effect of plant density and time and concentration of MC application. Leaf area index of cotton was found to be increased with increasing plant density but decreased as MC sprayed compared to control (Table 5). Leaf area index enumerated highest (1.06) from 2 ml MC $L^{-1}$ water sprayed at 25 DAE with 60 cm x 30 cm spacing ($S_0G_2$) which was followed by $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_{10}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray under 60 cm × 30 cm spacing); $S_2G_0$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$, $S_2G_8$, $S_2G_9$, $S_2G_{10}$ $S_2G_{11}$, $S_2G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE, respectively with water under 75 cm × 30 cm spacing) treatment combinations and it was marked lowest (0.53) at from 2 ml MC $L^{-1}$ water at 25 DAE with 45 cm × 30 cm spacing ($S_1G_2$) which was statistically at par with $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$,

$S_0G_9$, $S_0G_{10}$, $S_0G_{11}$, $S_0G_{12}$ (1to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, with water spray + 60 cm × 30 cm spacing), $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, with water spray + 45 cm × 30 cm spacing) and $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_7$, $S_2G_8$, $S_2G_9$, $S_2G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed at 25 to 75 DAE + 75 cm × 30 cm spacing) treatment combinations.

**Table 5. Combined effect of plant spacing and management of MC growth regulator on phenological characters of cotton**

| Treatments | Plant height (cm) | Internode length (cm) | Canopy size ($m^2$) | Leaf area index |
|---|---|---|---|---|
| **$S_0G_0$** | 104.58 ab | 4.82 a-d | 0.36 a-c | 0.79 a-f |
| **$S_0G_1$** | 78.75 c-e | 3.47 fg | 0.21 bc | 0.78 a-f |
| **$S_0G_2$** | 67.92 e | 3.33 g | 0.16 c | 1.06 a |
| **$S_0G_3$** | 68.75 e | 3.50 fg | 0.21 bc | 0.79 a-f |
| **$S_0G_4$** | 89.58 a-e | 4.65 a-e | 0.31 a-c | 0.76 a-f |
| **$S_0G_5$** | 94.17 a-d | 4.82 a-d | 0.32 a-c | 0.78 a-f |
| **$S_0G_6$** | 96.25 a-d | 3.67 e-g | 0.25 a-c | 0.78 a-f |
| **$S_0G_7$** | 85.00 b-e | 5.00 a-c | 0.33 a-c | 0.77 a-f |
| **$S_0G_8$** | 95.79 a-d | 3.86 d-g | 0.36 a-c | 0.75 a-f |
| **$S_0G_9$** | 97.79 a-c | 4.33 b-g | 0.32 a-c | 0.73 b-f |
| **$S_0G_{10}$** | 93.33 a-d | 4.15 b-g | 0.33 a-c | 0.77 a-f |
| **$S_0G_{11}$** | 87.08 a-e | 4.67 a-e | 0.34 a-c | 0.73 b-f |
| **$S_0G_{12}$** | 96.25 a-d | 3.98 c-g | 0.36 a-c | 0.73 b-f |
| **$S_1G_0$** | 99.17 a-c | 5.22 ab | 0.37 a-c | 0.72 c-f |
| **$S_1G_1$** | 88.75 a-e | 4.50 a-f | 0.33 a-c | 0.53 f |
| **$S_1G_2$** | 68.92 e | 3.33 g | 0.21 bc | 0.53 f |
| **$S_1G_3$** | 87.36 a-e | 4.82 a-d | 0.31 a-c | 0.56 ef |
| **$S_1G_4$** | 87.08 a-e | 4.82 a-d | 0.33 a-c | 0.65 d-f |
| **$S_1G_5$** | 96.67 a-c | 4.50 a-f | 0.30 a-c | 0.66 d-f |
| **$S_1G_6$** | 94.58 a-d | 4.30 b-g | 0.31 a-c | 0.67 c-f |
| **$S_1G_7$** | 92.92 a-d | 3.99 c-g | 0.30 a-c | 0.62 d-f |
| **$S_1G_8$** | 90.13 a-e | 4.28 b-g | 0.33 a-c | 0.62 d-f |
| **$S_1G_9$** | 99.17 a-c | 4.37 b-g | 0.36 a-c | 0.66 d-f |
| **$S_1G_{10}$** | 89.17 a-e | 4.00 c-g | 0.30 a-c | 0.59 d-f |
| **$S_1G_{11}$** | 85.42 b-e | 4.33 b-g | 0.25 a-c | 0.70 c-f |
| **$S_1G_{12}$** | 98.75 a-c | 4.99 a-c | 0.21 bc | 0.72 c-f |
| **$S_2G_0$** | 108.75 a | 5.50 a | 0.46 a | 1.04 ab |
| **$S_2G_1$** | 89.71 a-e | 4.83 a-d | 0.38 a-c | 0.63 d-f |
| **$S_2G_2$** | 76.25 c-e | 3.67 e-g | 0.39 a-c | 0.80 a-f |
| **$S_2G_3$** | 97.92 a-c | 3.63 e-g | 0.40 a-c | 0.98 a-c |
| **$S_2G_4$** | 80.00 c-e | 3.50 fg | 0.41 ab | 0.81 a-f |
| **$S_2G_5$** | 85.83 a-e | 4.67 a-e | 0.42 ab | 0.85 a-e |
| **$S_2G_6$** | 73.33 de | 4.17 b-g | 0.42 ab | 0.89 a-d |
| **$S_2G_7$** | 86.25 a-e | 4.48 a-f | 0.39 a-c | 0.83 a-f |
| **$S_2G_8$** | 85.00 be | 3.83 d-g | 0.40 a-c | 0.82 a-f |
| **$S_2G_9$** | 99.17 a-c | 5.00 a-c | 0.38 a-c | 0.80 a-f |
| **$S_2G_{10}$** | 81.67 b-e | 4.00 c-g | 0.25 a-c | 0.88 a-d |
| **$S_2G_{11}$** | 94.17 a-d | 4.00 c-g | 0.41 ab | 0.84 a-f |
| **$S_2G_{12}$** | 80.00 c-e | 4.17 b-g | 0.38 a-c | 0.89 a-d |
| **LSD $_{(0.05)}$** | **23** | **1.12** | **0.241** | **0.316** |
| **CV (%)** | **8.46** | **14.31** | **15.41** | **11.15** |

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

Here,
$S_0$= 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE

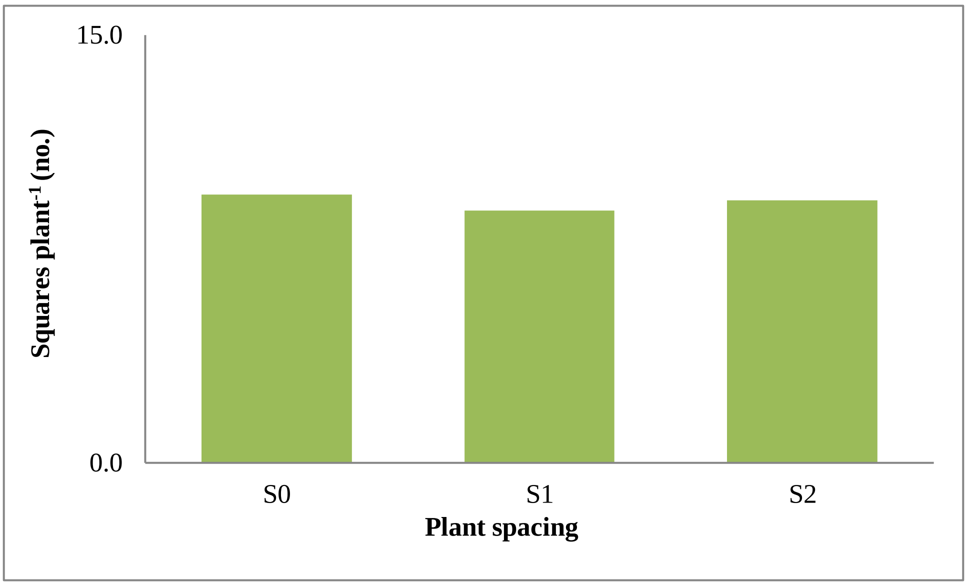
$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75DAE

### 4.2.3 Effect on yield contributing characters and yield of cotton.

#### 4.2.3.1 Squares plant$^{-1}$

**Effect of plant spacing**

Plant spacing insignificantly influenced the number of squares plant$^{-1}$ of cotton (Fig. 55). There was a trend to increase squares plant$^{-1}$ with the increase in plant spacing. The maximum squares plant$^{-1}$ (9.4) was produced from 60 cm × 30 cm spacing ($S_0$**).** The minimum squares plant$^{-1}$ (8.84) was counted from 45 cm x 30 cm spacing ($S_1$**)**. The higher number of squares could have produced due to more photosynthates as partitioned to the flowers. Parekh *et al.* (2018) and Yagia *et al.* (2014) reported that there was a trend to decrease squares plant$^{-1}$ with the decrease in plant spacing in spider lily crop.

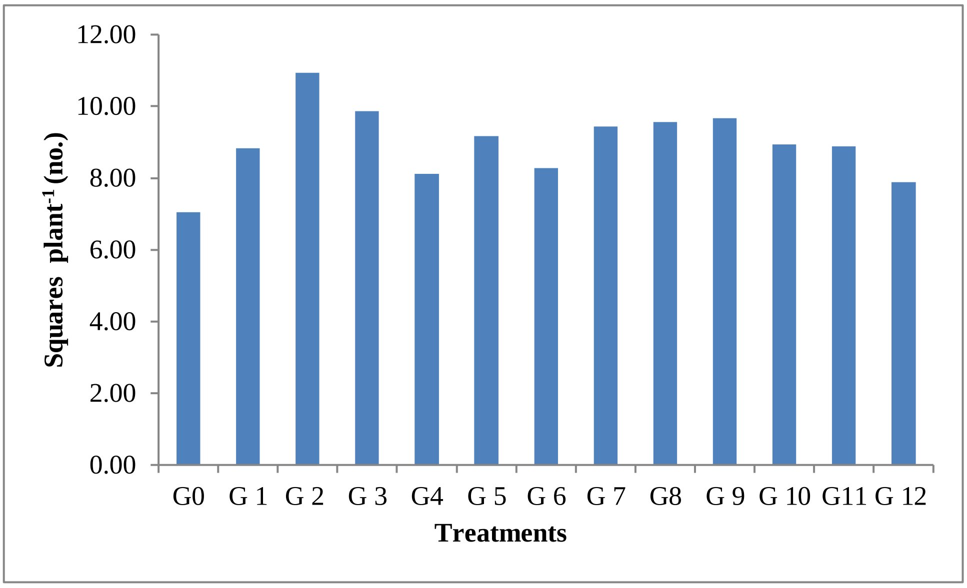



Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

**Figure 55. Effect of plant spacing on squares plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 1.926).**

**Effect of time of application and concentration of MC growth regulator**

The time of application and concentration of MC sprayed from 25 to 75 days after emergence (DAE) had significant effect on square formation (Fig. 56). Squares plant$^{-1}$ was observed highest (10.94) from 2 ml MC L$^{-1}$ water at 25 DAE ($G_2$**)** and it became lowest (7.04) at control ($G_0$) i.e. water spray. Chaplot **(**2015) and Sabale *et al.* (2018) reported maximum number of squares plant$^{-1}$ in early spraying in cotton which is corroborating to the present findings. Kataria and Khanpara (2012) obtained significantly increased squares (108) with decreasing plant height in cotton with Cycocel foliar spray @ 40 ppm at 90 DAS. Some other scientists had similar observations while working with different crops (Koley and Maitra, 2015 in gladiolus; Parmar *et al.*, 2015 in rose flowers; Jamil *et al.*, 2015 in *Hippeastrum*; Pal, 2019 in ornamental plants). Yasmeen *et al.* (2016) reported that combined application of MLE and MC at 45 days after blooming enhanced squares plant$^{-1}$ in Bt cotton.




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75 DAE

**Figure 56. Management of MC level influencing on squares plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 3.735).**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Combination of plant density and MC rates along with application time significantly influenced number of squares plant$^{-1}$ (Table 6). It was observed that plant spacing increased in combination with MC sprayed, increased the squares plant$^{-1}$ compared to control. Squares plant$^{-1}$ was marked highest (15.24) from 2 ml MC L$^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$) which was statistically at par with $S_0G_1$, $S_0G_6$, $S_0G_{11}$, $S_0G_{12}$ (2 ml MC L$^{-1}$ water sprayed at 50 DAE, 3 to 4 ml MC L$^{-1}$ water sprayed at 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_3$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_{10}$ (3 ml MC L$^{-1}$ water sprayed at 25 DAE, 2 to 4 ml MC L$^{-1}$ water sprayed at 50 DAE, 2 ml MC L$^{-1}$ water sprayed at 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_2$, $S_2G_7$, $S_2G_9$ and $S_2G_{12}$ (1 and 2 ml MC L$^{-1}$ water sprayed at 75 DAE, 3 ml MC L$^{-1}$ water sprayed at 50 DAE, 1and 4 ml MC L$^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing) treatment combinations and it became lowest (4.44) at water sprayed with 45 cm × 30 cm spacing ($S_1G_0$) which was followed by $S_0G_0$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$ (3 and 4 ml MC L$^{-1}$ water sprayed at 25 DAE, 1, 3 and 4 ml MC L$^{-1}$ water sprayed at 50 DAE, 1 and 2 ml MC L$^{-1}$ water sprayed at 75 DAE, with water under 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_2$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_9$, $S_1G_{11}$ (1, 2 and 4 ml MC L$^{-1}$ water sprayed at 25 DAE, 1 and 2 ml MC L$^{-1}$ water sprayed at 50 DAE, 1, 3 and 4 ml MC L$^{-1}$ water sprayed at 75 DAE, with water under 45 cm × 30 cm spacing); and $S_2G_0$, $S_2G_1$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_8$, $S_2G_{10}$ $S_2G_{11}$, $S_2G_{12}$ (1, 3 and 4 ml MC L$^{-1}$ water sprayed at 25 DAE, 1, 2 and 4 ml MC L$^{-1}$ water sprayed at 50 DAE, 2 to 4 ml MC L$^{-1}$ water sprayed at 75 DAE, with water under 75 cm × 30 cm spacing) treatment combinations.

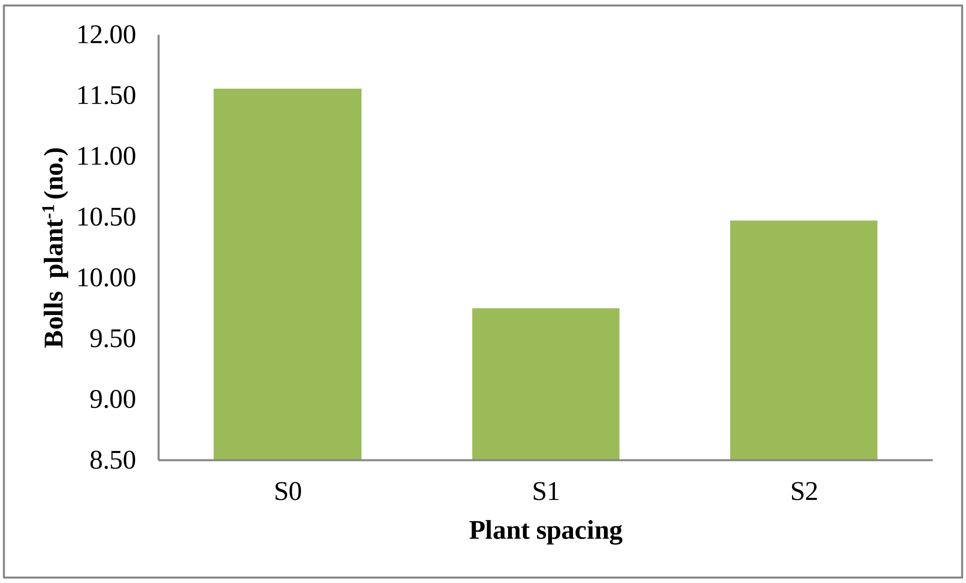
Cothren *et al.* (1983) opined that MC decreased plant height, intermodal length, increased leaf area but wider spacing increased final leaf size and number of shoots including fruiting branch number resulted in higher retention capacity of square plant$^{-1}$ in cotton. Parekh *et al.* (2018) reported that squares plant$^{-1}$ was increasing as the plants were widely spaced, highest being recorded at 90 x 90 cm level with foliar spray gibberellic acid at 250, 200 and 150 ppm and NAA at 200 and 150 ppm.

### 4.2.3.2 Bolls plant$^{-1}$

**Effect of plant spacing**

The spacing had significant effect on boll formation. Bolls plant$^{-1}$ were noticed increased as plant population decreased (Fig. 57). Bolls plant$^{-1}$ marked highest (11.56) from 60 cm × 30 cm spacing ($S_0$, control**)** and it became lowest (9.75) with 45 cm × 30 cm spacing ($S_1$).

CDB (2018) reported that maximum bolls plant$^{-1}$ (19.3) was recorded in case of wider plant spacing of 90 cm × 45 cm against the minimum (12.0) in closer plant spacing of 90 cm × 10 cm of hybrid variety DM-3. The results were also in line with the findings of Ahmad *et al* (2008), Bhalerao and Gaikwad (2010), Kumara *et al.* (2014), Singh *et al.* (2012), Rajakumar and Gurumurthy (2008), Xiao-yu *et al.* (2016), Sowmiya *et al.* (2018), Sylla *et al.* (2013) and Jahedi *et al.* (2013) while they had experiments on cotton. Oad *et al*. (2002) opined that in a dense population stand, the plants were subjected to severe competition from an early stage due to which very few or no vegetative branches formed, fruiting onset delays, and reduced bolls plant$^{-1}$ than in widely spaced cotton. While, widely spaced plants do not compete severely with each other in early stages of growth and relatively large vegetative branches are formed. Hake *et al*. (1991) suggested that plant spacing can alter boll distribution and crop maturity by manipulating soil water removal, radiation interception, humidity and wind movement in cotton. Jiang *et al. (*2017) opined that periodic alteration of plant density (PD) proposed to improve the light environment of plants' lower canopies and leaf photosynthesis thus produces more photosynthates to give support plant growth and fruit development and finally yield.



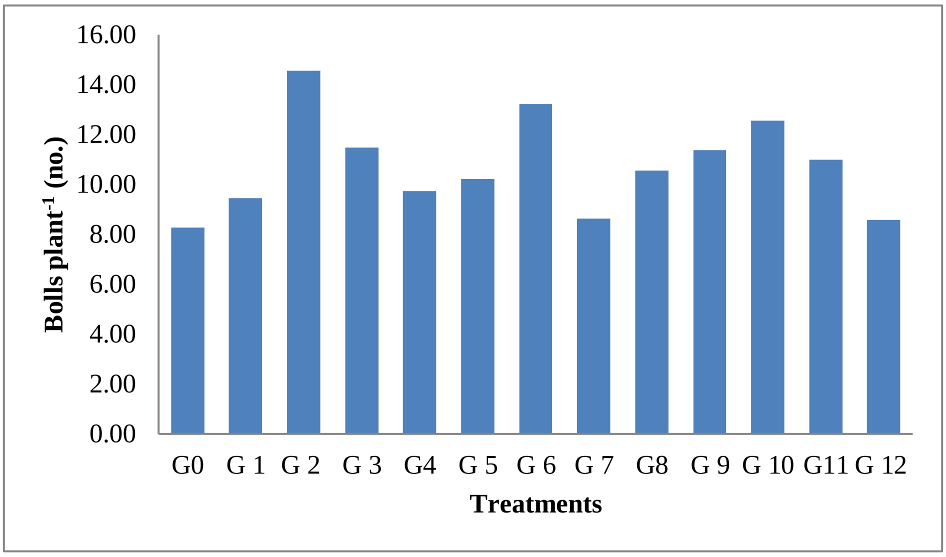

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

**Figure 57. Effect of plant spacing on bolls plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.977).**

**Effect of time of application and concentration of MC growth regulator**

The time of application and concentration of MC Growth regulator showed significant effect on boll formation (Fig. 58). Bolls plant$^{-1}$ was increased as MC sprayed up to 50 DAE. Bolls plant$^{-1}$ marked highest (14.56) from 2 ml MC L$^{-1}$ water at 25 DAE ($G_2$**)** and it became lowest (8.28) at control i.e. water spray ($G_0$).

Reema *et al.* (2017) reported that the maximum opened bolls plant$^{-1}$ (30.1) and un-opened bolls plant$^{-1}$ (4.0) were observed under Pix at 1000 ml/500 litres of water at bud formation in cotton. Similar results obtained in cotton that was in conformity with Gumber *et al.*, 2005; Kataria and Khanpara, 2012; Amit *et al.*, 2016; Arif and Yasmeen**,** 2016; Chaplot**,** 2015; Ali *et al.*, 2012; Ali *et al.*, 2009. Bons *et al.* (2015) opined that the plant growth regulating compounds actively regulate the growth and development by regulation of the endogenous processes and there exogenous applications have been exploited for modifying the growth response.




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 58. Management of MC level influencing on bolls plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 3.313).**

## Combined effect of plant spacing and time of application and concentration of MC growth regulator

The combined effect of plant spacing and MC levels along with time of application was significant (Table 6). Bolls plant$^{-1}$ were obtained highest (17.33) from 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$) which was statistically at par with $S_0G_{12}$ (4 ml MC $L^{-1}$ water sprayed at 75 DAE with 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_4$ (2 and 4 ml MC $L^{-1}$ water sprayed at 25 DAE with 45 cm × 30 cm spacing); $S_2G_2$ and $S_2G_{10}$ (2 ml MC $L^{-1}$ water sprayed at 25 and 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations and It became lowest (7) at water sprayed with 45 cm × 30 cm spacing ($S_1G_0$) which was statistically similar with $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water in 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray in 45 cm × 30 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_3$, $S_2G_5$, $S_2G_7$, $S_2G_8$, $S_2G_9$ and

$S_2G_{11}$ (1, 3 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray under 75 cm × 30 cm spacing) treatment combinations.

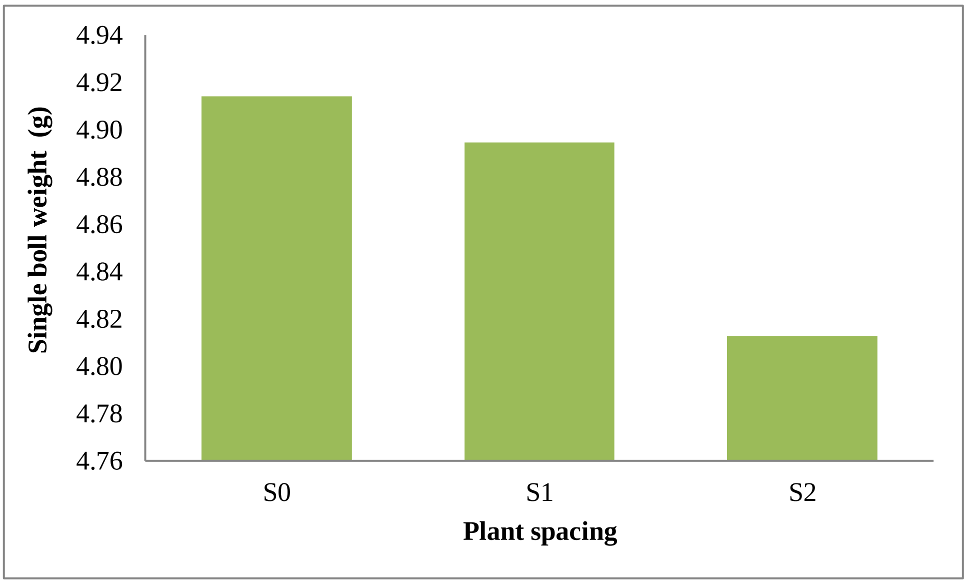
Oad *et al*. (2002) and Hake *et al*. (1991) reported that MC coupled with wider spacing enhanced better vegetative growth and flowering for better photosynthesis, water, nutrient, air, light and space sharing and consequently enhanced higher boll $plant^{-1}$. On the contrary, Iqbal *et al.* (2007) narrated that cotton grown in narrow plant spacing (15 and 23 cm) at high dose of fertilizer (150 kg $ha^{-1}$) with low dose of pix (2 x 100 ml $ha^{-1}$) increased the bolls $plant^{-1}$. Chormule and Patel (2017) reported that combination of wider plant spacing 60 cm x 45 cm and seed treatment of GA3 @ 150 ppm before sowing was found best suited combination, as it has good field emergence and produced significantly and comparatively the maximum fruits $plant^{-1}$ in okra.

#### 4.2.3.3 Weight of boll

**Effect of plant spacing**

Weight of single boll of cotton differed significantly due to variable plant spacing (Fig. 59). Weight of boll was marked increased as plant population increased. Weight of single boll varied from 4.81 to 4.91 g due to different plant spacings, the highest (4.91 g) being recorded with closer spacing 60 cm × 30 cm ($S_0$) and the lowest (4.81 g) with wider 75 cm × 30 cm spacing ($S_2$).

Singh (2015) obtained maximum boll weight (3.17 g) at closer spacing of 67.5 × 60 cm and minimum boll weight (3.12 g) with wider spacing of 67.5 × 75 cm in cotton. Jadhav *et al*. (2015) had similar observations in cotton experiment.



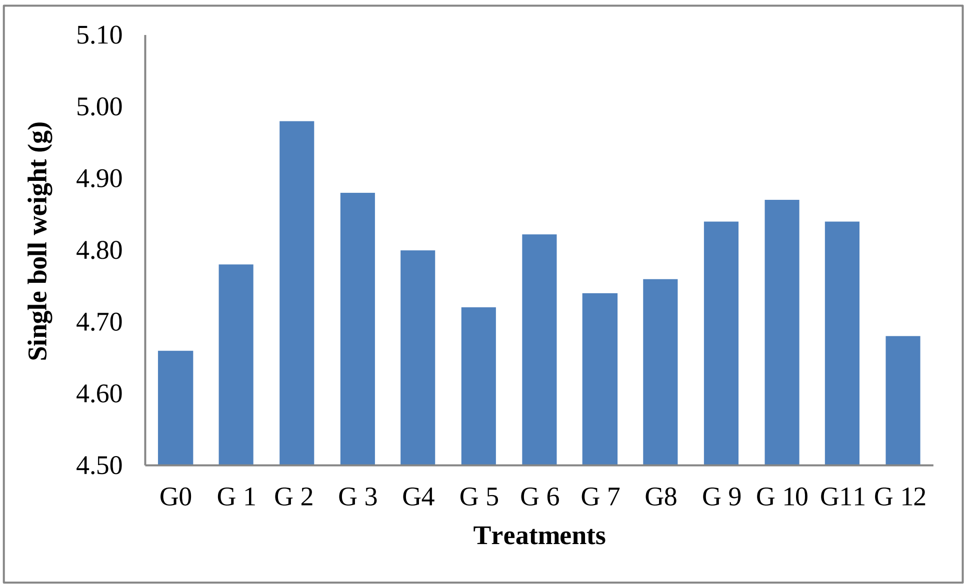
Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

**Figure 59. Effect of plant spacing on boll weight plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.137).**

**Effect of time of application and concentration of MC growth regulator**

MC application at different times exerted significant influence on weight of single boll (Fig. 60). Weight of single boll was found increased as MC spray increased up to 75 DAE. Boll weight marked highest (4.98) from 2 ml MC $L^{-1}$ water sprayed at 25 DAE ($G_2$) and it became lowest (4.66 g) with control ($G_0$) i.e. water sprayed at 25 DAE.

Zakaria (2016) reported that Cycocel and Alar increased opened boll weight. Echer and Rosolem (2017); Kumar *et al.* (2005); Copur *et al.* (2010) and Evangelos *et al.*, (2004) reported similar observation while spraying different growth regulators on cotton.




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 60. Management of MC level influencing on boll weight plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.20).**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Combined effect of plant spacing and MC sprayed at different times was significant in respect of weight of single boll (Table 6). Weight of boll increased as plant population and MC spray time and concentration increased related to control. Single boll weight marked highest (5.13 g) from 2 ml MC L$^{-1}$ water at 25 DAE with 45 cm × 30 cm spacing ($S_1G_2$**)** which was statistically at par with $S_0G_1$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_9$, $S_0G_{10}$ (1, 2 and 4 ml MC L$^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing), $S_1G_1$, $S_1G_3$, $S_1G_4$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (1 to 4 ml MC L$^{-1}$ water sprayed from 25 to 75 DAE, respectively with 45 cm × 30 cm spacing), $S_2G_2$, $S_2G_4$, $S_2G_5$, $S_2G_6$, and $S_2G_{12}$ (2 ml, 4, 1, 2 and 4 ml MC L$^{-1}$ water sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations and it became lowest (4.47 g) at water sprayed with 75 cm × 30 cm spacing ($S_2G_0$) followed by $S_0G_0$, $S_0G_2$ (1 to 4 ml MC L$^{-1}$ water sprayed from 25 to 75 DAE, respectively with water spray under 60 cm × 30 cm spacing), $S_1G_0$, $S_1G_5$ (1 to 4 ml MC L$^{-1}$ water sprayed from 25 to 75 DAE, under 45 cm × 30 cm spacing), $S_2G_1$, $S_2G_3$, $S_2G_7$, $S_2G_9$, $S_2G_{10}$ and $S_2G_{11}$ (1, 3, 3,1, 2 and 3 ml MC L$^{-1}$ water sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations**.**

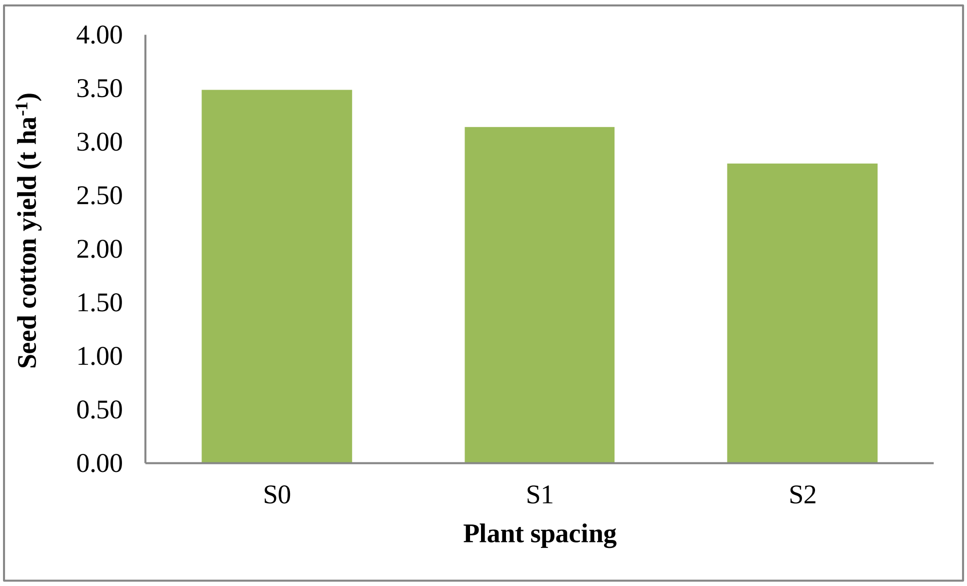
Oad *et al*. (2002) and Hake *et al*. (1991) opined that the lesser in vegetative growth of cotton at closer spacing (60 cm × 30 cm) might be due to higher competition for nutrient, light and space. MC treated plants produced short plants thus which partitioned more photosynthates towards lesser number of bolls which resulted in more boll weight.

### 4.2.3.4 Seed cotton yield

**Effect of plant spacing**

The effect of plant spacing showed significant influence on seed cotton yield (Fig. 61). Seed yield decreased gradually with wider spacing. Seed cotton yield varied from 2.80 to 3.49 t ha$^{-1}$. Spacing 60 cm × 30 cm ($S_0$**)** had the highest seed cotton yield (3.49 t ha$^{-1}$) and the lowest (2.80 t ha$^{-1}$) being recorded from 75 cm × 30 cm spacing ($S_2$**)**. Treatment $S_0$ (closer spacing) out yielded wider spacing ($S_2$) by 22.9 % more yield as the increased yield was added with greater plant population per unit area.

Yield was highest in 55,555 plants ha$^{-1}$ treatment confirmed by Awais *et al.* (2015). Firoz *et al.* (2007) reported that sowing with 60 x 30 cm plant spacing produced significantly highest yield (12.86 t ha$^{-1}$). The result was also in conformity with the findings in cotton of CDB (2018), Sowmiya and Sakthivel (2018), Mahi and Lokanadhan (2018), Kumar *et al.*, (2017), Udikeri and Shashidhara (2017), Rao *et al.* (2015), Hiwale *et al.* (2015), Munir *et al.* (2015), Sylla *et al.* (2013), Ali *et al.* (2012), Sher *et al.* (2017), Ali *et al.* (2009), Khan *et al.* (2002), Soomro *et al.*, 2000a, Soomro *et al.*, 2000b, Silva *et al.* (2006), Silvertooth (1999), Keren *et al.*(1983), Siebert ( 2006) and Wright *et al.* (2008). Liu *et al.* (2011) studied that planting pattern affects canopy structure of crops and influences other physiological characteristics such as light interception and radiation use efficiency. These results indicated that narrow-wide row planting patterns improved the canopy structure, allowed more IPAR to reach the middle–low strata of the canopy and enhanced the leaf photosynthetic characteristics of maize crops at silking stage compared with control resulting in higher yield. Jiang *et al. (*2017) opined that periodic alteration of plant density (PD) proposed to improve the light environment of plants' lower canopies and leaf photosynthesis thus produces more photosynthates to give support plant growth and fruit development and finally yield. Jiang *et al. (*2017) opined that periodic alteration of plant density (PD) improved the light environment of plants' lower canopies and leaf photosynthesis thus produces more photosynthates to give support plant growth and fruit development and finally yield.



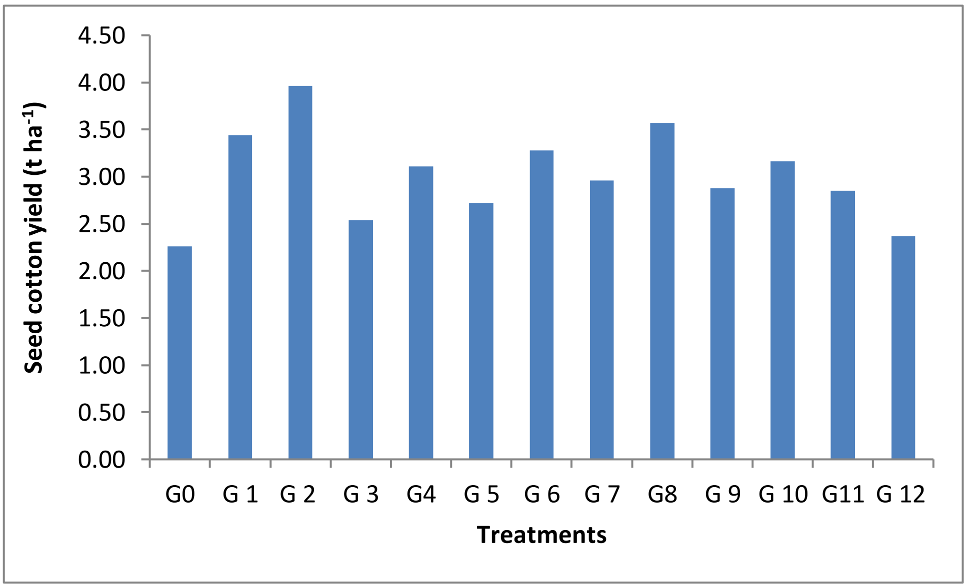

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants ha$^{-1}$)

$S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$)

**Figure 61. Effect of plant spacing on seed cotton yield (LSD $_{(0.05)}$ = 0.232).**

**Effect of time of application and concentration of MC growth regulator**

A significant variation in seed cotton yield was also observed due to the effect of MC application time and its concentration (Fig. 62). The range was between 2.26 to 3.96 t $ha^{-1}$. It was apparent that there is an insignificant decrease trend in seed cotton yield with increasing MC spray concentration. Seed cotton yield (3.96 t $ha^{-1}$) increased progressively reaching maximum at 2 ml MC $L^{-1}$ water sprayed at 25 DAE ($G_2$) and then declined. The lowest seed cotton yield (2.26 t $ha^{-1}$) was recorded in control treatment ($G_0$, water spray). Use of growth regulator (at 25 DAE) had 75.22 % more yield over no growth regulator use. Sabale *et al.* (2018) reported that higher seed cotton yield (1213.27 kg $ha^{-1}$) was obtained with application of NAA @ 30 ppm. The similar results of cotton yields under different growth regulator application were recorded in different experiments elsewhere (Fang *et al.*, 2019; Chang-chi *et al.*, 2019; Reema *et al.*, 2017; Arif and Yasmeen, 2016; Amit *et al.*, 2016; Chaplot, 2015; Kataria and Khanpara, 2012; Evangelos *et al.*, 2004) and also by Kamran *et al.*, 2017 in maize. Sebastian *et al.* (2019) argued that phytohormones determine the formation of flowers and its retention when shedding of leaves are minimum which enhances the development and ripening of fruits (pomegranate).




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC)

$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE

@ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 62 Effect of application time and concentration of MC on seed cotton yield (LSD $_{(0.05)}$ = 1.223)**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

The combined effect between plant spacing and time of MC spray and concentration on seed cotton yield was significant (Table 6). Seed cotton yield increased as plant population and MC spray increased up to optimum (2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) compared to control. Seed cotton yield showed highest (4.53 t $ha^{-1}$) from 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$**)** followed by $S_0G_1$, $S_0G_2$, $S_0G_7$, $S_0G_9$, $S_0G_{10}$, $S_0G_{12}$ (1, 2, 3, 1, 2 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_4$, $S_1G_7$, $S_1G_{10}$, $S_1G_{11}$ (2 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_2$, $S_2G_4$, $S_2G_7$, $S_2G_{10}$ and $S_2G_{12}$ (1, 2, 4, 3, 2 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations and the lowest (1.73 t $ha^{-1}$) was obtained from control at 25 DAE with 45 cm × 30 cm spacing ($S_2G_0$**)** which was statistically at par with $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_3$, $S_2G_5$, $S_2G_7$, $S_2G_8$, $S_2G_9$ and $S_2G_{11}$ (1, 3 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations.

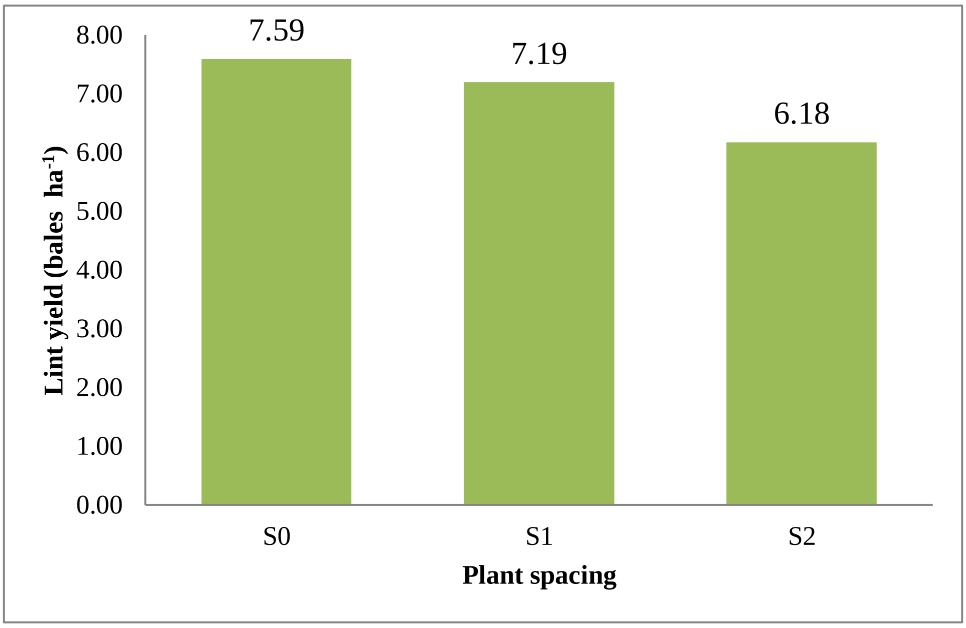
Zakaria (2016) reported that the intermediate plant density (222000 plants $ha^{-1}$) gave highest yields. Both Cycocel and Alar increased the seed-cotton yield $plant^{-1}$. Seed cotton yield increased as plant population increased as MC sprayed compared to control in cotton (Zhao *et al.*, 2019; Iqbal *et al.*, 2007; Copur *et al.*, 2010; Evangelos *et al.*, 2004; Golada *et al*, 2018) also noted the same in baby corn.

**4.2.3.5 Lint yield**

**Effect of plant spacing**

Lint yield of cotton showed considerable variation among the plant spacing (Fig. 63). The highest lint yield (7.59 bales ha$^{-1}$) obtained from 60 cm × 30 cm spacing ($S_0$) followed by spacing $S_1$ (45 cm × 30 cm). The wider spacing 75 cm × 30 cm ($S_2$) decreased the lint yield of cotton, which in turn produced lowest lint yield (6.18 bales ha$^{-1}$). It was indicated that lint yield decreased significantly with gradual plant population per unit area decreased.

This is in line with the findings of Singh (2015) in cotton. He observed that closer spacing of 67.5 × 60 cm gave maximum lint yield (777.8 kg ha$^{-1}$) and minimum (684.6 kg ha$^{-1}$) with wider spacing of 67.5 × 75 cm. Yield of lint of cotton was increased as plant population increased at closer spacing in cotton (Clawson *et al*., 2006; Shukla *et al.*, 2013; Xiao-yu *et al.*, 2016; Richard, 2006; Manuel *et al.*, 2019; Jahedi *et al.*, 2013; Singh *et al.*, 2014; Berry *et al.*, 2008).



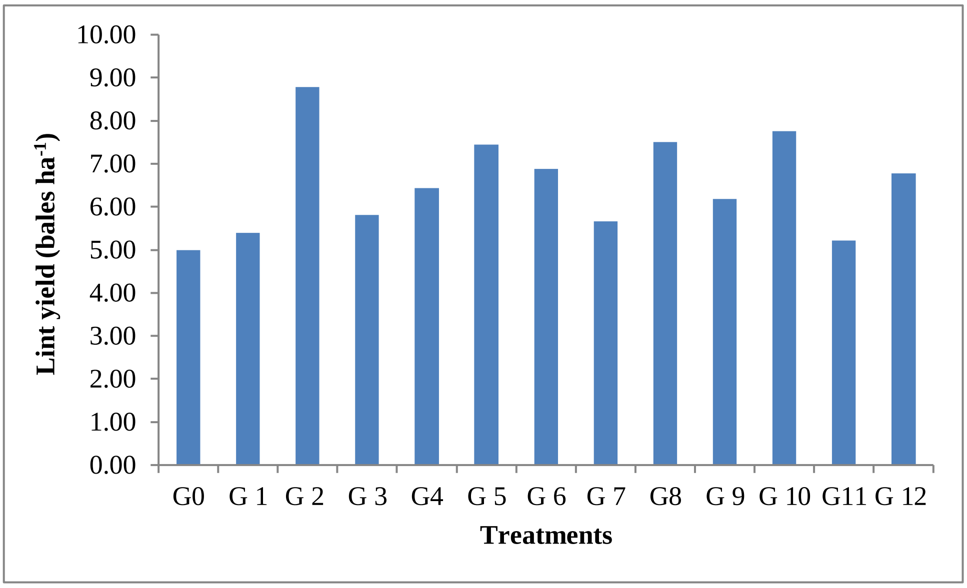

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from first year experiment as promising treatment.
$S_1$ = 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$ = 75 cm × 30 cm (44,444 plants ha$^{-1}$)

**Figure 63. Effect of plant spacing level on lint yield of cotton (LSD $_{(0.05)}$ = 0.512).**

**Effect of time of application and concentration of MC growth regulator**

Growth regulator at different time of application and concentration had a significant influence on the lint yield of cotton (Fig. 64). There was a general increase in lint yield up to $G_2$ and then declined progressively regardless of treatments. The highest lint yield (8.78 bales $ha^{-1}$) was observed from $G_2$ (2 ml MC $L^{-1}$ water sprayed at 25 DAE) and the lowest (4.99 bales $ha^{-1}$) from control ($G_0$).

Chaplot (2015) reported that the foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton by 57.3 per cent over water spray in cotton. McCarty *et al.* (2017) argued that various plant growth hormones and regulators have been increased the yield of cotton (*Gossypium hirsutum* L.) lint when applied to foliage in field tests which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation.




Here, $G_0$ = Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50 DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75 DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75 DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75 DAE

**Figure 64. Effect of application time and concentration of MC on lint yield of cotton ($LSD_{(0.05)}$ = 2.703).**

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Results obtained from combined effect of plant density and MC level along with application time were significant (Table 6). Lint yield increased as plant population increased with MC spray compared to control. Lint yield marked highest (9.43 bales $ha^{-1}$) from 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$**)** which was statistically similar with $S_0G_1$, $S_0G_2$, $S_0G_4$, $S_0G_6$, $S_0G_7$, $S_0G_9$, $S_0G_{10}$, $S_0G_{12}$ (1, 2, 4, 2, 3, 1, 2 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_7$, $S_1G_8$, $S_1G_{10}$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$, $S_2G_8$, $S_2G_9$, $S_2G_{10}$, $S_2G_{11}$ and $S_2G_{12}$ (1to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations. The lowest lint yield (3.82 bales $ha^{-1}$) was observed at water sprayed with 75 cm × 30 cm spacing ($S_2G_0$) which was statistically at par with $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_3$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_3$, $S_2G_5$, $S_2G_7$, $S_2G_8$, $S_2G_9$ and $S_2G_{11}$ (1, 3 and 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations.

**Table 6. Combined effect of plant spacing and management of MC growth regulator on yield attributes and yield of cotton**

| Treatments | Squares plant$^{-1}$ (no.) | Bolls plant$^{-1}$ (no.) | Boll weight (g) | Seed cotton yield (t ha$^{-1}$) | Lint yield (bales ha$^{-1}$) |
|---|---|---|---|---|---|
| **$S_0G_0$** | 6.33 ef | 7.33 fg | 4.70 d-g | 2.01fg | 4.44 fg |
| **$S_0G_1$** | 10.87 a-e | 11.33 b-g | 4.94 a-e | 3.17 a-g | 6.99 a-g |
| **$S_0G_2$** | 15.24 a | 17.33 a | 4.70 d-g | 4.53 a | 9.43 a |
| **$S_0G_3$** | 8.67 c-f | 9.00 b-g | 4.80 b-f | 2.20 c-g | 4.86 c-g |
| **$S_0G_4$** | 8.67 c-f | 9.33 b-g | 4.90 a-e | 2.53 b-g | 5.60 a-g |
| **$S_0G_5$** | 9.00 b-f | 9.07 b-g | 5.03 a-c | 2.10 d-g | 4.64 d-g |
| **$S_0G_6$** | 11.00 a-e | 10.67 b-g | 5.10 ab | 2.72 b-g | 6.00 a-g |
| **$S_0G_7$** | 8.00 c-f | 8.67 c-g | 4.80 b-f | 2.80 a-g | 6.20 a-g |
| **$S_0G_8$** | 8.67 c-f | 8.18 c-g | 4.81b-f | 2.29 b-g | 5.05 b-g |
| **$S_0G_9$** | 6.67 d-f | 10.00 b-g | 4.93 a-e | 3.13 a-g | 6.93 a-g |
| **$S_0G_{10}$** | 9.33 b-f | 11.33 b-g | 4.94 a-e | 3.35 a-g | 7.40 a-g |
| **$S_0G_{11}$** | 11.00 a-e | 8.00 d-g | 4.80 b-f | 2.29 b-g | 5.06 b-g |
| **$S_0G_{12}$** | 12.33 a-c | 13.67 ab | 4.80 b-f | 4.04 ab | 8.92 ab |
| **$S_1G_0$** | 4.44 f | 7.00 g | 4.69 d-g | 1.99 fg | 4.39 fg |
| **$S_1G_1$** | 8.00 c-f | 8.00 d-g | 4.97 a-e | 2.73 b-g | 6.04 a-g |
| **$S_1G_2$** | 9.50 b-f | 12.67 a-d | 5.13 a | 3.66 a-f | 8.08 a-f |
| **$S_1G_3$** | 11.00 a-e | 8.67 c-g | 4.83 a-f | 2.68 b-g | 5.93 a-g |
| **$S_1G_4$** | 9.00 b-f | 13.67 ab | 5.03 a-c | 3.54a-f | 7.83 a-f |
| **$S_1G_5$** | 8.67 c-f | 7.67 e-g | 4.77 c-g | 2.09 d-g | 4.61e-g |
| **$S_1G_6$** | 9.83 a-f | 9.00 b-g | 4.90 a-e | 2.28 b-g | 5.05 b-g |
| **$S_1G_7$** | 10.33 a-e | 10.33 b-g | 4.87 a-f | 3.51 a-g | 7.75 a-g |
| **$S_1G_8$** | 10.34 a-e | 10.05 b-g | 4.84 a-f | 2.62 b-g | 5.78 a-g |
| **$S_1G_9$** | 9.17 b-f | 7.67 e-g | 4.83 a-f | 2.08 e-g | 4.60 e-g |
| **$S_1G_{10}$** | 10.67 a-e | 12.33 b-e | 4.87 a-f | 3.55 a-f | 7.85 a-f |
| **$S_1G_{11}$** | 8.33 c-f | 11.33 b-g | 5.03 a-c | 3.87 a-d | 8.56 a-d |
| **$S_1G_{12}$** | 9.33 b-f | 7.33 fg | 4.97 a-e | 2.50 b-g | 5.52 a-g |
| **$S_2G_0$** | 7.33 c-f | 8.33 c-g | 4.47 g | 1.73 g | 3.82 g |
| **$S_2G_1$** | 10.00 a-f | 11.67 b-g | 4.67 e-g | 2.84 a-g | 6.28 a-g |
| **$S_2G_2$** | 12.00 a-d | 13.67 ab | 5.03 a-c | 3.97 a-c | 8.78 a-c |
| **$S_2G_3$** | 8.67 c-f | 9.67 b-g | 4.57 fg | 2.56 b-g | 5.66 a-g |
| **$S_2G_4$** | 8.67 c-f | 12.33 b-e | 5.00 a-d | 3.69 a-f | 8.15 a-f |
| **$S_2G_5$** | 8.67 c-f | 11.33 b-g | 4.83 a-f | 3.13 a-g | 6.92 a-g |
| **$S_2G_6$** | 9.33 b-f | 12.00 b-f | 4.87 a-f | 3.75 a-f | 8.29 a-f |
| **$S_2G_7$** | 11.33 a-e | 11.67 b-g | 4.77 c-g | 2.87 a-g | 6.35 a-g |
| **$S_2G_8$** | 9.33 b-f | 11.00 b-g | 4.80 b-f | 2.71 b-g | 5.98 a-g |
| **$S_2G_9$** | 10.33 a-e | 9.33 b-g | 4.70 d-g | 2.51 b-g | 5.54 a-g |
| **$S_2G_{10}$** | 8.67 c-f | 13.00 a-c | 4.77 c-g | 3.82 a-e | 8.43 a-e |
| **$S_2G_{11}$** | 6.67 d-f | 11.67 b-g | 4.70 d-g | 3.04 a-g | 6.72 a-g |
| **$S_2G_{12}$** | 14.59 ab | 12.00 b-f | 4.83 a-f | 4.03 ab | 8.92 ab |
| **LSD $_{0.05}$** | **5.649** | **4.873** | **0.311** | **1.784** | **3.942** |
| **CV (%)** | **11.15** | **14.83** | **4.47** | **11.45** | **11.45** |

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

Here,
$S_0$= 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE

$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75DAE

### 4.2.4 Effect of plant spacing and management of growth regulator on seed characteristics of cotton

#### 4.2.4.1 Seeds boll$^{-1}$

**Effect of plant spacing**

Seeds boll$^{-1}$ of cotton had considerable variation among the plant spacing (Table 11). The maximum seeds boll$^{-1}$ (119.61) was recorded at spacing 75 cm × 30 cm ($S_2$) and it was significantly different from all other spacings (Table 11). The lowest seeds boll$^{-1}$ (116.92) was marked from spacing 45 cm × 30 cm ($S_1$). Omadewu *et al.* (2019) reported that plant density had a positive effect on number of seeds boll$^{-1}$ in cotton. Similar result was reported by Khalil *et al.* (2010) in faba bean. On the contrary, Pitombeira (1972) reported that seed boll$^{-1}$ was not significantly affected by plant population in cotton and sorghum.

**Effect of time of application and concentration of MC growth regulator**

MC sprayed had significant effect on seeds boll$^{-1}$ of cotton over no growth regulator (Table 11). Seeds boll$^{-1}$ increased progressively over time of MC sprayed attaining the highest at 75 DAE. The highest seeds boll$^{-1}$ (122) was obtained from foliar sprayed at 3.0 ml L$^{-1}$ water at 75 DAE ($G_{11}$) and the lowest (109.33) was observed in 1.0 ml MC L$^{-1}$ water at 25 DAE ($G_1$).

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

The combined effect of different times and concentrations of MC sprayed from 25 to 75 days after emergence and different spacing increased significantly the number of seeds boll$^{-1}$ in some treatment combinations compared to control (Table 7). Seeds boll$^{-1}$ was marked highest (122.67) from 3 ml MC L$^{-1}$ water at 75 DAE with 60 cm × 30 cm spacing ($S_0G_{11}$) which was statistically similar with $S_0G_7$ (3 ml MC L$^{-1}$ water sprayed at 50 DAE with 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_4$ (2 and 4 ml MC L$^{-1}$ water sprayed at 25 DAE with 45 cm × 30 cm spacing); and $S_2G_{11}$ (2 ml MC L$^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing) treatment combinations and it became lowest (106.42) at 1 ml MC L$^{-1}$ water sprayed at 75 DAE with 45 cm × 30 cm spacing ($S_1G_8$) followed by $S_1G_8$, $S_1G_9$ (4 and 1 ml MC L$^{-1}$ water sprayed at 50 and 75 DAE, respectively with 45 cm × 30 cm spacing); and $S_2G_9$ (1 ml MC L$^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing).

Omadewu *et al.* (2019) reported that plant density and variety had a positive effect on cotton seed yield, lint yield and number of seeds boll$^{-1}$. Khalil *et al.* (2010) found that planting dates and population density significantly affected grain yield ha$^{-1}$. Plant density of 450,000 plants ha$^{-1}$ of faba bean took more grain pod$^{-1}$ (3.2). Pitombeira (1972) also reported that seed boll$^{-1}$ was not significantly affected by plant population.

**Table 7. Combined effect of plant spacing and MC level along with application time on seeds boll$^{-1}$ of cotton**

| Treatments | Seeds number boll$^{-1}$ | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 120.63 d-h | 116.83 no | 119.00 j-m |
| $G_1$ | 110.67 p | 108.00 r | 109.33 q |
| $G_2$ | 118.33 lm | 121.67 a-d | 121.00 c-f |
| $G_3$ | 120.00 f-j | 120.00 f-j | 120.00 f-j |
| $G_4$ | 119.33 h-l | 122.00 a-c | 119.67 g-k |
| $G_5$ | 120.00 f-j | 118.67 k-m | 118.67 k-m |
| $G_6$ | 118.67 c-f | 120.33 e-i | 119.33 h-l |
| $G_7$ | 121.67 a-d | 116.33 o | 120.67 d-g |
| $G_8$ | 119.27 i-m | 106.42 s | 117.00 no |
| $G_9$ | 121.00 c-f | 107.33 rs | 107.67 rs |
| $G_{10}$ | 120.00 f-j | 121.33 b-e | 120.67 d-g |
| $G_{11}$ | 122.67 a | 120.00 f-j | 122.33 ab |
| $G_{12}$ | 118.67 k-m | 118.00 mn | 118.67 k-m |
| **$LSD_{(0.05)}$** | | **1.32** | |
| **CV (%)** | | **5.93** | |

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

Here,
$S_0$= 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75DAE

### 4.2.4.2 Seed index

**Effect of plant spacing**

Seed index of cotton had considerable variation among the plant spacings (Table 11). The maximum seed index (12.96 g) was recorded at spacing 60 cm × 30 cm cm ($S_0$) and it was similar with 75 cm × 30 cm spacing. The lowest seed index (11.93 g) was recorded from spacing 45 cm × 30 cm ($S_1$). Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased.

### Effect of time of application and concentration of MC growth regulator

MC had significant effect on seed index of cotton (Table 11). Seed index increased progressively over time of MC sprayed attaining the highest at 25 DAE. The highest seed index (13.62 g) was obtained from control ($G_0$) which was statistically similar with $G_3$, $G_4$, $G_6$ and $G_{10}$ (foliar sprayed with 3, 4 and 2 ml MC $L^{-1}$ water from 25 to 75 DAE, respectively) and the lowest (11.26 g) at $G_5$ (1 ml MC $L^{-1}$ water at 50 DAE) which was followed by $G_2$, $G_5$ $G_8$ and $G_{11}$ (2, 1, 4 and 3 ml MC $L^{-1}$ water from 25 to 75 DAE respectively) treatments. Zhao *et al.* (2019) studied that the 100-seed weight significantly increased with MC applying under different plant densities in cotton.

### Combined effect of plant spacing and time of application and concentration of MC growth regulator

Different plant spacing and MC sprayed at different times and concentration significantly increased the seed index of cotton than control (Table 8). SI observed highest (15 g) from water sprayed with 60 cm × 30 cm spacing ($S_0G_0$) which was statistically similar with $S_0G_1$, $S_0G_7$, $S_0G_9$ (foliar sprayed with 1, 3 and 1 ml MC $L^{-1}$ water at 25 and 75 DAE, respectively under 60 cm × 30 cm spacing), $S_1G_1$, $S_1G_4$, $S_1G_7$, $S_1G_{10}$, $S_1G_{11}$ (foliar sprayed with 1, 4, 3, 2 and 3 ml MC $L^{-1}$ water at 25, 50 and 75 DAE, respectively under 45 cm × 30 cm spacing) and $S_2G_2$, $S_2G_5$, $S_2G_8$ and $S_2G_{10}$ (foliar sprayed with 2, 1, 4 and 2 ml MC $L^{-1}$ water sprayed at 25, 50 and 75 DAE, respectively with 75 cm × 30 cm spacing) and it was marked lowest (10.33 g) at ($S_0G_3$) 3 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing which was statistically similar with $S_0G_6$, $S_0G_{10}$, $S_0G_{11}$ (foliar sprayed 2 and 3 ml MC $L^{-1}$ water at 25, 50 and 75 DAE, + 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_5$, $S_1G_8$ (foliar sprayed with 2, 1 and 4 ml MC $L^{-1}$ water at 25 and 50 DAE, respectively + 45 cm × 30 cm spacing); $S_2G_3$, $S_2G_6$ and $S_2G_9$ (foliar sprayed with 3, 2 and 1 ml MC $L^{-1}$ watersprayed at 25, 50 and 75 DAE with 75 cm × 30 cm spacing). Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

**Table 8. Combined effect of plant spacing and MC level along with application time on seed index of cotton**

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

| Treatments | Seed index (g) | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 15.00 a | 12.54 ef | 12.99 c-e |
| $G_1$ | 14.00 a-c | 14.90 ab | 12.54 ef |
| $G_2$ | 13.69 b-e | 10.44 h | 14.69 ab |
| $G_3$ | 10.33 h | 12.56 d-f | 10.44 g-h |
| $G_4$ | 11.66 fg | 13.78 a-d | 12.56 d-f |
| $G_5$ | 12.55 d-f | 11.44 f-h | 13.78 a-d |
| $G_6$ | 10.99 gh | 13.63 b-e | 11.44 f |
| $G_7$ | 14.99 a | 14.96 a | 13.63 b-e |
| $G_8$ | 13.55 b-e | 10.89 gh | 14.96 a |
| $G_9$ | 15.00 a | 12.53 ef | 10.99 gh |
| $G_{10}$ | 10.34 h | 13.98 a-c | 14.99 a |
| $G_{11}$ | 11.44 f-h | 14.98 a | 13.55 b-e |
| $G_{12}$ | 13.66 b-e | 11.60 fg | 12.56 d-f |
| **$LSD_{(0.05)}$** | | **1.23** | |
| **CV (%)** | | **2.86** | |

Here,
$S_0$= 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants $ha^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE

$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75DAE

### 4.2.4.3 Lint index

**Effect of plant spacing**

Lint index of cotton had considerable variation among the plant spacings (Table 11). The maximum lint index (8.74 g) was recorded at spacing 60 cm × 30 cm ($S_0$) and the lowest lint index (7.71 g) was marked from spacing 45 cm × 30 cm ($S_1$). Darawsheh *et al*. (2009a) and Darawsheh *et al*. (2009b) reported that lint percentage significantly reduced by increasing plant stands or by narrow rows in cotton.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on lint index of cotton (Table 11). The highest lint index (9.99) was obtained from foliar sprayed at $G_3$ (3 ml MC $L^{-1}$ water at 25 DAE) which was statistically similar with $G_7$ (3 ml MC $L^{-1}$ water at 50 DAE) and the lowest (7.04) at $G_{12}$ (4 ml MC $L^{-1}$ water at 75 DAE) followed by $G_{10}$ (2 ml MC $L^{-1}$ water at 75 DAE). Zakaria et al. (2016) also observed that both Cycocel and Alar increased lint indices in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

The combined effect among different times and concentrations of MC sprayed from 25 to 75 days after emergence and different spacing significantly increased the lint index of cotton than control (Table 9). LI was marked highest (10.30 g) from 4 ml MC $L^{-1}$ water sprayed at 50 DAE with 60 cm × 30 cm spacing ($S_1G_7$**)** which was statistically similar with $S_0G_0$, $S_0G_1$, $S_0G_2$, $S_0G_9$ (foliar sprayed with 1, 2 and 1 ml MC $L^{-1}$ water at 25and 75 DAE, respectively with water spray under 60 cm × 30 cm spacing); $S_1G_1$, $S_1G_{10}$, $S_1G_{11}$ (foliar sprayed with 1, 2 and 3 ml MC $L^{-1}$ water at 25 and 75 DAE, respectively under 45 cm × 30 cm spacing) and $S_2G_2$, $S_2G_8$ and $S_2G_{10}$ (foliar sprayed with 2, 4 and 2 ml MC $L^{-1}$ water sprayed at 25, 50 and 75 DAE, respectively under 75 cm × 30 cm spacing) and it became lowest (7 g) at 2 ml MC $L^{-1}$ water at 25 DAE with 45 cm × 30 cm spacing ($S_2G_3$**)** which was statistically similar with $S_0G_3$, $S_0G_{10}$ (foliar sprayed with 3 and 2 ml MC $L^{-1}$ water at 25 and 75 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_5$, $S_1G_8$ (foliar sprayed with 2, 1, and 4 ml MC $L^{-1}$ water at 25, 50 and 75 DAE, respectively with 45 cm × 30 cm spacing); $S_2G_2$, $S_2G_8$ and $S_2G_{10}$ (foliar sprayed with 2, 4 and 2 ml MC $L^{-1}$ water sprayed at 25, 50 and 75 DAE, respectively with 75 cm × 30 cm spacing). Pitombeira (1972) reported that lint index was not significantly affected by plant population. Zakaria et al. (2016) also observed that both Cycocel and Alar increased lint indices.

**Table 9. Combined effect of plant spacing and MC level along with application time on lint index of cotton**

| Treatments | Lint index (g) | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 10.29 a | 8.45 h-k | 8.64 f-j |
| $G_1$ | 9.50 a-f | 10.10 a-c | 8.44 h-k |
| $G_2$ | 9.46 a-f | 7.10 mn | 9.82 a-e |
| $G_3$ | 7.08 mn | 8.21i-l | 7.00 n |
| $G_4$ | 7.78 f-j | 9.35 b-g | 8.49 g-k |
| $G_5$ | 8.46 h-k | 7.74 k-n | 9.26 c-h |
| $G_6$ | 7.47 l-n | 9.25 c-h | 7.70 k-n |
| $G_7$ | 9.95 a-d | 10.30 a | 9.12 d-h |
| $G_8$ | 8.89 f-i | 7.33 mn | 10.01a-c |
| $G_9$ | 10.21ab | 8.56 g-k | 7.32 m |
| $G_{10}$ | 7.02 mn | 9.46 a-f | 9.88 a-d |
| $G_{11}$ | 7.78 j-n | 10.07 a-c | 9.01 e-i |
| $G_{12}$ | 9.27 c-h | 7.88 j-m | 8.23 i-l |
| **$LSD_{(0.05)}$** | | **0.862** | |
| **CV (%)** | | **1.54** | |

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

Here,
$S_0$= 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants $ha^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE

$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75DAE

#### 4.2.4.4 Ginning out turn

#### Effect of plant spacing

Ginning out turn (GOT) of cotton had considerable variation among the plant spacing (Table 11). The maximum GOT (40.29 %) was recorded at spacing 60 cm × 30 cm ($S_0$) which was statistically at par with 75 cm × 30 cm spacing ($S_2$) and the lowest GOT (39.32 %) was marked from spacing 45 cm × 30 cm ($S_1$).

#### Effect of time of application and concentration of MC growth regulator

MC had significant effect on ginning out turn of cotton (Table 11). The highest ginning out turn (40.46 %) was obtained from foliar sprayed at $G_{10}$ (2 ml MC $L^{-1}$ water at 75 DAE) which was statistically similar with $G_4$, $G_6$, $G_8$ and $G_{10}$ (4, 2, 4 and 2 ml MC $L^{-1}$ water at 25, 50 and 75 DAE) treatments and the lowest (39.07 %) from $G_1$ (1 ml MC $L^{-1}$ water at 25 DAE) treatment.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Different concentration of MC sprayed at different times and various spacing increased significantly the Ginning out turn (GOT) or lint percentages of cotton than control (Table 10). GOT or lint percentages marked highest (40.93) from 3 ml MC $L^{-1}$ water at 75 DAE with 45 cm × 30 cm spacing ($S_2G_{11}$**)** which was statistically similar with $S_0G_2$ (foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) treatment combinations and it became lowest (39.10) from ($S_2G_7$**)** 3 ml MC $L^{-1}$ water sprayed at 50 DAE with 45 cm × 30 cm spacing which was statistically similar with $S_0G_5$ (foliar sprayed with 1 ml MC $L^{-1}$ water at 50 DAE with under 60 cm × 30 cm spacing); $S_1G_{11}$ (foliar sprayed with 3 ml MC $L^{-1}$ water at 75 DAE under 45 cm × 30 cm spacing); $S_2G_1$, $S_2G_3$ and $S_2G_5$ (foliar sprayed with 1, 3 and 1 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE, respectively under 75 cm × 30 cm spacing) treatment combinations.

**Table 10. Combined effect of plant spacing and MC level along with application time on ginning out turn of cotton**

| Treatments | Ginning out turn (%) | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 40.68 bc | 40.27 e-g | 39.94 i-k |
| $G_1$ | 39.43 n-p | 39.73 k-m | 39.23 p-r |
| $G_2$ | 40.87 ab | 40.47 c-e | 40.07 g-i |
| $G_3$ | 39.67 lm | 39.53 m-o | 39.13 r |
| $G_4$ | 40.03 hi | 40.43 d-f | 40.33 d-f |
| $G_5$ | 39.27 p-r | 39.37 o-q | 39.20 qr |
| $G_6$ | 40.47 c-e | 40.43 d-f | 40.23 f-h |
| $G_7$ | 39.90 i-k | 39.77 j-l | 39.10 r |
| $G_8$ | 39.63 l-n | 40.23 f-h | 40.08 g-i |
| $G_9$ | 40.50 cd | 39.60 l-n | 39.97 ij |
| $G_{10}$ | 39.43 n-p | 40.37 d-f | 39.73 k-m |
| $G_{11}$ | 40.47 c-e | 39.20 qr | 40.93 a |
| $G_{12}$ | 39.43 n-p | 40.47 c-e | 39.60 l-n |
| **LSD $_{(0.05)}$** | | **0.223** | |
| **CV (%)** | | **2.86** | |

In a column, figure(s) followed by same letter do not differ significantly at 5% level.

Here,
$S_0$= 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75DAE

**Table 11. Effect of plant spacing and MC level along with application time on seed number, seed index, lint index and ginning out turn of cotton**

| Treatments | Seeds boll$^{-1}$ (no.) | seed index (g) | lint index (g) | Ginning out turn (%) |
|---|---|---|---|---|
| **Effect of different levels of spacing** | | | | |
| **$S_0$** | 118.23 b | 12.96 a | 8.74 a | 40.29 a |
| **$S_1$** | 116.92 c | 11.93 c | 7.71 c | 39.32 b |
| **$S_2$** | 119.61 a | 12.29 b | 8.29 b | 40.26 a |
| **LSD** | **0.467** | **0.215** | **0.16** | **0.036** |
| **CV(%)** | **5.93** | **2.86** | **1.54** | **2.86** |
| **Effect of different application times and concentrations of MC** | | | | |
| **$G_0$** | 118.82 f | 13.62 a | 9.24 bc | 40.24 bc |
| **$G_1$** | 109.33 i | 12.21 cd | 8.93 c-e | 39.07 h |
| **$G_2$** | 121.00 b | 11.34 e | 7.67 f | 40.13 c |
| **$G_3$** | 120.00 cd | 13.32 ab | 9.99 a | 39.23 g |
| **$G_4$** | 120.67 bc | 12.94 a-c | 8.93 c-e | 40.41 a |
| **$G_5$** | 119.78 de | 11.26 e | 7.89 f | 39.42 f |
| **$G_6$** | 120.11 cd | 13.17 ab | 8.72 de | 40.33 ab |
| **$G_7$** | 119.56 d-f | 12.62 b-d | 9.70 ab | 39.89 d |
| **$G_8$** | 114.23 g | 11.89 de | 7.66 f | 40.40 a |
| **$G_9$** | 112.00 h | 12.74 bc | 8.56 e | 39.67 e |
| **$G_{10}$** | 120.67 bc | 13.48 a | 7.54 fg | 40.46 a |
| **$G_{11}$** | 122.00 a | 11.45 e | 9.22 b-d | 39.27 g |
| **$G_{12}$** | 119.11 ef | 12.26 cd | 7.04 g | 40.24 bc |
| **LSD** | **0.746** | **0.729** | **0.51** | **0.132** |
| **CV(%)** | **5.93** | **2.86** | **1.54** | **2.86** |

Means having same letters after numerical values in the same column indicates no significant difference at $P \leq 0.05$.

Here,
$S_0$= 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75DAE

### 4.2.5 Effect of plant spacing and management of growth regulator on lint characteristics of cotton

#### 4.2.5.1 Upper half mean length (UHML)

#### Effect of plant spacing

Upper half mean length (UHML) of cotton had considerable variation among the plant spacings (Table 12). The maximum UHML (30.53 mm) was recorded at spacing 45 cm ×

30 cm ($S_2$) which was significantly different from rest of the spacings. The lowest UHML (28.92 mm) was recorded from spacing 60 cm × 30 cm ($S_0$). Nichols *et al*. (2003) observed that fiber length was increased as plant population increased in cotton. Darawsheh *et al*. (2009 b) reported that 50% span length of lint was negatively affected ($P \leq 0.05$) by high plant density in narrow row. On the contrary, Pitombeira (1972) reported that fiber length (upper half mean) was not significantly affected by plant population.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on UHML of cotton (Table 12). The highest UHML (30.82 mm) was obtained from $G_8$ (foliar sprayed at 4.0 ml MC $L^{-1}$ water at 50 DAE) and the lowest (28.45 mm) at $G_6$ (2.0 ml MC $L^{-1}$ water sprayed at 50 DAE). Edivaldo *et al.* (1996) reported that the CCC increased fiber length in cotton (Silva *et al.*, 2016). On the contrary, Copur *et al.* (2010) reported that fiber length was not affected by the PGRs (except pix) treatments in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

The combined effect of plant spacing and MC sprayed at different times and concentration was found significant for upper half mean length (Tables 13 A and B). Variable concentration of MC and its application time increased UHML almost linearly in all planting density. However, UHML did not markedly increased with increase of MC concentration accompanied with application time. All treatments increased UHML than control. The highest UHML of lint (31.46 mm) was obtained from 1 ml MC $L^{-1}$ water at 25 DAE with 45 cm × 30 cm spacing ($S_1G_1$) and the lowest (26 mm) from water sprayed with 75 cm × 30 cm spacing ($S_2G_0$).

**4.2.5.2 Mean length (ML of lint)**

**Effect of plant spacing**

Upper half mean length (ML) of cotton had significant variation among the plant spacings (Table 12). The maximum ML (25.72 mm) was recorded at spacing 45 cm × 30 cm ($S_1$) followed by 60 cm × 30 cm. The lowest ML (23.96 mm) was marked from spacing 75 cm × 30 cm ($S_2$). Darawsheh *et al*. (2009 b) reported that 50% mean length of lint was negatively affected ($P \leq 0.05$) by high plant density in narrow row. On the contrary, Pitombeira (1972) reported that fiber length was not significantly affected by plant population.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on ML of cotton (Table 12). The highest ML (26.07 mm) was obtained from $G_8$ (foliar sprayed at 4.0 ml MC $L^{-1}$ water at 50 DAE) and the lowest (23.43 mm) at $G_6$ (2.0 ml MC $L^{-1}$ water at 50 DAE). Edivaldo *et al.* (1996) reported that the CCC increased fiber length in cotton (Silva *et al.*, 2016). On the contrary, Copur *et al.* (2010) reported that fiber length was not affected by the PGRs (except pix) treatments in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

ML of lint was significantly affected by the combined effect of plant spacing and MC sprayed at different times (Tables 13 A and B). All treatment combinations increased ML of lint compared to control. ML of lint highest (26.77 mm) from 1 ml MC $L^{-1}$ water sprayed at 25 DAE with 45 cm× 30 cm spacing ($S_1G_1$) and it became lowest (20.73 mm) at water sprayed with 75 cm × 30 cm spacing ($S_2G_0$).

**4.2.5.3 Uniformity index (UI) of lint**

**Effect of plant spacing**

Uniformity index (UI) of lint of cotton had considerable variation among the plant spacings (Table 12). The highest UI (84.26 %) was recorded at spacing 75 cm × 30 cm ($S_2$) and the lowest UI (82.69 %) was recorded from spacing 60 cm × 30 cm ($S_0$). Nichols *et al*. (2004) also reported negative impact of increased plant density on lint uniformity in cotton. Similar results were reported by Feng *et al.*, 2011; Valco *et al*., 2001 and Pitombeira, 1972.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on UI of cotton (Table 12). The maximum UI (84.56 %) was obtained from foliar sprayed at $G_8$ (4.0 ml MC $L^{-1}$ water sprayed at 50 DAE) and the lowest (82.29 %) at $G_6$ (2.0 ml MC $L^{-1}$ water foliar sprayed at 50 DAE) followed by $G_0$ (control). Edivaldo *et al.* (1996) reported that the CCC increased fiber uniformity in cotton (Hasab *et al.*, 2019). On the contrary, Copur *et al.* (2010) reported that fiber uniformity was not affected by the PGR (except pix) treatments in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

A significant variation in the uniformity index (UI) of lint of cotton was observed due to the combined effect of plant spacing and time of MC application and concentration (Table 13 A and B). It ranged between 79.43 and 85.09. Treatment of 4 ml MC $L^{-1}$ water sprayed at 75 DAE with 60 cm x 30 cm spacing ($S_0G_{12}$) showed the maximum UI (85.09) which was statistically similar with $S_0G_3$ (3 ml MC $L^{-1}$ water sprayed at 25 DAE with 60 cm x 30 cm spacing); $S_2G_9$ and $S_2G_{11}$ (1 and 3 ml MC $L^{-1}$ water sprayed at 75 DAE, respectively with 75 cm × 30 cm spacing) treatment combinations. The lowest (79.43) was noted at 4 ml MC $L^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing ($S_2G_{12}$) treatment combinations.

Copur *et al.* (2010) reported that fiber length, fiber fineness, fiber strength and fiber uniformity were not affected by the PGRs treatments. Silva *et al.* (2016) observed that the results showed that application of biostimulants caused changes in the fiber characteristics, related to length uniformity, micronaire, length and strength of the fiber. On the contrary, Nichols *et al*. (2004) and Valco *et al*. (2001) found negative impact of increased plant density on lint uniformity.

**4.2.5.4 Short fiber index (SFI) of lint**

**Effect of plant spacing**

Short fiber index (SFI) of lint of cotton had significant variation among the plant spacings (Table 12). The maximum SFI (9.08) was recorded at spacing 60 cm × 30 cm ($S_0$) and the lowest SFI (7.73) was marked from 45 cm × 30 cm spacing ($S_1$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on SFI of cotton (Table 12). The highest SFI (9.27) was obtained from foliar sprayed at $G_6$ (2.0 ml MC $L^{-1}$ water sprayed at 50 DAE) and the lowest (7.3) at $G_8$ (4.0 ml MC $L^{-1}$ water a sprayed at 50 DAE) treatment.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

SFI of lint was significantly affected by spacing and time of MC application and rates (Table 13 A and B). SFI of lint marked highest (12.5) from 3 ml MC $L^{-1}$ water sprayed at

75 DAE with 75 cm × 30 cm spacing ($S_2G_{11}$) and it became lowest (7) at 3 ml MC $L^{-1}$ water at 75 DAE with 60 cm × 30 cm spacing ($S_0G_{11}$) treatment combinations.

#### 4.2.5.1 Micronaire (Mic.) of lint

**Effect of plant spacing**

Micronaire of lint of cotton had significant variation among the plant spacings (Table 12). The maximum micronaire (4.52) was recorded at 60 cm × 30 cm spacing ($S_0$) and the minimum micronaire (3.94) was marked from 45 cm × 30 cm spacing ($S_1$). Darawsheh (2009b) reported that row spacing influenced most the micronaire readings.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on micronaire of cotton (Table 12). Significantly the highest micronaire (4.55) was obtained from $G_8$ (foliar sprayed at 4.0 ml MC $L^{-1}$ water at 50 DAE) and the lowest (3.84) at $G_2$ (2.0 ml MC $L^{-1}$ water sprayed at 25 DAE) which was statistically identical with $G_7$ (3.0 ml MC $L^{-1}$ water sprayed at 50 DAE) and similar with $G_1$ (1.0 ml MC $L^{-1}$ water sprayed at 25 DAE). Silva *et al.* (2016) and Hasab *et al.* (2019) observed that application of biostimulants caused changes in the fiber characteristics, related to micronnaire of the fiber. On the contrary, Copur *et al.* (2010) reported that fiber fineness was not affected by the PGRs (except pix) treatments .

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Micronaire of lint had significantly influenced by plant population time of MC application with rates (Tables 13 A and B). Irrespective of treatment combinations micronaire of lint ranged from 3.7 to 5.39 control in a few treatment combinations. Micronaire of lint highest (5.39) from 2 ml MC $L^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing ($S_2G_{10}$) which was statistically similar with $S_2G_6$ (2 ml MC $L^{-1}$ water sprayed at 50 DAE followed by the same spacing) treatment combinations and it became lowest (3.7) at 3 ml MC $L^{-1}$ water sprayed at 50 DAE with 45 cm × 30 cm spacing ($S_1G_7$) which was statistically similar with $S_0G_1$, $S_0G_2$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_{11}$ (foliar sprayed with 1to 3 ml MC $L^{-1}$ water at 25 to 75 DAE, respectively under 60 cm × 30 cm spacing); $S_1G_2$, $S_1G_4$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (foliar sprayed with 2 to 4 ml MC $L^{-1}$ water at 25 and 75 DAE, respectively under 45 cm × 30 cm spacing); $S_2G_2$ (foliar sprayed with 2 ml MC $L^{-1}$ water sprayed at 25 DAE under 75 cm × 30 cm spacing) treatment combinations.

Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in micronnaire of the fiber in cotton. Hasab *et al.* (2019) also reported that one plant hill$^{-1}$ was reflected on increasing lint fineness and micronnaire by (4.66 and 4.72) for summer seasons of 2016 and 2017 respectively. Darawsheh (2009b) also observed that the decrease of row spacing significantly decreased some fiber quality parameters. Row spacing and irrigation regime influenced most the micronnaire readings.

#### 4.2.5.6 Maturity ratio (MR)

**Effect of plant spacing**

Maturity ratio of lint of cotton had no significant variation among the plant spacings (Table 12). Numerically the maximum maturity ratio (0.85) was recorded at 60 cm × 30 cm spacing ($S_0$). The minimum maturity ratio (0.83) was obtained from 75 cm × 30 cm spacing ($S_2$). Feng *et al.* (2011) observed that increased plant density reduced maturity ratio.

**Effect of time of application and concentration of MC growth regulator**

MC had no significant effect on maturity ratio of cotton (Table 12). Numerically the higher maturity ratio (0.86) was obtained from $G_6$ (foliar sprayed at 2.0 ml MC L$^{-1}$ water at 50 DAE) and the lower (0.84) at $G_1$ (1.0 ml MC L$^{-1}$ water sprayed at 25 DAE). Edivaldo *et al.* (1996) reported that the CCC increased fiber maturity in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

The combined effect between plant spacing and MC sprayed at different times and concentration was found significant for maturity ratio (Tables 13 A and B). MR of lint became highest (0.86) from 2 ml MC L$^{-1}$ water sprayed at 50 DAE with 60 cm × 30 cm spacing ($S_0G_6$) followed by $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$, $S_0G_{12}$ (1 to 4 ml MC L$^{-1}$ water from 25 to 75 DAE with water spray in 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (1 to 4 ml MC L$^{-1}$ water from 25 to 75 DAE with water spray under 45 cm × 30 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$, $S_2G_8$, $S_2G_9$, $S_2G_{10}$, $S_2G_{11}$ and $S_2G_{12}$ (1 to 4 ml MC L$^{-1}$ water from 25 to 75 DAE with water spray + 75 cm × 30 cm spacing) treatment combinations and it became lowest (0.79) from foliar sprayed with 2 ml MC L$^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$) which was statistically at par with $S_0G_0$, $S_0G_1$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$, $S_0G_9$, $S_0G_{10}$, $S_0G_{11}$, $S_0G_{12}$ (1 to 4 ml MC $L^{-1}$ water from 25 to 75 DAE with water spray in 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$, $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water from 25 to 75 DAE with water spray under 45 cm × 30 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$, $S_2G_8$, $S_2G_9$, $S_2G_{10}$, $S_2G_{11}$ and $S_2G_{12}$ (1 to 4 ml MC $L^{-1}$ water from 25 to 75 DAE with water spray + 75 cm × 30 cm spacing) treatment combinations. Feng *et al.* (2011) reported that increased plant density reduced maturity ratio.

#### 4.2.5.7 Strength of lint

**Effect of plant spacing**

Strength of lint of cotton had significant variation among the plant spacings (Table 12). The maximum strength of lint (30.23 g $tex^{-1}$) was recorded at 45 cm × 30 cm spacing ($S_1$). The minimum strength of lint (28.81 g $tex^{-1}$) was obtained from 60 cm × 30 cm spacing ($S_0$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on strength of lint of cotton (Table 12). The highest strength of lint (31.03 g $tex^{-1}$) was obtained from $G_7$ (foliar sprayed at 3.0 ml MC $L^{-1}$ water at 50 DAE) which was significantly different from other treatments. The lowest (28.67 g $tex^{-1}$) was recorded at $G_{11}$ (3.0 ml MC $L^{-1}$ water sprayed at 75 DAE) which was statistically similar with $G_6$ (2.0 ml MC $L^{-1}$ water sprayed at 50 DAE). Silva *et al.* (2016) observed that application of bio-stimulants caused changes in the fiber characteristics related to strength of the fiber in cottton. On the contrary, Copur *et al.* (2010) and Pitombeira (1972) reported that fiber strength was not affected by the PGRs (except pix) treatments.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

The combined effect between plant spacing and MC sprayed at different times and rates was significant in respect of strength of lint (Table 13 A and B). Strength of lint marked highest (31.79 g $tex^{-1}$) from $S_1G_7$ (3 ml MC $L^{-1}$ water sprayed at 50 DAE) with 45 cm × 30 cm spacing which was statistically similar with $S_1G_0$ and $S_1G_4$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 DAE with water sprayed in 45 cm × 30 cm spacing) and it became lowest (26.32 g $tex^{-1}$) at 2 ml MC $L^{-1}$ water at 50 DAE with 75 cm × 30 cm spacing ($S_2G_6$)

followed by $S_2G_{11}$ and $S_2G_{12}$ (3 and 4 ml MC $L^{-1}$ water at 75 DAE with 75 cm × 30 cm spacing). Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in the fiber characteristics, related to strength of the fiber in cottton. Pitombeira (1972) found that fiber strength and fiber fineness were not significantly affected by plant population.

#### 4.2.5.8 Elongation of lint

**Effect of plant spacing**

Elongation of lint of cotton had significant variation among the plant spacings (Table 12). The maximum elongation of lint (6.06 %) was recorded at 75 cm × 30 cm spacing ($S_2$). The lowest elongation of lint (5.98 %) was marked from 45 cm × 30 cm spacing ($S_1$) followed by 60 cm × 30 cm spacing ($S_0$). Darawsheh (2009b) reported that row spacing influenced less the fiber elongation.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on elongation of lint of cotton (Table 12). The highest elongation of lint (6.13 %) was obtained from ($G_9$) which was statistically similar with $G_0$ and $G_1$ (1.0 ml MC $L^{-1}$ foliar sprayed at 25 DAE with water spray) and the lowest (5.89 %) was observed at $G_{11}$ (3.0 ml MC $L^{-1}$ water sprayed at 75 DAE) which was statistically at par with $G_2$ and $G_{10}$ (2.0 ml MC $L^{-1}$ water sprayed at 25 and 75 DAE) treatment.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Elongation of lint was significantly influenced by the interaction effect of plant spacing and MC sprayed at different times and rates (Table 13 A and B). The maximum elongation (6.38 %) was recorded from water sprayed at 25 DAE with 45 cm × 30 cm spacing ($S_1G_0$**)** which was statistically identical with $S_0G_3$ (3 ml MC $L^{-1}$ water sprayed at 25 DAE with 60 cm × 30 cm spacing) treatment combination and it became lowest (5.66 %) at 3ml MC $L^{-1}$ water sprayed at 25 DAE with 45 cm × 30 cm spacing ($S_1G_3$**)** followed by $S_1G_{10}$ (1ml MC $L^{-1}$ water sprayed at 75 DAE with 45 cm × 30 cm spacing) treatment combination.

Darawsheh (2009b) also observed that the decrease of row spacing significantly decreased some fiber quality parameters. Row spacing and irrigation regime influenced less the fiber elongation.

**4.2.5.9 Reflectance (Rd) of lint**

**Effect of plant spacing**

Reflectance of lint of cotton had significant variation among the plant spacings (Table 12). The maximum reflectance of lint (79.85) was recorded at 45 cm × 30 cm spacing ($S_1$). The minimum reflectance of lint (72.45) was recorded from 75cm × 30 cm ($S_2$) followed by 60cm × 30 cm spacing ($S_0$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on reflectance of lint of cotton (Table 12). The highest reflectance of lint (79.65) was obtained from $G_2$ (2.0 ml MC $L^{-1}$ water sprayed at 25 DAE) and the lowest (69.9) was recorded at $G_8$ (4.0 ml MC $L^{-1}$ water sprayed at 50 DAE) treatment.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Rd of lint was significantly affected by spacing and MC sprayed at different times and rates (Tables 13 A and B). Rd of lint became highest (84.5) from 2 ml MC $L^{-1}$ water sprayed at 75 DAE with 45 cm × 30 cm spacing ($S_1G_{10}$) which was statistically identical with $S_1G_{11}$ and $S_1G_{12}$ (3 to 4 ml MC $L^{-1}$ water sprayed at 75 DAE under 45 cm × 30 cm spacing, but similar with $S_1G_1$, $S_1G_2$, $S_1G_7$, $S_1G_9$ (1 to 3 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE under 45 cm × 30 cm spacing), $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_8$ and $S_2G_9$ (1 to 4 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE + 75 cm × 30 cm spacing) treatment combinations and it became lowest (53) at 4 ml MC $L^{-1}$ water sprayed at 50 DAE with 60 cm × 30 cm spacing ($S_0G_8$) followed by $S_2G_1$, $S_2G_6$, $S_2G_7$, $S_2G_{10}$, $S_2G_{11}$ and $S_2G_{12}$ (1 to 3 ml MC $L^{-1}$ water sprayed from 25 to 75 DAE + 75 cm × 30 cm spacing) treatment combinations.

**4.2.5.10 Yellowness (+b) of lint**

**Effect of plant spacing**

Yellowness of lint of cotton had significant variation among the plant spacings (Table 12). The maximum yellowness of lint (11.77) was recorded at 45 cm × 30 cm spacing ($S_1$). The lowest yellowness of lint (10.09) was marked from 75 cm × 30 cm spacing ($S_2$) followed by 60 cm × 30 cm spacing ($S_0$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on yellowness of lint of cotton (Table 12). The highest yellowness of lint (12.17) was obtained from $G_9$ (foliar sprayed at 1.0 ml MC $L^{-1}$ water at 75 DAE) which was statistically similar with $G_2$ and $G_5$ (1 to 2 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE) treatments and the lowest (8.95) was recorded at $G_8$ (foliar sprayed with 4.0 ml MC $L^{-1}$ water at 50 DAE) followed by $G_{10}$ and $G_{11}$ (foliar sprayed with 2 and 3 ml MC $L^{-1}$ water at 75 DAE) treatments.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Yellowness (+b) of lint was significantly affected by spacing and MC sprayed at different times and rates (Tables 13A and B). +b of lint became highest (13.5) from ($S_2G_8$**)** 4 ml MC $L^{-1}$ water sprayed at 50 DAE with 75 cm × 30 cm which was followed by $S_1G_7$, $S_1G_9$, $S_1G_{10}$, $S_1G_{11}$ and $S_1G_{12}$ (1 to 4 ml MC $L^{-1}$ water sprayed at 50 and 75 DAE, respectively under 45 cm × 30 cm spacing); $S_2G_2$, $S_2G_9$ (1 ml MC $L^{-1}$ water sprayed at 25 and 75 DAE, respectively under 75 cm × 30 cm spacing) treatment combinations and it became lowest (6.2) at 3 ml MC $L^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing ($S_2G_{11}$**)** which was statistically at par with $S_2G_{10}$ (2 ml MC $L^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm spacing) treatment combinations.

**Table 12. Effects of plant spacing and MC level on upper half mean length, mean length, uniformity index, short fiber index, micronaire, maturity ratio, strength, elongation, reflectance and yellowness of lint of cotton**

| Treatments | Upper half mean length (mm) | Mean length (mm) | Uniformity index (%) | Short fiber index | Maturity ratio | Micronaire | Strength (g $tex^{-1}$) | Elongation (%) | Reflectance | Yellowness |
|---|---|---|---|---|---|---|---|---|---|---|
| **Effect of different levels of spacings** | | | | | | | | | | |
| **$S_0$** | 28.92 c | 25.30 a | 82.69 c | 9.08 a | 0.85 | 4.52 a | 28.81 c | 6.00 b | 72.45 c | 10.15 b |
| **$S_1$** | 30.15 b | 25.72 a | 83.87 b | 7.73 b | 0.84 | 3.94 c | 30.23 a | 5.98 b | 79.85 a | 11.77 a |
| **$S_2$** | 30.53 a | 23.96 b | 84.26 a | 7.49 c | 0.83 | 4.01 b | 29.54 b | 6.06 a | 72.9 b | 10.09 b |
| **$LSD_{(0.05)}$** | 0.023 | 0.026 | 0.021 | 0.013 | NS | 0.037 | 0.121 | 0.025 | 0.241 | 0.449 |
| **CV (%)** | 0.12 | 0.16 | 0.04 | 0.25 | 8.82 | 1.42 | 0.65 | 0.66 | 2.54 | 6.65 |
| **Effect of different application times and concentrations of MC** | | | | | | | | | | |
| **$G_0$** | 29.24 j | 24.29 i | 82.97 j | 8.74 d | 0.85 | 4.03 e | 30.48 b | 6.12 ab | 75.6 e | 10.85 cd |
| **$G_1$** | 29.25 j | 24.31 i | 83.00 h | 8.67 e | 0.84 | 3.90 f | 29.34 d | 6.08 a-c | 73 g | 10.27 c-f |
| **$G_2$** | 30.43 d | 25.64 c | 84.26 c | 7.50 i | 0.83 | 3.84 f | 28.64 e | 5.91 fg | 79.65 a | 11.90 ab |
| **$G_3$** | 30.49 c | 25.67 c | 84.21 d | 7.50 i | 0.82 | 4.02 e | 30.41 b | 6.07 bc | 78.65 b | 11.07 b-d |
| **$G_4$** | 30.36 e | 25.53 d | 84.09 e | 7.60 h | 0.85 | 3.99 e | 29.95 c | 6.05 c | 77.5 c | 10.87 cd |
| **$G_5$** | 29.89 h | 25.01 g | 83.69 g | 7.90 f | 0.83 | 4.23 d | 29.40 d | 6.03 cd | 76.35 d | 11.23 a-c |
| **$G_6$** | 28.45 l | 23.43 k | 82.29 j | 9.27 a | 0.86 | 4.41 b | 28.06 f | 5.95 ef | 72.15 h | 10.17 d-f |
| **$G_7$** | 30.16 g | 25.32 f | 83.94 f | 7.73 g | 0.84 | 3.84 f | 31.03 a | 5.97 e | 73.65 f | 10.70 c-e |
| **$G_8$** | 30.82 a | 26.07 a | 84.56 a | 7.30 j | 0.85 | 4.55 a | 29.80 c | 5.98 de | 69.9 i | 8.95 g |
| **$G_9$** | 30.30 f | 25.46 e | 84.05 e | 7.63 h | 0.83 | 4.29 cd | 30.37 b | 6.13 a | 79 b | 12.17 a |
| **$G_{10}$** | 30.62 b | 25.84 b | 84.37 b | 7.47 i | 0.82 | 4.36 bc | 29.49 d | 5.92 fg | 73.65 f | 9.73 fg |
| **$G_{11}$** | 29.33 i | 24.41 h | 82.99 h | 8.97 c | 0.85 | 4.23 d | 28.20 f | 5.89 g | 73.35 fg | 9.83 e-g |
| **$G_{12}$** | 28.93 k | 23.96 j | 82.51 i | 9.07 b | 0.85 | 4.29 cd | 28.67 e | 6.05 c | 73.35 fg | 10.93 cd |
| **$LSD_{(0.05)}$** | **0.050** | **0.056** | **0.0443** | **0.028** | **NS** | **0.082** | **0.292** | **0.051** | **0.527** | **0.962** |
| **CV (%)** | **0.12** | **0.16** | **0.04** | **0.25** | **8.82** | **1.42** | **0.65** | **0.66** | **2.5** | **6.65** |

Means having same letters after numerical values in the same column indicates no significant difference at 5% level

Here,
$S_0$= 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants $ha^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants $ha^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml $L^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml $L^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml $L^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml $L^{-1}$ water at 50 DAE
$G_6$ = MC spray @ 2.0 ml $L^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml $L^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml $L^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml $L^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ water at 75DAE

**Table 13 A.**

## Combined effects of plant spacing and MC level on lint characteristics of cotton

| Treatments | Upper half mean length (mm) | Mean length (mm) | Uniformity index (%) | Short fiber index | Micronaire | Maturity ratio | Strength (g tex-1) | Elongation (%) | Reflectance | Yellowness |
|---|---|---|---|---|---|---|---|---|---|---|
| $S_0G_0$ | 30.12 no | 25.27 j-l | 84.48 bc | 7.53 m | 4.06 e-i | 0.85 ab | 30.47 e-h | 5.99 de | 74.5 ij | 10.53 f-i |
| $S_0G_1$ | 30.76 d-f | 25.83 fg | 80.26 t | 7.30 o | 3.81 lm | 0.84 ab | 29.68 i-l | 6.22 b | 76 f-h | 10.60 e-i |
| $S_0G_2$ | 30.60 gh | 25.80 fg | 84.48 bc | 7.10 p | 3.84 k-m | 0.79 b | 27.43 q | 5.93 ef | 74 j | 11.40 d-h |
| $S_0G_3$ | 30.57 g-i | 25.77 f-h | 85.01 a | 7.30 o | 4.03 f-j | 0.84 ab | 30.18 g-j | 6.38 a | 74 j | 11.50 c-g |
| $S_0G_4$ | 30.53 h-j | 25.72 g-i | 84.49 b | 7.50 m | 4.07 e-h | 0.83 ab | 29.05 m-p | 5.93 ef | 74 j | 10.40 g-i |
| $S_0G_5$ | 30.48 i-k | 25.67 h-j | 84.11 ij | 7.50 m | 3.71 m | 0.82 ab | 30.72 c-g | 6.22 b | 74.5 ij | 10.70 e-i |
| $S_0G_6$ | 30.43 j-l | 25.60 i-k | 84.31 e-g | 8.00 h | 3.83 k-m | 0.86 a | 29.04 m-p | 5.93 ef | 74.5 ij | 10.80 e-i |
| $S_0G_7$ | 30.40 k-m | 25.57 j-l | 83.57 m | 7.60 i | 3.83 k-m | 0.82 ab | 30.75 c-g | 6.05 cd | 74 j | 10.80 e-i |
| $S_0G_8$ | 30.39 k-m | 25.56 j-l | 84.08 ij | 7.40 n | 5.00 b | 0.84 ab | 28.55 op | 5.99 de | 53 m | 10.81e-i |
| $S_0G_9$ | 30.33 lm | 25.50 kl | 84.34 d-f | 7.90 i | 4.09 e-g | 0.85 ab | 30.08 h-j | 6.11 bc | 74.5 ij | 10.10g-i |
| $S_0G_{10}$ | 30.29 m | 25.45 l | 83.64 im | 7.90 i | 3.92 g-l | 0.82 ab | 29.96 h-k | 6.05 cd | 75.5 hi | 10.00 hi |
| $S_0G_{11}$ | 30.17 n | 25.32 m | 83.67 l | 7.00 q | 3.79 lm | 0.83 ab | 28.91 n-p | 5.81 gh | 74.5 ij | 10.20 g-i |
| $S_0G_{12}$ | 30.14 n | 25.29 m | 85.09 a | 7.30 o | 4.09 e-g | 0.85 ab | 29.17 l-o | 6.17 b | 74 j | 11.30 d-h |
| $S_1G_0$ | 30.63 gh | 25.83 fg | 84.50 b | 7.30 o | 4.03 f-j | 0.83 ab | 31.39 ab | 6.38 a | 74.8 ij | 10.10 g-i |
| $S_1G_1$ | 31.46 a | 26.77 a | 84.02 j | 7.60 l | 3.95 f-l | 0.84 ab | 29.82 i-k | 6.22 b | 82 bc | 11.9 0b-f |
| $S_1G_2$ | 31.21 b | 26.53 b | 83.90 k | 7.70 k | 3.83 k-m | 0.82 ab | 29.37 k-n | 5.93 ef | 81 cd | 12.00 b-e |
| $S_1G_3$ | 31.18 bc | 26.51 b | 83.92 k | 7.70 k | 3.91 h-l | 0.81 ab | 30.21 f-i | 5.66 i | 78.5 e | 9.70 ij |
| $S_1G_4$ | 31.08 c | 26.42 b | 83.91 k | 7.70 k | 3.83 k-m | 0.84 ab | 31.23 a-c | 5.99 de | 77.5 ef | 11.00 d-i |
| $S_1G_5$ | 30.83 d | 26.05 c | 83.11 p | 8.30 f | 3.89 i-l | 0.83 ab | 28.83 n-p | 5.93 ef | 77 fg | 11.10 d-i |
| $S_1G_6$ | 30.81 d | 26.03 c | 82.92 q | 8.50 e | 4.08 e-h | 0.85 ab | 28.81 n-p | 5.93 ef | 77 fg | 11.30 d-h |
| $S_1G_7$ | 30.80 d | 26.02 c | 83.44 n | 8.10 g | 3.70 m | 0.82 ab | 31.79 a | 5.93 ef | 81.5 b-d | 12.90 a-c |
| $S_1G_8$ | 30.79 de | 26.01 cd | 84.33 ef | 7.40 n | 4.34 d | 0.85 ab | 30.75 c-g | 5.85 fg | 74.25 j | 10.55 f-i |
| $S_1G_9$ | 30.78 de | 25.97 c-e | 84.11 ij | 7.60 l | 4.21 de | 0.83 ab | 30.21 f-i | 6.11 bc | 80.5 d | 13.20 ab |
| $S_1G_{10}$ | 30.76 d-f | 25.97 c-e | 84.43 b-d | 7.40 n | 3.78 i-m | 0.84 ab | 31.00 b-e | 5.99 de | 84.5 a | 12.90 a-c |
| $S_1G_{11}$ | 30.68 e-g | 25.89 d-f | 84.44 bc | 7.40 n | 3.83 k-m | 0.81 ab | 29.1 l-p | 5.93 ef | 84.5 a | 13.10 ab |
| $S_1G_{12}$ | 30.66 fg | 25.85 ef | 83.31 o | 7.80 j | 3.78 lm | 0.85 ab | 30.47 e-h | 5.87 fg | 84.5 a | 13.20 ab |

TABLE 13 B (Contd.)

| Treatment combinations | Upper half mean length (mm) | Mean length (mm) | Uniformity index (%) | Soft fiber index | Micro-naire | Maturity ratio | Strength (g tex$^{-1}$) | Elongation (%) | Reflectance | Yellowness |
|---|---|---|---|---|---|---|---|---|---|---|
| **$S_2G_0$** | 26 w | 20.73 v | 79.73 u | 11.l4 d | 4.00 f-k | 0.85 ab | 29.58 j-m | 5.99 de | 77.5 ef | 11.9 b-f |
| **$S_2G_1$** | 30.08 no | 25.23 mn | 84.14 hi | 11.1 d | 3.94 f-l | 0.84 ab | 28.52 p | 5.81 gh | 61 l | 8.3 j |
| **$S_2G_2$** | 30.01 o | 25.15 n | 80.5 r | 7.7 k | 3.86 j-m | 0.83 ab | 29.13 l-p | 5.87 fg | 84 a | 12.3 a-d |
| **$S_2G_3$** | 28.89 t | 25.01 o | 83.88 k | 7.5 m | 4.11ef | 0.82 ab | 30.85 b-e | 6.17 b | 84 a | 12 b-e |
| **$S_2G_4$** | 29.82 p | 24.94 op | 84.22 gh | 7.5 m | 4.04 e-i | 0.85 ab | 29.57 j-m | 6.22 b | 80.5 d | 11.2 d-h |
| **$S_2G_5$** | 29.82 p | 24.94 op | 84.25 fg | 7.9 i | 5.09 b | 0.86 ab | 28.64 op | 5.93 ef | 77.5 ef | 11.9 b-f |
| **$S_2G_6$** | 29.77 p | 24.88 p | 83.64 im | 11.3 c | 5.32 a | 0.82 ab | 26.32 r | 5.99 de | 65 k | 8.4 j |
| **$S_2G_7$** | 29.59 q | 24.69 q | 80.38 s | 7.5 m | 3.99 f-k | 0.84 ab | 30.55 d-h | 5.93 ef | 65 k | 8.4 j |
| **$S_2G_8$** | 29.24 r | 24.30 r | 84.30 e-g | 7.1 p | 4.30 d | 0.85 ab | 30.18 g-j | 6.11 bc | 82.5 b | 13.5 a |
| **$S_2G_9$** | 29.04 s | 24.08 s | 85.02 a | 7.4 n | 4.57 c | 0.83 ab | 30.82 b-f | 6.11 bc | 82 bc | 13.2 ab |
| **$S_2G_{10}$** | 26.67 u | 21.47 t | 84.39 c-e | 7.1 p | 5.39 a | 0.81 ab | 27.51 q | 5.72 hi | 61 l | 6.3 k |
| **$S_2G_{11}$** | 26.55 v | 21.34 u | 85.01 a | 12.5 a | 5.06 b | 0.85 ab | 26.59 r | 5.93 ef | 61 l | 6.2 k |
| **$S_2G_{12}$** | 26.45 v | 21.23 u | 79.43 v | 12.1 b | 5.00 b | 0.82 ab | 26.37 r | 6.11 bc | 61.5 l | 8.3 j |
| **LSD $_{(0.05)}$** | **0.107** | **0.119** | **0.095** | **0.06** | **0.175** | **0.094** | **0.621** | **0.11** | **1.125** | **1.444** |
| **CV (%)** | **0.12** | **0.16** | **0.04** | **0.25** | **1.42** | **0.84** | **0.65** | **0.66** | **2.54** | **6.65** |

Means having same letters after numerical values in the same column indicates no significant difference at 5% level

Here,
$S_0$= 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from first year experiment as promising treatment.
$S_1$= 45 cm × 30 cm (74,074 plants ha$^{-1}$)
$S_2$= 75 cm × 30 cm (44,444 plants ha$^{-1}$)

$G_0$= Water spray (control)
$G_1$ = Mepiquat Chloride spray (MC) @ 1.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = MC spray @ 2.0 ml L$^{-1}$ water at 25 DAE
$G_3$ = MC spray @ 3.0 ml L$^{-1}$ water at 25 DAE
$G_4$ = MC spray @ 4.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = MC spray @ 1.0 ml L$^{-1}$ water at 50 DAE

$G_6$ = MC spray @ 2.0 ml L$^{-1}$ water at 50 DAE
$G_7$ = MC spray @ 3.0 ml L$^{-1}$ water at 50DAE
$G_8$ = MC spray @ 4.0 ml L$^{-1}$ water at 50 DAE
$G_9$ = MC spray @ 1.0 ml L$^{-1}$ water at 75 DAE
$G_{10}$ = MC spray @ 2.0 ml L$^{-1}$ water at 75DAE
$G_{11}$ = MC spray @ 3.0 ml L$^{-1}$ water at 75DAE
$G_{12}$ = MC spray @ 4.0 ml L$^{-1}$ water at 75DAE

## 4.3 EXPERIMENT 03

**Yield and quality assessment of cotton plant spacing coupled with mepiquat chloride foliar spray management**

Another experiment was conducted during 2018-19 at the Sreepur farm with three spacing and nine MC spray level at different growth stages which are given in the chapter 3 (sub-title 3.1.3). The tested variety was CB 14.

The results obtained in the study have been presented either in table or figure which are followed by discussion.

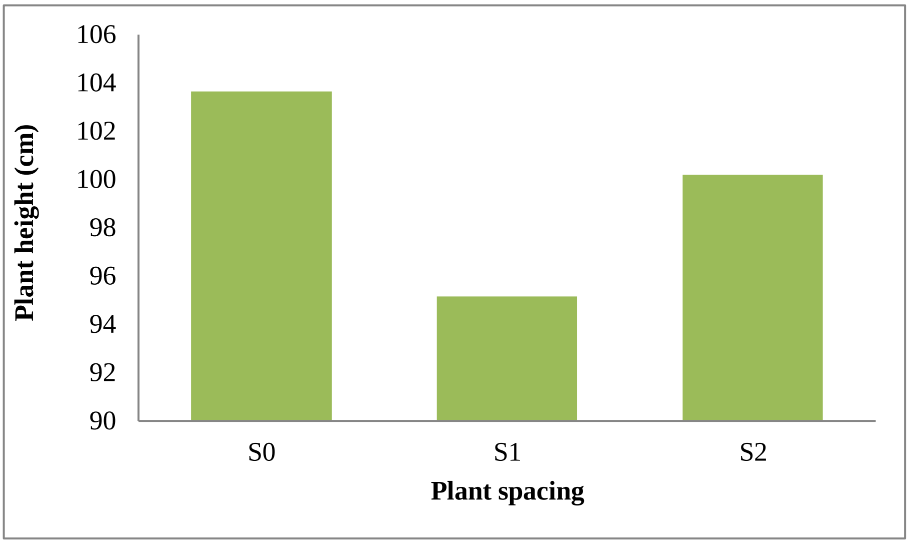
### 4.3.1 Effect of plant spacing and MC growth regulator (mepiquat chloride) on phenological characters of cotton

#### 4.3.1.1 Plant height

**Effect of plant spacing**

Significant influence was observed by plant spacing on plant height of cotton (Fig. 65). It was observed that plant height ranged from 95.16 to 103.64 cm with irrespective of treatments. The tallest plant (103.64 cm) was measured from 60 cm × 30 cm plant spacing ($S_0$) which was statistically similar with 60 cm × 20 cm plant spacing ($S_2$)**.** The shortest plant (95.16 cm) was measured from 90 cm ×10 cm spacing ($S_1$).

Baumhardt *et al.* (2018), Deotalu *et al.* (2013) and Jahedi *et al.* (2013) reported that plant height increased significantly with wider row spacing in cotton while Ponnuswami and Rani (2019) had similar observation as working with moringa.



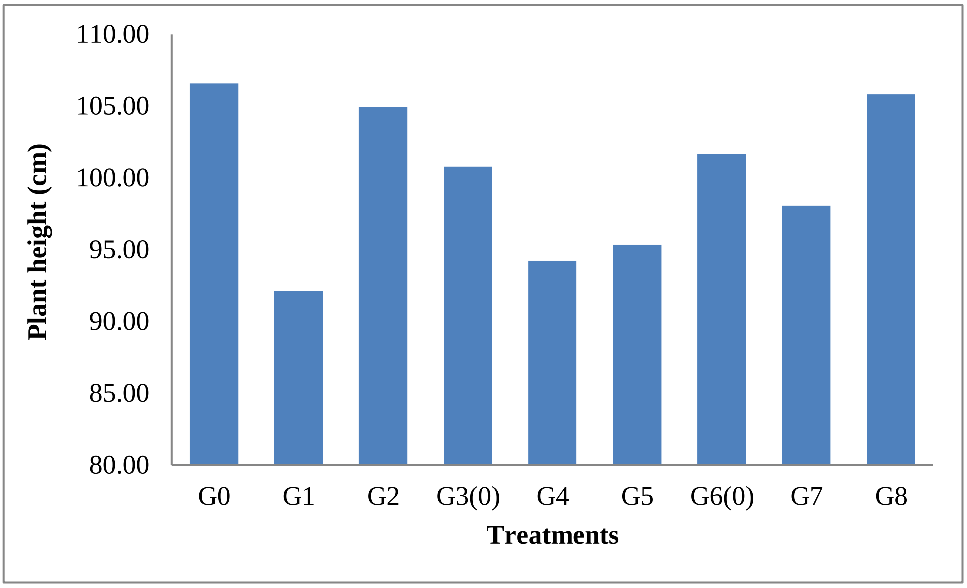

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)

**Figure 65. Influence of plant spacing on plant height of cotton (LSD $_{(0.05)}$ = 6.961).**

**Effect of time of application and concentration of MC growth regulator**

Growth regulator MC application time and its concentration was found to influence significantly the plant height (Fig. 66) which ranged between 92.13 to 106.57 cm. The tallest plant (106.57 cm) was measured from control ($G_0$) and the shortest (92.13 cm) from foliar sprayed at 2 ml MC L$^{-1}$ water at 25 DAE ($G_1$).

Kumar *et al.* (2005) reported that 50 ppm MC sprayed at 90 DAS was found to be effective than CCC in reducing cotton plant height. Shahr *et al.* (2015) noted reduced plant height of cotton by 19.5% than control using Pix regulator at 30 days after flowering. Some other scientists observed reduced plant height of different crops with different growth retardants (Amit *et al.*, 2016 in cotton; Niakan and Habibi, 2013 in cotton; Reddy *et al.*, 1990 in cotton; Zhang *et al.*, 2017 in spring wheat; Butcher and Malik, 2016 in oats; Spitzer *et al.*, 2015 in maize; Lucieli *et al.*, 2017 in maize; Kirkland, 1992 in canola; Setia *et al.*, 1995 in *Brassica carinata* ; Baylis and Dickst, 1983 in sunflower). Eveleigh *et al.* (2010) opined that any growth retardant reduces the production of plant hormone gibberellic acid, which in turn slows cell expansion and elongation thus both leaf growth and internode elongation is ceased down to reduce cotton plant height.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 66. Influence of time of application and concentration of MC on plant height of cotton (LSD$_{(0.05)}$ = 8.672).**

### The combined effect of plant spacing along with time of application and concentration of growth regulator

Significant variation was found in plant height due to combined effect of plant density and MC level (Table 14). Plant height increased with the increase of plant spacing (lower plant density) irrespective of growth regulator application time. Irrespective of plant population, gradual shorter plants were observed when plants sprayed with MC compared to control which indicated that MC reduces plant height. Plant height of cotton was highest (113.7 cm) from 2 ml MC $L^{-1}$ water at 25 DAE with 90 cm × 10 cm spacing ($S_1G_1$) which was statistically similar with $S_0G_0$, $S_0G_2$, $S_0G_3$, $S_0G_5$, $S_0G_6$, $S_0G_7$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_3$ (foliar sprayed with 4 ml MC $L^{-1}$ water at 25 DAE, respectively with water spray in 90 cm × 10 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_6$, and $S_2G_7$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25 and 25 and 50 DAE, respectively with water spray in 60 cm × 20 cm spacing); and it was noticed lowest (89.83 cm) from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE in 60 cm x 30 cm spacing ($S_0G_1$) followed by $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_7$, $S_0G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at

50, 25 and 50 DAE, respectively with 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing); $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$ and $S_2G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 50 and 25 and 50 DAE, respectively with 60 cm × 20 cm spacing). The findings are corroborated to Zhao *et al.* (2019) who stated that application of MC reduced plant height under different plant densities in cotton. Similar result was reported by Lucieli *et al.* (2017) in maize.

**Table 14. Combined effect of plant spacing and mepiquat chloride application time and concentration on plant height of cotton**

| Treatments | Plant height (cm) | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 111.30 a | 103.73 a-d | 110.23 a |
| $G_1$ | 89.83 d | 113.70 a | 109.20 ab |
| $G_2$ | 110.70 a | 102.17 a-d | 109.73 a |
| $G_{3(0)}$ | 102.87 a-d | 99.23 a-d | 94.47 b-d |
| $G_4$ | 94.47 b-d | 92.73 d | 92.43 d |
| $G_5$ | 102.47 a-d | 91.87 d | 91.77 d |
| $G_{6(0)}$ | 108.33 a-c | 94.13 cd | 101.37 a-d |
| $G_7$ | 100.73 a-d | 92.83 d | 99.40 a-d |
| $G_8$ | 93.30 d | 89.93 d | 93.17 d |
| $LSD_{(0.05)}$ | 15.02 | | |
| CV (%) | 9.24 | | |

Means having same letters after numerical values in the same column indicates no significant difference at $P \leq 0.05$.

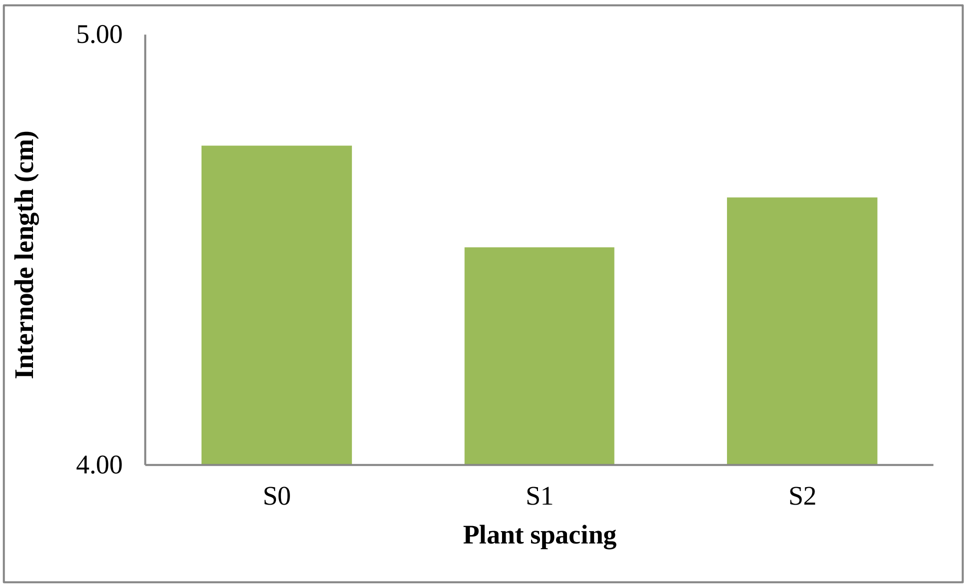
Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)
$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

#### 4.3.1.2 Internodal length

**Effect of plant spacing**

There was no significant difference among the plant spacings in respect of internodal length (Fig. 67). It varied from 4.51 to 4.74 cm, plant spacing 60 cm × 30 cm ($S_0$) had the highest (4.74 cm) internode length which was statistically similar with 60 cm × 20 cm spacing ($S_2$). The lowest (4.51 cm) being recorded from 90 cm × 10 cm spacing ($S_1$).

Baumhardt *et al.* (2018) narrated that internode increased significantly with increased row spacing in cotton. Similar information was reported by Singh *et al.* (2017) in tomato.



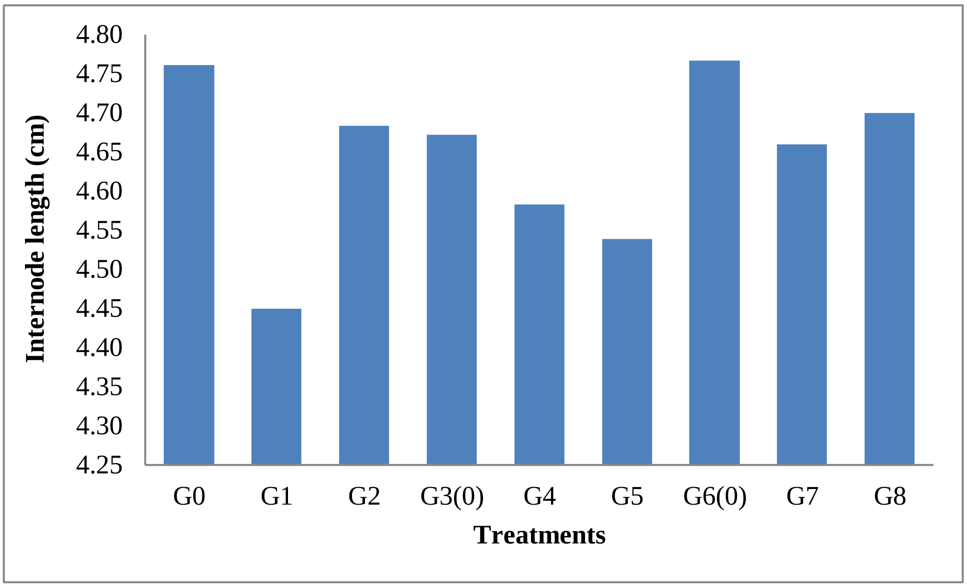

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

**Figure 67. Influence of plant spacing on internode length of cotton (LSD $_{(0.05)}$ = 0.271).**

**Effect of time of application and concentration of MC growth regulator**

MC level and its application time had significant influence on internodal length (Fig. 68). Internode of cotton plant was observed highest (4.77 cm) from water spray ($G_6$) and it was marked lowest (4.45 cm) from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE ($G_1$). Internodal length reduced as MC sprayed compared to control.

Priyanka and Dalvi (2019) reported that internodal length reduced as MC sprayed compared to control. Application of mepiquat chloride (mc @ 15ml and 10 ml 10 $L^{-1}$ of water) at square and flower formation stage was found effective in reducing internode length in cotton. This finding was in agreement with the findings of other researchers, Shahr *et al.*, 2015 in cotton; Gu *et al.*, 2014 in cotton; Eveleigh *et al.*, 2010 in cotton and Volterrani *et al.*, 2015 in bermuda grass.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 68. Influence of time of application and concentration of MC on internode length of cotton ($LSD_{(0.05)}$ = 0.30).**

**The combined effect of plant spacing along with time of application and concentration of growth regulator**

Combined effect of plant density and MC level had significant variation in internodal length. Internodal length increased progressively and significantly irrespective of treatment combinations (Table 15). Internodal length decreased as plant population increased and internodal length reduced with MC sprayed compared to control. Internode of cotton plant marked highest (5.13 cm) from foliar sprayed with 90 cm × 10 cm spacing ($S_1G_6$) which was statistically similar with $S_0G_0$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing); $S_1G_0$ (control, foliar sprayed with water spray in 90 cm × 10 cm spacing); $S_2G_3$, $S_2G_5$, $S_2G_6$, $S_2G_7$ and $S_2G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 50 and 25 and 50 DAE, respectively with water spray in 60 cm × 20 cm spacing) treatment combinations. The lowest (4.3 cm) was obtained from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE in 60 cm × 30 cm spacing ($S_0G_1$). which was statistically similar with $S_0G_0$, $S_0G_2$, $S_0G_7$ (foliar sprayed with 4 and 2 ml MC $L^{-1}$ water at 25 and 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_7$, $S_1G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at

25, 50, 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$ and $S_2G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 60 cm × 20 cm spacing) treatment combinations. Iqbal *et al.* (2007) suggested that internodal length decreased in narrow plant spacing with MC sprayed in cotton.

**Table 15. Combined effect of plant spacing and mepiquat chloride application time and concentration on internodal length of cotton**

| Treatments | Internodal length (cm) | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 4.82 a-f | 4.77 a-f | 4.60 b-f |
| $G_1$ | 4.30 f | 4.42 d-f | 4.57 c-f |
| $G_2$ | 4.80 a-f | 4.33 ef | 4.58 c-f |
| $G_{3(0)}$ | 4.95 a-c | 4.47 c-f | 4.68 a-f |
| $G_4$ | 4.83 a-e | 4.43 c-f | 4.60 b-f |
| $G_5$ | 4.87 a-d | 4.45 c-f | 4.62 a-f |
| $G_{6(0)}$ | 5.12 ab | 5.13 a | 4.75 a-f |
| $G_7$ | 4.47 c-f | 4.50 c-f | 4.70 a-f |
| $G_8$ | 5.12 ab | 4.47 c-f | 4.70 a-f |
| $LSD_{(0.05)}$ | 0.5203 | | |
| CV (%) | 7.76 | | |

Means having same letters after numerical values in the same column indicates no significant difference at $P \leq 0.05$.

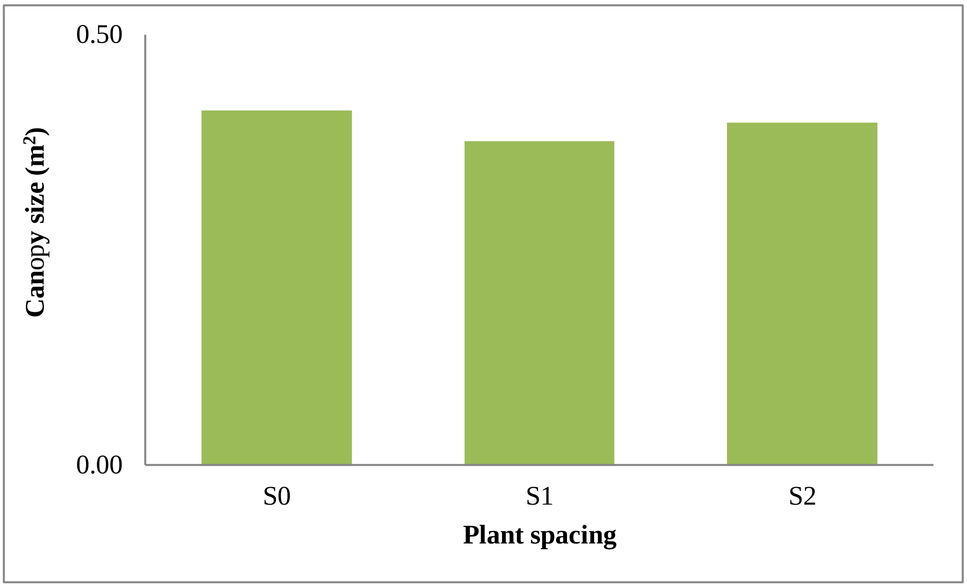
Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

#### 4.3.1.3 Leaf canopy size

**Effect** of p**lant spacing**

There was no significant difference among the spacings in respect of leaf canopy size. Leaf canopy size slightly increased by 60 cm × 30 cm spacing but it was not significant (Fig. 69). Cotton leaf canopy size enumerated highest (0.41 $m^2$) from 60 cm × 30 cm spacing ($S_0$) and marked lowest (0.38 $m^2$) with 90 cm × 10 cm spacing ($S_1$). Stewart *et al.* (1997) reported that leaf canopy size in peanuts increased as plant density decreased compared to control (Emilie and Kufimfutu, 1995 in oats; Liu *et al.*, 2011 in maize; Ponnuswami and Rani, 2019 in moringa).

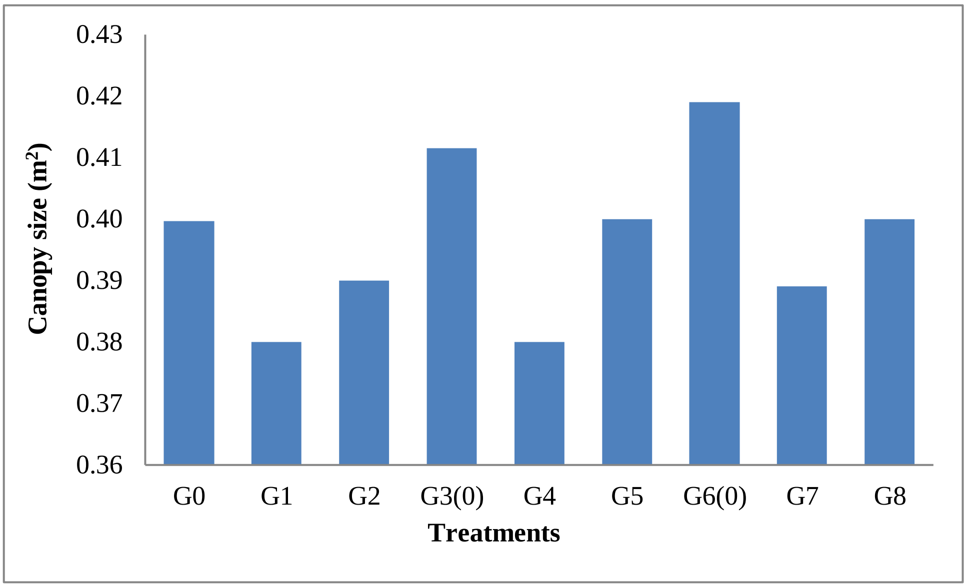



Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)

**Figure 69. Influence of plant spacing on canopy size of cotton (LSD $_{(0.05)}$ = 0.087).**

### Effect of time of application and concentration of MC growth regulator

Leaf canopy size obtained at different application time and concentration of MC differed significantly which ranges from 0.38 to 0.42 m$^2$ (Fig. 70). Cotton leaf canopy size enumerated highest (0.42 m$^2$) from control or without MC ($G_6$) and it was marked lowest (0.38 m$^2$) at 2 ml MC L$^{-1}$ water at 25 DAE ($G_1$) which was identical with $G_4$ (2 ml MC L$^{-1}$ water at 50 DAE). Gu *et al.* (2014) reported that canopy structure became more compact with the decrease of leaf area index due to the application of MC in cotton. Zhao *et al.* (2019) found that leaf canopy size was decreased as MC sprayed compared to control in cotton (Gollagi *et al.*, 2019 in guava; Singh and Chanana, 2005 in guava; Edgerton, 1983 in apple). Eveleigh *et al.* (2010) opined that plant hormone reduced the production of the gibberellic acid, which in turn slowed cell expansion resulting in reduced canopy (leaf growth) in cotton.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 70. Influence of time of application and concentration of MC on canopy size of cotton ($LSD_{(0.05)}$ = 0.034).**

**Combined effect of plant spacing along with time of application and concentration of growth regulator**

A significant variation in leaf canopy size was observed due to combined effect of plant spacing and time of application and concentration of MC (Table 16). Leaf canopy size varied from 0.32 to 0.47 $m^2$ due to different treatment combinations. Leaf canopy size is increased as plant density decreased but decreased as MC sprayed compared to control. Cotton leaf canopy size was marked highest at (0.47 $m^2$) from water sprayed with 90 cm × 10 cm spacing ($S_1G_0$) which was statistically similar with $S_0G_3$, $S_0G_4$, $S_0G_6$ (foliar sprayed with 2 ml MC $L^{-1}$ water at 50 DAE with water spray in 60 cm × 30 cm spacing); $S_1G_0$ (control, foliar sprayed with water spray in 90 cm × 10 cm spacing); $S_2G_0$, $S_2G_2$, $S_2G_3$, $S_2G_6$, $S_2G_7$ and $S_2G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25 and 25 and 50 DAE, respectively with water spray in 60 cm × 20 cm spacing) treatment combinations; and enumerated lowest (0.32 $m^2$) from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was statistically similar with $S_0G_2$, $S_0G_7$, $S_0G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25 and 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing); $S_1G_1$, $S_1G_2$, $S_1G_5$, $S_1G_7$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing); and $S_2G_5$ (foliar sprayed with 4 ml MC $L^{-1}$ water at 50 DAE with 60 cm × 20 cm spacing) treatment combinations. Zhao *et al*. (2019) reported that application of MC resulting in a lower and more compact plant canopy in cotton.

**Table 16. Combined effect of plant spacing and mepiquat chloride application time and concentration on canopy size of cotton**

| Treatments | Canopy size ($m^2$) | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 0.40 b-d | 0.47 a | 0.43 ab |
| $G_1$ | 0.32 e | 0.37 b-e | 0.40 b-d |
| $G_2$ | 0.38 b-e | 0.35 de | 0.40 a-c |
| $G_{3(0)}$ | 0.42 a-c | 0.40 b-d | 0.41a-d |
| $G_4$ | 0.41 a-d | 0.39 b-d | 0.39 b-d |
| $G_5$ | 0.39 b-d | 0.38 b-e | 0.36 c-e |
| $G_{6(0)}$ | 0.41 a-d | 0.40 b-d | 0.42 a-c |
| $G_7$ | 0.41 b-e | 0.35 de | 0.41 a-d |
| $G_8$ | 0.41 b-e | 0.40 b-d | 0.41 ab |
| **$LSD_{(0.05)}$** | **0.0596** | | |
| **CV (%)** | **19.28** | | |

Means having same letters after numerical values in the same column indicates no significant difference at $P \leq 0.05$.

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)

$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml L$^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml L$^{-1}$ water at 50 DAE

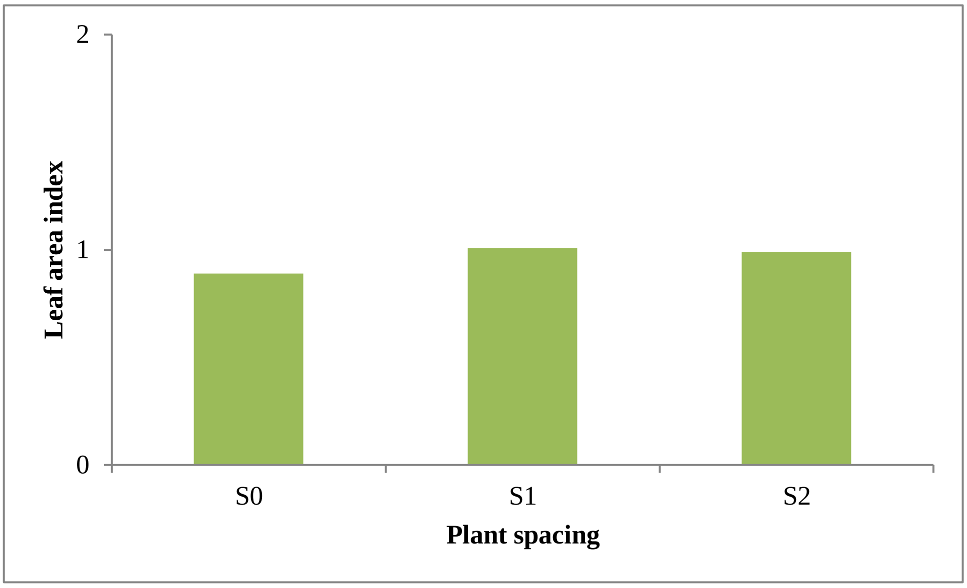
$G_5$ = 4.0 ml L$^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml L$^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml L$^{-1}$ water at 25 and 50 DAE

#### 4.3.1.4 Leaf area index

**Effect** of p**lant spacing**

Leaf area index varied insignificantly due to different plant densities ranges from 0.89 to 1.01 (Fig. 71). The maximum leaf area index (1.01) was obtained from 90 cm × 10 cm spacing ($S_1$) which was statistically similar with 60 cm × 20 cm spacing ($S_2$). The minimum LAI (0.89) was produced by 60 cm × 30 cm spacing ($S_0$).

Sowmiya and Sakthivel (2018) reported that the narrow plant spacing of 60 cm x 15 cm had significantly higher leaf area index in cotton. Similar information was also reported by Pengcheng *et al.*, 2015 in cotton and Darawsheh and Aivalakis, 2007 in cotton. Ricaurte *et al.* (2016) argued that sowing density is a major management factor that affects growth and development of crops by modifying the canopy light environment and interplant competition for water and nutrients in bean.

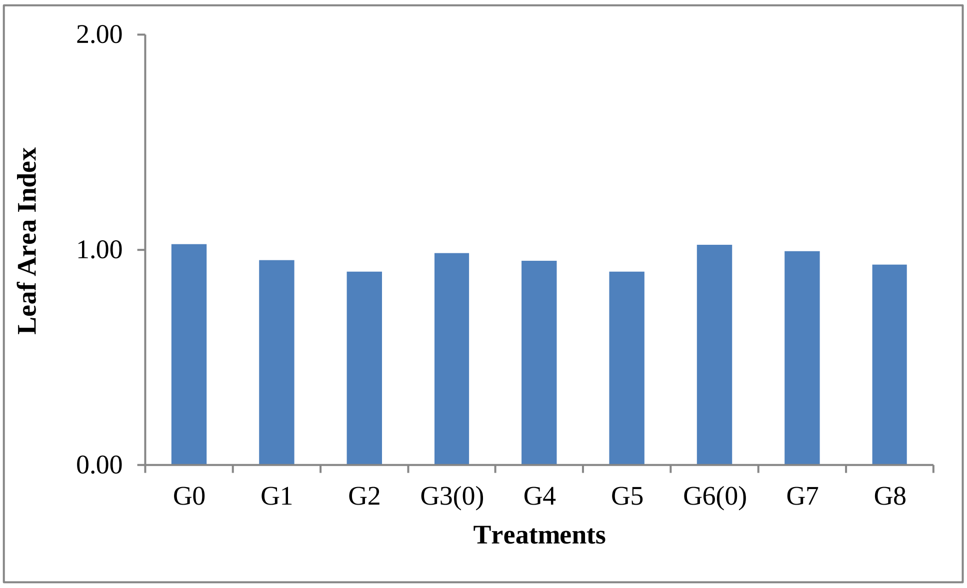



Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

**Figure 71. Influence of plant spacing on LAI of cotton (LSD $_{(0.05)}$ = 0.161).**

**Effect of time of application and concentration of MC growth regulator**

Combination of growth regulator for MC level and its application time effect on LAI of cotton was insignificant (Fig. 72). The mean LAI varied from 0.90 to 1.03 due to MC levels and application time. However, the highest value for LAI (1.03) was recorded from $G_0$ (without MC) and the lowest (0.90) from 4ml MC $L^{-1}$ water at 25 DAE ($G_2$) which was statistically identical with $G_5$ (4ml MC $L^{-1}$ water at 50 DAE). Amit *et al.* (2016) reported that application of MC @ 300 ppm, TIBA @ 100 ppm and MH @ 250 ppm reduced leaf area index than control in cotton. Leaf area index of cotton was decreased as MC sprayed compared to control (Kumar *et al.*, 2005).




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 72. Influence of time of application and concentration of MC on LAI of cotton ($LSD_{(0.05)}$ = 0.162).**

**The combined effect of plant spacing along with time of application and concentration of growth regulator**

Combined effect of plant density and MC level on LAI was significant. Leaf area index is increased as plant density increased but decreased as MC sprayed compared to control (Table 17). Leaf area index was marked highest (1.23) from $S_1G_3$ treatment combination **(**without MC with 90 cm × 10 cm spacing) which was statistically similar with $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing); $S_2G_0$, $S_2G_3$, $S_2G_6$ and $S_2G_8$ (foliar sprayed with 4 ml MC $L^{-1}$ water at 25 and 50 DAE with water spray in 60 cm × 20 cm spacing) treatment combinations. The lowest (0.72) from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was statistically similar with $S_0G_0$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing), $S_1G_4$, $S_1G_7$, $S_1G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 50 and 25 and 50 DAE, respectively with 90 cm × 10 cm spacing), $S_2G_0$, $S_2G_1$, $S_2G_2$,

$S_2G_3$, $S_2G_4$, $S_2G_5$ and $S_2G_7$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 60 cm × 20 cm spacing) treatment combinations.

. **Table 17. Combined effect of plant spacing and mepiquat chloride application time and concentration on leaf area index of cotton**

| Treatments | Leaf area index | | |
|---|---|---|---|
| | $S_0$ | $S_1$ | $S_2$ |
| $G_0$ | 0.88 cd | 1.17 ab | 0.97 a-d |
| $G_1$ | 0.72 d | 1.05 a-c | 0.92 b-d |
| $G_2$ | 0.85 cd | 1.07 a-c | 0.93 b-d |
| $G_{3(0)}$ | 0.88 cd | 1.23 a | 0.96 a-d |
| $G_4$ | 0.85 cd | 0.99 a-d | 0.87 cd |
| $G_5$ | 0.85 cd | 1.07 a-c | 0.90 b-d |
| $G_{6(0)}$ | 0.91 b-d | 1.11 a-c | 1.05 a-c |
| $G_7$ | 0.88 cd | 0.96 a-d | 0.88 cd |
| $G_8$ | 0.91 b-d | 1.05 a-c | 1.03 a-c |
| $LSD_{(0.05)}$ | 0.2803 | | |
| CV (%) | 20.12 | | |

Means having same letters after numerical values in the same column indicates no significant difference at $P \leq 0.05$.

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE

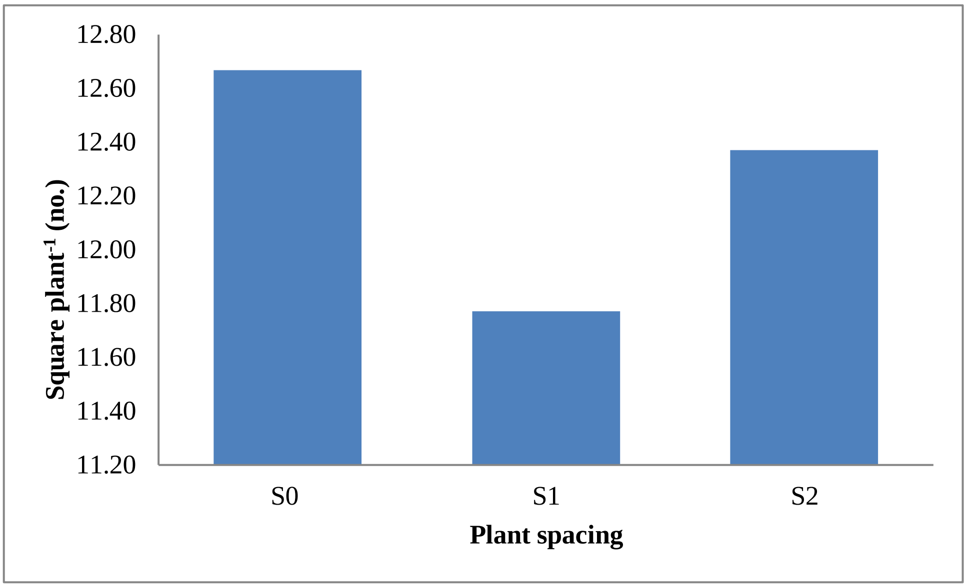
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

### 4.3.3 Effect of plant spacing and time of application and concentration of mepiquat chloride on yield contributing characters and yield of cotton

#### 4.3.3.1 Squares plant$^{-1}$

**Effect of plant spacing**

Squares plant$^{-1}$ of cotton varied significantly with plant spacings which ranged from 11.77 to 12.67 (Fig. 73). Squares plant$^{-1}$ increased with the decrease of plant population. Spacing of 60 cm × 30 cm ($S_0$) showed maximum squares plant$^{-1}$ (12.67) while squares plant$^{-1}$ was minimum (11.77) in spacing of 90 cm × 10 cm ($S_1$). The higher number of squares could have produced due to more photosynthates as partitioned to the flowers. Parekh *et al.* (2018) and Yagia *et al.* (2014) reported that there was a trend to decrease squares plant$^{-1}$ with the decrease in plant spacing in spider lily crop.



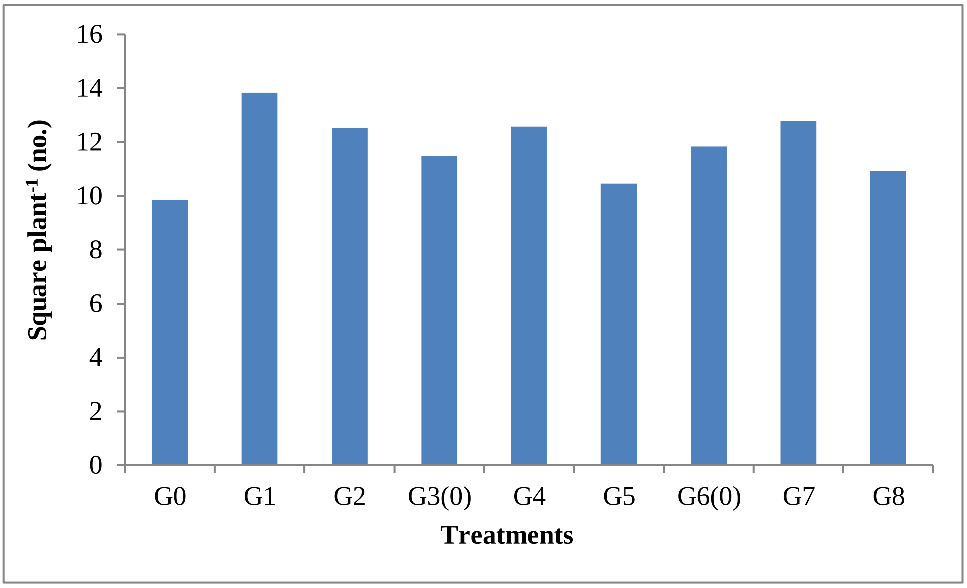

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

**Figure 73. Effect of plant spacing level on squares plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.452).**

## Effect of time of application and concentration of MC growth regulator

Squares plant$^{-1}$ varied significantly due to different rate and application time of MC (Fig. 74). Different concentration of MC along with application time enhanced plant growth which increased squares than control plants. The maximum squares plant$^{-1}$ (13.83) was recorded in plants treated with 2 ml MC $L^{-1}$ water at 25 DAE ($G_1$) and the control plants ($G_0$) treatment produced the minimum (9.83).

Chaplot (2015) and Sabale *et al.* (2018) reported maximum number of squares plant$^{-1}$ in early spraying in cotton which is corroborating to the present findings. Kataria and Khanpara (2012) obtained significantly increased squares (108) with decreasing plant height in cotton with Cycocel foliar spray @ 40 ppm at 90 DAS. Some other scientists had similar observations while working with different crops (Koley and Maitra, 2015 in gladiolus; Parmar *et al.*, 2015 in rose flowers; Jamil *et al.*, 2015 in *Hippeastrum*; Pal, 2019 in ornamental plants and Raoofi *et al.*, 2014 in leafy vegetables). Yasmeen *et al.* (2016) reported that combined application of MLE and MC at 45 days after blooming enhanced squares plant$^{-1}$ in Bt cotton.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 74. Effect of application time of mepiquat chloride spray and its concentration on squares plant$^{-1}$ of cotton (LS $D_{(0.05)}$ = 0.55).**

**Combined effect of plant spacing along with time of application and concentration of growth regulator**

Due to combined effect of plant density level and MC level squares plant$^{-1}$ differed significantly ranging from 10.00 to 16.60 (Table 18). Significantly the highest squares plant$^{-1}$ (16.6) was obtained from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) and it became lowest (10.00) from $S_1G_3$ (water sprayed with 90 cm × 10 cm spacing).

Cothren *et al.* (1983) opined that MC decreased plant height, intermodal length, increased leaf area but wider spacing increased final leaf size and number of shoots including fruiting branch number resulted in higher retention capacity of square plant$^{-1}$ in cotton. Parekh *et al.* (2018) reported that squares plant$^{-1}$ was increasing as the plants were widely spaced, highest being recorded at 90 x 90 cm level with foliar spray gibberellic acid at 250, 200 and 150 ppm and NAA at 200 and 150 ppm.

#### 4.3.3.2 Bolls plant$^{-1}$

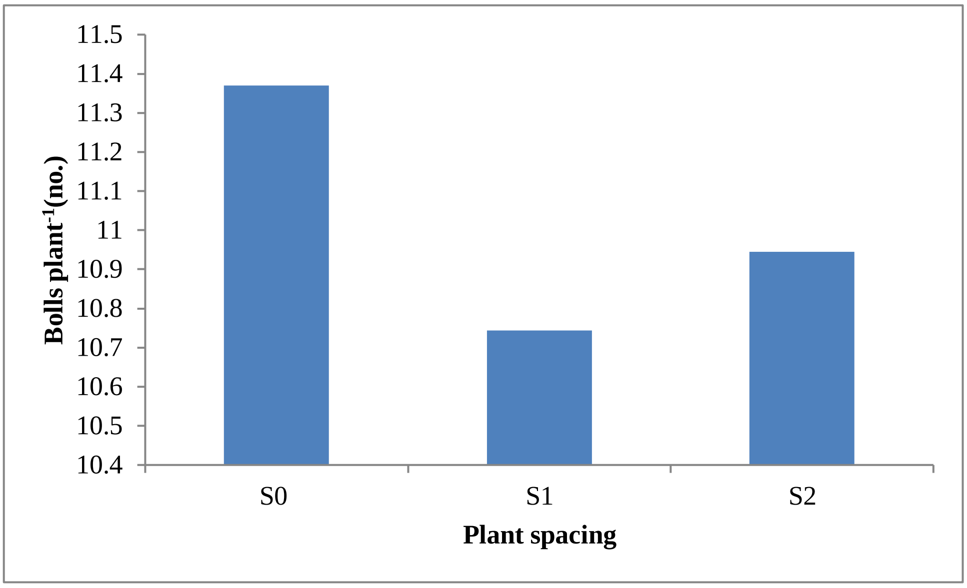
**Effect** of **plant spacing**

Bolls plant$^{-1}$ of cotton varied significantly with plant densities which ranged from 10.74 to 12.37 (Fig. 75). Bolls plant$^{-1}$ increased with the decrease of plant population. Wider 60 cm × 30 cm spacing ($S_0$) showed maximum bolls plant$^{-1}$ (11.37) while bolls plant$^{-1}$ was minimum (10.74) in closer 90 cm × 10 cm spacing ($S_1$)**.**

CDB (2018) reported that maximum bolls plant$^{-1}$ (19.3) was recorded in case of wider plant spacing of 90 cm × 45 cm against the minimum (12.0) in closer plant spacing of 90 cm × 10 cm of hybrid variety DM-3. The results were also in line with the findings of Ahmad *et al* (2008), Bhalerao and Gaikwad (2010), Kumara *et al.* (2014), Singh *et al.* (2012), Rajakumar and Gurumurthy (2008), Xiao-yu *et al.* (2016), Sowmiya and Sakthivel (2018), Sylla *et al.* (2013) and Jahedi *et al.* (2013) while they had experimented on cotton.

Oad *et al*. (2002) opined that in a dense population stand, the plants were subjected to severe competition from an early stage due to which very few or no vegetative branches formed, fruiting onset delays, and reduced bolls plant$^{-1}$ than in widely spaced cotton. While, widely spaced plants do not compete severely with each other in early stages of growth and relatively large vegetative branches are formed.

Hake *et al*. (1991) suggested that plant spacing can alter boll distribution and crop maturity by manipulating soil water removal, radiation interception, humidity and wind movement in cotton.




Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

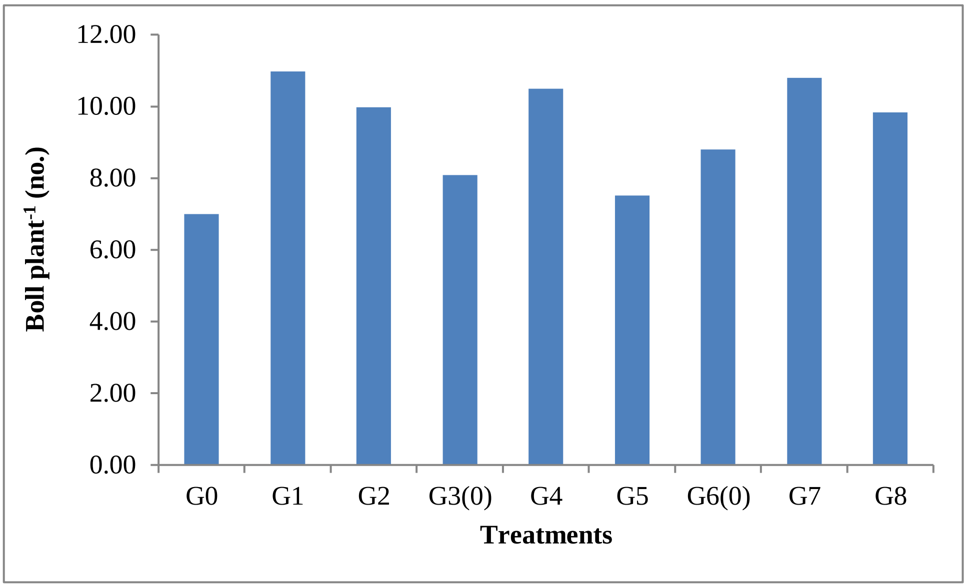
**Figure 75. Effect of plant spacing level on bolls plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.4517).**

### Effect of time of application and concentration of MC growth regulator

Bolls plant$^{-1}$ varied significantly due to different application time and concentration of MC (Fig. 76). Different concentration of MC along with application time enhanced plant growth which increased bolls than control plants. The maximum bolls plant$^{-1}$ (10.97) was recorded in plants treated with 2 ml MC $L^{-1}$ water at 25 DAE ($G_1$) and the control plants ($G_0$) produced the minimum (7).

Reema *et al.* (2017) reported that the maximum opened bolls plant$^{-1}$ (30.1) and un-opened bolls plant$^{-1}$ (4.0) were observed under Pix at 1000 ml / 500 litres of water at bud formation in cotton. Similar results obtained in cotton that was in conformity with Gumber *et al.*, 2005; Kataria and Khanpara, 2012; Amit *et al.*, 2016; Arif and Yasmeen**,** 2016; Chaplot**,** 2015; Ali *et al.*, 2012 and Ali *et al.*, 2009.

Bons *et al.* (2015) opined that the plant growth regulating compounds actively regulate the growth and development by regulation of the endogenous processes and there exogenous applications have been exploited for modifying the growth response.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 76. Effect of application time of mepiquat chloride spray and its concentration on bolls plant$^{-1}$ of cotton (LSD $_{(0.05)}$ = 0.55).**

**The combined effect of plant spacing along with time of application and concentration of MC growth regulator**

Due to combined effect of plant density level and MC level bolls plant$^{-1}$ differed significantly ranging from 5.97 to 16.60 (Table 18). The highest bolls plant$^{-1}$ (16.6) obtained from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was significantly different from all other treatment combinations. The lowest (5.97) was observed at water sprayed with 90 cm × 10 cm spacing ($S_1G_6$) which was statistically similar with $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$ and $S_1G_8$ (foliar sprayed with 2 and 4 ml MC $L^{-1}$ water at 25, 50 and 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing) treatment combinations.

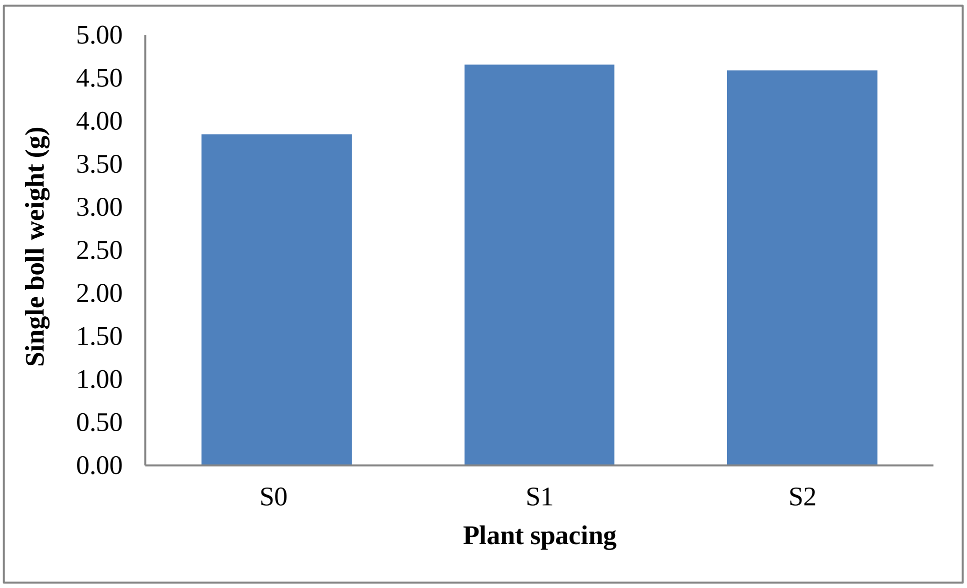
Oad *et al*. (2002) and Hake *et al*. (1991) reported that MC coupled with wider spacing enhanced better vegetative growth and flowering for better photosynthesis, water, nutrient, air, light and space sharing and consequently enhanced higher boll plant$^{-1}$. On the contrary, Iqbal *et al.* (2007) narrated that cotton grown in narrow plant spacing (15 and 23 cm) at high dose of fertilizer (150 kg ha$^{-1}$) with low dose of pix (2 x 100 ml ha$^{-1}$) increased the bolls plant$^{-1}$. Chormule and Patel (2017) reported that combination of wider plant spacing 60 cm x 45 cm and seed treatment of GA3 @ 150 ppm before sowing was found best suited combination, as it has good field emergence and produced significantly and comparatively the maximum fruits plant$^{-1}$ in okra.

### 4.3.3.3 Weight of boll

**Effect of plant spacing**

Variation in Plant density had significant variation in boll weight (Fig. 77). Weight of boll plant$^{-1}$ increased as plant population increased. The highest single boll weight (4.66 g) plant$^{-1}$ was obtained at closer 90 cm × 10 cm spacing ($S_1$) which was statistically similar with 60 cm × 20 cm spacing ($S_2$) and the lowest (3.84 g) from 60 cm × 30 cm spacing ($S_0$).

These findings are in conformity with the findings reported by Singh *et al.* (2015) who obtained maximum boll weight (3.17 g) at closer spacing of 67.5 × 60 cm and minimum boll weight (3.12 g) with wider spacing of 67.5 × 75 cm in cotton. Similar result was also reported by Jadhav *et al.* (2015) in cotton.



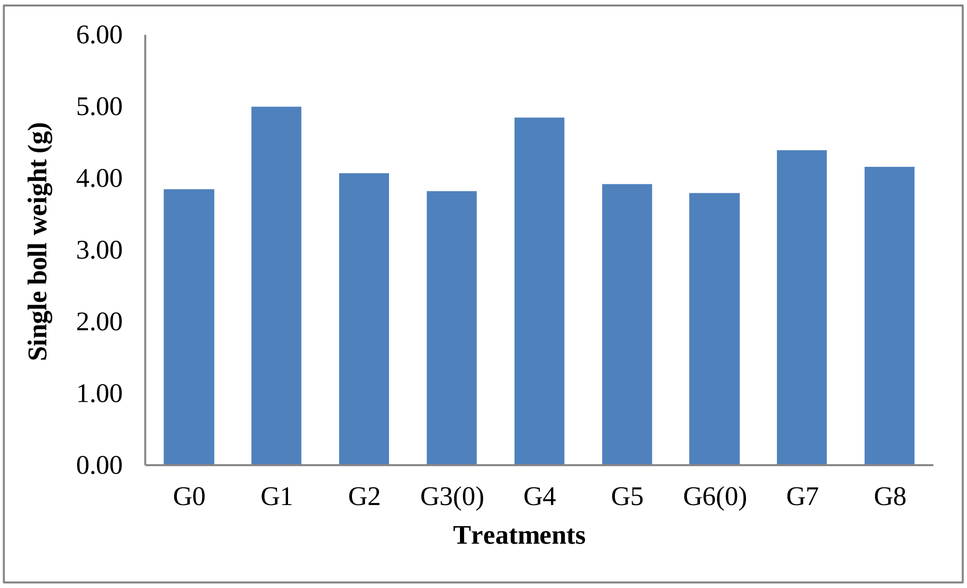

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)

**Figure 77. Effect of plant spacing level on boll weight of cotton (LSD $_{(0.05)}$ = 0.42).**

**Effect of time of application and concentration of MC growth regulator**

The weight of boll obtained at different times of MC sprayed along with concentration differ significantly (Fig. 78). Single boll weight of cotton showed a declining trend irrespective of time of MC sprayed and its concentration. Weight of single boll was increased as MC spray increased in parity with control. Single boll weight marked highest (5.0 g) from 2 ml $L^{-1}$ at 25 DAE ($G_1$) and it became lowest (3.84 g) from control ($G_0$) which was statistically similar with $G_3$ and $G_6$ (without MC).

Zakaria (2016) reported that Cycocel and Alar increased opened boll weight. Echer and Rosolem (2017); Kumar *et al.* (2005); Copur *et al.* (2010) and Evangelos *et al.*, (2004) reported similar observation while spraying different growth regulators on cotton.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 78. Effect of mepiquat chloride spray and its application time on single boll weight of cotton ( LSD $_{(0.05)}$ = 0.221).**

**Combined effect of plant spacing along with time of application and concentration of growth regulator**

Combined effect of plant density level and MC level was significant on boll weight plant$^{-1}$ (Table 18). Weight of boll increased as plant population increased and MC spray increased boll weight in comparison to control. Single boll weight marked highest (5.13 g) from foliar sprayed with 2 ml MC L$^{-1}$ water at 25 DAE with 90 cm × 10 cm spacing ($S_1G_1$) which was statistically similar with $S_1G_0$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$, $S_1G_8$ (foliar sprayed with 2 and 4 ml MC L$^{-1}$ water at 25, 50 and 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$ and $S_2G_4$ (foliar sprayed with 2 and 4 ml MC L$^{-1}$ water at 25 and 50 DAE, respectively with water spray in 60 cm × 20 cm spacing) treatment combinations. The lowest (3.8 g) was recorded at water sprayed with 60 cm × 30 cm spacing ($S_0G_6$) which was statistically similar with $S_0G_0$, $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_7$, $S_0G_8$ (foliar sprayed with 2 and 4 ml MC L$^{-1}$ water at 25, 50, 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing); $S_2G_6$ and $S_2G_8$ (foliar sprayed with 4 ml MC L$^{-1}$ water at 25 and 50 DAE with water spray in 60 cm × 20 cm spacing) treatment combinations.

Oad *et al*. (2002) and Hake *et al*. (1991) opined that the lesser in vegetative growth of cotton at closer spacing (60 cm × 30 cm) might be due to higher competition for nutrient, light and space. MC treated plants produced short plants thus which partitioned more photosynthates towards lesser number of bolls which resulted in more boll weight.

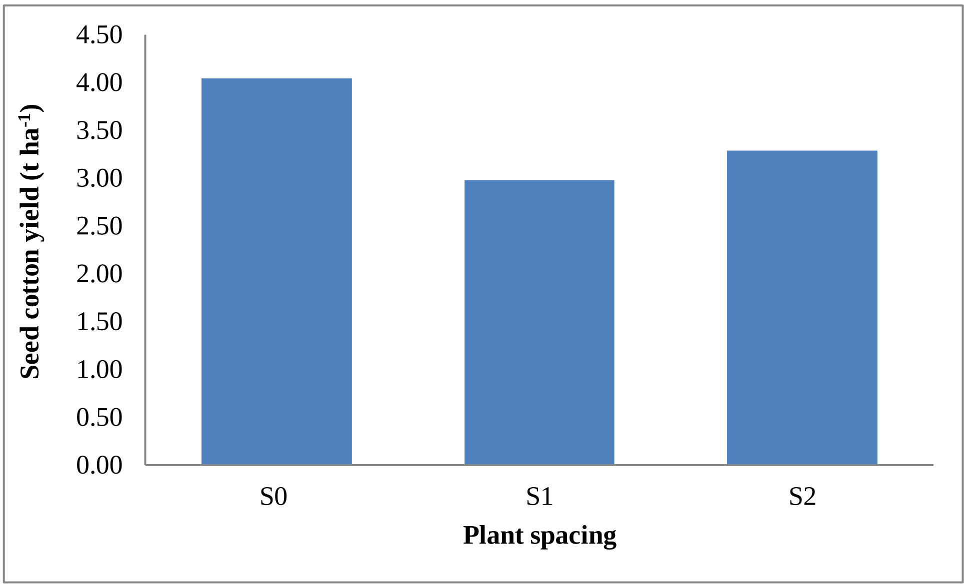
#### 4.3.3.4 Seed cotton yield

**Effect** of **plant spacing**

Plant density produced a significant influence on seed cotton yield (Fig. 79). The closest spacing of 60 cm x 30 cm ($S_0$) recorded the highest seed cotton yield (4.04 t ha$^{-1}$). The 90 cm x 10 cm spacing ($S_1$) gave the lowest seed cotton yield (2.98 t ha$^{-1}$). Treatment $S_0$ (close spacing) out yielded over $S_1$, wider spacing by 37.57 % more yield as the increased yield was added with greater plant population per unit area.

Yield was highest in 55,555 plants ha$^{-1}$ treatment confirmed by Awais *et al.* (2015). Firoz *et al.* (2007) reported that sowing with 60 x 30 cm plant spacing produced significantly highest yield (12.86 t ha$^{-1}$). The result was also in conformity with the findings in cotton of CDB (2018), Sowmiya and Sakthivel (2018), Mahi and Lokanadhan (2018), Kumar *et al.*, (2017), Udikeri and Shashidhara (2017), Rao *et al.* (2015), Hiwale *et al.* (2015), Munir *et al.* (2015), Sylla *et al.* (2013), Ali *et al.* (2012), Sher *et al.* (2017), Ali *et al.* (2009), Khan *et al.* (2002), Soomro *et al.*, 2000a, Soomro *et al*. (2000b), Silva *et al.* (2006), Silvertooth (1999), Keren *et al.*(1983), Siebert *et al*. ( 2006) and Wright *et al*.(2008). Liu *et al.* (2011)

studied that planting pattern affects canopy structure of crops and influences other physiological characteristics such as light interception and radiation use efficiency. These results indicated that narrow-wide row planting patterns improved the canopy structure, allowed more IPAR to reach the middle–low strata of the canopy and enhanced the leaf photosynthetic characteristics of maize crops at silking stage compared with control resulting in higher yield.




Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)

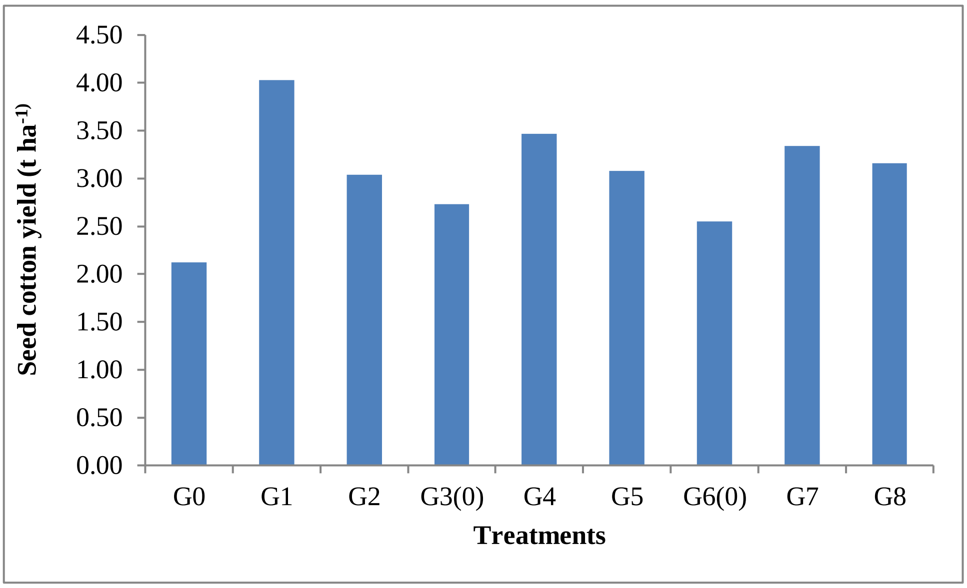
**Figure 79. Effect of plant spacing level that effect on seed cotton yield of cotton (LSD $_{(0.05)}$ = 0.387).**

**Effect of time of application and concentration of MC growth regulator**

MC sprayed had significant effect on seed cotton yield (Fig. 80). Application of 2 ml MC L$^{-1}$ water at 25 DAE ($G_1$) produced the highest seed cotton yield (4.03 t ha$^{-1}$). The lowest seed cotton yield (2.12 t ha$^{-1}$) was obtained from control ($G_0$) treatment. Use of growth regulator (at 25 DAE) had 90.09 % more yield over no growth regulator use.

Sabale *et al.* (2018) reported that higher seed cotton yield (1213.27 kg ha$^{-1}$) was obtained with application of NAA @ 30 ppm. The similar results of cotton yields under different growth regulator application were recorded in different experiments elsewhere (Fang *et* *al.*, 2019; Chang-chi *et al.*, 2019; Reema *et al.*, 2017; Arif and Yasmeen, 2016; Amit *et al.*, 2016; Chaplot, 2015; Kataria and Khanpara, 2012; Evangelos *et al.*, 2004) and also by Kamran *et al.*, 2017 in maize.

Sebastian *et al.* (2019) argued that phytohormones determine the formation of flowers and its retention when shedding of leaves are minimum which enhances the development and ripening of fruits in pomegranate.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 80. Effect of application time of mepiquat chloride and its concentration on seed cotton yield of cotton (LSD $_{(0.05)}$ = 0.248).**

**The combined effect of plant spacing along with time of application and concentration of growth regulator**

Seed cotton yield had differed significantly due to combined effect of plant density level and MC level which ranged from 1.67 to 4.67 t ha$^{-1}$ (Table 18). Seed cotton yield decreased as plant population increased from 55555 to 111111 and also MC spray increased yield compared to control. Seed cotton yield marked highest (4.67 t ha$^{-1}$) from foliar sprayed with 2 ml MC L$^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was followed by $S_0G_8$ (foliar sprayed with 4 ml MC L$^{-1}$ water at 25 and 50 DAE with same spacing) and $S_1G_7$ (foliar sprayed with 2 ml MC L$^{-1}$ water at 25 and 50 DAE with 90 cm × 10 cm spacing) treatment combinations. The lowest (1.67 t ha$^{-1}$) seed cotton yield was recorded at water sprayed with the same spacing ($S_0G_6$) which was statistically similar with $S_0G_0$ and $S_0G_3$ (control, water sprayed with same spacing); $S_2G_0$ and $S_2G_6$ (control, water sprayed in 60 cm × 20 cm spacing) treatment combinations.

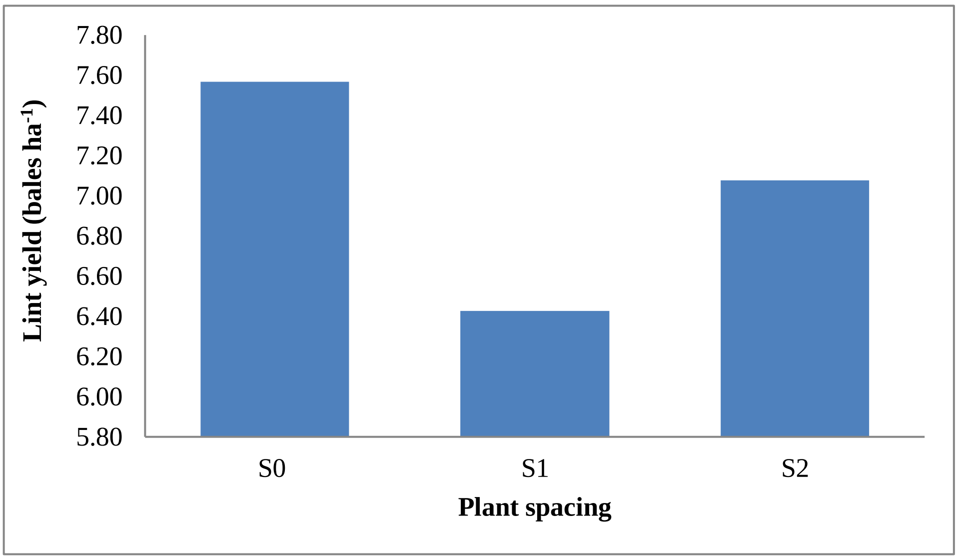
Zakaria *et al.* (2016) reported that the intermediate plant density (222000 plants ha$^{-1}$) gave highest yields. Both Cycocel and Alar increased the seed-cotton yield plant$^{-1}$. Seed cotton yield increased as plant population increased as MC sprayed compared to control in cotton (Zhao *et al.*, 2019; Iqbal *et al.*, 2007; Copur *et al.*, 2010; Evangelos *et al.*, 2004). Golada *et al.* (2018) noted the same observation in baby corn.

#### 4.3.3.5 Lint yield

**Effect** of **plant spacing**

Lint yield ha$^{-1}$ of cotton varied significantly due to influence of plant density (Fig. 81). The highest lint yield (7.57 bales ha$^{-1}$) of cotton was obtained from 60 cm × 30 cm spacing ($S_0$) followed by 60 cm x 20 cm spacing ($S_2$). The plant spacing of 90 cm x 10 cm gave the lowest yield (6.43 bales ha$^{-1}$). It was indicated that lint yield increased significantly with closer spacing up to a certain limit.

Singh (2015) observed that maximum lint yield (777.8 kg ha$^{-1}$) was recorded at closer spacing of 67.5 × 60 cm and minimum lint yield (684.6 kg ha$^{-1}$) with wider spacing of 67.5 × 75 cm. Yield of lint of cotton was increased as plant population increased at closer spacing in cotton (Clawson *et al.*, 2006; Shukla *et al.*, 2013; Xiao-yu *et al.*, 2016; Richard, 2006; Manuel *et al.*, 2019; Jahedi *et al.*, 2013; Singh *et al.*, 2014 and Berry *et al.*, 2008).

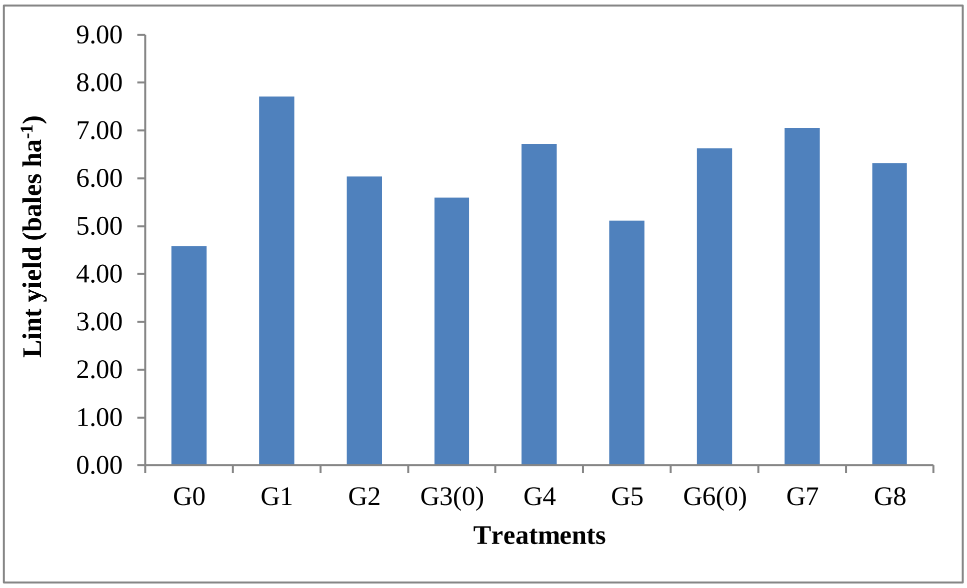



Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)

**Figure 81. Effect of plant spacing level on lint yield of cotton (LSD $_{0.05}$ = 0.834).**

### Effect of time of application and concentration of MC growth regulator

Different concentration of MC sprayed from 25 to 50 days after emergence (DAE) had also significant effect on lint yield of cotton (Fig. 82). The highest lint yield (7.71 bales $ha^{-1}$) of cotton was obtained from foliar sprayed with 2 ml MC $L^{-1}$ water at 25 DAE ($G_1$) and the lowest (4.57 bales $ha^{-1}$) from control ($G_0$). Chaplot (2015) reported that the foliar application of NAA at 100 ppm brought about significantly higher mean seed cotton by 57.3 per cent over water spray in cotton. McCarty *et al.* (2017) argued that various plant growth hormones and regulators have been increased the yield of cotton lint when applied to foliage in field tests which resulted due to better, balanced plant growth and greater partitioning of assimilates towards yield formation.




$G_0$ = Water spray (control) at 25 DAE
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray (control) at 25 and 50 DAE
$G_7$= 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

**Figure 82. Effect of time of application of MC growth regulator and its concentration on lint yield of cotton (LSD $_{(0.05)}$ = 0.535).**

### Combined effect of plant spacing along with time of application and concentration of MC growth regulator

Combined effect of plant density level and MC level was found significant (Table 18). The lint yield varied between 3.60 to 10.06 bale $ha^{-1}$. Lint yield decreased as plant population increased from 555555 to 111111 and MC spray increased lint yield compared to control. Lint yield became highest (10.06 bales $ha^{-1}$) from foliar sprayed with 2 ml MC $L^{-1}$ water at

25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) followed by $S_0G_8$ (foliar sprayed with 4 ml MC $L^{-1}$ water at 25 and 50 DAE with same spacing) and $S_1G_7$ (foliar sprayed with 2 ml MC $L^{-1}$ water at 25 and 50 DAE with 90 cm × 10 cm spacing) treatment combinations. The lowest (3.60 bales $ha^{-1}$) was recorded at water sprayed with 60 cm × 30 cm spacing ($S_0G_6$) which was statistically at par with $S_0G_0$ and $S_0G_3$ (control, water sprayed with same spacing); $S_2G_0$ and $S_2G_6$ (control, water sprayed in 60 cm × 20 cm spacing) treatment combinations.

| Treatments | Squares plant$^{-1}$ (no.) | Bolls plant$^{-1}$ (no.) | Single boll weight (g) | Seed cotton yield (t ha$^{-1}$) | Lint yield (bale ha$^{-1}$) |
|---|---|---|---|---|---|
| **$S_0G_0$** | 14.30 bc | 14.30 bc | 3.87 f | 1.78 jk | 3.83 jk |
| **$S_0G_1$** | 16.60 a | 16.60 a | 3.93 f | 4.67 a | 10.06 a |
| **$S_0G_2$** | 14.97 b | 14.97 bc | 3.87 f | 3.84 b-e | 8.26 b-e |
| **$S_0G_{3(0)}$** | 13.80 c-e | 8.43 d | 3.83 f | 1.76 jk | 3.78 jk |
| **$S_0G_4$** | 14.20 b-d | 14.20 bc | 3.93 f | 3.84 b-e | 8.27 b-e |
| **$S_0G_5$** | 13.8 c-e | 13.80 c | 3.90 f | 3.88 b-d | 8.36 b-d |
| **$S_0G_{6(0)}$** | 12.67 fg | 8.37 d | 3.80 f | 1.67 k | 3.60 k |
| **$S_0G_7$** | 14.33 bc | 8.43 d | 3.90 f | 3.90 b-d | 8.40 b-d |
| **$S_0G_8$** | 13.00 ef | 13.80 c | 3.83 f | 4.24 ab | 9.14 ab |
| **$S_1G_0$** | 12.67 fg | 6.57 e | 5.10 ab | 2.53 g-i | 5.44 hi |
| **$S_1G_1$** | 14.00 cd | 7.63 d | 5.13 a | 3.96 bc | 8.53 bc |
| **$S_1G_2$** | 13.00 ef | 6.60 e | 5.11 ab | 3.89 b-d | 8.37 b-d |
| **$S_1G_{3(0)}$** | 10.00 h | 6.27 e | 5.00 ab | 2.56 gh | 5.52 h |
| **$S_1G_4$** | 14.67 bc | 6.53 e | 5.10 ab | 4.10 b | 8.84 b |
| **$S_1G_5$** | 13.00 ef | 6.37 e | 5.07 ab | 3.55 c-f | 7.66 c-f |
| **$S_1G_{6(0)}$** | 14.43 bc | 5.97 e | 4.93 ab | 2.63 g | 5.67 gh |
| **$S_1G_7$** | 14.43 bc | 6.23 e | 4.97 ab | 4.27 ab | 9.19 ab |
| **$S_1G_8$** | 14.67 bc | 5.97 e | 4.97 ab | 3.48 d-f | 7.5 d-g |
| **$S_2G_0$** | 12.67 fg | 8.07 d | 4.83 a-c | 2.10 i-k | 4.52 i-k |
| **$S_2G_1$** | 13.33 d-f | 8.23 d | 4.93 ab | 3.49 d-f | 7.53 d-g |
| **$S_2G_2$** | 13 ef | 8.17 d | 4.9 ab | 3.47 d-f | 7.48 d-g |
| **$S_2G_{3(0)}$** | 13.00 ef | 8.00 d | 4.5 cd | 2.13 h-j | 4.58 ij |
| **$S_2G_4$** | 14.33 bc | 8.03 d | 4.77 a-c | 3.36 f | 7.25 fg |
| **$S_2G_5$** | 13.33 d-f | 8 d | 4.73 bc | 3.31 f | 7.14 fg |
| **$S_2G_{6(0)}$** | 12.00 g | 7.8 d | 3.93 f | 2.07 jk | 4.46 jk |
| **$S_2G_7$** | 14.33 bc | 8.00 d | 4.33 de | 3.42 ef | 7.37 e-g |

| | | | | | |
|---|---|---|---|---|---|
| **$S_2G_8$** | 12.67 fg | 7.87 d | 4.00 ef | 3.49 d-f | 7.52 d-g |
| **LSD (0.05)** | **0.953** | **0.953** | **0.383** | **0.430** | **0.927** |
| **CV (%)** | **6.64** | **6.64** | **12.18** | **15.83** | **15.83** |

**Table 18. Combined effect of plant spacing and MC mepiquat chloride spray on yield contributing characters and yield of cotton**

Means having same letters after numerical values in the same column indicates no significant difference at $P \leq 0.05$.

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

### 4.3.4 The effect of plant spacing along with time of application and concentration of growth regulator on seed characteristics of cotton

#### 4.3.4.1 Seeds $boll^{-1}$

**Effect of plant spacing**

Seeds $boll^{-1}$ of cotton had significant variation among the plant spacing (Table 19). The maximum seeds $boll^{-1}$ (120.85) was recorded at 60 cm × 30 cm spacing ($S_0$) followed by 90 cm × 10 cm spacing ($S_1$) and the lowest seeds $boll^{-1}$ (117.93) was observed from 60 cm × 20 cm spacing ($S_2$). Omadewu *et al.* (2019) reported that plant density had a positive effect on number of seeds $boll^{-1}$ in cotton. Similar result was reported by Khalil *et al.*, 2010 in faba bean. On the contrary, Pitombeira (1972) reported that seed $boll^{-1}$ was not significantly affected by plant population in cotton and sorghum.

**Effect of time of application and concentration of MC growth regulator**

MC sprayed had significant effect on seeds $boll^{-1}$ of cotton over no growth regulator (Table 19). Seeds $boll^{-1}$ increased progressively over time of MC sprayed attaining the highest at 25 DAE. The highest seeds $boll^{-1}$ (121) was obtained from control ($G_0$) which was followed by $G_1$ (foliar sprayed at 2 ml MC $L^{-1}$ water at 25 DAE). The lowest seeds $boll^{-1}$ (116.22) of cotton was observed in 4.0 ml $L^{-1}$ water at 75 DAE ($G_8$).

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

MC sprayed from 25 to 50 days after emergence (DAE) and different spacing had significantly increased the number of seeds boll$^{-1}$ than control (Table 20). The maximum seed boll$^{-1}$ (122.67) was counted from $S_0G_1$ (2 ml MC L$^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) and it was significantly different from all other treatment combinations. Seeds boll$^{-1}$ became lowest (107) at $S_1G_6$ (water sprayed with 90 cm × 10 cm spacing) treatment combination.

#### 4.3.4.2 Seed index

**Effect** of p**lant spacing**

Seed index of cotton had significant variation among the plant spacings (Table 19). The maximum seed index (8.59 g) was recorded at spacing 60 cm × 30 cm ($S_0$). The lowest seed index (7.7 g) was marked from spacing 60 cm × 20 cm ($S_2$). Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on seed index of cotton (Table 19). Seed index increased progressively over time of MC sprayed attaining the highest at 25 DAE. The highest seed index (12.22 g) was obtained from control ($G_0$) which was statistically similar with $G_1$, $G_3$ and $G_6$ (2 ml MC L$^{-1}$ water at 25 DAE with water spray) treatment and the lowest (9.9 g) at $G_4$ (2 ml MC L$^{-1}$ water at 50 DAE) treatment. Zhao *et al.* (2019) studied that the 100-seed weight significantly increased with MC applying under different plant densities in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Different spacing and MC spray increase Seed Index (SI) of cotton significantly than control (Table 20). SI marked highest (14.22) from water sprayed with 60 cm x 30 cm spacing ($S_0G_0$) which was statistically similar with $S_0G_2$, $S_0G_3$ (4 ml MC L$^{-1}$ water foliar sprayed at 25 DAE with water in 60 cm x 30 cm spacing); and $S_2G_7$ (foliar sprayed with 2ml MC L$^{-1}$ water at 25 and 50 DAE under 60 cm x 20 cm spacing) treatment combinations and it became lowest (10) from $S_2G_8$ (foliar sprayed with 4 ml MC L$^{-1}$ water at 25 and 50 DAE in 60 cm × 20 cm spacing) treatment combinations. Zhao *et al.* (2019) studied that the 100-seed weight significantly decreased as plant density increased, while this parameter significantly increased with MC applying under different plant densities in cotton.

#### 4.3.4.3 Lint index

**Effect** of p**lant spacing**

Lint index of cotton had significant variation among the plant spacings (Table 19). The maximum lint index (8.59 g) was recorded at 60 cm × 30 cm spacing ($S_0$) followed by $S_1$ (90 cm × 10 cm) and the lowest lint index (7.05 g) was recorded from spacing of 60 cm × 20 cm ( $S_2$).

**Effect of time of application and concentration of MC growth regulator**

Application of MC had significant effect on lint index of cotton (Table 19). The highest lint index (8.56 g) was obtained from foliar sprayed at $G_1$ (2ml MC $L^{-1}$ water foliar sprayed at 25 DAE) which was statistically similar with $G_3$ and $G_5$ (foliar sprayed with 4 ml MC $L^{-1}$ water at 50 DAE with water) treatments and the lowest (6.61 g) was recorded at $G_7$ (2 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE) which was statistically at par with $G_6$ (control i.e. without MC spray). Zakaria (2016) also observed that both Cycocel and Alar increased lint indices in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Spacing and MC spray increase Lint Index (LI) of cotton significantly than control (Table 20). LI marked highest (9.53) from 4 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_2$) which was statistically similar with $S_0G_0$ (without MC in 60 cm × 30 cm spacing), $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$ and $S_1G_7$ (2, 4 and 2 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE in 90 cm x 10 cm spacing) and $S_2G_7$ (2 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE in 60 cm x 20 cm spacing) treatment combinations and the lowest (6.55 g) was obtained from $S_2G_6$ which was statistically identical with $S_2G_8$ (4ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE with water spray in 60 cm × 30 cm spacing ) which was also statistically similar with $S_1G_0$, $S_1G_5$ (4 ml MC $L^{-1}$ water foliar sprayed at 50 DAE with water spray in 90 cm x 10 cm spacing), $S_2G_0$ and $S_2G_3$ (control with 60 cm x 20 cm spacing) treatment combinations.

### 4.3.4.4 Ginning out turn

**Effect of plant spacing**

Ginning out turn (GOT) of cotton had significant variation among the plant spacing (Table 19). The maximum GOT (39.56 %) was recorded at spacing 60 cm × 30 cm ($S_0$) followed by $S_1$ (90 cm × 10 cm) and the lowest GOT (38.37 %) from spacing of 60 cm × 20 cm ($S_2$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on ginning out turn of cotton (Table 19). The highest ginning out turn (39.69 %) was obtained from foliar sprayed at $G_0$ (control) which was statistically similar with $G_2$, $G_3$, $G_5$ and $G_7$(2 to 4 ml MC $L^{-1}$ water foliar sprayed at 25, 50 and 25 and 50 DAE; respectively) treatments and the lowest (38.23 %) at $G_8$ (4 ml MC $L^{-1}$ water at 25 DAE) which was statistically similar with $G_4$ and $G_6$ (2 and 4 ml MC $L^{-1}$ water at 50 and 25 and 50 DAE, respectively with control) treatments.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Spacing and MC spray increased ginning out turn (GOT) of cotton significantly than control (Table 20). GOT or lint percentages observed highest (41.27) from 2 ml $L^{-1}$ MC at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was statistically similar with $S_1G_4$ (2 ml MC $L^{-1}$ water sprayed at 50 DAE in 90 cm x 10 cm spacing); $S_2G_1$ (2 ml MC $L^{-1}$ water foliar sprayed at 25 DAE in 60 cm x 20 cm spacing); and it became lowest (38.9) at water sprayed with 90 cm × 10 cm spacing ($S_0G_0$) which was statistically similar with $S_0G_3$, $S_0G_5$ (4 ml MC $L^{-1}$ water sprayed at 50 DAE with water spray in 60 cm × 30 cm spacing); $S_1G_0$, $S_1G_2$ (4 ml MC $L^{-1}$ water sprayed at 25 DAE with water spray in 90 cm x 10 cm spacing) and $S_2G_0$, $S_2G_2$ and $S_2G_6$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 DAE with water spray in 60 cm x 20 cm spacing).

**Table 19. Effect of plant spacing and MC level along with application time on seeds boll$^{-1}$, seed index, lint index and ginning out turn of cotton**

| Treatments | Seeds boll$^{-1}$ (no.) | Seed index (g) | Lint index ((g) | Ginning out turn (%) |
|---|---|---|---|---|
| **Effect of different levels of spacings** | | | | |
| $S_0$ | 120.85 a | 8.59 a | 8.59 a | 39.56 a |
| $S_1$ | 119.70 ab | 7.92 b | 7.79 a | 39.53 a |
| $S_2$ | 117.93 b | 7.70 c | 7.05 b | 38.37 b |
| **LSD** | **2.71** | **0.175** | **0.968** | **0.916** |
| **CV (%)** | **11.16** | **0.62** | **0.95** | **0.95** |
| **Effect of different application times and concentrations of MC** | | | | |
| $G_0$ | 121.00 a | 12.22 a | 7.97 b | 39.69 a |
| $G_1$ | 120.67 a | 11.97 ab | 8.56 a | 38.63 b |
| $G_2$ | 119.00 b | 10.90 bc | 7.90 b | 39.58 a |
| $G_{3(0)}$ | 120.00 bc | 12.15 a | 8.43 a | 39.50 a |
| $G_4$ | 119.89 c | 9.90 d | 7.77 b | 38.50 bc |
| $G_5$ | 118.22 d | 11.00 bc | 8.33 a | 39.46 a |
| $G_{6(0)}$ | 117.78 e | 12.15 a | 7.11 c | 38.43 bc |
| $G_7$ | 119.56 f | 11.00 bc | 6.78 cd | 39.37 a |

| | | | | |
|---|---|---|---|---|
| $G_8$ | 116.22 g | 11.45 bc | 6.61 d | 38.23 c |
| **LSD** | **0.354** | **0.547** | **0.276** | **0.343** |
| **CV (%)** | **6.97** | **0.82** | **1.25** | **1.25** |

Means having same letters in the same column indicates no significant difference at $P \leq 0.05$.

**Table 20. Combined effect of plant spacing and application time of mepiquat chloride and its concentration on seed characteristics of cotton**

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plant ha$^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants ha$^{-1}$)
$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml L$^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml L$^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml L$^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml L$^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml L$^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml L$^{-1}$ water at 25 and 50 DAE

| **Treatment** | **Seed boll$^{-1}$ (no.)** | **Seed index (g)** | **Lint index (g)** | **Ginning out turn (%)** |
|---|---|---|---|---|
| **$S_0G_0$** | 121.00 bc | 14.22 a | 9.14 ab | 39.13 ij |
| **$S_0G_1$** | 122.67 a | 10.11 l | 7.11 l-o | 41.27 a |
| **$S_0G_2$** | 121.00 bc | 14.13 a | 9.53 a | 40.27 c-f |
| **$S_0G_{3(0)}$** | 120.33 de | 13.82 ab | 8.90 bc | 39.17 ij |
| **$S_0G_4$** | 121.00 bc | 11.25 h-j | 7.26 k-m | 40.23 c-f |
| **$S_0G_5$** | 120.33 de | 13.21 bc | 8.56 c-e | 39.33 g-j |
| **$S_0G_{6(0)}$** | 121.33 b | 12.12 e-h | 7.86 h-j | 40.33 c-f |
| **$S_0G_7$** | 120.67 cd | 13.01 b-e | 8.50 c-f | 39.50 g-i |
| **$S_0G_8$** | 119.33 g | 12.9 c-f | 8.40 d-g | 40.43 b-e |
| **$S_1G_0$** | 115.00 i | 11.00 i-l | 7.00 l-p | 38.90 j |
| **$S_1G_1$** | 121.00 bc | 12.15 e-g | 8.16 e-h | 40.17 d-f |
| **$S_1G_2$** | 120.67 cd | 13.12 b-d | 8.81 b-d | 39.17 ij |
| **$S_1G_{3(0)}$** | 119.33 g | 12.05 f-h | 7.90 hi | 39.60 g-i |
| **$S_1G_4$** | 121.33 b | 11.97 gh | 7.95 g-i | 40.93 ab |
| **$S_1G_5$** | 121.00 bc | 10.20 kl | 6.74 op | 39.80 f-h |
| **$S_1G_{6(0)}$** | 107.00 j | 11.35 g-i | 7.43 j-l | 40.57 b-d |
| **$S_1G_7$** | 119.67 fg | 13.45 a-c | 8.92 bc | 39.87 e-g |
| **$S_1G_8$** | 116.33 h | 11.04 i-k | 7.24 k-m | 40.60 b-d |
| **$S_2G_0$** | 119.67 fg | 10.37 j-l | 6.75 n-p | 39.43 g-j |
| **$S_2G_1$** | 121.00 bc | 12.23 d-g | 8.08 f-h | 40.77 a-c |
| **$S_2G_2$** | 121.00 bc | 10.90 i-l | 7.1 l-o | 39.43 g-j |
| **$S_2G_{3(0)}$** | 115.00 i | 10.68 i-l | 6.94 m-p | 40.40 b-e |
| **$S_2G_4$** | 120.67 cd | 11.50 g-i | 7.59 i-k | 39.77 f-h |
| **$S_2G_5$** | 120.33 de | 11.00 i-l | 7.20 k-n | 40.57 b-d |
| **$S_2G_{6(0)}$** | 120.00 ef | 10.12 l | 6.55 p | 39.30 h-j |
| **$S_2G_7$** | 119.33 g | 14.22 a | 9.22 ab | 40.33 c-f |
| **$S_2G_8$** | 120.33 de | 10.00 m | 6.55 p | 39.57 g-i |
| **LSD $_{0.05}$** | **0.578** | **0.894** | **0.450** | **0.560** |
| **CV (%)** | **6.97** | **0.82** | **1.25** | **1.25** |

Means having same letters in the same column indicates no significant difference at $P \leq 0.05$.

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants ha$^{-1}$)
$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml L$^{-1}$ water at 25 DAE
$G_5$ = 4.0 ml L$^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)

as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plant $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE

$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

### 4.3.5 Effect of plant spacing and combination of application time of mepiquat chloride spray and its concentration on lint characteristics of cotton

#### 4.3.5.1 Upper half mean length (UHML)

**Effect of plant spacing**

Upper half mean length (UHML) of cotton had considerable variation among the plant spacings (Table 21). The maximum UHML (31.04 mm) was recorded at spacing 60 cm × 30 cm ($S_0$). The lowest UHML (30.57 mm) was marked from spacing 60 cm × 20 cm ($S_{2.}$). Darawsheh *et al*. (2009 b) reported that 50% span length of lint was negatively affected ($P \leq 0.05$) by high plant density in narrow row. On the contrary, Pitombeira (1972) reported that fiber length (upper half mean) was not significantly affected by plant population. Nichols *et al*. (2003) observed that fiber length was increased as plant population increased in cotton.

**Effect of time of application and concentration of MC growth regulator**

Application of MC had significant effect on UHML of cotton (Table 21). The highest UHML (31.36 mm) was obtained from $G_0$ (control) and the lowest (30.58 mm) at $G_8$ (4.0 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE) followed by $G_3$ (control).

Silva *et al.* (2016) and Edivaldo *et al.* (1996) reported that the CCC increased fiber length in cotton. On the contrary, Copur *et al.* (2010) reported that fiber length was not affected by the PGRs (except pix) treatments in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

UHML of lint was significantly affected by plant population and variable rates along with spray time of MC spray (Table 22). UHML of lint was found to be increased with increased plant density irrespective of MC levels. The spacing 60 cm × 30 cm accompanied with 2 ml $L^{-1}$ MC at 25 DAE ($S_0G_1$) gave the maximum UHML (31.66 mm) of lint which was statistically similar with $S_0G_6$ (water sprayed in 60 cm × 30 cm spacing), $S_1G_8$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE in 90 cm x 10 cm spacing) and $S_2G_5$ (4 ml MC $L^{-1}$ water foliar sprayed at 50 DAE in 60 cm x 20 cm spacing) treatment combinations. The minimum UHML of lint (30.26 mm) recorded from water sprayed with 90 cm × 10 cm spacing ($S_1G_0$) which was statistically similar with $S_0G_0$, $S_0G_{4,}$ $S_0G_5$, $S_0G_8$ (2 and 4 ml MC $L^{-1}$ water foliar sprayed at 50, 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing) and $S_2G_2$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 DAE with 60 cm x 20 cm spacing) treatment combinations.

Copur *et al.* (2010) reported that fiber length, fiber fineness, fiber strength and fiber uniformity were not affected by the PGRs treatments. Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in the fiber characteristics, related to length and strength of the fiber. Nichols *et al*. (2003) found that fiber length was increase as plant population increased. Pitombeira (1972) obtained that lint index, seed index, seed $boll^{-1}$, fiber length (upper half mean), fiber strength and fiber fineness were not significantly affected by plant population.

#### 4.3.5.2 Mean length (ML of lint)

**Effect of plant spacing**

Upper half mean length (ML) of cotton had significant variation among the plant spacings (Table 21). The maximum ML (26.30 mm) was recorded at spacing 60 cm × 30 cm ($S_0$). The minimum ML (25.77 mm) was marked from spacing 60 cm × 20 cm ($S_2$). Darawsheh *et al*. (2009 b) reported that 50% span length of lint was negatively affected ($P \leq 0.05$) by high plant density in narrow row. On the contrary, Pitombeira (1972) reported that fiber length was not significantly affected by plant population.

**Effect of time of application and concentration of MC growth regulator**

Application of MC had significant effect on ML of cotton (Table 21). The higher ML (26.67 mm) was obtained from $G_0$ (water sprayed) and the lower (25.77 mm) at $G_8$ (4.0 ml MC $L^{-1}$ water at 25 and 50 DAE). Edivaldo *et al*. (1996) reported that the CCC increased fiber length in cotton (Silva *et al.*, 2016). On the contrary, Copur *et al.* (2010) reported that fiber length was not affected by the PGRs (except pix) treatments in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Plant population and time of application and MC doses had significant influence on ML of lint (Table 22). ML of lint marked highest (27.01 mm) from 2 ml $L^{-1}$MC at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was statistically similar with $S_1G_8$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE with 90 cm x 10 cm spacing) and it became lowest (25.42 mm) at 2 ml $L^{-1}$ MC at 25 DAE with 90 cm × 10 cm spacing ($S_1G_1$) which was statistically similar with $S_0G_0$, $S_0G_4$, $S_0G_5$, $S_0G_8$ (2 and 4 ml MC $L^{-1}$ water at 50 and 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing) and $S_2G_2$ (4 ml

MC $L^{-1}$ water foliar sprayed at 25 DAE with 60 cm x 20 cm spacing) treatment combinations.

Copur *et al.* (2010) reported that fiber length, fiber fineness, fiber strength and fiber uniformity were not affected by the PGRs treatments. Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in the fiber characteristics, related to length and strength of the fiber. Nichols *et al*. (2003) found that fiber length was increase as plant population increased. Pitombeira (1972) reported that lint index, seed index, seed $boll^{-1}$, fiber length (upper half mean), fiber strength and fiber fineness were not significantly affected by plant population.

#### 4.3.5.3 Uniformity index (UI) of lint

**Effect of plant spacing**

Uniformity index (UI) of lint of cotton had considerable variation among the plant spacings (Table 21). The highest UI (84.72 %) was recorded at spacing 60 cm × 30 cm ($S_0$) followed by 90 cm × 10 cm ($S_1$) and the lowest UI (84.29 %) was obtained from spacing 60 cm × 20 cm ($S_2$). Nichols *et al*. (2004) also reported negative impact of increased plant density on lint uniformity in cotton. Similar resuls were reported by Valco *et al*., 2001; Pitombeira, 1972 and Feng *et al.*, 2011).

**Effect of time of application and concentration of MC growth regulator**

Application of MC had significant effect on UI of cotton (Table 21). The maximum UI (85.06 %) was obtained from foliar sprayed at $G_0$ (without MC) and the minimum (84.28 %) at $G_8$ (4.0 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE). Edivaldo *et al.* (1996) reported that the CCC increased fiber uniformity in cotton (Hasab *et al.*, 2019). On the contrary, Copur *et al.* (2010) reported that fiber uniformity was not affected by the PGR (except pix) treatments in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

A significant variation in the UI of lint was observed due to the combined effect of plant spacing and MC levels (Table 22). UI of lint was found to be increased with increasing plant density irrespective of MC levels. The treatment combination of $S_1G_8$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE in 90 cm x 10 cm spacing) produced the maximum UI of lint (85.15) and it was statistically similar with $S_0G_3$, $S_0G_6$ (water sprayed in 60 cm × 30 cm spacing), $S_1G_4$, $S_1G_7$ (2 ml MC $L^{-1}$ water foliar sprayed at 50 and 25 and 50 DAE, respectively in 90 cm x 10 cm spacing), $S_2G_5$ and $S_2G_6$ (4 ml MC $L^{-1}$ water foliar sprayed at 50 DAE with water spray in 60 cm x 20 cm spacing) treatment combinations. The minimum (83.98) was noticed from $S_0G_1$combinations (2 ml MC $L^{-1}$ water foliar sprayed at 25 DAE with 60 cm × 30 cm spacing) which was statistically similar with $S_0G_4$ and $S_0G_8$ (2 and 4 ml MC $L^{-1}$ water foliar sprayed at 50 and 25 and 50 DAE, respectively with same spacing) treatment combinations.

Copur *et al.* (2010) reported that fiber length was not affected by the PGRs treatments. Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in the fiber characteristics, related to length and strength of the fiber. Nichols *et al*. (2003) found that fiber length was increase as plant population increased. Pitombeira (1972) showed that fiber length, fiber strength and fiber fineness were not significantly affected by plant population.

#### 4.3.5.4 Short fiber index (SFI) of lint

**Effect of plant spacing**

Short fiber index (SFI) of lint of cotton had significant variation among the plant spacings (Table 21). The highest SFI (7.50) was recorded at spacing 60 cm × 30 cm ($S_0$) and the lowest SFI (7.24) was obtained from 60 cm × 20 cm spacing ($S_2$) followed by 90 cm × 10 cm spacing ($S_1$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on SFI of cotton (Table 21). The higher SFI (7.5) was obtained from foliar sprayed at $G_0$ (water sprayed) and the lower (7.07) at $G_8$ (4.0 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE).

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

SFI of lint was significantly affected by plant spacing and MC spray rate along with spray time (Table 22). The maximum SFI of lint (7.7) was recorded from 2 ml $L^{-1}$ MC at 25 DAE with 60 cm × 30 cm spacing i.e. $S_0G_1$ treatment combinations which was statistically similar with $S_0G_4$ combinations (2 ml MC $L^{-1}$ water at 50 DAE with 60 cm × 30 cm spacing). The minimum SFI of lint (7) was recorded from $S_1G_8$ i.e. foliar sprayed with 4 ml MC $L^{-1}$ water at 25 and 50 DAE in 90 cm × 10 cm spacing which was statistically identical with $S_2G_5$ (4 ml MC $L^{-1}$ water foliar sprayed at 50 DAE in 60 cm x 20 cm spacing) treatment combination.

#### 4.3.5.5 Micronaire (Mic.) of lint

**Effect of plant spacing**

Micronaire of lint of cotton had significant variation among the plant spacings (Table 21). The maximum micronaire (4.97) was recorded at 60 cm × 30 cm spacing ($S_0$) and the minimum micronaire (4.58) was marked from 60 cm × 20 cm spacing ($S_2$). Darawsheh (2009b) reported that row spacing influenced most the micronaire readings.

**Effect of time of application and concentration of MC growth regulator**

Application of MC had significant effect on micronaire of cotton (Table 21). The highestmicronaire (5.01) was obtained from $G_0$ (control) and the lowest (3.99) at $G_8$ (4.0 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE). Hasab *et al.* (2019) and Silva *et al.* (2016) observed that application of biostimulants caused changes in the fiber characteristics, related to micronnaire of the fiber. On the contrary, Copur *et al.* (2010) reported that fiber fineness was not affected by the PGRs (except pix) treatments.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Micronaire of lint had significantly influenced by Plant population and MC spray level (Table 22). Micronaire of lint marked highest (5.21) from 2 ml $L^{-1}$ MC at 25 and 50 DAE with 60 cm × 20 cm spacing ($S_2G_7$) and it became lowest (2.22) at 4 ml $L^{-1}$ MC at 50 DAE with 90 cm × 10 cm spacing ($S_1G_5$).

Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in the fiber characteristics, related to length uniformity, micronnaire, length and strength of the fiber. Hasab *et al.* (2019) also obtained that the treatment (one plant $hill^{-1}$) was exceeded by producing the highest plant height, number of sympodia, leaf area, dry weight, boll weight and the number of open bolls which reflected on increasing lint fineness and micronnaire by (4.66 and 4.72) for summer seasons (2016 and 2017) respectively. Darawsheh (2009b) also observed that the decrease of row spacing significantly decreased some fiber quality parameters but differed between normal and limited irrigation regimes. Of the fiber properties investigated, row spacing and irrigation regime influenced most the micronnaire readings.

#### 4.3.5.6 Maturity ratio (MR)

**Effect of plant spacing**

Maturity ratio of lint of cotton had insignificant variation among the plant spacings (Table 21). Numerically the maximum maturity ratio (0.88) was recorded at 60 cm × 30 cm spacing ($S_0$). The lowest maturity ratio (0.86) was marked from 60 cm × 20 cm spacing ($S_2$). Feng *et al.* (2011) observed that increased plant density reduced maturity ratio.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on maturity ratio of cotton (Table 21). The higher maturity ratio (0.88) was obtained from $G_0$ (control) and the lower (0.84) at $G_2$ (4 ml MC $L^{-1}$ water sprayed at 25 DAE). Edivaldo *et al.* (1996) reported that the CCC increased fiber maturity in cotton.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Plant population and MC spray rate along with spray time had significant influence on Maturity ratio (MR) of lint (Table 22). MR increased irrespective of treatment combinations. MR of lint observed highest (0.88) from 2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing ($S_0G_1$) which was statistically identical with $S_0G_4$ (foliar sprayed with 2 ml MC $L^{-1}$ water at 50 DAE + 60 cm × 30 cm spacing); $S_1G_3$, $S_1G_6$ (water sprayed in 90 cm × 10 cm spacing); $S_2G_1$ and $S_2G_5$ ( 2 and 4 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE, respectively + 60 cm x 20 cm spacing) treatment combinations and followed by $S_0G_0$, $S_0G_3$, $S_0G_5$, $S_0G_6$, $S_0G_7$, $S_0G_8$ (foliar sprayed with 4, 2 and 4 ml MC $L^{-1}$ water at 50 and 25 and 50 DAE, respectively with water spray in 60 cm × 30 cm spacing), $S_1G_0$, $S_1G_1$, $S_1G_4$, $S_1G_8$ (2 and 4 ml MC $L^{-1}$ water sprayed at 25, 50 and 25 and 50 DAE; respectively with water spray in 90 cm × 10 cm spacing) $S_2G_0$, $S_2G_2$, $S_2G_3$, $S_2G_6$, $S_2G_7$ and $S_2G_8$ (4,2 and 4 ml MC $L^{-1}$ water foliar sprayed at 25, 25 and 50 DAE; respectively with water spray in 60 cm x 20 cm spacing) treatment combinations and it became lowest (0.78) at $S_1G_5$ (4 ml $L^{-1}$ MC at 50 DAE with 90 cm × 10 cm spacing) treatment combination. Feng *et al.* (2011) reported that increased plant density reduced both fineness and maturity ratio.

**4.3.5.7 Strength of lint**

**Effect of plant spacing**

Strength of lint of cotton had significant variation among the plant spacings (Table 21). The maximum strength of lint (32.32 g $tex^{-1}$) was recorded from 60 cm × 30 cm spacing ($S_0$) and the minimum maturity ratio (30.23 g $tex^{-1}$) was marked at 60 cm × 20 cm spacing ($S_2$).

**Effect of time of application and concentration of MC growth regulator**

MC spray rate and time had significant effect on strength of lint of cotton (Table 21). The higher strength of lint (34.68 g $tex^{-1}$) was obtained from $G_0$ (without MC) and and the lower (29.62 g $tex^{-1}$) at $G_8$ (4 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE) which was statistically similar with $G_6$ (water sprayed). Silva *et al.* (2016) observed that application of bio-stimulants caused changes in the fiber characteristics related to strength of the fiber in cottton. On the contrary, Copur *et al.* (2010) reported that fiber strength was not affected by the PGRs (except pix) treatments (Pitombeira, 1972).

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Strength of lint was significantly affected by plant spacing and MC spray rate along with spray time (Table 22). Strength of lint marked highest (43.4 g $tex^{-1}$) from $S_1G_5$ (4 ml $L^{-1}$ MC at 50 DAE with 90 cm × 10 cm spacing) treatment combination and it became lowest (28.81 g $tex^{-1}$) at $S_1G_8$ (4 ml $L^{-1}$ MC at 25 and 50 DAE with 90 cm × 10 cm spacing) which was statistically similar with $S_0G_0$ and $S_0G_1$ (2 ml MC $L^{-1}$ water sprayed at 25 DAE with water sprayed in 90 cm × 10 cm spacing) treatment combinations. Copur *et al.* (2010) reported that fiber length, fiber fineness, fiber strength and fiber uniformity were not affected by the PGRs treatments. Silva *et al.* (2016) observed that the results showed that application of bio-stimulants caused changes in the fiber characteristics, related to length uniformity, micronnaire, length and strength of the fiber. Pitombeira (1972) found that lint index, seed index, seed $boll^{-1}$, fiber length (upper half mean), fiber strength and fiber fineness were not significantly affected by plant population

#### 4.3.5.8 Elongation of lint

**Effect of plant spacing**

Elongation of lint of cotton had significant variation among the plant spacings (Table 21). The maximum elongation of lint (6.42 %) was recorded at 60 cm × 30 cm spacing ($S_0$). The minimum elongation of lint (6.25 %) was marked from 60 cm × 20 cm spacing ($S_2$). Darawsheh (2009b) reported that row spacing influenced less the fiber elongation.

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on elongation of lint of cotton (Table 21). The highest elongation of lint (6.66 %) was obtained from control ($G_0$) and the lowest (6.03 %) at $G_8$ (4.0 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE).

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Elongation of lint was significantly influenced by the interaction effect of plant spacing and MC sprayed at different times and rates (Table 22). The highest elongation (7.12 %) was recorded from $S_2G_6$ (water sprayed with 60 cm × 20 cm spacing**)** treatment combinations and it became lowest (5.87 %) at $S_2G_8$ (4 ml MC $L^{-1}$ water sprayed at 25 and 50 DAE with 60 cm × 20 cm spacing**)**. Darawsheh (2009b) also observed that the decrease of row spacing significantly decreased some fiber quality parameters. Row spacing and irrigation regime influenced less the fiber elongation.

**4.3.5.9 Reflectance (Rd) of lint**

**Effect of plant spacing**

Reflectance of lint of cotton had no significant variation among the plant spacings (Table 21). Numerically the maximum reflectance of lint (76.64) was recorded at 60 cm × 30 cm spacing ($S_0$). The minimum reflectance of lint (73.68) was marked from 60 cm × 20 cm spacing ($S_2$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on reflectance of lint of cotton (Table 21). The higher reflectance of lint (76.56) was obtained from $G_0$ (water sprayed) which was statistically similar with $G_1$, $G_2$, $G_4$, $G_5$, $G_6$ and $G_7$ (2 to 4 ml MC $L^{-1}$ water foliar sprayed at 25, 50 and 25 and 50 DAE, respectively with control) and the lower (73.6) at $G_8$ (4.0 ml MC $L^{-1}$ water foliar sprayed at 25 and 50 DAE) followed by $G_1$, $G_2$, $G_3$, $G_4$, $G_5$, $G_6$, $G_7$ and $G_8$ (2 to 4 ml MC $L^{-1}$ water foliar sprayed at 25, 50 and 25 and 50 DAE, respectively with control) treatments.

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Plant density and MC spray rate along with spray time significantly affected the Rd of lint (Table 22). Rd of lint became highest (80.54) from water sprayed with 90 cm × 10 cm spacing ($S_1G_0$) which was statistically similar with $S_0G_5$ (foliar sprayed with 4 ml MC $L^{-1}$ water at 50 DAE in 60 cm × 30 cm spacing), $S_1G_1$, $S_1G_2$, $S_1G_4$, $S_1G_6$, $S_1G_8$ (2 and 4 ml MC $L^{-1}$ water sprayed at 25, 50 and 25 and 50 DAE, respectively with water spray in 90 cm × 10 cm spacing) $S_2G_0$, $S_2G_2$, $S_2G_6$, and $S_2G_8$ (4 ml MC $L^{-1}$ water foliar sprayed at 25 and 25 and 50 DAE, respectively with water spray in 60 cm x 20 cm spacing) treatment combinations and it became lowest (72.8) from water sprayed with 60 cm × 30 cm spacing ($S_0G_0$) which was statistically identical with $S_0G_1$, $S_0G_2$, $S_0G_3$, $S_0G_4$, $S_0G_5$, $S_0G_6$ $S_0G_7$, $S_0G_8$ (2 and 4 ml MC $L^{-1}$ water at 25, 50 and 25 and 50 DAE, respectively with water spray under 60 cm × 30 cm spacing); $S_1G_1$, $S_1G_2$, $S_1G_3$, $S_1G_4$, $S_1G_5$, $S_1G_6$, $S_1G_7$ and $S_1G_8$ (2 and 4 ml MC $L^{-1}$ water sprayed at 25, 50 and 25 and 50 DAE with water spray under 90 cm × 10 cm spacing); $S_2G_0$, $S_2G_1$, $S_2G_2$, $S_2G_3$, $S_2G_4$, $S_2G_5$, $S_2G_6$, $S_2G_7$ and $S_2G_8$ (2 and 4 ml MC $L^{-1}$ water foliar sprayed at 25, 50 and 25 and 50 DAE, respectively with water spray in 60 cm x 20 cm spacing) treatment combinations.

### 4.3.5.10 Yellowness (+b) of lint

**Effect of plant spacing**

Yellowness of lint of cotton had significant variation among the plant spacings (Table 21). The maximum yellowness of lint (13.79) was recorded at 60 cm × 30 cm spacing ($S_0$) followed by 90 cm × 10 cm spacing ($S_1$). The lowest yellowness of lint (13.26) was obtained from 60 cm × 20 cm spacing ($S_2$).

**Effect of time of application and concentration of MC growth regulator**

MC had significant effect on yellowness of lint of cotton (Table 21). The higher yellowness of lint (13.7) was obtained from $G_0$ (control) and the lower (13.33) at $G_8$ (foliar sprayed with 4.0 ml MC $L^{-1}$ water at 25 and 50 DAE).

**Combined effect of plant spacing and time of application and concentration of MC growth regulator**

Yellowness (+b) of lint was significantly affected by spacing and MC sprayed at different times and rates (Table 22). +b of lint varied from 12.6 to 13.9 and marked highest (13.9) from $S_0G_0$ (water sprayed with 60 cm × 30 cm spacing**)** followed by $S_0G_2$ (4 ml MC $L^{-1}$ water at 25 DAE with water spray in 60 cm × 30 cm spacing) treatment combination and the lowest (12.6) was recorded from $S_1G_1$ (2 ml MC $L^{-1}$ water sprayed at 25 DAE with 90 cm × 10 cm spacing) treatment combination.

**Table 21. Effects of plant spacing and MC level on upper half mean length, mean length, uniformity index, short fiber index, micronaire, maturity ratio, strength, elongation, reflectance and yellowness of lint of cotton**

| Treatments | Upper half mean length (mm) | Mean length (mm) | Uniformity index (%) | Short fiber index | Maturity ratio | Micronaire | Strength (g $tex^{-1}$) | Elongation (%) | Reflectance | Yellowness |
|---|---|---|---|---|---|---|---|---|---|---|
| **Effect of different levels of spacings** | | | | | | | | | | |
| **$S_0$** | 31.04 a | 26.3 a | 84.72 a | 7.50 a | 0.88 | 4.97 a | 32.32 a | 6.42 a | 76.64 | 13.79 a |
| **$S_1$** | 30.95 b | 26.21 b | 84.68 a | 7.26 b | 0.87 | 4.80 b | 30.62 b | 6.36 b | 74.72 | 13.69 a |
| **$S_2$** | 30.57 c | 25.77 c | 84.29 b | 7.24 b | 0.86 | 4.58 c | 30.23 c | 6.25 c | 73.68 | 13.26 b |
| **LSD** | 0.053 | 0.059 | 0.047 | 0.034 | NS | 0.202 | 0.063 | 0.011 | NS | 0.105 |
| **CV (%)** | 0.12 | 0.16 | 0.04 | 0.25 | 2.28 | 1.42 | 0.65 | 0.66 | 2.54 | 6.65 |
| **Effect of different application times and concentrations of MC** | | | | | | | | | | |
| **$G_0$** | 31.36 a | 26.67 a | 85.06 a | 7.50 a | 0.88 a | 5.01 a | 34.68 a | 6.66 a | 76.56 a | 13.70 a |
| **$G_1$** | 30.75 d | 25.98 d | 84.49 e | 7.30 d | 0.87 ab | 4.85 ef | 30.24 e | 6.37 d | 74.72 d | 13.62 b |
| **$G_2$** | 30.68 de | 25.89 e | 84.42 f | 7.30 d | 0.84 c | 4.83 f | 30.12 f | 6.22 e | 74.64 d | 13.57 c |
| **$G_{3(0)}$** | 30.63 ef | 25.86 e | 84.37 f | 7.23 e | 0.85 bc | 4.73 g | 30.01 g | 6.06 f | 73.84 e | 13.43 e |
| **$G_4$** | 30.96 b | 26.21 b | 84.74 b | 7.43 b | 0.86a-c | 4.97 b | 32.37 b | 6.53 b | 75.68 b | 13.63 b |
| **$G_5$** | 30.95 b | 26.19 b | 84.60 c | 7.40 bc | 0.87 ab | 4.91 c | 31.44 c | 6.42 c | 75.68 b | 13.53 d |
| **$G_{6(0)}$** | 30.92 b | 26.17 b | 84.57 cd | 7.39 bc | 0.85 bc | 4.89 cd | 30.79 d | 6.41 c | 75.28 c | 13.53 d |
| **$G_7$** | 30.84 c | 26.07 c | 84.53 de | 7.37 c | 0.87 ab | 4.87 de | 30.24 e | 6.38 d | 75.12 c | 13.63 b |
| **$G_8$** | 30.58 f | 25.77 f | 84.28 g | 7.07 f | 0.88 a | 3.99 h | 29.62 h | 6.03 g | 73.6 e | 13.33 f |
| **LSD** | **0.067** | **0.074** | **0.059** | **0.042** | **0.018** | **0.025** | **0.079** | **0.011** | **0.318** | **0.018** |
| **CV (%)** | **0.12** | **0.16** | **0.04** | **0.25** | **2.28** | **1.42** | **0.65** | **0.66** | **2.54** | **6.65** |

Means having same letters in the same column indicates no significant difference at 5% level of significance

Here,
$S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment
$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE
$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE

$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE
$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE
NS= Not significant

**Table 22. Combined effect of plant spacing and application time and concentration of mepiquat chloride on lint characters of** cotton

| Treatments | Upper half mean length (mm) | Mean length (mm) | Uniformity index (%) | Short fiber index | Micronaire | Maturity ratio | Strength (g $tex^{-1}$) | Elongation (%) | Reflec-tance (Rd) | Yellowness (+b) |
|---|---|---|---|---|---|---|---|---|---|---|
| $S_0G_0$ | 30.37 i-l | 25.54 j-m | 84.10 ij | 7.6 b | 4.78 jk | 0.87 ab | 28.9 q | 6.38 h | 72.8 h | 13.9 a |
| $S_0G_1$ | 31.66 a | 27.01 a | 83.98 k | 7.7 a | 5.02 b | 0.88 a | 28.91 q | 6.05 n | 72.8 h | 13.7 d |
| $S_0G_2$ | 30.39 i-k | 25.56 j-l | 84.11 h-j | 7.6 b | 4.89 gh | 0.84 b | 29.15 p | 6.49 f | 72.8 h | 13.9 a |
| $S_0G_{3(0)}$ | 31.24 bc | 26.56 c | 85.02 ab | 7.1 f | 4.78 jk | 0.87 ab | 31.76 f | 6.74 b | 73.6 g | 13.8 b |
| $S_0G_4$ | 30.27 kl | 25.43 lm | 84.02 jk | 7.67 ab | 4.94 g | 0.88 a | 30.07 lm | 6.09 m | 75.28 e | 13.77 c |
| $S_0G_5$ | 30.38 i-l | 25.55 j-m | 84.10 ij | 7.6 b | 4.70 lm | 0.85 ab | 29.95 mn | 6.17 k | 76.8 cd | 13.7 d |
| $S_0G_{6(0)}$ | 31.54 a | 26.85 b | 85.13 ab | 7.0 b | 4.85 hi | 0.87 ab | 31.95 e | 6.11 l | 73.6 g | 13.7 d |
| $S_0G_7$ | 30.42 ij | 25.59 jk | 84.12 h-j | 7.6 b | 4.7 im | 0.86 ab | 31.22 g | 6.22 j | 72.8 h | 13.8 b |
| $S_0G_8$ | 30.30 j-l | 25.46 k-m | 84.03 jk | 7.6 b | 4.50 o | 0.87 ab | 30.15 l | 5.99 o | 72.8 h | 13.8 b |
| $S_1G_0$ | 30.26 l | 25.62 j | 84.17 hi | 7.5 c | 4.57 n | 0.85 ab | 31.35 g | 6.22 j | 80.54 a | 13.3 g |
| $S_1G_1$ | 30.97 d-f | 25.42 m | 84.63 d | 7.3 e | 4.57 n | 0.86 ab | 30.92 h | 6.67 c | 77.86 b | 12.6 i |
| $S_1G_2$ | 30.97 d-f | 26.21 f | 84.63 d | 7.3 e | 4.65 m | 0.84 b | 30.83 hi | 6.17 k | 77.86 b | 12.7 h |
| $S_1G_{3(0)}$ | 30.48 i | 25.67 j | 84.22 h | 7.5 c | 5.09 b-d | 0.88 a | 29.91 no | 6.43 g | 74.4 f | 13.4 f |
| $S_1G_4$ | 31.32 bc | 26.64 c | 85.06 a-c | 7.1 f | 4.83 ij | 0.87 ab | 30.08 lm | 6.05 n | 77.34 bc | 13.4 f |
| $S_1G_5$ | 30.94 ef | 26.17 fg | 84.58 de | 7.3 e | 2.22 p | 0.78 c | 43.40 a | 6.62 d | 74.4 f | 13.4 f |
| $S_1G_{6(0)}$ | 31.21 c | 26.53 cd | 85.00 c | 7.1 f | 5.06 c-e | 0.88 a | 32.23 d | 6.74 b | 76.8 cd | 13.6 e |
| $S_1G_7$ | 31.34 b | 26.65 c | 85.04 a-c | 7.1 f | 5.11 bc | 0.84 b | 33.34 b | 6.67 c | 74.4 f | 13.3 g |
| $S_1G_8$ | 31.65 a | 26.96 ab | 85.15 a | 7.0 g | 5.13 b | 0.86 ab | 28.81 q | 6.22 j | 76.26 d | 13.6 e |
| $S_2G_0$ | 31.07 d | 26.41 de | 85.00 c | 7.1 f | 4.85 hi | 0.87 ab | 29.78 o | 6.05 n | 76.26 d | 13.4 f |
| $S_2G_1$ | 30.85 fg | 26.07 gh | 84.51 ef | 7.3 e | 5.13 b | 0.88 a | 30.53 k | 6.43 g | 73.6 g | 13.7 d |
| $S_2G_2$ | 30.38 i-l | 25.55 j-m | 84.10 ij | 7.6 b | 5.13 b | 0.85 ab | 30.75 i | 6.56 e | 76.26 d | 13.7 d |
| $S_2G_{3(0)}$ | 31.05 de | 26.39 e | 84.99 c | 7.1 f | 4.74 kl | 0.87 ab | 30.69 ij | 6.43 g | 72.8 h | 13.7 d |
| $S_2G_4$ | 30.68 h | 25.89 i | 84.39 g | 7.4 d | 5.04 d-f | 0.84 b | 30.57 jk | 6.05 n | 72.8 h | 13.4 f |
| $S_2G_5$ | 31.55 a | 26.86 b | 85.13 ab | 7.0 g | 4.74 kl | 0.88 a | 30.70 ij | 6.32 i | 72.8 h | 13.8 b |
| $S_2G_{6(0)}$ | 31.32 bc | 26.64 c | 85.06 a-c | 7.1 f | 5.0 f | 0.85 ab | 32.92 c | 7.12 a | 76.54 d | 13.6 e |
| $S_2G_7$ | 30.76 gh | 25.97 hi | 84.43 fg | 7.4 d | 5.21 a | 0.86 ab | 29.77 o | 6.38 h | 73.6 g | 13.6 e |
| $S_2G_8$ | 30.88 fg | 26.10 f-h | 84.52 d-f | 7.3 e | 4.87 hi | 0.87 ab | 29.90 no | 5.87 p | 76.8 cd | 13.7 d |
| **$LSD_{0.05}$** | **0.120** | **0.133** | **0.107** | **0.076** | **0.046** | **0.033** | **0.143** | **0.011** | **0.636** | **0.019** |
| **CV (%)** | **0.23** | **0.3** | **0.07** | **0.61** | **0.56** | **0.13** | **0.27** | **0.11** | **5.33** | **0.08** |

Means having same letters in the same column indicates no significant difference at 5% level of significance

Here, $S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment

$S_1$ = 90 cm × 10 cm (1,11,111 plants $ha^{-1}$)
$S_2$ = 60 cm × 20 cm (83,333 plants $ha^{-1}$)

$G_0$ = Water spray at 25 DAE (control)
$G_1$ = 2.0 ml $L^{-1}$ water at 25 DAE
$G_2$ = 4.0 ml $L^{-1}$ water at 25 DAE

$G_{3(0)}$ = Water spray at 50 DAE (control)
$G_4$ = 2.0 ml $L^{-1}$ water at 50 DAE
$G_5$ = 4.0 ml $L^{-1}$ water at 50 DAE

$G_{6(0)}$ = Water spray at 25 and 50 DAE (control)
$G_7$ = 2.0 ml $L^{-1}$ water at 25 and 50 DAE
$G_8$ = 4.0 ml $L^{-1}$ water at 25 and 50 DAE

# CHAPTER V

# SUMMARY AND CONCLUSION

Three experiments were carried out during three consecutive growing seasons of 2016-17, 2017-18, 2018-19 at the Cotton Seed Multiplication, Training and Research Farm, Sreepur, Gazipur, Bangladesh to determine the yield and quality performance of cotton in relation to high plant densities or low spacings and time of spray in combination with concentration of mepiquat chloride.

The first experiment was carried out during 2016-17 that consist of 5 (five) plant spacings, $S_0$ = 90 cm × 45 cm (24,691 plants $ha^{-1}$) as a recommended spacing, $S_1$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$), $S_2$ = 60 cm × 40 cm (41,666 plants $ha^{-1}$) $S_3$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$) and $S_4$ = 75 cm × 40 cm (33,333 plants $ha^{-1}$) and 6 (six) times of MC sprays, $G_0$ = water spray (without MC) as control, $G_1$ = Foliar spray at 25 days after emergence (DAE), $G_2$ = Foliar spray at 50 DAE , $G_3$ = Foliar spray at 75 DAE, $G_4$ = Foliar spray at 100 DAE, $G_5$ = Foliar spray at 125 DAE, mepiquat chloride @ 1.0 ml $L^{-1}$ was applied by spraying on cotton plant leaves.

The second experiment was conducted during 2017-18, comprised of 3 (three) plant spacings viz., $S_0$ = 60 cm × 30 cm (55,555 plants $ha^{-1}$) as check selected from first year experiment as promising treatment, $S_1$ = 45 cm × 30 cm (74, 074 plants $ha^{-1}$), and $S_2$ = 75 cm × 30 cm (44,444 plants $ha^{-1}$) and 13 (thirteen) MC spray time and concentration combinations, $G_0$ = Water spray (without MC) as control, $G_1$ = Mepiquat Chloride (MC) spray @ 1.0 ml $L^{-1}$ at 25 DAE, $G_2$ = MC spray @ 2.0 ml $L^{-1}$ at 25 DAE, $G_3$ = MC spray @ 3.0 ml $L^{-1}$ at 25 DAE, $G_4$ = MC spray @ 4.0 ml $L^{-1}$ at 25 DAE , $G_5$ = MC spray @ 1.0 ml $L^{-1}$ at 50 DAE, $G_6$ = MC spray @ 2.0 ml $L^{-1}$ at 50 DAE, $G_7$ = 3 MC spray @.0 ml $L^{-1}$ at 50 DAE, $G_8$ = MC spray @ 4.0 ml $L^{-1}$ at 50 DAE, $G_9$ = MC spray @ 1.0 ml $L^{-1}$ at 75 DAE, $G_{10}$ = MC spray @ 2.0 ml $L^{-1}$ at 75 DAE, $G_{11}$ = MC spray @ 3.0 ml $L^{-1}$ at 75 DAE and $G_{12}$ = MC spray @ 4.0 ml $L^{-1}$ at 75 DAE.

The third experiment was conducted during 2018-19, comprising three plant spacings, $S_0$= 60 cm × 30 cm ( 55,555 plants $ha^{-1}$) as check selected from 1st and 2nd year's experiment, $S_1$= 90 cm × 10 cm ( 1,11,111 plants $ha^{-1}$), and $S_2$= 60 cm × 20 cm (83,333 plants $ha^{-1}$) and nine MC concentrations along with times of application viz., $\mathbf{G_0}$ **=** Water spray (control) at 25 DAE, $\mathbf{G_1}$ **=** Mepiquat Chloride spray @ 2.0 ml $L^{-1}$ water at 25 DAE, $\mathbf{G_2}$ **=** Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 25 DAE, $\mathbf{G_{3(0)}}$ **=** Water spray (control) at 50 DAE, $\mathbf{G_4}$ **=** Mepiquat Chloride spray @ 2.0 ml $L^{-1}$ water at 50 DAE, $\mathbf{G_5}$ **=** Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 50 DAE, $\mathbf{G_{6(0)}}$ **=** Water spray (control) at 25 &50 DAE, $\mathbf{G_7}$ **=** Mepiquat Chloride spray @ 2.0ml $L^{-1}$ water at 25 & 50 DAE, $\mathbf{G_8}$ **=** Mepiquat Chloride spray @ 4.0 ml $L^{-1}$ water at 25 & 50 DAE, concentrations of mepiquat chloride were selected from the second year's performance.

These three experiments were laid out in split plot design with three replications. Plant density was randomly assigned to the main plot and MC spray time and concentration combinations in the subplots.

The data presented here only those collected at harvest. In the first year experiment, maximum LAI (0.75), squares plant$^{-1}$ (13.78), bolls plant$^{-1}$ (14.40), single boll weight (4.94 g), seed cotton yield (4.2 t ha$^{-1}$), lint yield (9.08 bales ha$^{-1}$), LI (9.36 g), UHML (30.28 mm), UI (84.05 %), micronaire (4.33) and elongation (6.39 %) but minimum plant height (91.59 cm), internode (4.46), leaf canopy size (0.29 m$^2$), bolls plant$^{-1}$ (11.17), GOT (38.47 %), SFI (7.65) and yellowness (+b) 6.77 were obtained from 60 cm × 30 cm spacing ($S_1$). Maximum plant height (97.66 cm), internode length (4.94 cm), leaf canopy size (0.32 m$^2$), GOT (40.53 %), MR (0.85), Strength (31.29 g tex$^{-1}$) and reflectance (65) but minimum LAI (0.67) and lint yield (3.66 bale ha$^{-1}$) observed from control, 90 cm × 45 cm ($S_0$). Lowest lint index (7.33 g) was marked from spacing 60 cm × 40 cm i.e. $S_2$. The maximum SFI (7.79) and yellowness of lint (7.22) but lowest squares plant$^{-1}$ (11.67), seed cotton yield (2.57 t ha$^{-1}$), boll weight (4.63 g), UHML (30.06 mm), ML (25.20 mm) and UI (83.83%) was marked from spacing of 75 cm × 30 cm ($S_3$). The highest ML (25.71 mm), but lowest micronaire (4.27), strength of lint (30.69 g tex$^{-1}$), elongation of lint (6.30%) and reflectance of lint (62.4) was recorded at spacing 75 cm × 40 cm ($S_4$).

Maximum squares plant$^{-1}$ (13.57), bolls plant$^{-1}$ (15.87), weight of single boll (5.03 g), seed cotton yield (4.02 t ha$^{-1}$), lint yield (6.79 bales ha$^{-1}$), seeds boll$^{-1}$ (119.4) and strength of lint (31.59 g tex$^{-1}$) but minimum plant height (81.98 cm), internodal length (3.76 cm) and leaf canopy size (0.17 m$^2$) were found from $G_1$ (1 ml MC L$^{-1}$ water at 25 DAE) treatment. Highest plant height (115.87 cm), internodal length (6.14 cm), leaf canopy size (0.40 m$^2$), LAI (1.61) and Rd (71.1) but the lowest squares plant$^{-1}$ (10.93), bolls plant$^{-1}$ (10.53), seed cotton yield (2.1 t ha$^{-1}$), lint yield (4.64 bale ha$^{-1}$) and ginning out turn (41 %) were observed from control ($G_0$); Maximum micronaire (4.44) and elongation of lint (6.48 %) but the lowest LI (7.27 g), MR(0.80), +b (6.7) and SFI (7.46) were recorded by $G_4$ (at 100 DAE) treatment; minimum LAI (0.36), GOT (38 %), UHML (29.86 mm), ML (24.98 mm) and UI (83.65 %) were obtained by $G_3$ (at 75 DAE) treatment; the higher seed index (13.74 g), lint index (9.47 g), SFI (7.94), and yellowness of lint (7.29) but lower seeds boll$^{-1}$ (114.6), micronaire (4.13), elongation (6.25%) and Rd (52.7) were obtained from foliar sprayed at $G_2$ (50 DAE) treatment; the highest UHML (30.60 mm), ML (25.81 mm), UI (84.33%) and MR (0.85) but lower weight of single boll (4.33 g), SI (11.01 g), strength (30.17 g tex$^{-1}$) and lower +b (6.7) were obtained from foliar sprayed at $G_5$ (at 125 DAE) treatment.

Combined influence of plant density and time of application and concentration of growth regulator developed the maximum squares plant$^{-1}$ (16.5), bolls plant$^{-1}$ (16), weight of bolls plant$^{-1}$ (5.14 g), seed cotton yield (4.06 t ha$^{-1}$), lint yield (8.97 bale ha$^{-1}$), UHML of lint (30.78 mm), ML (27.01 mm), UI (84.63 %), micronaire (4.61) and strength of lint (33.08 g tex$^{-1}$) but the minimum plant height (86.64 cm), internode (3 cm), leaf area (0.26), lint index (6.44 g), ginning out turn (38.27 %) and SFI of lint (7.33) were observed by $S_1G_1$ (1 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) treatment combination. The higher plant height (127.48 cm), internode (6.67 cm) and canopy size (0.45 $m^2$) but the lower weight of single boll (4.57 g), seed cotton yield (1.2 t $ha^{-1}$), lint yield (2.66 bale $ha^{-1}$), UHML of lint (29.56 mm), and +b of lint (6.33) were obtained by $S_0G_0$ (water sprayed with 90 cm × 45 cm spacing). The highest LAI (1.72) but lowest canopy size (0.16 $m^2$) and seeds $boll^{-1}$ (100.33) generated by $S_0G_3$ (1 ml MC $L^{-1}$ water sprayed at 75 DAE with 90 cm × 45 cm spacing), lower squares $plant^{-1}$ (11) and bolls $plant^{-1}$ (10) were also obtained from $S_1G_0$; seeds $boll^{-1}$ became highest (121.67) due to $S_1G_5$ (foliar sprayed at 125 DAE with 60 cm × 30 cm spacing), treatment combination; highest seed index (15) and lint index (10 g) of cotton became at $S_0G_4$ (foliar sprayed at 100 DAE with 90 cm × 45 cm spacing); maximum ginning out turn or lint percentages (40.8 %) but lowest Rd (58.7) observed at $S_1G_3$; SFI of lint became higher (8.1) but ML (24.68 mm), seed index (10.12 g) and UI (83.42) of lint marked the lower from $S_3G_3$ (foliar sprayed at 75 DAE with 75 cm × 30 cm spacing),; maximum MR (0.89) but micronaire of lint became lowest (3.92) from $S_4G_3$; lower MR (0.81) recorded from $S_0G_5$ (foliar sprayed at 125 DAE with 90 cm × 45 cm spacing); strength of lint became lowest (29.91 g $tex^{-1}$) from $S_2G_0$ (water sprayed with 60 cm × 40 cm spacing),; elongation of lint became highest (6.62 %) from $S_2G_5$ (foliar sprayed at 125 DAE with 60 cm × 40 cm spacing), but it became lowest (6.15 %) from $S_2G_3$ (foliar sprayed at 75 DAE with 60 cm × 40 cm spacing); Rd became higher (79.1) from $S_4G_1$ (foliar sprayed at 25 DAE with 75cm × 40 cm spacing); maximum MR (0.89) and +b (7.67) of lint obtained from $S_4G_4$ (foliar sprayed at 100 DAE with 75 cm × 40 cm spacing); SFI was marked lowest (7.33) from foliar sprayed at 25 DAE with 60 cm × 30 cm spacing ($S_1G_1$).

In the second year experiment levels of plant spacing maximum squares $plant^{-1}$ (10.21), bolls $plant^{-1}$ (11.56), weight of bolls (4.91 g), seed cotton yield (3.49 t $ha^{-1}$), lint yield (7.59 bales $ha^{-1}$), seed index (12.96 g), lint index (8.74 g), GOT (40.29 %), SFI (9.08), micronaire (4.52) and maturity ratio (0.85) but lower plant height (84.84 cm), internodal length (4.16 cm), leaf canopy size (0.33$m^2$), UHML (28.92), UI (82.69 %) and strength of lint (28.81 g $tex^{-1}$) was recorded at spacing of 60 cm × 30 cm ($S_0$); higher LAI (0.80), ML (25.72 mm), strength (30.23 g $tex^{-1}$), Rd (79.85) and +b (11.77) but lower squares $plant^{-1}$ (8.84), bolls $plant^{-1}$ (9.75), seeds $boll^{-1}$ (116.92), SI (11.93 g), LI (7.71 g), GOT (39.32 %), SFI (7.73), micronaire (3.94) and elongation (5.98 %) were obtained by 45 cm × 30 cm spacing ($S_1$). Maximum plant height (93.89 cm), internodal length (4.48 cm), leaf canopy size (0.39 $m^2$), seeds $boll^{-1}$ (119.61), UHML (30.53 mm), UI (84.26) and elongation (6.06 %) and but minimum LAI (0.74), boll weight (4.81 g), seed cotton yield (2.80 t $ha^{-1}$), lint yield (6.18 bales $ha^{-1}$), ML (23.96 mm), MR (0.83), Rd (72.45) and +b (10.09)) were observed from 75 cm×30 cm spacing ($S_2$).

Highest squares $plant^{-1}$ (10.94), bolls $plant^{-1}$ (14.56), single boll weight (4.98 g), seed cotton yield $ha^{-1}$ (3.96 t $ha^{-1}$), lint yield (8.78 bales $ha^{-1}$) and Rd (79.65) but minimum plant height (82.92 cm), internodal length (3.21 cm), leaf canopy size (0.32 $m^2$), LAI (0.64) and micronaire (3.84) were observed by $G_2$ (2 ml MC $L^{-1}$ water at

25 DAE) treatment; maximum plant height (97.22 cm), internodal length (4.8 cm), leaf canopy size (0.37 $m^2$), LAI (0.90), seed index (13.62 g) and elongation (6.12 %) but minimum squares $plant^{-1}$ (7.04), bolls $plant^{-1}$ (8.28), boll weight (4.66 g), seed cotton yield (2.26 t $ha^{-1}$) and lint yield (4.99 bale $ha^{-1}$) were obtained from control ($G_0$ treatment) . Besides, the lower SI (11.26 g) at $G_5$ (1 ml MC $L^{-1}$ water at 50 DAE); higher seeds $boll^{-1}$ (122) but minimum strength (28.67 g $tex^{-1}$) and elongation (5.89 %) marked from 3 ml MC $L^{-1}$ water at 75 DAE ($G_{11}$); higher ginning out turn (40.46 %) were observed by $G_{10}$ treatment; the lower seeds $boll^{-1}$ (109.33), GOT (39.07 %) and MR (0.84) of cotton was observed in 1.0 ml MC $L^{-1}$ water at 25 DAE ($G_1$); the highest LI (9.99 g) and the lower ML (23.43 mm) marked at $G_3$ (3.0 ml MC $L^{-1}$ water at 25 DAE); the higher SFI (9.27) and maturity ratio (0.86) but lowest UHML (28.45) and UI (82.29 %) was obtained from foliar sprayed at $G_6$ (2.0 ml MC $L^{-1}$ water sprayed at 50 DAE) treatment; maximum UHML (30.82), ML (26.07 mm), UI (84.56 %) and micronaire (4.55) but lower SFI (7.3), +b (8.95) and Rd (69.9) was marked from foliar sprayed at $G_8$ (4.0 ml MC $L^{-1}$ water sprayed at 50 DAE) treatment; the higher strength of lint (31.03 g $tex^{-1}$) was obtained from $G_7$ (foliar sprayed at 3.0 ml MC $L^{-1}$ water at 50 DAE) treatment; the higher yellowness of lint (12.17) was obtained from $G_9$ (foliar sprayed at 1.0 ml MC $L^{-1}$ water at 75 DAE); the lower LI (7.04 g) marked at $G_{12}$ (4 ml MC $L^{-1}$ water at 75 DAE) treatment.

Combined influence of plant density and time of application and concentration of growth regulator exposed that the higher squares $plant^{-1}$ (15.24), bolls $plant^{-1}$ (17.33), seed cotton yield (4.53 t $ha^{-1}$), lint yield (9.43 bale $ha^{-1}$), LAI (1.06), and GOT (40.87%) but the lower plant height (67.92 cm), internode (3.33 cm), canopy size (0.16 $m^2$) and MR of lint (0.79) were obtained from $S_0G_2$ (2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) treatment combination. Furthermore, maximum plant height (108.75 cm), internode (5.50 cm) and leaf canopy size (0.46 $m^2$) but minimum boll weight (4.47 g), seed cotton yield (1.73 t $ha^{-1}$) lint yield (3.82 bale $ha^{-1}$), UHML (26 mm) and ML (20.73 mm) of lint observed by $S_2G_0$ (water sprayed with 75 cm × 30 cm spacing) treatment combination; highest boll weight $plant^{-1}$ (5.13 g) but lower (3.33 cm) internode (identical) and leaf area index (0.53) recorded by $S_1G_2$ (2 ml MC $L^{-1}$ water at 25 DAE with 45 cm × 30 cm spacing); maximum elongation (6.38 %) of lint and minimum squares $plant^{-1}$ (4.44) and bolls $plant^{-1}$ (7) observed by $S_1G_0$ (water sprayed with 45 cm × 30 cm spacing) treatment combination; highest UHML (31.46 mm) and ML (26.77 mm) of lint found by $S_1G_1$ (1 ml MC $L^{-1}$ water at 25 DAE with 45 cm × 30 cm spacing) treatment combination; higher seeds $boll^{-1}$ (122.67) but lowest lint SFI (7) observed by $S_0G_{11}$ (3 ml MC $L^{-1}$ water at 75 DAE with 60 cm × 30 cm spacing); lower seeds $boll^{-1}$ (106.42) were found by $S_1G_8$ (4 ml MC $L^{-1}$ water at 50 DAE with 45 cm × 30 cm spacing); lower GOT (39.10%) found by $S_2G_7$ (3 ml MC $L^{-1}$ water at 50 DAE with 75 cm × 30 cm spacing); higher SI (15 g) by $S_0G_0$; highest LI (10.30 g), strength of lint (31.79 g $tex^{-1}$) but lowest micronaire (3.7) from $S_1G_7$ (3 ml MC $L^{-1}$ water at 50 DAE with 45 cm × 30 cm spacing), but lowest LI (7 g) by $S_2G_3$ (3 ml MC $L^{-1}$ water at 25 DAE with 75 cm × 30 cm spacing); $S_0G_{12}$ (4 ml MC $L^{-1}$ water at 75 DAE with 60 cm × 30 cm spacing) showed the maximum UI (85.09) and the lowest UI (79.43) was noted by $S_2G_{12}$ (4 ml MC $L^{-1}$ water at 75 DAE with 75 cm × 30 cm spacing); highest micronaire (5.39) showed by $S_2G_{10}$ (2 ml MC $L^{-1}$ water at 75 DAE with 75 cm × 30 cm spacing); highest MR (0.86) found by $S_0G_6$ (2ml MC $L^{-1}$ water at 50 DAE with 60 cm × 30 cm spacing); SFI of lint became highest (12.5) but +b of lint became lowest (6.2) by $S_2G_{11}$ (3 ml MC $L^{-1}$ water at 75 DAE with 75 cm × 30 cm spacing); strength of lint became lowest (26.32 g $tex^{-1}$) by $S_2G_6$ (2 ml MC $L^{-1}$ water at 50 DAE with 75 cm × 30 cm spacing); lowest Rd of lint (53) found by $S_0G_8$ (4 ml MC $L^{-1}$ water at 50 DAE with 60 cm × 30 cm spacing); Rd became highest (84.5) from $S_1G_{10}$ (2 ml MC $L^{-1}$ water at 75 DAE with 45 cm × 30 cm spacing); +b of lint became highest (13.5) from $S_2G_8$ (4 ml MC $L^{-1}$ water at 50 DAE with 75 cm × 30 cm spacing); lowest elongation (5.66 %) at 3ml MC $L^{-1}$ water sprayed at 25 DAE with 45 cm × 30 cm spacing ($S_1G_3$); lowest SI (10.33 g) marked from $S_0G_3$ (3 ml $L^{-1}$ at 25 DAE with 60 cm × 30 cm spacing) treatment combination.

In the third year experiment levels of plant spacing manifested highest boll weight (4.66 g), leaf area index (1.01) but lowest plant height (95.16 cm), internode length (4.51 cm), leaf canopy size (0.38 $m^2$), squares $plant^{-1}$ (11.77), bolls $plant^{-1}$ (11.37), seed cotton yield (2.98 t $ha^{-1}$) and lint yield (6.43 bale $ha^{-1}$) were also obtained by $S_1$ (90 cm × 10 cm). The higher plant height (103.64 cm), internode length (4.74 cm), leaf canopy size (0.41 $m^2$), squares $plant^{-1}$ (12.67) and bolls $plant^{-1}$ (11.37), seed cotton yield (4.04 t $ha^{-1}$), lint yield (7.57 bale $ha^{-1}$), seeds $boll^{-1}$ (120.37), SI (8.59 g), LI (8.59 g), GOT (39.56%), UHML of lint (31.04 mm), ML of lint (26.30 mm), UI (84.72 %), SFI (7.5), micronaire (4.97), MR (0.88), strength of lint (32.32 g $tex^{-1}$), elongation (6.42%), Rd of lint (76.64) and +b of lint (13.7) but lower LAI (0.89) and boll weight (3.84 g) were observed by $S_0$ (60 cm × 30 cm as control); the lower seeds $boll^{-1}$ (117.93), SI (7.7 g), LI (7.05 g), GOT (38.37 %), UHML of lint (30.57 mm) and ML of lint (25.77 mm), UI (84.29 %), SFI (7.24), micronaire (4.58), MR (0.86), strength of lint (30.23 g $tex^{-1}$), elongation (6.25%), Rd of lint (73.68) and +b of lint (13.26) were observed by $S_2$ (75 cm × 30 cm spacing).

Growth regulator (mepiquat chloride) at different times of application and its concentration exposed that the higher squares $plant^{-1}$ (13.83), bolls $plant^{-1}$ (10.97), boll weight $plant^{-1}$ (5 g), seed cotton yield (4.03 t $ha^{-1}$), lint yield (7.71 bale $ha^{-1}$) and lint index (8.56 g) but Shortest plant height (92.13 cm) and internode (4.45 cm), lower canopy size (0.38 $m^2$) and LAI (0.90) were observed by $G_1$ (2.0 ml MC $L^{-1}$ water at 25 DAE) treatment; maximum plant height (106.57 cm), internode (4.77 cm), canopy size (0.42 $m^2$), LAI (1.03), seeds $boll^{-1}$ (121), SI (12.22 g), GOT (39.69 %), UHML of lint (31.36 mm), ML of lint (26.67 mm), UI (85.06), SFI (7.5), micronaire (5.01), MR (0.88), strength of lint (34.68 g $tex^{-1}$), elongation (6.66 %), Rd of lint (76.56) and +b of lint (13.7) but minimum squares $plant^{-1}$ (9.83), bolls $plant^{-1}$ (6.87), boll weight $plant^{-1}$ (3.84 g), seed cotton yield (2.12 t $ha^{-1}$), lint yield (4.57 bales $ha^{-1}$and) and MR (0.84) were obtained from control (without MC application); lower seeds $boll^{-1}$ (116.22), LI (6.61 g), UHML of lint (30.58 mm) and ML of lint (25.77 mm), UI

(84.28 %), SFI (7.07), micronaire (3.99), strength of lint (29.62 g $tex^{-1}$), elongation (6.03 %), Rd of lint (73.6) and +b of lint (13.33) were obtained by $G_8$ (4.0 ml MC $L^{-1}$ water at 25 and 50 DAE); lowest GOT (38.5 %) from $G_3$ (3 ml MC $L^{-1}$ water at 25 DAE); the lower SI (9.9 g) marked from $G_4$ (2 ml MC $L^{-1}$ water at 50 DAE) treatment.

Combined influence of plant spacing and time of application and concentration of growth regulator exposed that the higher seed cotton yield (4.67 t $ha^{-1}$), lint yield (10.06 bales $ha^{-1}$), bolls $plant^{-1}$ (16.6), squares $plant^{-1}$ (16.6), seeds $boll^{-1}$ (122.67), GOT (41.27 %), UHML (31.66 mm), ML (27.01 mm), SFI (7.7) and MR (0.88) of lint but lower plant height (89.83 cm), internode (4.3 cm), leaf canopy size (0.32 $m^2$), leaf area index (0.72) and UI (83.98 %) were obtained by $S_0G_1$ (2 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) treatment combination; the higher SI (14.22 g) and +b of lint (13.9) but lower boll weight $plant^{-1}$ (3.8 g), seed cotton yield (1.67 t $ha^{-1}$), lint yield (3.60 bale $ha^{-1}$); GOT (39.13%) and Rd of lint (72.8) were observed from $S_0G_1$ (water sprayed with 60 cm × 30 cm spacing) treatment combination; higher plant height (113.7 cm), boll weight $plant^{-1}$ (5.13 g) but lower +b of lint (12.6) and ML (25.42 mm) from $S_1G_1$; higher internode (5.13 cm) but lower bolls $plant^{-1}$ (5.97) and seeds $boll^{-1}$ (107) obtained from $S_1G_6$ (water sprayed with 90 cm × 10 cm spacing) treatment combination; higher leaf canopy size (0.47 $m^2$), leaf area index (1.17) and Rd of lint (80.54) but lower UHML (30.26 mm) were observed from water sprayed with 90 cm × 10 cm spacing; lowest squares $plant^{-1}$ (10) obtained from $S_1G_3$ (water sprayed with 90 cm × 10 cm spacing) treatment combination; SI became lowest (10 g) from foliar sprayed at 4 ml MC $L^{-1}$ water at 25 and 50 DAE with 60 cm × 20 cm spacing ($S_2G_8$ treatment combination); LI marked highest (9.53 g) from $S_0G_2$ (4 ml MC $L^{-1}$ water at 25 DAE with 60 cm × 30 cm spacing) treatment combination; highest elongation (7.12 %) but lowest LI (6.55 g) from $S_2G_6$ (water sprayed at 50 DAE with 60 cm × 20 cm spacing); highest strength (43.4 g $tex^{-1}$) but lower MR of lint (0.78) from $S_1G_5$ (4 ml MC $L^{-1}$ water at 50 DAE with 90 cm × 10 cm spacing); highest micronaire (5.21) from $S_2G_7$ (2 ml MC $L^{-1}$ water at 25 and 50 DAE with 60 cm × 20 cm spacing) treatment combination; highest UI (85.15 %) but lowest micronaire (2.22), SFI (7) and strength (28.81 g $tex^{-1}$) of lint became at $S_1G_8$ (4 ml MC $L^{-1}$ water at 25 and 50 DAE with 90 cm × 10 cm spacing); lowest elongation (5.87 %) at $S_2G_8$ (4 ml MC $L^{-1}$ water at 25 and 50 DAE with 60 cm × 20 cm spacing) treatment combination.

Plant characters and yield of cotton responded to different plant spacing. Maximum boll weight (4.94 g), seed cotton yield (4.04 t $ha^{-1}$), lint yield (8.08 bales $ha^{-1}$), leaf canopy size (0.41 $m^2$), seeds $boll^{-1}$ (120.37), LI (9.36 g), UHML of lint (31.04 mm), ML (26.30 mm), UI (84.72 %), SFI (9.08), micronaire (4.97), MR (0.88), strength of lint (32.32 g $tex^{-1}$), elongation (6.42 %) and +b of lint (13.79) but minimum leaf canopy size (0.29 $m^2$), lower boll weight (3.84 g), UHML of lint (28.92 mm) and micronaire (3.94) were observed at 60 cm × 30 cm (55555 plants $ha^{-1}$) spacing; higher squares $plant^{-1}$ (13.78), bolls $plant^{-1}$ (14.40) and GOT (40.53 %) but lower LAI (0.67), seed cotton yield (2.1 t $ha^{-1}$), lint yield (4.66 bales $ha^{-1}$) and +b of lint (6.77) were found from 90 cm × 45 cm spacing (24691 plants $ha^{-1}$); maximum leaf area index (1.009) were obtained from 90 cm×10 cm (1,11,111 plants $ha^{-1}$) spacing. Results showed that there was a trend to increase seed cotton yield with the closest spacing.

Lowest SI (7.7 g), GOT (38.37%) and SFI (7.24) marked from 60 cm × 20 cm spacing; higher Rd of lint (15.97) but minimum plant height (84.84 cm) and internodal length (4.18 cm) observed from 45 cm×30 cm spacing; highest SI (13.52 g) but lower seeds $boll^{-1}$ (114) and Rd of lint (6.2) at 75 cm × 40 cm spacing; lowest squares $plant^{-1}$ (8.84), bolls $plant^{-1}$ (9.75), LI (7.7 g), UI (82.69), MR (0.81), strength of lint (28.81 g $tex^{-1}$) and elongation (5.98 %) by 45 cm × 30 cm spacing; highest GOT (38.37 %), UHML of lint (30.57 mm), UI (84.29), SFI (7.24), micronaire (4.58), MR (0.86) but lowest ML (23.96 mm) was recorded from 75 cm × 30 cm spacing.

Maximum bolls $plant^{-1}$ (15.87) marked from 1.0 ml MC $L^{-1}$ water at 25 DAE; lower plant height (81.41 cm), canopy size (0.17 $m^2$), LAI (0.36) and GOT (38.34%) from 1.0 ml MC $L^{-1}$ water at 75 DAE; maximum squares $plant^{-1}$ (13.83), boll weight $plant^{-1}$ (5 g), seed cotton yield (4.03 t $ha^{-1}$) and lint yield (8.78 bales $ha^{-1}$) observed from 2.0 ml MC $L^{-1}$ water at 25 DAE; maximum from 2.0 ml MC $L^{-1}$ water at 75 DAE; higher SI (13.74 g) and SFI (7.94) of lint but lower Rd of lint (5.27) obtained from 1.0 ml MC $L^{-1}$ water at 50 DAE; higher seeds $boll^{-1}$ (122) 3.0 ml MC $L^{-1}$ water at 75 DAE. Results revealed that there was a trend to increase seed cotton yield with the increase of MC concentration. There is a tendency for more parameters to develop on the first two fruiting positions and after that they are not effective following treatments.

Highest plant height (115.87 cm), internodal length (6.14 mm), canopy size (0.42 $m^2$), LAI (1.61), UHML (31.36 mm), ML (26.67 mm), UI (85.06), micronaire (5.01), MR (0.88), strength (34.68 g $tex^{-1}$), elongation (6.66 %) and +b of lint (13.70) but lower squares $plant^{-1}$ (7.04), bolls $plant^{-1}$ (6.87), boll weight (3.84 g), seed cotton yield (2.12 t $ha^{-1}$), lint yield (4.57 bales $ha^{-1}$) and UI (82.29 %) were observed in water spray; highest Rd of lint (15.93) but lower internodal length (3.71 mm) and micronaire (3.84) obtained from 2.0 ml MC $L^{-1}$ water at 25 DAE; lowest UHML (28.45 mm), ML (23.43 mm) and SI (9.9 g) of lint from 2.0 ml MC $L^{-1}$ water at 50 DAE; highest LI (9.99 g) at 3.0 ml MC $L^{-1}$ water at 25 DAE; lower LI (6.61 g) from 4.0 ml MC $L^{-1}$ water at 75 DAE; highest GOT (40.5%) but lowest MR (0.80) at 1.0 ml MC $L^{-1}$ water at 100 DAE; lower SFI (7.07) from 4.0 ml MC $L^{-1}$ water at 25 and 50 DAE; lowest strength of lint (28.20 g $tex^{-1}$) and elongation (5.89 %) by 3.0 ml MC $L^{-1}$ water at 75 DAE; lowest +b of lint (6.70) at 1.0 ml MC $L^{-1}$ water at 125 DAE; lower seeds $boll^{-1}$ (109.33) from 1.0 ml MC $L^{-1}$ water at 25 DAE.

Maximum squares $plant^{-1}$ (16.6), bolls $plant^{-1}$ (17.33), seed cotton yield (4.67 t $ha^{-1}$), lint yield (10.06 bale $ha^{-1}$), ginning out turn (41.27%), upper half mean length (31.66 mm) and maturity ratio (0.88) of lint but lower plant height (67.92 cm) and leaf canopy size (0.16$m^2$) were observed in the crop raised from 60 cm × 30 cm spacing

(55,555 plants ha$^{-1}$) with 2 ml MC L$^{-1}$ water sprayed at 25 DAE. The higher seed index (15) was observed at 60 cm × 30 cm spacing (55,555 plants ha$^{-1}$) from control. Higher boll weight (5.14 g) obtained from 1 ml MC L$^{-1}$ water sprayed at 25 DAE with 60 cm × 30 cm (55,555 plants ha$^{-1}$) spacing; maximum seeds boll$^{-1}$ (122.67) found at 3 ml MC L$^{-1}$ water sprayed at 75 DAE with 60 cm × 30 cm spacing (55555 plants ha$^{-1}$); higher lint index (10.3), and mean length (27.01 mm) but lower internode length (3 cm) were recorded at 1 ml MC L$^{-1}$ water sprayed at 25 DAE with 60 cm × 30 cm spacing (55555 plants ha$^{-1}$) spacing; The combined effect of spacing and MC indicates that higher concentration of MC with highest spacing failed to give the higher yield of cotton irrespective of time of application.

Maximum leaf area index (1.72) was found from 90 cm × 45 cm (24,691plants ha$^{-1}$) spacing with 1 ml MC L$^{-1}$ water sprayed at 75 DAE; higher uniformity index (85.15%) from 4 ml MC L$^{-1}$ water sprayed at 25 and 50 DAE with 90 cm × 10 cm (1,11,111 plants ha$^{-1}$) spacing; higher short fiber index (12.5) from 3 ml MC L$^{-1}$ water sprayed at 75 DAE with 75 cm × 30 cm (44,444 plants ha$^{-1}$) spacing; superior micronaire (5.39) from 2 ml L$^{-1}$ MC sprayed at 75 DAE with 75 cm × 30 cm (44,444 plants ha$^{-1}$) spacing; highest strength (43.4 g tex$^{-1}$) from 4 ml MC L$^{-1}$ water sprayed at 50 DAE with 90 cm×10 cm (1,11,111 plants ha$^{-1}$) spacing; higher elongation (7.12 %) from water spray with 60 cm × 20 cm (83,333 plants ha$^{-1}$) spacing; highest reflectance (16.9) from 2 ml MC L$^{-1}$ water at 75 DAE sprayed with 45 cm × 30 cm (74,074 plants ha$^{-1}$) spacing; higher yellowness (13.9) from water sprayed with 60 cm × 30 cm spacing (55555 plants ha$^{-1}$) spacing. The results were not remarkably affected by plant spacing but increased significantly due to some treatments of MC compared to control.

From the results and discussion of three experiments it may be concluded as follows -

1) Mepiquat chloride (MC) as growth retardant has influenced in restructuring (short stature) cotton plants which can produce more cotton yield and its quality under dense plant population management (closer spacing) compared to wider spacing without growth hormone.
2) Mepiquat chloride (MC) foliar spray @ 2 ml L$^{-1}$ water at 25 DAE along with plant spacing 60 cm x 30 cm (55,555 plants ha$^{-1}$) gave higher yield and quality of cotton over controls.

**Recommendation**

Results indicated that growth retardant, Mepiquat chloride (MC) has positive influence in the improvement of cotton yield and quality as it has been emerged for three years research at one location. So, this type of research could be further upgraded including potential varieties/lines along with different growth retardant phytohormones under different concentrations and time of foliar application across different cotton growing areas where Mepiquat chloride as check treatment. It would have benefited cotton farmers with short durated (restructured) cotton varieties / lines to accommodate other crops for increasing cropping intensity of Bangladesh.

# REFERENCES

Abro, G. H., Syed, T. S., Umer, M. I. and Zhang, J. 2004. Effect of application of a growth regulator and micronutrients on insect pest infestation and yield components of cotton. *J. Entom.* **1**(1): 12-16.

Alam, S. M., Shereen, A. and Khan, M. (2002). Growth response of wheat cultivars to naphthalene acetic acid (NAA) and ethrel. *Pak. J. Bot.* **34**(2): 135-137.

Ahmad, S., Iqbal, M., Hayat, K., Islam, N. U., Ashraf, F. and Sadiq, M. A. (2008). Effect of cotton leaf curl virus, yield components and fibre properties of cotton genotypes underarrying plant spacing and nitrogen fertilizer. *Sci. Technol. Dev.* **27**: 33-41.

Almeida, A. Q. D. and Rosolem, C. A. (2012). Cotton root and shoot growth as affected by application of mepiquat chloride to cotton seeds. *Acta Sci. Agron. Maringa.* **34**(1): 61-65.

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

Ali, S. S., Abro, G. H., Rustamani, M. A. and Nizamani, S. M. (2012). Effect of application of plant growth regulators on *Earias vittella* (Fabricius), infestation and yield components of cotton. *J. Basic Appl. Sci.* **8**: 677-682.

Al-Suhaibani , N., El-Hendawy, S. and Schmidhalter U. (2013). Influence of varied plant density on growth, yield and economic return of drip irrigated faba bean (*Vicia faba* L.). *Turkish J. Field Crops.* **18**(2): 185-197.

Amit, K., Deol, J. S. and Brar, A. S. (2016). Response of different *Bt* cotton (*Gossypium hirsutum* L.) hybrids to canopy modification practices. *J. Appl. Nat. Sci.* **8** (3): 1188 – 1197.

Arif, M. H. and Yasmeen, A. (2016). Morphological and physiological response of cotton to exogenous application of growth regulators, *Academia, J. Agric. Res.* **4**(8): 467-477.

Awais, M., Wajid, A., Ahmad, A., Saleem, M. F., Bashir, M. U., Saeed, U., Hussain, J. and Habib-ur-Rahman, M. (2015). Nitrogen fertilization and narrow plant spacing stimulates sunflower productivity. *Turkish J. Field Crops.* **20**(1): 99-108.

Bairagi, S., Pandit, M., Sidhya, K. P., Adhikary, S. and Koundinya, A. V. V. (2015). Impacts of date of planting and crop geometry on growth and yield of baby corn (*Zea mays* var. rugosa) Department of Vegetable Crops, Bidhan Chandra Krishi Viswavidyalaya Mohanpur-741252, Nadia, West Bengal. Agriculture and Ecological Research Unit, Indian Statistical Institute, Kolkata, India.

Balkcoma, S., Pricea, A. J., Santenb, E. V., Delaneyb, D. P., Boykinc , D. L., Arriagaa, F. J., Bergtoldd, J. S., Korneckia, T. S. and Randy, L. (2010). Row spacing, tillage system, and herbicide technology affects cotton plant growth and yield. *Field Crops Res.* **117**: 219–225.

Ballare, C. L., Scopel, A. L., Radosevich, S. R. and Kendrick, R. E. (1992). "Phytochrome-mediated phototropism in deetiolated seedlings: occurrence and ecological significance." *Plant Physiol.* **100(**1): 170–177.

Baumhardt, R. L., Schwartz, R. C., Marek, G. W. and Bell, J. M. (2018). Planting geometry efects on the growth and yield of dryland cotton. *Agric. Sci.* **9:** 99-116.

Baylis, A. and Dickst, J. (1983). Investigations into the use of plant growth regulators in oil-seed sunflower (*Helianthus annuus* L.) husbandry. *The J. Agric. Sci.* **100**(3): 723-730.

Berry, N. B. O, Faircloth, J. C., Edmisten, K. L., Collins, G. D., Stewart, A. M., Abaye, A. O., Herbert, D. A. and Haygood, Jr. R. A. (2008). Plant population and planting date effects on cotton (*Gossypium hirsutum* L.) growth and yield, agronomy and soils. The *J. Cotton Sci.* **12:** 178–18.

Bhalerao, P. D. and Gaikwad, G. (2010). Productivity and profitability of Bt cotton (*Gossypium hirsutum*) under various plant geometry and fertilizer levels. *Indian J. Agron.* **55**(1): 60-63.

Bons, H. K., Kaur, N. and Rattanpa, H. S. (2015). Quality and quantity improvement of citrus: role of plant growth regulators. *Int. J. Agric. Environ. Biotechnol.* **8**(2): 433-447.

Boquet, D. J. and Coco, A. B. (1993). Cotton yield and growth interactions among cultivars, row spacings, and soil types under two levels of Pix. pp. 1370-1372

Boshra, E. S. (2013). Bearing regulation of "langra" mango trees. *J. Plant Production, Mansoura Univ.* **4**(10): 1493 – 1499.

Butcher, T. and Malik, R. (2016). Managing lodging in Williams oats by using plant growth regulator (Moddus®Evo). GRDC Research Update.

Cao, Y., Xiao Y., Huang, H., Xu, J. , Hu, W. and Wang, N. (2016). Simulated warming shifts the flowering phenology and sexual reproduction of *Cardamine hirsuta* under different Planting densities. *Sci. Rep.* **6**. Article number : 27835.

Chang-chi, C., Thomas, H. J., Louis, B. A. and Deeter, B. (2019). Effect of plant growth regulators under short -season conditions on pink bollworm populations, cotton yields and defoliation. *USDA-ARS*. pp: 150-153.

Chaplot, P. C. (2015). Response of cotton, *Gossipium hirsutum* L. to plant growth regulators, Directorate of Extension Education. *Int. J. Farm Sci.* **4**(4): 59-63.

Chormule, S. R. and Patel, J. B. (2017). Effect of spacing and plant growth regulators on plant growth parameters, seed yield and its attributes in okra [*Abelmoschus esculentus* (L.) Moench]. *Int. J. Pure Appl. Biosci.* **5**(5): 366-379.

Choudhury, S., Islam, N., Sarkar, M.D. and Ali, M.A. (2107). Growth and Yield of Summer Tomato as Influenced by Plant Growth Regulators. *Int. J. Sustainable Agric*. **5**(1): 25-28.

Cimen, I., Basbag, S., Temiz, M. and Sagir, A. (2004). The Effect of Paclobutrazol, Growth Retardant, on Cotton Growth and Verticillium Wilt (*Verticillium dahliae* Kleb.). *Pl. Path. J.* **3**(1): 35-39.

Clawson, E. L., Cothren, J. T. and Blouin, D. C. (2006). Nitrogen fertilization and yield of cotton in ultra-narrow and conventional row spacings. *Agron. J.* **98**: 72–79.

Copur, O., Demirel, U. and Karakus, M. (2010). Effects of several plant growth regulators on the yield and fiber quality of cotton (*Gossypium hirsutum* L.). *Not. Bot. Hort. Agrobot. Cluj*. **38**(3): 104-110

Cothren, J. T., Albers, D. W., Urwiler, M. J. and Guthrie, D. S. (1983). Comparative growth analysis of mepiquat chloride-treated cotton cultured under controlled environment. Proc. Tenth Ann. Meet. *Plant Growth Regulator Soc. Am., Lake Alfred.* FL., 253-261.

CDB. (2018). Cotton Extension and Research Report. Cotton Development Board, Khamarbari, Farmgate, Dhaka, Bangladesh. pp. 10-125.

Darawsheh, M. K., Khah, E. M., Aivalakis, G., Chachalis, D. and Sallaku, F. (2009 a). Cotton row spacing and plant density cropping systems I. Effects on accumulation and allocation of dry mass and LAI. *J. Food Agric. Environ.* **7**(3 and 4): 258-261.

Darawsheh, M. K., Chachalis, D., Aivalakis, G. and Khah, E. M. (2009 b). Cotton row spacing and plant density cropping systems II. Effects on seed cotton yield, boll components and lint quality. *J. Food Agric. Environ.* **7**(3 and 4): 262-265.

Deotalu, A. S., Kubde, K. J., Paslawar, A. N., Chaudhari, D. P. and Tiwari, V. A. (2013). Growth and yield of hirsutum varieties as influenced by plant spacing and fertilizer levels under rainfed condition. *Ann. Pl. Physiol.* **27** (1): 30-32.

Echer, F. R. and Rosolem, C. A. (2017). Plant growth regulation: a method for fine-tuning mepiquat chloride rates in cotton. *Agropec. Trop., Goiania*. **47**(3): 286-295.

Edgerton, L. J. (1983). Effects of some growth regulators on branching and flowering of young apple trees. *Acta Hortic.* **137**: 77-82.

Edivaldo C., Alleoni, L. R. F. and Ferraz, C. A. M. (1996). Effects of planting density and growth regulator on cotton crop. *Bragantia* [online]. **55**(2): 309-316.

Emilie, E. R. and Kufimfutu, B. B. (1995). Crop planting pattern effects on early growth and canopy shape of cultivated and wild oats (*Avena fatua*). *Weed Sci.* **43**(1): 88-94.

Ernst, D., kovar, M. and cerny, I. (2016). Effect of two different plant growth regulators on production traits of sunflower. *J. Cent. European Agric.* **17**(4): 998-1012.

Evangelos, D. G., Derric , K. M. O, Bibi, A. C. and Brown, R. S. (2004). Effect of the Plant Growth Regulator PGR-IV Plus as a Safener for Glyphosate Applications in Cotton. *Summaries of Arkansas Cotton Res. AAES Res. Series.* **533.**

Eveleigh, R., Marshall , J., Kelly, D., Ford, B. and James. (2010). Cotton Seed Distributors Ltd., “Shenstone” Culgoora Road, Wee Waa, NSW 2388.

Fahad, S., Hussain, S., Saud, S., Hassan, S., Ihsan, Z., Shah, A., N., Wu, C., Yousaf, M., Nasim, W., Alharby, H., Alghabari, F. and Huang, J. (2016). Exogenously applied plant growth regulators enhance the morpho-physiological growth and yield of rice under high temperature. *Plant Physiol. Biochem.* **103**: 191–198.

Fang, S., Binglin, C., Kai, G., Shanshan, W., Wei, H. and Zhiguo, Z. (2019). Foliar and seed application of plant growth regulators affects cotton yield by altering leaf physiology and floral bud carbohydrate accumulation. Field Crops Res. **231**:105-114.

Feng L., Bufon, V. B., Mills, C. I., Hequet, E., Bordovsky, J. P., Keeling, W., Boman, R. and Bednarz, C. W. (2011). Effects of irrigation, cultivar and plant density on cotton within-boll fiber quality. **103**(2)*: 297-303.*

Firoz, Z. A, Islam, M. A., Mohiuddin, M. and Rahman, M. M. (2007). Yield and yield attributes of okra as influenced by planting time and plant spacing in hill slope condition. *Progress. Agric*. **18**(2): 67-73.

Gadade, S.B., Shinde, V.S., Deosarkar, D. B. and Shinde, S.S. (2017). Effect of plant growth regulators on growth andyield of okra (*Abelmoschus esculentus* L.), *India. Plant Archives*. **17**(1): 177-180.

Ganvir, S., Ghanbahadur, M and Khargkharate, V. K. ( 2013). Response of hirsutum cotton to high plant density, fertilizers and moisture conservation. *Ann. Pl. Physiol.* **27**(1): 33-37.

Ghosh, S. N., Bera, B., Kundu, A. and Roy, S. (2009). Effect of plant growth regulators on fruit retention, yield and physico-chemical characteristics of fruits in ber 'banarasi karka' grown in close spacing. *Acta Hortic.* **840**(49): 357-362

Ghule, P. L., Jadhav, J. D., Palve, D.K. and Dahiphale, V.V. (2013). Bt cotton and its leaf area index (LAI), ginning (%), lint index(g), earliness index and yield contributing characters. *Int. Res. J. Agric. Econ. Stat.* **4**(1): 85-90.

Golada S. L., Sharma, G. L., Nepalia, V. and Puniya, R. (2018). Response to different levels of spacing, nitrogen and plant growth regulators on baby corn. *Agric. Sci. Digest.* **38**(3): 159-165.

Gollagi, S. G., Ravi, G. K., Veena, G. L. and Muralidhara, B. M. (2019). Role of plant growth regulators in guava (*Psidium guajava* L.) cultivation. *J. Pharmacognosy and Phytochem*. **8**(3): 805-808.

Gomez, K. A. and Gomez, A. A. (1984). Statistical Procedures for Agricultural Research. 2nd Edn., pp. 13-175.

Gu, S., Jochem, B. E., Zhang, L., Mao, L., Zhang, S., Zhao, X.and Liu, S. (2014). Part of a special issue on functional–structural plant modelling, Modelling the structural response of cotton plants to mepiquat chloride and population density. *Ann. Bot.*. **114:** 877–887.

Gumber, R. K., Singh, M. and Kumawat, P. D. (2005). Growth regulators for enhancing seed cotton yield, yield components and fibre quality in american cotton (*Gossypium hirsutum* ), Punjab Agricultural University, Abohar, India.

Hake, K., Burch, T., Harvey, L., Kerby, T. and Supak, J. (1991). Plant population In: Cotton Physiology. Today Newsletter. *Natl. Cotton Counc. Am., Memphis, TN.* **2**: 4.

Hasab, O. S. and Al-Naqeeb, M. A. (2019). Effect of topping and plant densities on growth and yield of cotton. *Iraqi J. Agric. Sci.* **50** (Special Issue): 8- 19.

Heitholt, J. J. and Sassenrath-Cole, G. F. (2010). Inter-plant competition: growth responses to plant density and row spacing. *Physiol. of Cotton.* Pp. 179-186.

Hiwale, S. D., Khargakharate, V. K., Patil, S. S. and Nichal, A. D. (2015). Effect of *Hirsutum* cotton to high plant density and fertilizer doses on yield and nutrient uptake under rainfed condition. *Int. J. Curr. Microbiol. App. Sci*. **6**(Special Issue): 2653-2658.

Iqbal, M., Hayat, K. and Noor-ul-Islam (2007). Cotton response to mepiquat chloride and nitrogen under ultra narrow plant spacing. *Asian J. Plant Sci.* **6**: 87-92.

Iqbal, N., Nasrullah, H. M. and Sindhu, C. M. S. (2002). Effect of row spacing on seed cotton yield. *J. Agric. Res.* **40**: 181-185.

Iqbal, M., Khan, N. I., Khan, R. S. A., Hayat, K. and Chang, M. A. (2005). Cotton response to mepiquat chloride under varying plant density under an arid environment. *The Pakistan Cottons.* **49**: 11-19.

Jadhav, D. A, Chavan, S. G., Gokhale, D. N. and Nayak, S. K. (2015). Influence of plant geometry, growth regulator and nutrient management on performance of *Bt* cotton under irrigated condition. *Intl. J. Trop. Agric.* **33**(2): 1755-1759.

Jahedi, M. B., Vazin, F. and Ramezani, M. R. (2013). Effect of row spacing on the yield of cotton cultivars. *Cercetari Agronomice in Moldova*. **XLVI** (4): 156.

Jamil, M. K. M., Rahman, M. M., Hossain, M. M., Hossain, T. and Karim, A. J. M. S. (2015). Effect of plant growth regulators on flower and bulb production of hippeastrum (*Hippeastrum hybridum* Hort.). *Bangladesh J. Agric. Res.* **40**(4): 591-600.

Jiang C., Johkan M., Hohjo, M., Tsukagoshi, S., Ebihara, M., Nakaminami, A. and Maruo, T. (2017). Responses of Leaf Photosynthesis, Plant Growth and Fruit Production toPeriodic Alteration of Plant Density in Winter Produced Single-truss Tomatoes. *The Hort. J.* **86**(4): 511–518.

Kamran, M., Cui, W., Ahmad, I., Meng, X., Zhang, X., Su, W., Chen, J., Ahmad, S., Fahad, S., Han, Q. and Liu, T. (2017). Effect of paclobutrazol, a potential growth regulator on stalk mechanical strength, lignin accumulation and its relation with lodging resistance of maize. *Plant Growth Regulation*. **8:** 342.

Kataria, G. K. and Khanpara, M. D. (2012). Effects of cycocel and mepiquat chloride on physiology, growth and yield of irrigated bt cotton (*Gossypium hirsutum* L.), Agric. *Int.J. Sci. Res*. **1**(1): 90-91.

Keren, R., Meiri, A. and Kalo, Y. (1983). Plant spacing effect on yield of cotton irrigated with saline waters. *Plant Soil*. **74**(3): 461-465.

Khalil, S. K., Wahab, A., Rehman, A., Muhammad, F., Wahab, S., Khan, A. Z., Zubair, M., Shah, M. K., Khalil, I. H. and Amin, R. (2010). Density and planting date influence phenological development assimilate partitioning and dry matter production of faba bean. *Pak. J. Bot.* **42**(6): 3831-3838.

Khan, M. B., Hussain, N. and Asif, H. (2002). Growth and yield of cotton influenced by various nitrogen levels and plant population. *Int. J. Agri. Biol.* **3**: 5-7.

Kirkland, K. J. (1992). Effect of triapenthenol plant-growth regulator on canola height, yield, side branches and pod density. *Can. J. Plant Sc*. **72**(4): 1153-l156.

Koley, P. and Maitra, S. (2015). Studies on the effect of plant growth regulators on growth, development, flowering, corm and cormlet production of gladiolus (*Gladiolus Grandiflorus* L.). International

Conference on Agriculture, Food Science, Natural Resource Management and Environmental Dynamics: The Technology, People and Sustainable Development.

Kumar, S., Ghatty, S. and Satyanarayana, J. (2012). Paclobutrazol treatment as a potential strategy for higher seed and oil yield in field-grown *Camelina sativa* L. Crantz. *BMC Res Notes.* **5:** 137.

Kumar, K. K. K., Patil, B. C. and Chetti, M. B. (2005). Effect of plant growth regulators on physiological components of yield in hybrid cotton. *Indian J. Plant Physiol.* **10**(2): 187-190.

Kumar, P., Karle, A. S., Singh, D. and Verma, L. (2017). Effect of high density planting system (hdps) and varieties on yield, economics and quality of desi cotton. *Int. J. Curr. Microbiol. App. Sci*. **6**(3): 233-238.

Kumara, O., Naik, T. B and Kumar, B. M. A. (2014). Response of *Bt* cotton hybrids on planting density and fertility levels on growth and yield. *Intl. J. Agri. Sci.* **10**(1): 421-425.

Lucieli S., L., Sangoi-Murilo, L., Durli, M., Panison, F. and Voss, R. (2017). Growth regulator and maize response to the increase in plant density. *Pesq. agropec. bras.* **52**(11). PAB. Print version *ISSN 0100-204X*On-line version ISSN 1678-3921.

Liaqat, W., Jan M. F., Ahmadzai, M. D., Ahamd, H. and Rehan, W. (2018). Plant spacing and nitrogen affects growth and yield of cotton. *J. Pharmacognosy and Phytochem.* **7**(2): 2107-2110.

Lima, R. d. L. S. d., Campos, A.R. F., Azevedo, C. A. V. d., Calado, J. A. W. and Silva, S. d. S. R. d. (2016). Effects of planting density on vegetative growth and production components of jatropha (*Physic nut* L.). *AJCS*. **10**(5): 632-636

Liu, T., Song, F., Liu, S. and Zhu, X. (2011). Canopy structure, light interception, and photosynthetic characteristics under different narrow-wide planting patterns in maize at silking stage. *Spanish J. Agric.l Res*. **9**(4): 1249-1261.

Livingston, S.D., Stichler, C.R. and Landivar, J.A. (1996). Using mepiquat chloride on the Texas coast too reduce cotton plant height. Texas Agricultural Extension Service. The Texas A and M University System. College Station. Texas. B-6042. pp 1-7.

Mahi, E. I. T. and Lokanadhan, S. (2018). Yield and Yield Components of Winter Cotton (*Gossypium hirsutum* L.) Genotypes Influenced by Plant Spacings. *Int. J. Plant Soil Sci*. **20**(6): 1-6.

Maity, U., Dutta, P. and Layek, B. (2016). Effect of Plant Growth Regulators on Growth, Yield and Quality of Okra [*Abelmoschus esculentus* (L.) Moench] *J. Agroecol. Nat. Res. Management*. **3**(3): 251-253

Manenji, B. T., Mushipe, H., Chagonda, I., Mabarani, M. T. and Chandiposha, M. (2016). Effects of tianda 2116 plant growth regulator on growth and yield of winter wheat (*Triticum aestivum* L.). *American J. of Plant Sci*. **7**: 326-332.

Manuel, G., Vilain, L., Rondon, T. and Sanchez, J. (2019). Sowing density effects in cotton yields and its components. *Agronomy*. **9**(349): 1-9

McCarty, J. C., Jenkins, J. N., Russell, W. H. and Martin, J. W. (2017). Effects of plant density on boll retention and yield of cotton in the mid-south, genetics and sustainable agriculture research unit. *American J. Plant Sci*. **8**: 891-906.

Montgomery, E. G. (1911). Correlation studies in corn. *Nebraska Agric. Exp. Sta. Ann. Rep.* **24**:108-159.

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

Nasir , M., Ahmad, M. A., Hussain S. and Ismaeel, M. (2019). Significance of Plant Growth Regulators (PGR's) on the Growth and Yield of Wheat Crop. *Sci. J. Chem.* **7**(5): 98-104.

Niakan, M. and Habibi, A. (2013). Effect of pix regulator on vegetative growth of cotton plant. *Ann. Biol. Res*. **4**(1): 53-58.

Nichols, S. P., Snipes, C. E. and Jones, M. A. (2004). Cotton growth, lint yield, and fiber quality as affected by row spacing and cultivar. *J. Cotton Sci.* **8**: 1-12.

Nichols, S. P., Snipes, C. E. and Jones, M. A. (2003). Evaluation of row spacing and mepiquat chloride in cotton. *J. Cotton Sci.* **7**: 148-155.

Oad, F. C., Samo, M. A., Qayyum, S. M. and Oad, N. L. (2002). Performance of different cotton varieties under two row spacings. *Asian J. Plant Sci.* **1**(2): 134-135.

Omadewu, L. I., Iren, O. B and Eneji, A. E. (2019). Yield of cotton cultivars as influenced by nitrogen rates and plant density in Yalingo, Nigeria. *World Sci. News.* **127**(3): 106-122.

Pal, S. L. (2019). Role of plant growth regulators in floriculture. *An overview J. Pharmacognosy Phytochem*. **8**(3): 789-796.

Pan, S., Rasul, F., Wu, L., Tian, H., Zw, M., Meiyang, D. and Tang, X. (2013). Roles of plant growth regulators on yield, grain qualities and antioxidant enzyme activities in super hybrid rice (*Oryza sativa* L.). *Rice (New York, N.Y.)*. **6:** 9.

Parekh, D. D., Masu, M. M., Satodiya, B. N., Patel, H. C. and Shah, N. I. (2018). Effect of different spacing and plant growth regulators on growth parameters of spider lily under middle gujarat agro climatic conditions. *Int. J. Sci. Environ. Technol.* **7**(1): 292 – 298.

Parmar, A. R., Chovatia, R. S. and Karetha, K. M. (2015). Effect of plant growth regulators on flower yield, vase life and economics of dutch rose (*Rosa hybrida* Linn.) cv. 'Passion' under polyhouse condition. *The Asian J. Hort.* **10**(2): 286-291.

Pendharkar, A. B., Kalhapure, A. M., Solunke, S. S and Alse, U. N. (2010). Response of *Bt* cotton hybrids to different plant spacing under rainfed condition. *Ann. Pl. Physiol.* **24** (1): 25-27.

Pengcheng L., Helin, D., Aizhong, L., Jingran, L., Miao, S., Guoping, W., Shaodong, L., Xinhua Z. and Yabing, L. (2015). Effects of planting density and nitrogen fertilizer interaction on yield and nitrogen use efficiency of cotton[J]. *Transactions of the Chinese Society of Agricultural Engineering*. **1**(23): 122－130.

Pitombeira, J. B. (1972). Effect of plant population on agronomic characteristics and yield of cotton and grain sorghum, A Thesis Submitted to the Faculty of the department of agronomy and plant genetics, Degree of master of science with a major in agronomy, In the Graduate College, The university of Arizona.USA.

Ponnuswami, V. and Rani, E. A. (2019). Organic leaf production of moringa (*Moringa oleifera* Lam.) cv. PKM-1 for higher leaf yield and quality parameters under ultra high density planting system. *Adv. Plants Agric. Res.* **9**(1): 206–214.

Priyanka, B. and Dalvi, D. (2019). Efffect of plant growth regulators on yield and yield contributing character of Bt cotton (*Gossypium hirsutum* L). *J. Pharmacognosy Phytochem.* **8**(3): 132-134.

Rademacher, W. (2016). Chemical regulators of gibberellin status and their application in plant production. *Ann. Plant* Reviews. **49**: 359–403.

Rajakumar, D. and Gurumurthy, S. (2008). Effect of plant density and nutrient spray on the yield attributes and yield of direct sown and poly bag seedling planted hybrid cotton. *Agric. Sci. Digest.* **28**(3): 174-177.

Rao, M., S., Krishnamurthi, M. and Pipat, W. (2002). Effect of plant growth regulator on the yield and quality of sugarcane. Mitr Phol Sugarcane Research Centre, Chaiyaphum, Thailand. Agricultural science and technology information. Thai National AGRIS Centre was established in March 13, 1980 by General National FAO Committee, Ministry of Agriculture and Cooperatives cooperated with Food and Agriculture Organization of the United Nations [FAO].

Rao, S., Shashidhar, S., Vinayak H., Shantappa, D. and Nataraj, M. (2015). Response of transplanted Bt cotton (*Gossypium hirsutum* L.) to different plant geometry. *Environment and Ecology*. **33** (1A): 396-398.

Raoofi, M. M., Dehghan, S., Keighobadi, M. and Poodineh, O. (2014). Effact of naphthalene acetic acid in agriculture and the role of increase yield. Intl. J. *Agric. Crop. Sci.* **7**(14): 1378-1380.

Reddy, V. R., Baker, D. N. and Hodges, H. F. (1990). Temperature and mepiquat chloride effects on cotton canopy architecture. *Agron. J.* **82**: 190-195.

Reema, V., Chachar, Q. I., Chachar, S. D., Chachar, N. A., Laghari, A., Vistro, S. A. and Kumbhar, I. (2017). Impact of plant growth regulators on the growth and yield of cotton. *Int. J. Agri. Tech.* **13**(3): 353-362.

Ricaurte, J. J., Clavijo, M. J. A., Sinclair, T. R., Rao, I. M. and Beebe, S. 2016. Sowing density effect on common bean leaf area development. *Crop Sci.* **56**: 1-9.

Richard, A. Q. (2006). Effect of 1 m and 1.5 m row spacing on yield and fibre quality of upland cotton in Warren, NSW, Australia. Faculty of Agriculture and Environment. The University of Sydney, Sydney NSW. Research Paper.

Sabale, S. S., Lahane, G. R. and Shaikh, S. A. (2018). Effect of various plant growth regulators on yield of American cotton (*Gossypium hirsutum*). *Journal of Pharmacognosy and Phytochemistry*. **7**(5): 1203-1209.

Sarwar, N., Atique-ur-rehman, Farooq, O., Mubeen, K., Wasaya, A., Nouman, W., Ali, M. Z. and Shehzad, M. (2017). Exogenous application of gibberellic acid improves the maize crop productivity under scarce and sufficient soil moisture condition. *Cercetari Agronomice in Moldova*. **4**(172): 65-73.

Sebastian, K., Arya, M. S., Reshma, U. R., Anaswara, S. J. and Thampi S. S. (2019). Impact of plant growth regulators on fruit production. *Int. J. Curr. Microbiol. App. Sci*. **8**(2): 800-814.

Setia, R. C., Bhathal, G. and Setia, N. (1995). Influence of paclobutrazol on growth and yield of *Brassica carinata. A. Br. Plant Growth Regul.* **16:** 121–127.

Siebert, J. D., Stewart, A. M. and Leonard, B. R. (2006). Comparative growth and yield of cotton planted at various densities and configurations. *Agron. J.* **98**: 562-568.

Shahr, M., Asfaram, H. and Mirshekari, B. (2015). Effect of hormonal growth regulator spraying and topping on some agronomic traits in the newly released cotton (*Gossypium hirsutum L.*) cultivars. *IJALS.* **8**(2): 115-120.

Shamili, M. and Kashi, A. A. K. (2007). A study of the effect of plant density, and planting time on vegetative and reproductive traits of tareh irani (*Allium ampeloprasum*). *Iranian J. Agric. Sci.* **38**(2): 251 - 256.

Sher, A., Khan, A., Cai, L. J., Ahmad, M. I., Asharf, U. and Jamoro, S. A. (2017) Response of Maize Grown Under High Plant Density; Performance, Issues and Management - A Critical Review. *Adv. Crop Sci. Tech.* **5**: 275.

Shukla, U. N., Khakare, M. S., Srivastava, V. K., Kumar, R., Singh, S., Kumar, V. and Kumar, K. (2013). Effect of spacings and fertility levels on growth, yield and quality of cotton (*Gossypium hirsutum* L.) hybrids under rainfed condition of vidarbha. *The Bioscan*. **8**: 561-567.

Silva, A. V., Chiavegato, E. J., Carvalho, L. H. and Kubiak, D. M. (2006). Crescimento edesenvolvimento do algodoeiro em diferentes configuracoes de semeadura. *Bragantia*. **65**(1): 407 –411.

Silva, P. T., Macedo, F. G., Camacho, M. A., Santos, C., Santi, A., Krause, W. and Rambo, J. R. (2012). Spacing and plant density effect on reproductive development of herbaceous cotton. *Sci. plena*. **8**(5):1-8.

Silva R. D. A., Santos, J. L., Oliveira, L. S., Mauricio, S. R. S. and Saad, M. S. D. S. (2016). Biostimulants on mineral nutrition and fiber quality of cotton crop. R. *Bras. Eng. Agríc. Ambiental*. **20**(12): 1062-1066.

Silvertooth, J. C. (1999). Row spacing, plant population, and yield relationships. Arizona cotton comments. Cooperative Extension, The University of Arizona. USA.

Singh, H., Sharma, P., Kumar, P. and Dhillon, N. S. (2017). Influence of spacing and pruning on growth characteristics, yield and economics of tomato (*Solanum lycopersicum* L.) grown under protected environment, department of vegetable science and floriculture. *Int. J. Curr. Microbiol. App. Sci*. **6**(9): 1833-1838.

Singh, A., Singh, T. and Singh, A. (2014). Productivity potential, quality and economic viability of hybrid Bt cotton (*Gossypium hirsutum* L.)-based intercropping systems under irrigated conditions. *Indian J. Agron.* **59**(3): 385-391.

Singh, G. and Chanana, Y. R. (2005). Influence of pruning intensity and pruning frequency on vegetative and reproductive attributes in guava ‘L-49’. Abstract of 1st International Guava Symposium, CISH, Lucknow. India.

Singh, P. and Singh, J. (1975). Chemical deblossoming in guava to avoid rainy season. *crops. Sci. Cult.* **41**: 162-163.

Singh, J., Babar, S., Abraham, S., Venugopalan, M. V. and Majumdar, G. (2012). Fertilization of high density, rainfed cotton grown on vertisols of India. *Better Crops.* **96**(2): 26-28.

Singh, K. (2015). Effect of agronomic manipulations on growth, yield attributes and seed cotton yield of American cotton under semi-arid conditions. *Int. J. Agric. Sci.* **11**(1): 134-137.

Soomro, A. R., Soomro, A. W., Memon, A. M., Arain, M. H. and Memon, A. A.. (2000 a). Yield response of four cotton cultivars under varying plant spacings at CCRI, Sakrand, Sindh. *Pak. J. Biol. Sci.* **3**: 1807-1808.

Soomro, A. R., Channa, M. H., Channa, A. A., Dayo, G. N., Kalwar, G. H. and Memon. A. H. (2000 b). Yield performance of three cotton cultivars under varying plant spacings at Ghotki, Upper Sindh. *The Pak. Cottons*. **44**: 57-60.

Sowmiya, R. and Sakthivel, N. (2018). Effect of planting geometry on growth and yield of cotton. *Madras Agric. J.* **105**(1-3): 30-32.

Spitzer, T., Misa, P. and Bilovsky, J. K. (2015). Management of maize stand height using growth regulators. *Plant Protect Sci.* **51**: 223–230.

Stewart, S. D., Bowen, K. L., Mack, T. P. and Edwards, J. H. (1997). Impact of row spacing and planting date on the canopy environment, abundance of lesser cornstalk borer and other arthropods, and incidence of aflatoxigenic fungi in peanuts. *Peanut Sci*. **24**: 52-59.

Sylla, N. A., Maleia, M. P. and Abudo, J. (2013). Effect of plant density on seed cotton yield. *African Crop Sci. Conference Proceedings*. **11:** 101 – 104.

Thakur, Y., Chandel, J. S. and Verma, P. (2017). Effect of plant growth regulators on growth, yield and fruit quality of strawberry (Fragaria x ananassa Duch.) under protected conditions. *J. Appl. Nat. Sci.* **9**(3): 1676 -1681.

Udikeri, M. and Shashidhara, G. B. (2017). Performance of compact cotton genotypes under high density planting system at different fertilizer levels. *J. Farm Sci.* **30**(4): 460-466.

Valco, T. D., Anthony, W. S. and Mcalister III, D. D. (2001). Ultra narrow row cotton ginning and textile performance results. In Proc. Beltwide Cotton Conf. Anaheim, GA, 9-13 Jan., Natl. Cotton Counc. Am., Memphis, TN.213. pp. 355-357

Volterrani, M., Grossi, N., Gaetani, M., Caturegli, L., Nikolopoulou, A., Lulli, F. and Magni, S. (2015). The effect of increasing application rates of nine plant growth regulators on the turf and stolon characteristics of pot-grown ‘patriot’ hybrid bermuda grass. *Hort Tech.* **25**(3): 479-483.

Wright, D. L., Marois, J. J., Sprenkel, R. K. and Rich, J. R. (2008). Production of ultra narrow row cotton. Publ. SS-AGR-83, Inst, Food And Agric. Sci. Agron. Deptt. Florida Cooperative Extension Service, Univ. Florida. USA.

Xiao-yu, Z., Ying-chun, H., Ya-bing, L., Guo-ping, W., Wen-li, D., Xiao-xin, L., Shu-chun, M. and Feng, L. (2016). Effects of plant density on cotton yield components and quality. *J. Int. Agric.* **15**(7): 1469–1479.

Yasmeen, A., Arif, M., Labar, N. H., Waqas, M. and Qadir, A. (2016). Growth, yield and quality response of cotton as influenced by growth regulators, planting geometry and fertilizer application under agro-climatic conditions of multan. *Int. J. Agric. Biol*. **18**(6): 1109-1121.

Yagia, M. I., widad, M. O., Mohammed M. and Almubarak, A. A. (2014). Effect of Nitrogen and Spacing in Growth, Yield and Quality of *Celocia cristata*. *Int. J. Sci.: Basic and Applied Res.* **18(**1): 132-142.

Zakaria, M. S. (2016). Cotton seed yield and its quality as affected by mineral nutrients and plant growth retardants. *Cogent Biol.* **2**: 1-29.

Zhang, Y., Su, S., Tabori, M., Yu, J., Chabot, D., Baninasab, B., Wang, X., Ma, B., Li, C. and Khanizadeh, S. (2017). Effect of selected plant growth regulators on yield and stem height of spring wheat in Ontario. *J. Agric. Sci*. **9**(12): 30.

Zhao, W., Yan, Q., Hongkun, Y., Xiaoni, Y., Leran, W., Binglin, C., Yali, M. and Zhou, Z. (2019). Effects of mepiquat chloride on yield and main properties of cotton seed under different plant densities. *J. Cotton Res.* **2**: 1-10.

# CHAPTER VII

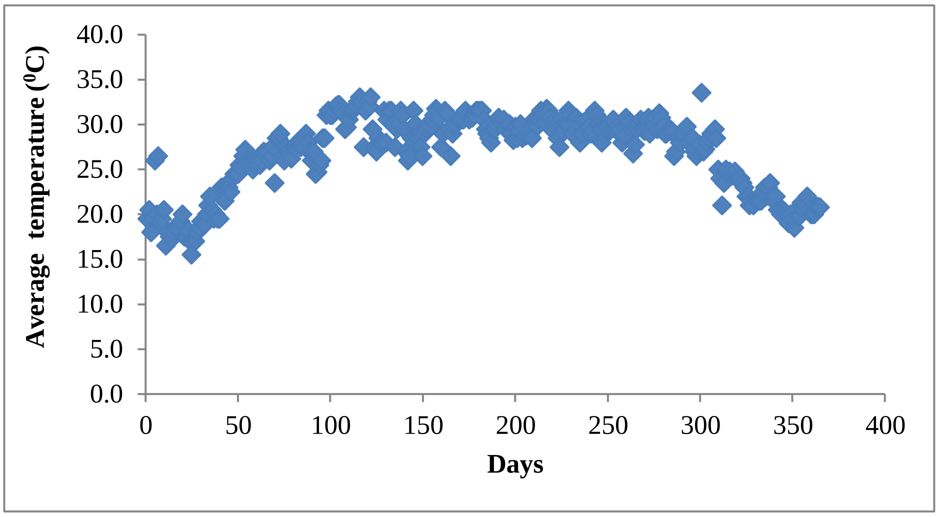
# APPENDICES

**Appendix I. Cropping history of the experimental site**

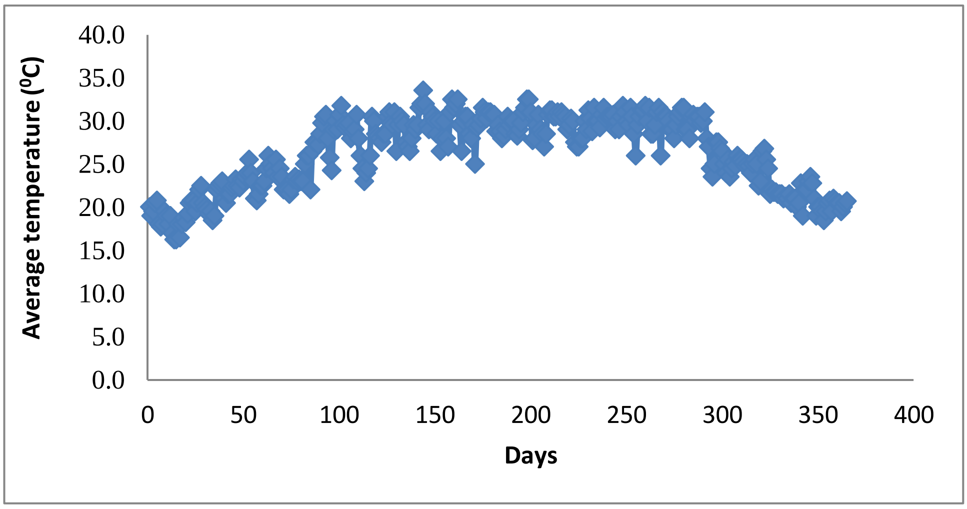
| Year | Kharif crop | Rabi crop |
|---|---|---|
| **2017** | **Experiment 1** | Dhaincha |
| **2018** | **Experiment 2** | Dhaincha |
| **2019** | **Experiment 3** | Dhaincha |

**Appendix IIa. Monthly average temperatures during the growing period**

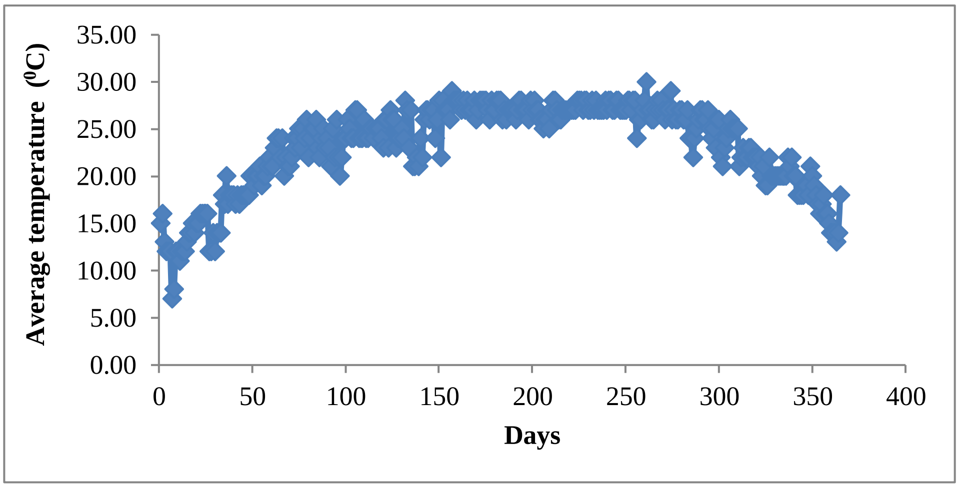
2016




2017

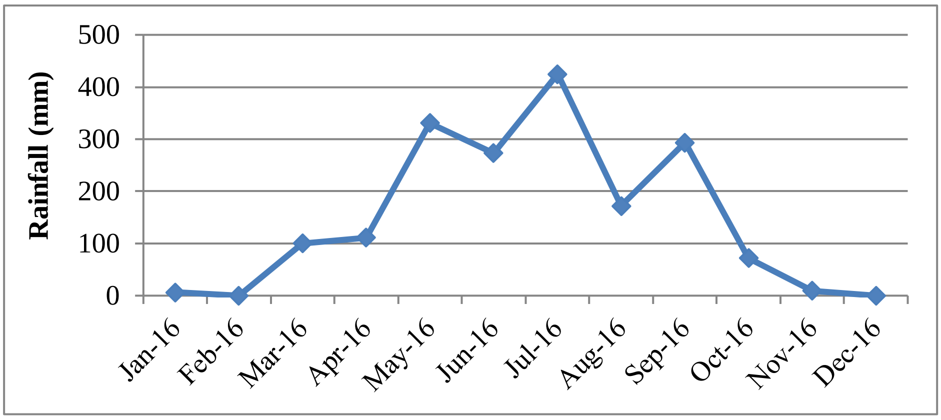



2018

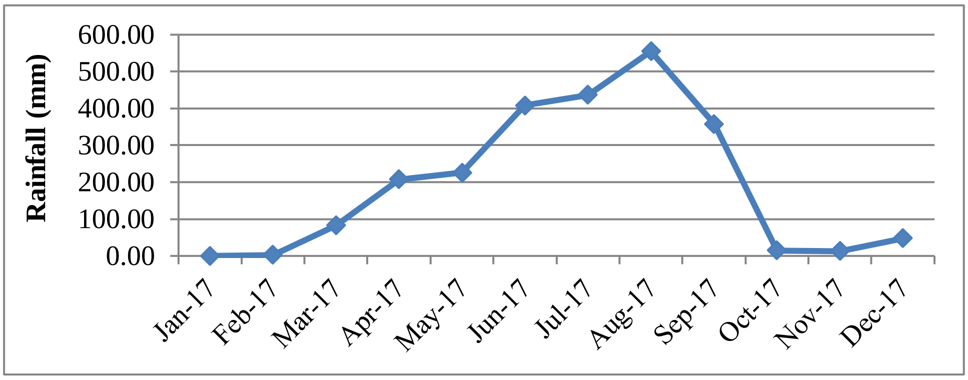


**Appendix IIb. Monthly rainfall during the growing period**

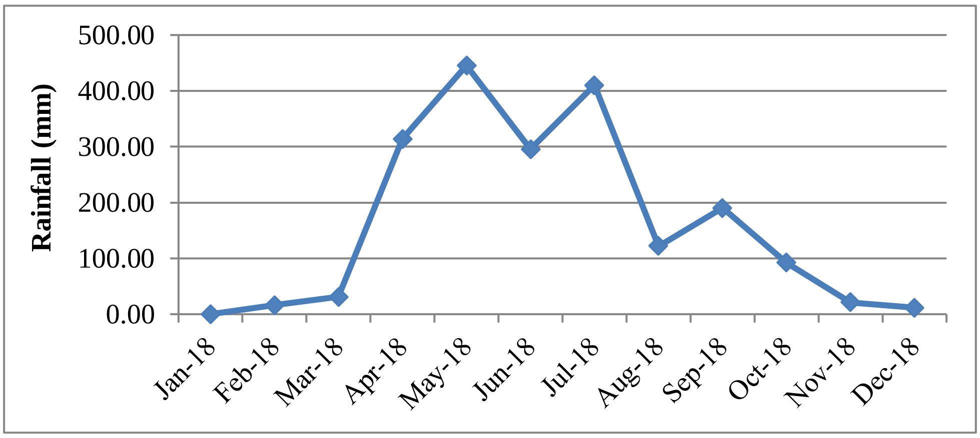
**2016**




2017

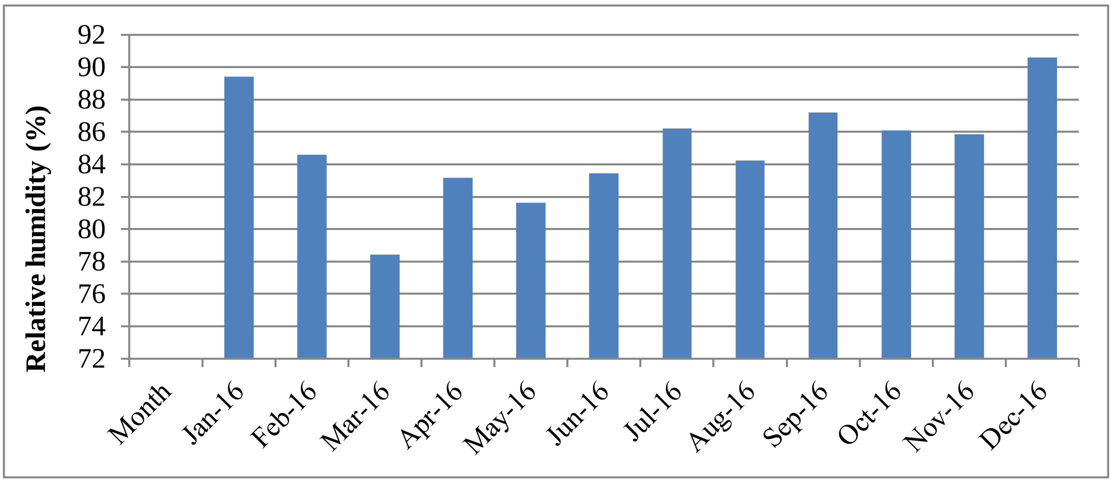



2018

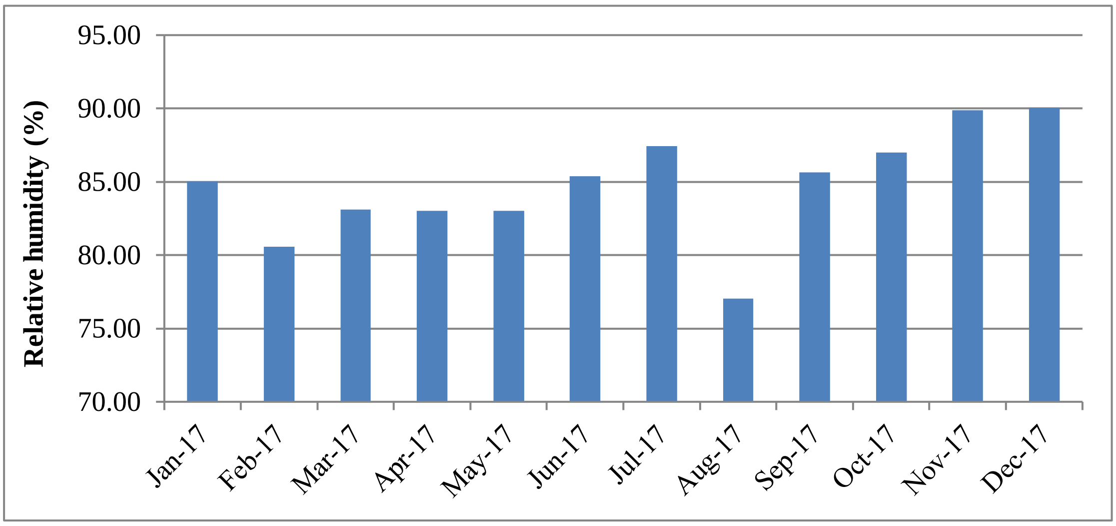


**Appendix IIc. Monthly relative humidity during the growing period**

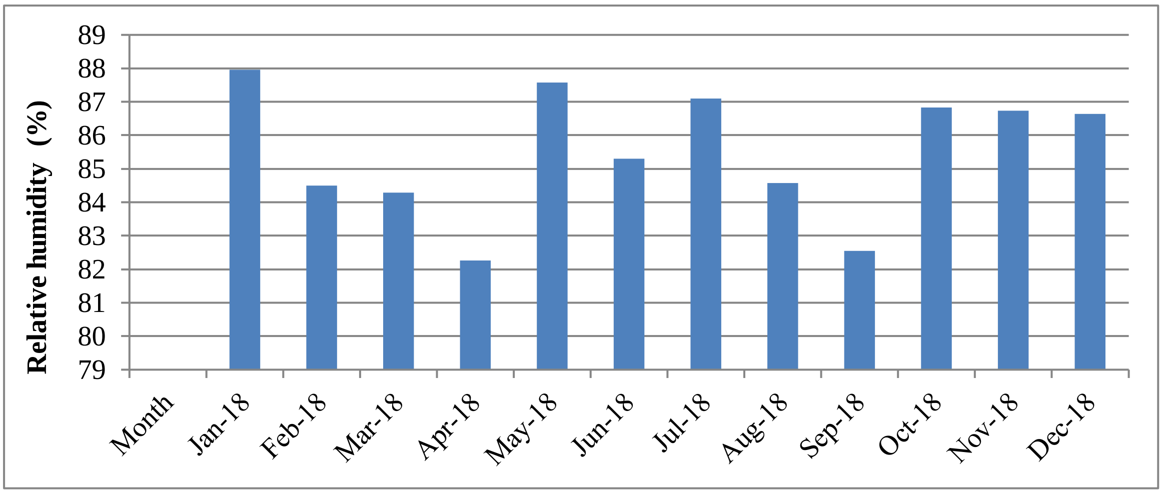
**2016**




2017




2018



**Appendix III. Summary of analysis of variance for phonological characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (first year experiment)**

| Source of Variation | df | Mean square values at harvest | | | |
|---|---|---|---|---|---|
| | | Plant height | Internode length | Canopy size | LAI |
| **Replication** | 2 | 679.03 | 0.0039 | 0.00021 | 0.00279 |
| **Spacing (A)** | 4 | 135.24 | 0.7121** | 0.0017 | 0.02068* |
| **Error (a)** | 8 | 71.04 | 0.1783 | 0.00185 | 0.01939 |
| **MC treatment (B)** | 5 | 2193.53* | 11.3947* | 0.1277** | 3.0851** |
| **Spacing (A) × MC treatment (B)** | 20 | 175.57* | 0.2297** | 0.00302* | 0.01409* |
| **Error(b)** | 50 | 130.1 | 0.6021 | 0.00175 | 0.01235 |

*5% level of significance

**1% level of significance

**Appendix IV. Summary of analysis of variance for yield and yield attributing characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (first year experiment)**

| Source of Variation | df | Mean square values at harvest | | | | |
|---|---|---|---|---|---|---|
| | | Square plant$^{-1}$ | Boll plant$^{-1}$ | Boll weight | Seed cotton yield ha$^{-1}$ | Lint yield ha$^{-1}$ |
| **Replication** | 2 | 0.349941 | 0.2111 | 0.075 | 0.03723 | 0.1818 |
| **Spacing (A)** | 4 | 6.8907** | 12.1944* | 0.14156** | 5.81493** | 28.3993* |
| **Error (a)** | 8 | 8.4475 | 0.3361 | 0.04181 | 0.01045 | 0.051 |
| **MC treatment (B)** | 5 | 15.2815* | 15.2644* | 0.15647** | 0.55294** | 2.7005** |
| **Spacing (A ) × MC treatment (B)** | 20 | 4.2344** | 7.0811** | 0.06869* | 0.39184* | 1.9137*** |
| **Error (b)** | 50 | 5.2352 | 0.7378 | 0.05084 | 0.03893 | 0.1901 |

*5% level of significance

**1% level of significance

**Appendix V. Summary of analysis of variance for seed characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (first year experiment)**

| Source of Variation | df | Mean square values at harvest | | | |
|---|---|---|---|---|---|
| | | Seed boll$^{-1}$ | SI | LI | GOT |
| **Replication** | 2 | 176.4 | 1.087 | 1.087 | 1.087 |
| **Spacing (A)** | 4 | 72.25** | 0.13983** | 0.13983** | 0.13983** |
| **Error (a)** | 8 | 57.692 | 0.33658 | 0.33658 | 0.33658 |
| **MC treatment (B)** | 5 | 64.98** | 0.0968* | 0.0968* | 0.0968* |
| **Spacing (A) × MC treatment (B)** | 20 | 81.863** | 0.40297** | 0.40297** | 0.40297** |
| **Error (b)** | 50 | 64.9 | 0.26053 | 0.26053 | 0.26053 |

*5% level of significance
**1% level of significance

**Appendix VI. Summary of analysis of variance for lint characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (first year experiment)**

| | df | Mean square values at harvest | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UHML | ML | UI | SFI | Strength | Elongation | Micronaire | MR | Rd | +b |
| **Replication** | 2 | 0.04233 | 0.31622 | 0.01791 | 0.01497 | 0.49252 | 0.02865 | 0.02738 | 1.47003 | 4.9891 | 5.86245 |
| **Spacing (A)** | 4 | 0.12883 | 0.6616** | 0.1324 | 0.0607 | 0.9593 | 0.022 | 0.0101 | 5.94401* | 5.757 | 0.6244* |
| **Error (a)** | 8 | 0.32583 | 0.29183 | 0.26371 | 0.11655 | 0.6724 | 0.04302 | 0.07289 | 1.144004 | 2.919 | 0.19598 |
| **MC treatment (B)** | 5 | 0.9446** | 1.5641** | 0.785** | 0.3879* | 3.7127** | 0.1283** | 0.1940** | 2.8801 | 133.71** | 0.9381** |
| **Spacing (A) × MC treatment (B)** | 20 | 0.1527** | 0.4379** | 0.1128* | 0.0483* | 0.859** | 0.0257* | 0.0602* | 1.5740** | 1.463** | 0.2064** |
| **Error (b)** | 50 | 0.16972 | 0.45757 | 0.13404 | 0.05941 | 1.05109 | 0.03053 | 0.03747 | 1.576004 | 3.043 | 0.35187 |

*5% level of significance
**1% level of significance

**AppendixVII. Summary of analysis of variance for phonological characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (second year experiment)**

| Source of Variation | df | Mean square values at harvest | | | |
|---|---|---|---|---|---|
| | | Plant height | Internode length | Canopy size | LAI |
| **Replication** | 2 | 3790.55 | 9.15289 | 3.057003 | 0.08479 |
| **Spacing (A)** | 2 | 893.01** | 0.83148** | 1.007003 | 0.0483 |
| **Error (a)** | 4 | 58.35 | 1.11453 | 6.344004 | 0.02565 |
| **MC treatment (B)** | 12 | 117.73 | 0.77337** | 2.319004** | 0.03166** |
| **Spacing (A) × MC treatment (B)** | 24 | 210.9** | 0.71579** | 8.303004* | 0.05179** |
| **Error (b)** | 72 | 281.25 | 0.51233 | 1.161003 | 0.04993 |

*5% level of significance
**1% level of significance

**Appendix VIII. Summary of analysis of variance for yield and yield attributing characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (second year experiment)**

| Source of Variation | df | Mean of square values at harvest | | | | |
|---|---|---|---|---|---|---|
| | | Square plant$^{-1}$ | Boll plant$^{-1}$ | Boll weight | Seed cotton yield ha$^{-1}$ | Lint yield ha$^{-1}$ |
| **Replication** | 2 | 7.4819 | 8.8875 | 0.04082 | 0.85596 | 4.18038 |
| **Spacing (A)** | 2 | 17.8036 | 27.1912** | 0.08419** | 1.7845** | 8.71524** |
| **Error (a)** | 4 | 9.2648 | 2.3868 | 0.04687 | 0.13406 | 0.65471 |
| **MC treatment (B)** | 12 | 5.5988 | 23.6316** | 0.06969** | 1.75334** | 8.56307** |
| **Spacing (A) × MC treatment (B)** | 24 | 14.4287** | 10.6533** | 0.05867** | 1.23042** | 6.0092** |
| **Error (b)** | 72 | 15.7991 | 12.4297 | 0.04506 | 1.69347 | 8.27065 |

**1% level of significance

**Appendix IX. Summary of analysis of variance for seed characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (second year experiment)**

| Source of Variation | df | Mean of square values at harvest | | | |
|---|---|---|---|---|---|
| | | Seed boll$^{-1}$ | SI | LI | GOT |
| **Replication** | 2 | 1.182 | 0.0027 | 0.0027 | 0.0027 |
| **Spacing (A)** | 2 | 68.931** | 0.04071** | 0.04071** | 0.04071** |
| **Error (a)** | 4 | 154.169 | 1.32655 | 1.32655 | 1.32655 |
| **MC treatment (B)** | 12 | 133.652** | 0.33307* | 0.33307 | 0.33307* |
| **Spacing (A) × MC treatment (B)** | 24 | 26.372** | 0.2888** | 0.2888** | 0.2888** |
| **Error (b)** | 72 | 49.102 | 0.38364 | 0.38364 | 0.38364 |

*5% level of significance
**1% level of significance

**Appendix X. Summary of analysis of variance for lint characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (second year experiment)**

| Source of Variation | df | Mean square values at harvest | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UHML | ML | UI | SFI | Strength | Elongation | Micronaire | MR | Rd | +b |
| **Replication** | 2 | 0.0012 | 0.0015 | 0.001 | 0.0004 | 0.0611 | 0.00087 | 0.00354 | 1.235 | 0.143 | 0.4405 |
| **Spacing (A)** | 2 | 27.238** | 32.77** | 25.817** | 28.465** | 19.358** | 0.0696** | 3.8889** | 1.46 | 26.33** | 36.632** |
| **Error (a)** | 4 | 0.0014 | 0.0017 | 0.0011 | 0.0004 | 0.0365 | 0.00158 | 0.00347 | 1.235 | 0.1455 | 0.5027 |
| **MC treatment (B)** | 12 | 4.8789** | 6.001** | 5.1132** | 4.569** | 7.7356** | 0.0570** | 0.4622** | 9.5500 | 3.122** | 6.784** |
| **Spacing (A) × MC treatment (B)** | 24 | 5.618** | 6.885** | 5.4036** | 5.0521** | 3.0126** | 0.0858** | 0.4526** | 1.1350** | 6.769** | 14.482** |
| **Error (b)** | 72 | 0.0028 | 0.0035 | 0.0022 | 0.0009 | 0.0969 | 0.00293 | 0.00759 | 1.235006 | 0.3143 | 1.0477 |

*5% level of significance
**1% level of significance

**Appendix XI. Summary of analysis of variance for phonological characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (third year experiment)**

| Source of Variation | df | Mean of square values at harvest | | | |
|---|---|---|---|---|---|
| | | Plant height | Internode length | Canopy size | LAI |
| **Replication** | 2 | 317.498 | 1.03891 | 0.00675 | 0.09095 |
| **Spacing (A)** | 2 | 491.219 ** | 0.37632 | 0.00877 | 0.11466 |
| **Error (a)** | 4 | 84.851 | 0.12884 | 0.01336 | 0.04536 |
| **MC treatment (B)** | 8 | 274.614** | 0.1342 ** | 0.00188** | 0.02091 |
| **Spacing (A) × MC treatment (B)** | 16 | 67.68 ** | 0.07597 * | 0.00185 ** | 0.03704 * |
| **Error (b)** | 48 | 83.716 | 0.10046 | 0.00132 | 0.02913 |

*5% level of significance
**1% level of significance

**Appendix XII. Summary of analysis of variance for the yield and yield attributing characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (third year experiment)**

| Source of Variation | df | Mean of square values at harvest | | | | |
|---|---|---|---|---|---|---|
| | | Square plant$^{-1}$ | Boll plant$^{-1}$ | Boll weight | Seed cotton yield ha$^{-1}$ | Lint yield ha$^{-1}$ |
| **Replication** | 2 | 5.59 | 3.59 | 0.05444 | 0.64007 | 2.9717 |
| **Spacing (A)** | 2 | 235.077** | 233.07** | 0.3737** | 1.46667** | 6.8093** |
| **Error (a)** | 4 | 0.377 | 0.357 | 0.30815 | 0.26235 | 1.218 |
| **MC treatment (B)** | 8 | 25.35** | 25.25** | 2.455** | 6.27076** | 29.1134** |
| **Spacing (A) × MC treatment (B)** | 16 | 7.976** | 7.876** | 0.0655** | 0.39125** | 1.8165** |
| **Error (b)** | 48 | 0.377 | 0.337 | 0.05414 | 0.06868 | 0.3189 |

*5% level of significance
**1% level of significance

**Appendix XIII. Summary of analysis of variance for seed characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (third year experiment)**

| Source of Variation | df | Mean square values at harvest | | | |
|---|---|---|---|---|---|
| | | Seed $boll^{-1}$ | SI | LI | GOT |
| **Replication** | 2 | 103.37 | 0.99123 | 0.99123 | 0.99123 |
| **Spacing (A)** | 2 | 44.333 | 0.26716 | 0.26716 | 0.26716 |
| **Error (a)** | 4 | 55.481** | 0.14049** | 0.14049** | 0.14049** |
| **MC treatment (B)** | 8 | 18.389** | 0.17262** | 0.17262** | 0.17262** |
| **Spacing (A) × MC treatment (B)** | 16 | 30.569** | 0.24785** | 0.24785** | 0.24785** |
| **Error (b)** | 48 | 27.486 | 0.24546 | 0.24546 | 0.24546 |

*5% level of significance
**1% level of significance

**Appendix XIV. Summary of analysis of variance for lint characters as influenced by plant spacing along with time of application and concentration of mepiquat chloride (third year experiment)**

| Source of Vari | df | Mean of square values at harvest | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UHML | ML | UI | SFI | Strength | Elongatior | Micronair | MR | Rd | +b |
| **Replication** | 2 | 0.0049 | 0.00605 | 0.00387 | 0.00198 | 0.0069 | 0.00004 | 0.00071 | 1.235006 | 1.723029 | 0.00012 |
| **Spacing (A)** | 2 | 1.6691** | 2.1595** | 15299** | 0.5468** | 33.294** | 0.2044** | 1.0357** | 1.46000 | 0.2311 | 2.1490** |
| **Error (a)** | 4 | 0.0049 | 0.00605 | 0.00387 | 0.00198 | 0.0069 | 0.00004 | 0.00071 | 1.235006 | 2.412031 | 0.00012 |
| **MC treatment** | 8 | 0.4994** | 0.6515** | 0.4799** | 0.1459** | 23.013** | 0.3844** | 0.8583** | 9.5500** | 6.9400** | 0.1237* |
| **Spacing (A) ×** | 16 | 0.5111** | 0.6609** | 0.466** | 0.1318** | 20.448** | 0.1984** | 0.9074** | 1.1350** | 0.0124** | 0.1482* |
| **Error (b)** | 48 | 0.0049 | 0.00605 | 0.00387 | 0.00198 | 0.0069 | 0.00004 | 0.00071 | 1.235006 | 8.59032 | 0.00012 |

*5% level of significance
**1% level of significance

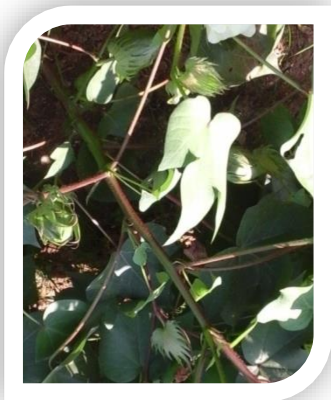
Appendix XV. Cost benefit ratio of cotton production with mepiquat chloride application over water spray

| Cost of production with mepiquat chloride application | | | | Cost of production without mepiquat chloride application | CB ratio (with mepiquat chloride application) | CB ratio (without mepiquat chloride application) |
|---|---|---|---|---|---|---|
| **Details of inputs** | **Amoun t(Kg / ha)** | **Price (Kg/L)** | **Total cost (taka/ ha)** | | | |
| **Cotton seed** | 12 | 22 | 264 | 264 | **1.61** | **1.64** |
| **Urea** | 220 | 17 | 3740 | 3740 | | |
| **TSP** | 350 | 24 | 8400 | 8400 | | |
| **MoP** | 400 | 16 | 6400 | 6400 | | |
| **Gypsum** | 100 | 12 | 1200 | 1200 | | |
| **Zinc Sulphate** | 15 | 200 | 3000 | 3000 | | |
| **Boron** | 15 | 500 | 7500 | 7500 | | |
| **Mag Sulf** | 15 | 80 | 1200 | 1200 | | |
| **Lime** | 250 | 12 | 3000 | 3000 | | |
| **Cowdung** | 5000 | 1 | 5000 | 5000 | | |
| **Pesticide GI** | 1 | 1200 | 1200 | 1200 | | |
| **Pesticide GII** | 1 | 800 | 800 | 800 | | |
| **Fungicide** | 1 | 1000 | 1000 | 1000 | | |
| **Pheromone trap** | 40 | 100 | 4000 | 4000 | | |
| **Molasses trap** | | | 500 | 500 | | |
| **Herbicide** | 2 | 700 | 1400 | 1400 | | |
| **Mepiquat Chloride** | 3 | 800 | 2400 | 0 | | |
| **Labour** | 40 | 550 | 22000 | 22000 | | |
| **Irrigation** | bulk | | 5000 | 5000 | | |
| **Total cost** | | | **78004/=** | **75604/=** | | |

| Income | Production (t/ha) | Rate (tk/kg | Total income |
|---|---|---|---|
| **Seed cottton** | 3 | 60 | 180000 |
| **stalk** | 1 | 20 | 20000 |
| **Gross return** | | | **200000** |

B

A



C

D

E

**Plate 1 Canopy of cotton plant at different dates (25, 50, 75, 100 and 125 DAE) as influenced by mepiquat chloride foliar spray(A, B, C, D and E, respectively)**

I

II

III


IV

V

VI

**Plate 2.1 Showing comparison effect of cotton plant spacing of 60 cm × 30 cm (I, III, and V) over conventional spacing of 90 cm × 45 cm (II, IV and VI) at different growth stages of cotton (2016-17)**

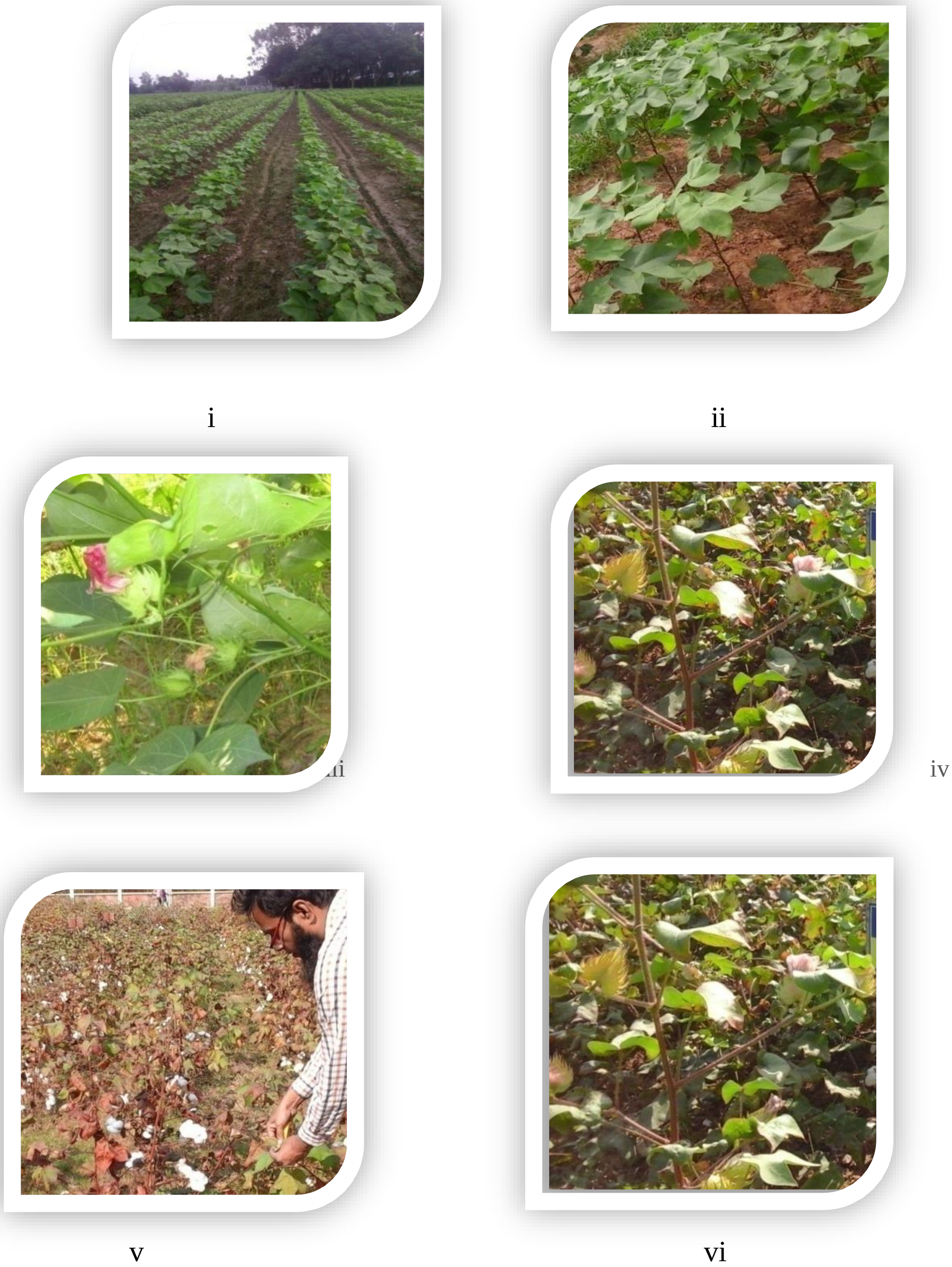



**Plate 2.2 Showing comparison effect of cotton plant spacing of 60 cm × 30 cm (i, iii, and v) over conventional spacing of 90 cm × 45 cm (ii, iv and vi) at different growth stages of cotton (2017-18)**

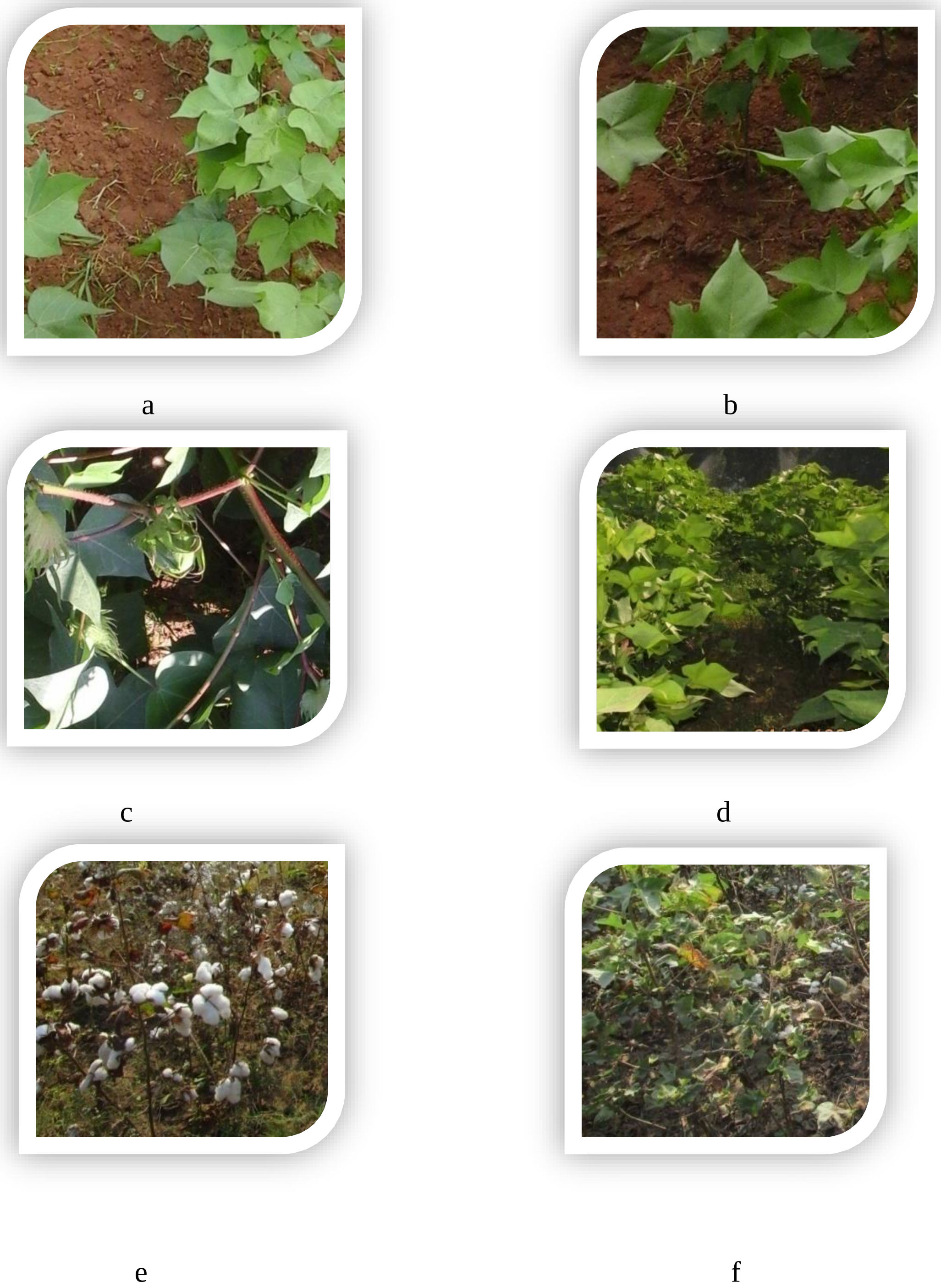



**Plate 2.3 Showing comparison effect of cotton plant spacing of 60 cm × 30 cm (a, c, and e) over conventional spacing of 90 cm × 45 cm (b, d and f) at different growth stages of cotton (2018-19)**

A B

C D

**Plate 3.1 Comparison between mepiquat chloride spray (A and C) @ 1 ml $L^{-1}$ water at 25 DAE over water spray (B and D) or control (2016-17)**

I

II

III

IV

**Plate 3.2 Comparison between mepiquat chloride spray (I and III) @ 2 ml $L^{-1}$ water at 25 DAE over water spray (II and IV) or control (2017-18)**

i

ii

iii

iv

**Plate 3.3 Comparison between mepiquat chloride spray at vegetative and harvesting stage (i and iii) @ 2 ml $L^{-1}$ water at 25 DAE over water spray (ii and iv) or control (2018-19)**

A

B

C

**Plate 4.1 Comparison between combined effect of mepiquat chloride spray @ 2 ml $L^{-1}$ water at 25 DAE with 60 cm × 30 cm (A and B) over water spray (C) or control (2016-17)**

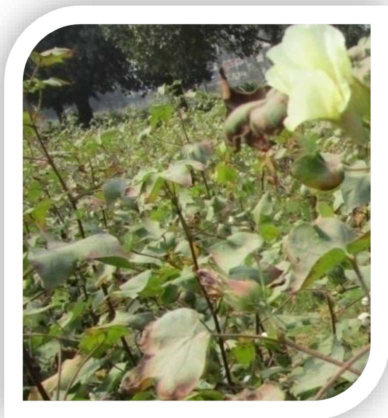

a

b

**Plate 4.2 Comparison between combined effect of mepiquat chloride spray (a) @ 2 ml $L^{-1}$ water at 25 DAE with 60 cm × 30 cm over water spray (b) or control (2017-18)**


i

ii

**Plate 4.3 Comparison between (i) combined effect of mepiquat chloride spray @ 2 ml $L^{-1}$ water at 25 DAE with 60 cm × 30 cm over (ii) water spray or control (2018-19)**

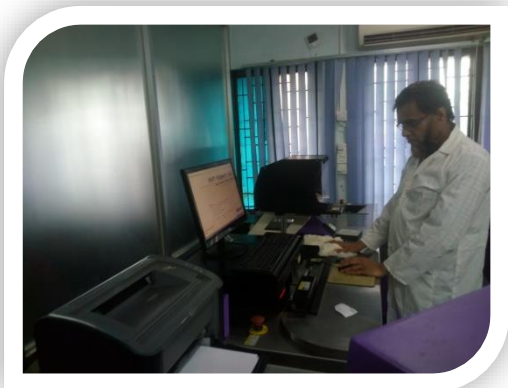


**Plate 5 Lint character analysis with the help of HVT (High Volume Tester)**