International Journal of Plant & Soil Science

34(20): 635-644, 2022; Article no.IJPSS.88736
ISSN: 2320-7035

Impact of Growth Retardant and Defoliant on Morpho-physiological Traits and Yield Improvement in Cotton

K. Dharani [a*], V. Ravichandran [a], S. Anandakumar [b], N. Sritharan [c] and N. Sakthivel [d]

[a] Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, India.
[b] Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore, India.
[c] Department of Rice, Tamil Nadu Agricultural University, Coimbatore, India.
[d] Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, India.

Authors' contributions

This work was carried out in collaboration among all authors. Authors KD and VR design the study, carried out all the experiments, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. SA, NS, and N. Sakthivel managed the analysis of the study and manuscript proofing. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i2031198

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/88736

Original Research Article

Received 12 April 2022
Accepted 24 June 2022
Published 01 July 2022

ABSTRACT

In cotton, mechanized harvesting has gained popularity in recent years due to labor-intensive process and shortage of labor. Moreover, mechanized harvesting of cotton depends on plant morphological characters like plant height, internodal length and synchronized boll maturity and opening etc. Mechanized harvesting enhancing the harvesting efficiency of cotton which is achieved by the use of some chemicals to attain good lint yield and fibre quality. With this background, the field experiment was conducted to study the impact of growth retardant and defoliant on morpho-physiological traits and yield improvement in cotton (CO 17) during 2021-2022 by following randomized block design with four treatments and five replications. The current study revealed that spraying of 0.015% mepiquat chloride (MC) at square formation and boll development stage significantly reduced the leaf area, plant height, total dry weight and boll number when compared to control. However, chlorophyll content and normalized difference vegetation index (NDVI) were recorded higher in 0.015% mepiquat chloride (MC) applied

**Corresponding author: E-mail: dharanibala577@gmail.com;*

treatments than control. Moreover, spraying of mepiquat chloride (0.015%) at square formation and boll development stage followed by spraying of 0.9% sodium chlorate (SC) at 60% boll bursting stage significantly increased the seed cotton yield compared to other treatments and recorded maximum seed cotton yield of 25.22% compared to control. Results clearly indicate that application of MC followed by SC could be a better practice for canopy management in cotton, resulting in improved efficiency of mechanical harvesting and good lint yield and fibre quality.

Keywords: Cotton; growth retardant; mepiquat chloride; defoliant; sodium chlorate; yield.

1. INTRODUCTION

In India, cotton (Gossypium *spp* L.) is a most essential fibre crop commercially grown to maximize profits by selling high quality fibre, with a significant impact on agriculture, industrial development, job creation, and the economy. It is an indeterminate and perennial tropical plant. India is having 12.35 million hectares of largest area, estimated production of 34.06 million bales and 469 kg/ha of yield under cotton cultivation [1]. Generally, cotton harvesting is a labor-intensive process in almost all the developing countries where it is done by hand picking. In India, usually two to five picking is followed and manual picking is costlier than other cultural operations. Hand picking of cotton is also a difficult task as it caused various health hazards to the labors. Therefore, mechanized harvesting has gained popularity in recent years due to a severe labor shortage. Mechanized harvesting of cotton rectifies these problems and also provide timely sowing of following crops but it requires equal and shorter plant height. Thus, several chemicals are used to increase the efficiency of mechanical harvesting of cotton to achieve good lint yield and fibre quality. When these chemicals are applied correctly and according to the label guidelines, the time between boll maturity and crop harvest can be decreased. Their primary aim is to target physiological processes within the cotton plant, which can be used to control foliage, cause defoliation or desiccation and stimulate the synchronized opening of cotton bolls. Harvest aid chemicals speed up the harvest of a mature crop and reduce the risk of yield or fibre quality loss before harvest.

Increased foliage can result in unwanted shade within the plant canopy and leads to abscission of fruits and yield losses. MC is a plant growth inhibitor used extensively in cotton canopy management to prevent excessive growth and yield loss. It is used to shorten plant height and internodal distance. Additionally, sodium chlorate ($NaClO_3$) used as a defoliant and desiccant in cotton production. Defoliant application prior to cotton harvest has several advantages, including reduced leaf trash content in collected lint, faster dew drying and early boll opening due to full sun exposure [2]. Thus, application of Mepiquat Chloride and Sodium Chlorate helps to enhance the mechanical harvesting of cotton by altering physiological process of plant. However, the effect of growth inhibitor and defoliant on cotton canopy management and leaf defoliation are not studied well. Thus, it has the need to study about it. Therefore, this present study was conducted with an objective to evaluate the effects of mepiquat chloride (MC) and sodium chlorate (SC) on morpho-physiological traits and yield improvement in cotton.

2. MATERIALS AND METHODS

The field experiment was conducted in the Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore (111N; 771E; 426.7m MSL) from September 2021 to February 2022. The experiment was laid out by following randomized block design (RBD) with five replications and four treatments. Cotton variety CO 17 is a short duration and having zero monopodia with short sympodial length was used as a test crop. The cotton seeds were bought from the Department of Cotton, Tamil Nadu Agricultural University, Coimbatore.

2.1 Treatment Details

The experiment had four treatments *viz.,* T1 - Control, T2 - Spraying of Mepiquat Chloride (0.015%) at square formation stage followed by Sodium Chlorate (0.9%) at 60% boll bursting stage, T3 - Spraying of Mepiquat Chloride (0.015%) at boll development stage followed by Sodium Chlorate (0.9%) at 60% boll bursting stage, T4 - Spraying of Mepiquat Chloride (0.015%) at square formation and boll development stage followed by Sodium Chlorate (0.9%) at 60% boll bursting stage. In this present study, effects of MC and SC on morpho-physiological parameters, leaf defoliation percentage, boll opening percentage and antioxidant enzyme activities of cotton (CO 17) were recorded.

2.2 Plant Height

Plants are randomly chosen and tagged from each replication of four treatments. The plant height is measured from base of the stem to the tip of the plant and expressed in cm.

2.3 Leaf Area

Cotton leaves were collected from all the treatments with replication and used for measuring the leaf area by using leaf area meter (LICOR, Model LI 3000) and leaf area was denoted as cm^2 $plant^{-1}$.

2.4 Dry Matter Production

Above-ground portion of plants were harvested from each replication of four treatments and oven dried at 50°C for one week to achieve a consistent weight. Then, using an analytical balance, dry matter production (DMP) was calculated and reported as g $plant^{-1}$.

2.5 NDVI

Green Seeker, a handheld crop sensor which was utilized to detect the Normalized Difference Vegetation Index (NDVI, Trimble).

2.6 Chlorophyll Content

The photosynthetic pigments were determined using dimethyl sulfoxide (DMSO) [3] method followed by spectrophotometer readings at 645 and 663 nm, the following formula was used to estimate total chlorophyll and the values provided in mg g^{-1} of fresh weight.

$$\text{Total chlorophyll} = (8.02 \text{ x OD at } 663) - (20.2 \text{ x OD at } 645)\text{x}\frac{V}{W \text{ x } 1000}$$

Where,

OD - Optical Density
V - Supernatant’s final volume
W - Weight of the sample taken (gram)

2.7 Number of Bolls per Plant

After application of sodium chlorate, five plants from each treatment were tagged. Then bolls per plant was recorded and expressed as number. One week after application of sodium chlorate, the seed cotton yield was calculated as gram $plant^{-1}$.

2.8 Statistical Analysis

The information gathered on various parameters from field experiments was statistically evaluated in Randomized Block Design (RBD) using AGRES software. The critical difference (CD) was calculated with 5% probability.

3. RESULTS AND DISCUSSION

3.1. Plant Height

Increased vegetative growth causes shadowing inside the canopy, resulting in fruit abscission and a decrease in yield [4]. Cotton canopy management by MC is the one of the tactics used in agriculture to enhance the yield of cotton. MC application altered the plant canopy and increased the cotton yield by increasing air flow [5]. Because of the limited boll setting %, increase in plant density reduced boll weight, lint yield, and no. of bolls per plant. The adequate plant density enhanced the lint yield by increasing the no. of bolls per area [6]. Our results showed that plant height was reduced by spraying of 0.015% MC at square formation and boll development stage and 0.9% SC at boll bursting stages of cotton, compared to control (Fig. 1.). However, spraying of 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage (T4) recorded significantly lesser of 59.60, 80.40 and 98.96 cm plant height at 66, 86 and 126 DAS, respectively, compared to other treatments, followed by 0.015% MC at square formation stage and 0.9% SC at 60% Boll bursting stage treatment (T2). Plant height was higher in control among all other treatments at 66, 86 and 126 DAS and it recorded maximum of 77.90, 135.40 and 155.72 cm respectively. Overall, spraying of MC decreased the plant height over control. Similarly, foliar spraying of MC (250 ppm) at 80 DAS or MC (125 ppm) at 60 and 80 DAS reduced plant height by 11.2 and 8.1 percent, respectively, over control [7]. Zhao and Oosterhuis. [8] also observed that MC application improved leaf CO 2 -exchange rate, reduced plant height, and increased starch content of the leaf. Magnitskiy et al. [9] found that plant growth inhibitors can diminish internodal length and vegetative development by delaying cell division and elongation of plant aerial parts, as well as restricting gibberellin production.

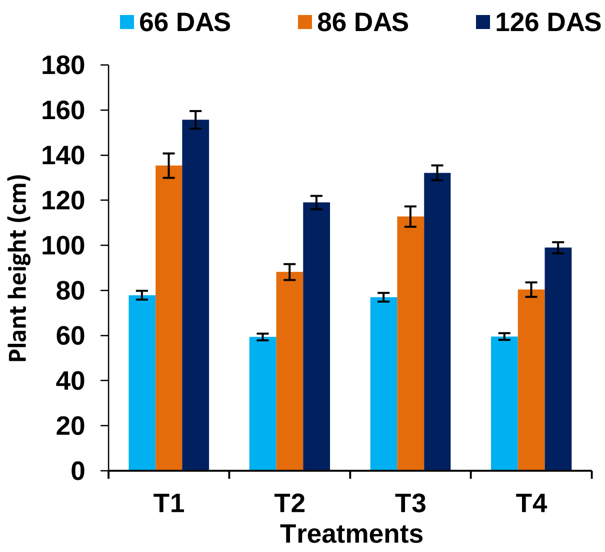

Fig. 1. Effect of mepiquat chloride on plant height (cm) of cotton variety (CO 17)

T1 - Control
T2 - 0.015% MC at square formation stage followed by 0.9% SC at 60% Boll bursting stage
T3 - 0.015% MC at boll development stage followed by 0.9% SC at 60% Boll bursting stage
T4 - 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage

3.2 Leaf Area

Excessive shadowing inside the plant canopy resulted in abscission of fruit and yield loss. Application of MC resulted in decreased and more compact plant and have a reduced leaf area index due to smaller leaf size and mature faster [6]. Shortened stem, reduced leaf expansion, petiole length, node number and faster maturity of cotton crop are all visible consequences of MC, according to Bogiani and Rosolem. [10] In cotton variety 'DDH-11,' application of 50 ppm MC at 90 DAS was effectively reduced leaf area, plant height and also resulted in increased boll weight and higher yield than control [11]. In our study, Fig. 2. showed that leaf area was significantly decreased due to the application of 0.015% MC and 0.9% SC. During 66 DAS, the minimum leaf area was observed in T4 (5109.19 cm^2 $plant^{-1}$) and statistically on par with T2 and highest leaf area was recorded in T3 with the value of 9082.23 cm^2 $plant^{-1}$ and on par with T1 (Control) (9006.19 cm^2 $plant^{-1}$). Similarly, the leaf area was significantly reduced in T4 (5329.69 cm^2 $plant^{-1}$) followed by T2 (4997.60 cm^2 $plant^{-1}$) and T3 (5962.78 cm^2 $plant^{-1}$) over control (9975.43 cm^2 $plant^{-1}$) during 86 DAS. MC treatment declined the leaf area, plant height and no. of leaves are connected with stunted vegetative growth [12,13]. Similar to MC, foliar application of SC also reduced leaf area at 126 DAS in T4 (4458.97 cm^2 $plant^{-1}$) next to T2 (4972.05 cm^2 $plant^{-1}$) and T3 (5223.73 cm^2 $plant^{-1}$) compared to T1 (11146.59 cm^2 $plant^{-1}$).

3.3. Total Dry Weight

Nagashima et al. [14] reported that seed treatment of cotton with MC reduced the shoot and root growth and overall plant height. Because of the decreased leaf area and compact structure, the plants with MC application showed reduced competition for nutrients and light intensity [6]. These findings were supported by Rosolem et al. [15] who found that when applying MC, the dry matter production was reduced due to the change in the source-sink ratio. The experimental results indicated that total dry matter production or total biomass production was statistically reduced by application of MC and SC (Fig. 3.). At 66 days after sowing, total dry weight of T2 (41.91 g per plant) and T4 (42.33 g per plant) were reduced significantly over T1 (52.67 g per plant) and T3 (54.60 g per plant).

During 86 DAS, spraying of MC (0.015%) reduced the total dry weight of plants subjected to the foliar application of 0.015% MC at square formation stage and boll development stage + 0.9% SC at 60% Boll bursting stage (T4) (64.93

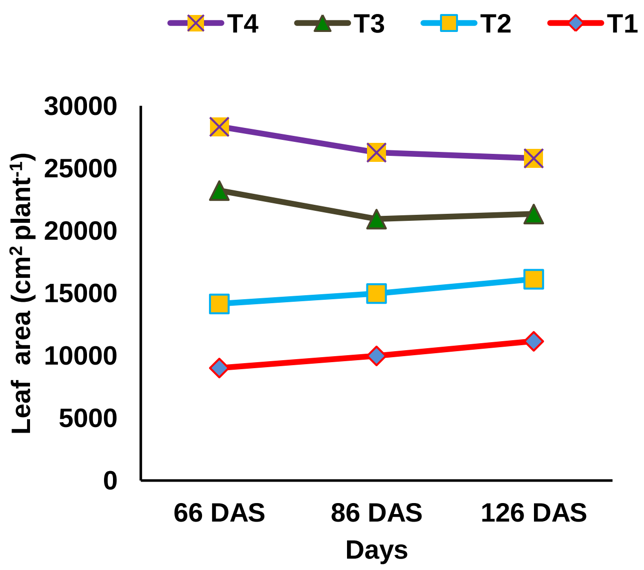

Fig. 2. Effect of mepiquat chloride and sodium chlorate on leaf area (cm^2 plant^{-1}) of cotton variety (CO 17)

T1 - Control
T2 - 0.015% MC at square formation stage followed by 0.9% SC at 60% Boll bursting stage
T3 - 0.015% MC at boll development stage followed by 0.9% SC at 60% Boll bursting stage
T4 - 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage

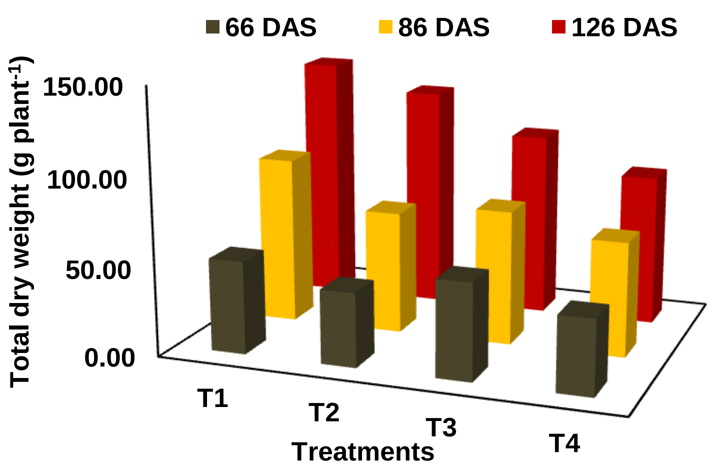

Fig. 3. Effect of mepiquat chloride and sodium chlorate on total dry weight (g plant^{-1}) of cotton variety (CO 17)

T1 - Control
T2 - 0.015% MC at square formation stage followed by 0.9% SC at 60% Boll bursting stage
T3 - 0.015% MC at boll development stage followed by 0.9% SC at 60% Boll bursting stage
T4 - 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage

g per plant) followed by T2 (69.34 g per plant) and T3 (76.06 g per plant) over T1 (94.65 g plant^{-1}). Treatment of seeds with MC or foliar spraying of MC reduced the dry matter production or no influence on DMP has been recorded [16]. Similarly, Raut et al. [17] reported that spraying of MC reduced shoot dry weight compared to control. Ashraf et al. [18] observed significant loss in biomass due to the application of defoliants. Experimental results obtained showed that total dry weight was effectively reduced due to the application of SC in T4 next to T3 and T2 compared to control at 126 DAS (Fig. 3.). Dry matter production had a significant reduction on defoliant treated soybean [19].

3.4 Normalized Difference Vegetation Index (NDVI)

In cotton, the NDVI has been used to determine the maturity of the crop, leaf area, dry weight, plant height to node ratio, no. of nodes, nitrogen status of the plant, and lint production [20]. According to Vellidis et al. [21] NDVI could be favorably used to apply growth regulator to cotton and used to form the basis for decentralization of defoliant application zones for the cotton crop. In this current study, application of MC showed a positive effect on NDVI at 66 and 86 DAS over control (Fig. 4). However, Spraying of SC at 60% boll bursting stage reduced the NDVI value (Fig. 4). Spraying of 0.015% MC at square formation stage and boll development stage + 0.9% SC at 60% Boll bursting stage (T4) had highest NDVI of 0.91 and 0.83 during 66 and 86 DAS respectively next to 0.015% MC at square formation stage + 0.9% SC at 60% Boll bursting stage (T2) (0.90 and 0.82 at 66 and 86 DAS respectively). The control plant showed declined NDVI of 0.83 and 0.83 at 66 and 86 DAS respectively. At three days after spraying of SC, NDVI of T2 (0.53), T3 (0.51) and T4 (0.51) was reduced compared to control (0.77). NDVI corresponds with photosynthetic efficiency and predicted wheat output in a various agricultural locations [22]. In winter wheat, NDVI helps to assess the photosynthetic efficiency, wheat grain production and nitrogen uptake [23].

3.5 Chlorophyll Content

Chlorophyll plays an important role in photosynthesis. MC increased the amount of chlorophyll content in cotton leaves that were dark green in color. plants that has been treated with MC usually has thicker, "leathery" leaves with more chlorophyll. Increase in chlorophyll a and chlorophyll b was observed in MC treated plants at 66 and 86 DAS, a same trend was observed in total chlorophyll. According to Pal et al. [24] growth retardants have a significant impact on leaf chlorophyll content. In onion, they observed that, application of MC (125 g a.i.ha-1) at 35 DAT produced the highest total chlorophyll (2.37 mg/g), followed by 125 g a.i.ha-1 of MC at 50 DAT (2.33 mg/g) over control (1.92 mg/g). In our study, we found that application of mepiquat chloride significantly increased the amount of

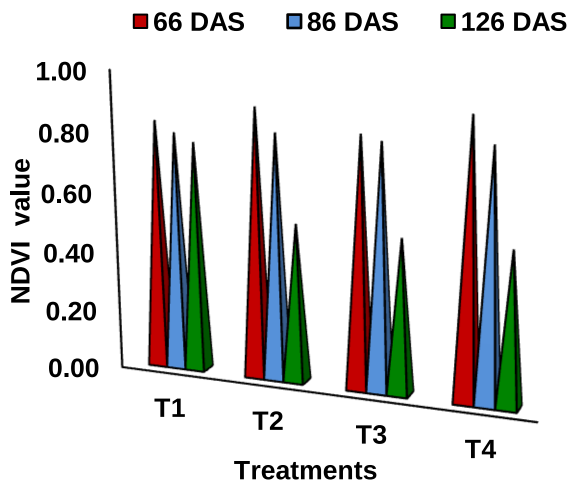

Fig. 4. Effect of mepiquat chloride and sodium chlorate on NDVI value of cotton variety (CO 17)
T1 - Control
T2 - 0.015% MC at square formation stage followed by 0.9% SC at 60% Boll bursting stage
T3 - 0.015% MC at boll development stage followed by 0.9% SC at 60% Boll bursting stage
T4 - 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage

total chlorophyll in cotton (CO 17) (Fig. 5.). At 66 DAS, T4 and T2 had the maximum amount of chlorophyll a, chlorophyll b and total chlorophyll compared to T1 and T3. T4 had highest total chlorophyll content of 2.06 mg g^{-1} FW over control (1.81 mg g^{-1} FW) at 86 DAS. At 86 DAS had no significant difference on chlorophyll b. Spraying of SC reduced the chlorophyll content (Fig. 5.). The chlorophyll a, chlorophyll b content of SC treated plant significantly reduced compared to control. Therefore, total chlorophyll content of T2 (0.99 mg g^{-1} FW), T3 (0.93 mg g^{-1} FW) and T4 (0.90 mg g^{-1} FW) was decreased over control (1.33 mg g^{-1} FW) due to the application of SC. Rigon et al. [25] found that seed treatment with MC decreased seedling vigour, leaf area, plant height, chlorophyll, sugar and starch content and total dry weight. Similarly, increased chlorophyll content due to MC treatment was observed by Zhao and Oosterhuis. [8]. They also suggested that the increase could be connected to a higher specific leaf weight. MC treatment has a positive effect on chlorophyll content of cotton leaves. Amount of chlorophyll a, chlorophyll b and total chlorophyll in cotton has been increased in MC treated plant over control [17]. Jin et al. [26] observed the negative effect on chlorophyll a and chlorophyll b at 24 hr due to the application of defoliants. The total chlorophyll content had a significant reduction due to the application of various defoliants [27].

3.6 No of Bolls Per Plant

Lu et al. [28] found that no difference was observed from no. of bolls per plant, boll weight and lint production with respect to Xinsaili (defoliant) treatment. In this present study, Fig. 6 shows that highest boll number was observed in T1 (control) with the value of 35 compared to T3 (0.015% MC at boll development stage + 0.9% SC at 60% Boll bursting stage) (26) and on par with T4 (0.015% MC at square formation stage and boll development stage + 0.9% SC at 60% Boll bursting stage) (26). Cotton plants treated with 0.015% MC at square formation stage + 0.9% SC at 60% Boll bursting stage had lowest number of bolls (T3)(23) compared with other treatments. Similarly, Kerby et al. [29] reported that application of MC reduces vegetative growth, by translocating nutrients to developing bolls and shifted higher proportion of boll production to lower nodal positions as compared to control.

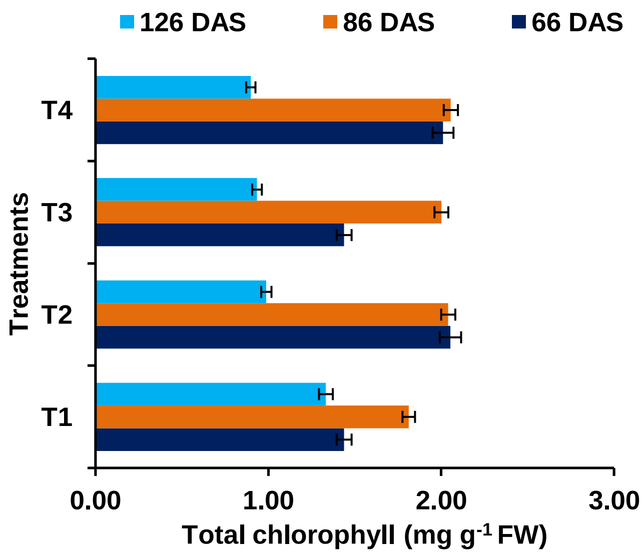

Fig. 5. Effect of mepiquat chloride and sodium chlorate on total chlorophyll (mg g^{-1} FW) of cotton variety (CO 17)

T1 - Control
T2 - 0.015% MC at square formation stage followed by 0.9% SC at 60% Boll bursting stage
T3 - 0.015% MC at boll development stage followed by 0.9% SC at 60% Boll bursting stage
T4 - 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage

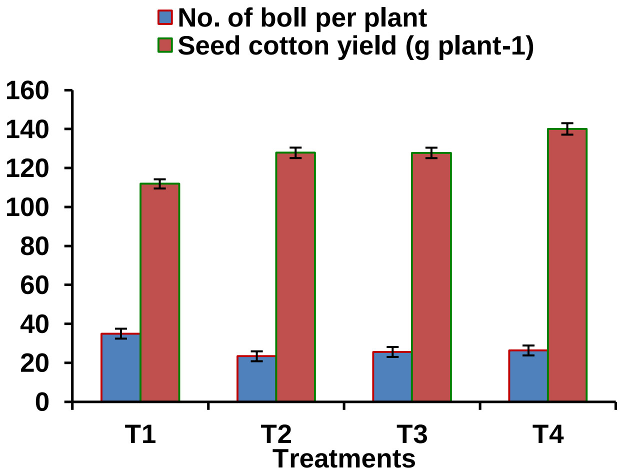

Fig. 6. Effect of mepiquat chloride and sodium chlorate on number of bolls per plant and seed cotton yield (g plant^{-1}) of cotton variety (CO 17)

T1 - Control
T2 - 0.015% MC at square formation stage followed by 0.9% SC at 60% Boll bursting stage
T3 - 0.015% MC at boll development stage followed by 0.9% SC at 60% Boll bursting stage
T4 - 0.015% MC at square formation stage and boll development stage followed by 0.9% SC at 60% Boll bursting stage

3.7 Seed Cotton Yield

Application of MC improved the yield of cotton crop and also improves the fibre quality [5]. In comparison to MC application at 50 DAS, MC application at 70 DAS improved seed cotton yield plant^{-1} (23%) and ultimate cotton yield (23%) [30]. In our study, Seed cotton yield was observed at 126 DAS which had a significant difference between control and other treatments (Fig. 6.). T4 plants (0.015% MC at square formation stage and boll development stage + 0.9% SC at 60% Boll bursting stage) had the higher seed cotton yield of 140.12 g per plant which was on par with T2 (0.015% MC at square formation stage + 0.9% SC at 60% Boll bursting stag) (127.83 g plant^{-1}) and T3 (0.015% MC at boll development stage + 0.9% SC at 60% Boll bursting stage) (127.80 g plant^{-1}) over T1 (control) (111.90 g plant^{-1}). Plant growth inhibitors such as cycocel and MC are reported to decrease the length of internode, resulting in lower plant height and increased photosynthates transfer to reproductive sinks (bolls), which lead to higher yields [31].

4. CONCLUSION

Mechanical harvesting of cotton is dependent on the plant canopy, which could be influenced by application of growth retardant chemicals followed by defoliants to increase the efficiency of mechanical harvesting and good lint yield and fibre quality. Hence, our study concluded that foliar spraying of 0.015 % MC during square formation and boll development stage significantly reduced the leaf area, plant height, total dry weight and no. of bolls when compared to control, however chlorophyll content and normalized difference vegetation index (NDVI) were increased significantly than control. Moreover, spraying of mepiquat chloride (0.015%) at square formation and boll development stage followed by spraying of 0.9% sodium chlorate (SC) at 60% boll bursting stage significantly increased the seed cotton yield compared to other treatments and recorded maximum seed cotton yield of 25.22 % compared to control. Therefore, it clearly indictes that application of MC followed by SC could be a better practice for canopy management in cotton, resulting in improving the efficiency of mechanical harvesting and good lint yield and fibre quality.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. The Cotton corporation of India Ltd. Statistical cotton balance sheet. Committee on Cotton Production and Consumption (COCPC). 2021-2022;3.

2. Awan HU, Awan IU, Mansoor M, Khawani AA, Khan MA, Khattak B. Effect of defoliant application at different stages of boll maturity and doses of sulfur on yield and quality of upland cotton. Sarhad Journal of Agriculture. 2012;28(2).
3. Hiscox JD, Israelstam GF. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany. 1979;57(12):1332-1334.
4. Cook DR, Kennedy CW. Early flower bud loss and mepiquat chloride effects on cotton yield distribution. Crop Science. 2000;40(6):1678-1684.
5. Tung SA, Huang Y, Hafeez A, Ali S, Liu A, Chattha MS, Ahmad S, Yang G. Morpho-physiological Effects and Molecular Mode of Action of Mepiquat Chloride Application in Cotton: A Review. Journal of Soil Science and Plant Nutrition. 2020; 20(4):2073-2086.
6. Ren X, Zhang L, Du M, Evers JB, van der Werf W, Tian X, Li Z. Managing mepiquat chloride and plant density for optimal yield and quality of cotton. Field Crops Research. 2013;149:1-10.
7. Deol JS, Brar ZS. Effect of different spacing and mepiquat chloride on cotton (*Gossypium hirsutum* L.) productivity. J Cotton Res Dev 2003;17: 247-48.
8. Zhao D, Oosterhuis DM. Pix plus and mepiquat chloride effects on physiology, growth, and yield of field-grown cotton. Journal of Plant Growth Regulation. 2000; 19(4).
9. Magnitskiy SV, Pasian CC, Bennett MA, Metzger JD. Controlling height and seedling emergence of French marigold and celosia plugs with plant growth regulators. Journal of Environmental Horticulture. 2006;24(3):165-168.
10. Bogiani JC, Rosolem CA. Sensibility of cotton cultivars to mepiquat chloride. Pesquisa Agropecuaria Brasileira. 2009; 44(10):1246-1253.
11. Kumar KAK, Ravi V, Patil BC, Chetti MB. Influence of plant growth regulators on morpho physiological traits and yield attributes in hybrid cotton (DHH-11). Annals of Biology. 2006;*22*(1):53.
12. Souza, FSD, Rosolem CA. Rainfall intensity and mepiquat chloride persistence in cotton. Scientia Agricola. 2007;64(2):125-130.
13. Gu S, Evers JB, Zhang L, Mao L, Zhang S, Zhao X, Liu S, Werf WVD, Li Z. Modelling the structural response of cotton plants to mepiquat chloride and population density. Annals of Botany. 2014;114(4):877-887.
14. Nagashima GT, Marur CJ, Yamaoka RS, Miglioranza E. Development of cotton plant from seeds soaked with mepiquat chloride. Pesquisa Agropecuária Brasileira. 2005; 40:943-946.
15. Rosolem CA, Oosterhuis DM, Souza FSD. Cotton response to mepiquat chloride and temperature. Scientia Agricola. 2013; 70(2):82-87.
16. Nagashima GT, Miglioranza E, Marur CJ, Yamaoka RS, Dos Reis Silva JG. Development of cotton in response to mode of application and doses of mepiquat chloride in seeds/Desenvolvimento do algodoeiro em resposta a modo de aplicacao e doses de cloreto de mepiquat via sementes. Ciencia Rural. 2010;40(1).
17. Raut SA, Meshram JH, Lal EP. Effect of mepiquat chloride on cotton var Suraj shoot and root growth behaviour. International Journal of Chemical Studies. 2019;7(3):946-950.
18. Ashraf AM, Ragavan T, Begam SN. Standardize the dose and timing of defoliant application to facilitate synchronized maturity for mechanical harvesting of rainfed cotton (*Gossypium hirsutum*). Indian Journal of Agronomy. 2020;65(4):444-450.
19. Islam MT. Effects of defoliation on photosynthesis, dry matter production and yield in soybean. Bangladesh Journal of Botany. 2014;43(3):261-265.
20. Foote W, Edmisten K, Wells R, Collins G, Roberson G, Jordan D, Fisher L. Influence of nitrogen and mepiquat chloride on cotton canopy reflectance measurements. Journal of Cotton Science. 2016;20(1): 1-7.
21. Vellidis G, Ortiz B, Ritchie G, Peristeropoulos A, Perry C, Rucker K. Using Green Seeker to drive variable rate application of plant growth regulators and defoliants on cotton. Precision Agriculture. 2009;9(9):940-955.
22. Benedetti R, Rossini p. On the use of NDVI profiles as a tool for agricultural statistics: The case study of wheat yield estimate and forecast in Emilia Romagna. Remote Sensing of Environment. 1993;45(3):311-326.
23. Raun WR, Solie JB, Johnson GV, Stone ML, Lukina EV, Thomason WE, Schepers JS. In-season prediction of potential grain yield in winter wheat using canopy

reflectance. Agronomy Journal. 2001; 93(1):131-138.

24. Pal SK, Singh S, Yadav KS, Kumar R, Kumar A. Effect of mepiquat chloride on growth and yield of onion (*Allium cepa*). Annals of Plant and Soil Research. 2017; 19(4):377-380.
25. Rigon JPG, Beltrao NDM, Capuani S, de Brito Neto JF. Initial growth of the castor bean soaked in mepiquat chloride and nitrogen topdressing fertilization. Revista Verde de Agroecologia e Desenvolvimento Sustentável. 2011;6(4).
26. Jin D, Wang X, Xu Y, Gui H, Zhang H, Dong Q, Sikder RK, Yang G, Song M. Chemical Defoliant Promotes Leaf Abscission by Altering ROS Metabolism and Photosynthetic Efficiency in Cotton. International Journal of Molecular Sciences. 2020;21(8):2738.
27. Chandrasekaran P, Ravichandran V, Senthil A, Mahalingam L, Sakthivel N. Impact of chemical defoliants on chlorophyll fluorescence, biochemical parameters, yield and fiber quality of high density cotton. Indian Journal of Agricultural Research. 2021;1-7.
28. Lu MENG, Zhang LZ, Qi HK, Du MW, Zuo YL, Zhang MC, Tian XL, LI ZH. Optimizing the application of a novel harvest aid to improve the quality of mechanically harvested cotton in the North China Plain. Journal of Integrative Agriculture. 2021; 20(11):2892-2899.
29. Kerby TA, Plant RE, Horrocks RD. Height-to-node ratio as an index of early season cotton growth. Journal of Production Agriculture. 1997;10(1):80-83.
30. Murtza K, Ishfaq M, Akbar N, Hussain S, Anjum SA, Bukhari NA, Algarawi AM, Hatamleh AA. Effect of mepiquat chloride on phenology, yield and quality of cotton as a function of application time using different sowing techniques. Agronomy. 2022;12(5):1200.
31. Kumar KAK, Patil BC. Chetti MB. Effect of plant growth regulators on physiological components of yield in hybrid cotton. Indian Journal of Plant Physiology. 2005; 10:187-90.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/88736