Research Article

Application Frequency and Dosage of Mepiquat Chloride as a Growth Regulator for Coker Cotton Variety in Ecuador

Luis Fernando Díaz-Toral[1], Carlos Eddy Alvarado-Zamora[1], Ernesto Gonzalo Cañarte-Bermúdez[2]*, José Bernardo Navarrete-Cedeño[2], Gilmar Jesús Cañarte-Cañarte[1] and Fernando David Sánchez-Mora[1]*

[1]*Departamento de Ciencias Agronómicas, Facultad de Ingeniería Agronómica, Universidad Técnica de Manabí, Lodana, Ecuador;* [2]*Departamento de Entomología, Instituto Nacional de Investigaciones Agropecuarias (INIAP). Portoviejo, Manabí, Ecuador.*

Abstract | The aim of this research was to determine the appropriate time and dose of application of mepiquat chloride (MC), as a plant growth regulator (PGR), in the Coker cotton commercial variety. This field trial was carried out during February-August 2020 in La Teodomira experimental farm of the National Institute of Agricultural Research (INIAP, Lodana, Manabí, Ecuador), with three periods of application and four doses of growth regulator in addition to control (without regulator). A randomized complete block design in additive factorial arrangement was used, with four repetitions. The variables, such as plant height (cm), stem diameter (cm), plant height increase (cm/day) in productive stage, apical internodes length (cm), leaf greenness index (SPAD), total number of branches/plant, total number of flower buds/plant, total number of cotton bolls/plant, weight (g) of ten unopened cotton bolls (g) and yield of raw cotton (kg ha^{-1}), were recorded. The data obtained were subjected to ANOVA, and comparison of means was done by Tukey's test ($P<0.05$). The results indicated that the application of mepiquat chloride at 50 days after sowing (DAS) performed better in most of the agronomic and productive variables evaluated in this study. The leaf greenness index variable reported higher values with doses greater than 300 mL. The application of the MC, allowed to reduce the height of the plants, contributing to the good structure of the plant, efficiently using its nutritional resources. When the growth regulator was applied at a single time, that is at 50 DAS, the best average yield of raw cotton was obtained (4,642 kg ha^{-1}). Meanwhile, the most efficient dose was that of 300 mL of MC, with which the highest yield (4,613 kg ha^{-1}) of raw cotton was obtained.

Received | February 13, 2024; **Accepted** | March 19, 2024; **Published** | April 15, 2024
***Correspondence** | Ernesto Gonzalo Cañarte-Bermúdez and Fernando David Sánchez-Mora, Departamento de Ciencias Agronómicas, Facultad de Ingeniería Agronómica, Universidad Técnica de Manabí, Lodana, Ecuador; Departamento de Entomología, Instituto Nacional de Investigaciones Agropecuarias (INIAP). Portoviejo, Manabí, Ecuador; **Email:** ernesto.canarte@iniap.gob.ec, fernando.sanchez@utm.edu.ec
Citation | Díaz-Toral, L.F., C.E. Alvarado-Zamora, E.G. Cañarte-Bermúdez, J.B. Navarrete-Cedeño, G.J. Cañarte-Cañarte and F.D. Sánchez-Mora. 2023. Application frequency and dosage of mepiquat chloride as a growth regulator for coker cotton variety in ecuador. *Sarhad Journal of Agriculture,* 39(Special issue 2): 27-36.
DOI | https://dx.doi.org/10.17582/journal.sja/2023/39/s2.27.36
Keywords | *Gossypium hirsutum*, Plant growth regulator, Plant height, Raw cotton yield

Introduction

Cotton (*Gossypium hirsutum* L.) crop is an important commercial crop in the United States, India, Pakistan, Turkey, Brazil, Indonesia and China (FAO, 2018), and cotton is used mainly in clothing making and home apparels (draperies, curtains, bedspreads, etc.) due to its softness, good strength and color retention properties (Dunne *et al*., 2016). On the other hand, due to high oil and protein content in the seed, it is also used for the manufacture of cosmetics, soaps and glycerin, as well as, for livestock fodder (Brubaker *et al*., 1999).

Cotton cultivation in Ecuador experienced its peak productivity during the years 1970 to 1990, with a notable milestone in 1974 when it covered 36,000 hectares of land. This period marked its economic significance due to the high demand for its raw material, which served the needs of spinning mills, companies engaged in edible fats and oils production, textile industries, as well as less impactful sectors like pasta and cotton cake production (Sion, 1992). Various circumstances, including bad climatic and economic conditions have led to the significant reduction of cultivated areas (FAO, 2017). Currently, cotton fiber production in the country is concentrated in the cantons of Tosagua (Manabí) and Pedro Carbo (Guayas) (Espinosa and Suárez-Duque, 2019; Cañarte-Bermúdez *et al*., 2020).

G. hirsutum, a perennial shrub, naturally grows to heights of 1.5 to 2 meters. However, for commercial cultivation, it is essential to manage the height of cotton plants. This can be achieved through manual methods; when the plants surpass 1.3 meters within 80 days, pruning of the terminal bud on the main stem is required (Sion, 1992), or through the use of 5s (Gahan and Zavala, 1999; Cadena *et al*., 2002; Morales *et al*., 2004). Plant growth regulators (PGR) are organic compounds, which in small doses inhibit or delay vegetative growth, cell division and expansion, thus regulating plant height and sprouts, without showing malformations in leaves and stems, achieving as a result, a modification of vegetative and reproductive growth of plants (Weaver, 1982).

Cotton plants respond adequately to the use of PGR, allowing to manage this balance between vegetative growth and reproductive development (Reyes, 2014). Mepiquat chloride, as per the IUPAC (International Union of Pure and Applied Chemistry) nomenclature system, formally named 1,1-dimethylpiperidin-1-ium chloride (chemical formula C7H16ClN), is an exogenous growth inhibitor used in agriculture to regulate vegetative and reproductive growth of crops by inhibiting the biosynthesis of gibberellins, which is a substance that acts in the plant blocking the process of biosynthesis of gibberellic acid (GA), making it impossible to synthesize an enzyme in the pathway. As a result, the amount of GA in plant tissue is reduced, and cell growth and elongation are controlled (Schott and Heydenfort, 1981; Hake *et al*., 1991; EPA, 1997; Rosolem *et al*., 2013; Wang *et al*., 2014).

Several studies done by the Environmental Protection Agency (EPA, 1997) have shown that MC it is practically non-toxic to freshwater, estuarine, and marine fish and aquatic invertebrates, but some potential concerns remain regarding its moderate toxicity to small mammals at high doses. Li *et al*. (2012) found that the degradation period of mepiquat chloride within cotton plants and soil ranged from 2.51 to 3.85 days and from 0.56 to 10.50 days, respectively, this rapid degradation of MC, significantly reduces its potential for long-term persistence and bioaccumulation in the food chain.

In cotton, MC is used to prevent excessive plant growth and shape ideal plant type for mechanical cultivation, results in higher precocity and lower height and consequently increases yield and reduces crop costs, thus improve productivity (McCarty and Hedin, 1994; Leal *et al*., 2020; Wang *et al*., 2023). It is also recommended that the use of growth regulators in cotton should not exceed 300 mL ha^{-1} before flowering and 500 mL ha^{-1} at the beginning of flowering (Garcia and Carnero, 1991), due to the fact that this could be reducing production at harvest time.

Cotton cultivation in Ecuador is inadequately managed, for instance, the use of growth regulators lacks clear guidelines regarding appropriate dosages and the optimal timing for application. The lack of clarity frequently impacts production and leads to unnecessary investments. This issue likely stems from the absence of updated technology tailored to the specific local environmental conditions, essential for the correct utilization of growth regulators.

Given these challenges, this investigation was initiated to address the issues related to usage of growth regulators in cotton crop in Ecuador. The primary goal of this study was to assess the optimal timing and dosage for the application of mepiquat chloride in cotton cultivation, in order to enhance productivity, improve fiber quality, and optimize the harvesting process, specifically within the unique conditions of the province of Manabí, Ecuador.

Materials and Methods

Location

This research was performed during the rainy season of 2020, between the months of February to August; in La Teodomira farm of the Portoviejo Experimental Station of the National Institute of Agricultural Research (INIAP) located at Lodana, Santa Ana, Manabí. Experimental site geographical coordination are 01°09´51" S and 80°23´24" W, at an altitude of 60 meters above sea level. The experiment was established on land flat topography and clay loam soil. The climatic conditions during the production of cotton trial are presented in Table 1.

Table 1: *Monthly climatic conditions during the evaluation cotton trials in the Lodana, Santa Ana, Ecuador.*

Months	Temperature (°C)			Precipitation (mm)	Relative humidity (%)	Heliophany (Hours)
	Min.	Aver.	Max.			
February	23.6	27.7	31.7	93.3	86.6	39.5
March	22.9	27.5	32.0	124.4	84.4	110.8
April	22.4	27.5	32.6	73.3	87.5	139.4
May	22.2	27.1	31.9	26.5	85.9	98
June	21.7	26.0	30.4	14.3	82.4	69.6
July	21.0	25.6	30.3	4.1	80.8	72.9
August	19.9	25.8	31.6	0	77.5	136.6

Source: *INAMHI, National Institute of Meteorology and Hydrology. Meteorological Yearbooks: 2020. Quito, Ecuador.*

Field trial description

Seeds of the commercial Coker cotton variety were used, which corresponds to one of the only two materials marketed in Ecuador in the last few years. This variety is a medium-long fiber material, medium size (1.20 to 1.30 m high with growth regulator), adapted to the environmental conditions of two Pacific coastal provinces of Ecuador, i.e. Manabí and Guayas.

The experiment was carried out utilizing a randomized complete block design, organized in an additive factorial arrangement, and with four blocks. The study investigated two main factors: A, application frequency of Degolpe® mepiquat chloride (MC-1, 1-dimethylpiperidin-1-ium chloride) (at 50 days after sowing (DAS), 50-70 DAS, and 50-70-80 DAS), and B, the dosage of application (300, 600, 900, and 1200 mL of MC per hectare), alongside a control group without any growth regulator. Details of the treatments are shown in Table 2.

Table 2: *Treatments used in the present investigation.*

Treatment	Factors	
	Application frequency (DAS)	Dosage (mL ha^{-1})
1	50	300
2	50	600
3	50	900
4	50	1200
5	50 - 70	300
6	50 - 70	600
7	50 - 70	900
8	50 - 70	1200
9	50 - 70 - 80	300
10	50 - 70 - 80	600
11	50 - 70 - 80	900
12	50 - 70 - 80	1200
13	Control without MC	

DAS = days after sowing

Crop management

Mechanized methods were used to prepare the soil, and a thorough chemical analysis was performed. The sowing was done manually, placing four seeds/site, with a distance of 1.1 m between rows and 0.3 m between plants. Thinning was made 15 days after sowing (DAS), leaving one plant per site. The seeds were treated with thiodicarb + imidacloprid, at doses of 25 mL kg^{-1} of seed. For weed control, the application of the pre-emergent herbicide (pendimethalin 4 L ha^{-1}) + a contact post-emergence herbicide (paraquat 4 L ha^{-1}) was carried out, and the insecticide chlorpyrifos (1 L ha^{-1}) was added, to control pests present in the soil. Subsequently, at 20 DAS, the herbicide haloxyfop methyl (0.6 L ha^{-1}) was applied in post-emergent.

Additionally, two complementary manual weeds were carried out until the closure of the crop canopy. Biweekly pest and disease assessments were conducted. For pest control, chlorpyrifos (Lorsban®)

was applied and for soil fungi, benomyl (Benocor®), in doses of 3 mL L^{-1} water, at 20 DAS. A week later, the application of fungicide was repeated. Fertilization was performed based on soil analysis, at 20 and 56 DAS. The mixture of Urea + YaraMila® was used in a ratio of 1:2 (100 + 200). The application of the growth regulator was carried out according to the treatments.

The start date of the MC application must coincide with the period of emission of flower buds and beginning of flowering, which is the time of greatest growth activity of the cotton plant. For the application of the regulator, a Solo™ motor backpack mister was used, with a water consumption of 600, 750 and 900 L ha^{-1}. Finally, two harvest passes were carried out collecting cotton bolls at 126 and 162 DAS.

Data collection

Before recording the variables, five plants were randomly selected within the productive area of each experimental unit, from which relevant information on various agronomic and productive variables was collected. Plant height (cm) was recorded at 125 DAS, until before the first harvest, in each plant, the height was taken from the surface of the soil to the apex of the plant. The stem diameter of the marked plants was determined at 125 DAS, at a height of 10 cm from the surface of the soil, using a digital vernier caliper. Plant height increase (cm/day) in the productive stage was related between 73 to 125 DAS. Apical internodes length of each marked plant was determined at 128 DAS. The leaf greenness index was examined at 120 DAS, in the five labeled plants. For this, the Minolta SPAD 502 plus™ chlorophyll meter was used, the data was recorded in the upper third of the plant, in leaves exposed to light. These measurements were made between 11:00 am to 14:00 pm.

The total number of branches/plant was counted at 91 DAS. The total number of flower buds/plants was registered at 100 DAS. The total number of cotton bolls/plants was counted at 125 DAS. The weight (g) of ten unopened cotton bolls per each plot was registered at 134 DAS.

In each of the two harvest passes made at 126 and 162 DAS, the weight of raw cotton in the useful plot area (kg) was recorded. Subsequently, the production was accumulated in kg $plot^{-1}$ and from this, it was transformed to yield per hectare (kg ha^{-1}). An economic analysis of the treatments was performed by calculating a partial budget, using the CIMMYT methodology with calculation of net profit, variable costs and marginal rate of return (CYMMYT, 1988).

Statistical analysis

Prior to the analysis of variance (ANOVA), the tests of Shapiro-Wilk and Bartlett were performed to verify the existence of normality in the residues and homogeneity of variances in the treatments, respectively. When the F test was significant between treatments, comparisons were made in between means using Tukey's test ($P<0.05$). In addition, comparisons were made between groups, factorial vs. control, by orthogonal contrasts. Statistical analyses were performed with software R (R Studio Team, 2019). The graphs were made with GraphPad Prism® software, version 5.01.

Results and Discussion

At 125 DAS, a statistically significant difference ($P<0.05$) was observed in the plant height variable due to application frequency of mepiquat chloride as plant growth regulator (MC) (Table 3). In a single application of the growth regulator at 50 DAS, the plants exhibited a significantly increased height of 123.09 cm, conducive to optimal crop production. In contrast, plants subjected to two applications at 50 and 70 DAS displayed a notably lower average height of 105.94 cm at 125 DAS. This reduction of 17.15 cm in height observed in the doubly treated plants is attributed to the cumulative impact of the growth regulator applications (Table 3). Regarding the various doses tested, although no statistically significant differences were found, it is noteworthy that the application of the lowest dose (300 mL ha^{-1}) resulted in taller plants measuring 118.15 cm at 125 days (Table 3). These results are similar to Murtza *et al.* (2022), who evaluated the high-yielding cotton line PB-896 found in an early application of MC (50 DAS) to reduce the morphological attributes of cotton. Pereira *et al.* (2008) found that with a single application of MC at 40 days after cotton germination, the plants reduced their height significantly compared to fractional applications of two and three times. According to Cordeiro *et al.* (2021) mepiquat chloride applied at early stages of cotton growth (first flower buds) reduced root length regardless of the rate used, and this happens approximately 2 weeks after application, regardless of the cultivar.

Table 3: *Average values of application frequency and dosage of mepiquat chloride as a growth regulator on agronomic traits in the Coker cotton variety, Teodomira, Santa Ana.*

Factors	Plant height (cm)	Stem diameter (mm)	Daily height increase (cm/day) in productive stage	Apical internodes length (cm)	Leaf greenness index (SPAD)
Application frequency (A)	P<0.05	P>0.05	P<0.01	P<0.01	P<0.01
50 DAS	123.09 a	17.21	0.54 a	2.40 a	51.75 b
50 –70 DAS	105.94 b	16.56	0.30 b	1.94 b	55.01 a
50 –70 –80 DAS	111.66 ab	16.75	0.35 b	1.92 b	55.81 a
Dosage - mL ha^{-1} (B)	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
300 mL	118.15	17.00	0.46	2.19	53.06
600 mL	111.73	16.70	0.37	2.05	54.86
900 mL	113.50	16.96	0.38	1.92	54.54
1200 mL	110.87	16.70	0.38	2.17	54.30
Interaction AxB	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Mean	113.56	16.84	0.40	2.08	54.19
CV (%)	12.63	9.20	31.88	18.00	5.32

Means followed by the same letter did not differ statistically from each other according to Tukey's test (P<0.05). DAS = days after sowing.

In the comparison between the factorial treatment and the control group (absence of PGR), statistical differences were evident (P<0.01) at 125 DAS (Figure 1A). The factorial treatment involving MC exhibited a significant diminished plant height, registering a reduction of 33.69 cm attributable to the application's impact. These results confirm the regulatory action of the growth regulator, i.e., MC, since this substance in the plant makes impossible the synthesis of the enzyme involved in the production of gibberellic acid (GA) in plant tissue, thus reducing cell growth and elongation (Schott and Heydenfort, 1981; Hake *et al*., 1991; Rosolem *et al*., 2013). MC reduced plant gibberellin synthesis between 2 and 10 days after application (Cordeiro *et al*., 2021). It is worth noting that this reduction in plant growth did not exert any discernible influence on stem diameter (Table 3; Figure 1B), that could mean that the reduction of the height of the plant does not affect its robustness and development.

The growth-regulating effect of MC may vary depending on the variety of cotton. For instance, Pereira *et al*. (2008) found that the BRS 201 variety had a greater growth in height than the BRS Camaçari variety when MC was applied to both. The increase in height was greater at 77 days after germination, but the use of a plant growth regulator (PGR) did not allow the plants to exceed a height of 43 cm. Similarly, in a trial conducted by Poquiviqui (1999), it was found that the use of MC had a significant effect (P = 0.0046) on the reduction in total height of the plants, with the plants treated with MC being on average 6.8 cm shorter than those that did not receive the treatment. In this experiment, this reduction was 33.69 cm in plants treated with MC at 125 DAS.

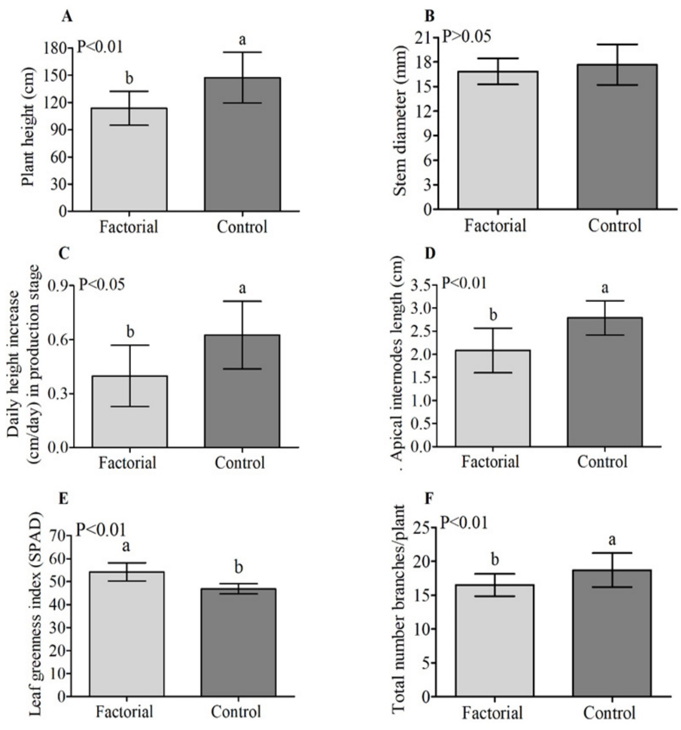

Figure 1: *Comparative analysis between treatments with growth regulator vs. control (no growth regulator), in plant height (cm) (A), stem diameter (mm) (B), daily height increase (cm/day) in production stage (C), apical internodes length (cm) (D), leaf greenness index (SPAD)(E) and total number branches/plant (F) in the Coker cotton variety.*

The daily increase in plant height in production showed a highly significant response (P<0.01) to frequency of application of the growth regulator (Table 3). When the MC was applied at a single instance (at 50 DAS), the plants exhibited a significantly higher daily growth rate during the production stage (73-125 DAS) in comparison to the other two treatments involving MC application on two or three occasions (Table 3). The length of the five apical internodes showed statistically significant difference (P<0.01) in the frequency application of MC (Table 3). Specifically, when the PGR was applied at 50 DAS, internodes exhibited greater length, while the other two application periods resulted in statistically equal, shorter internodes. In the orthogonal comparison between treated and untreated plants with PGR, significant differences were noted in the daily height increase (cm) during the production stage and the length of internodes (Figure 1C, D).

Comparable findings were reported by Reddy *et al.* (1990) and Wang *et al.* (2014), demonstrating reductions in internode length compared to the control group. Similarly, Wang *et al.* (2020) noted a significant reduction in plant height and internode length following the application of mepiquat chloride PGR. This reduction was attributed to a notable decrease in the number of cells in the plant. In contrast, Cadena *et al.* (2002) did not observe significant differences in this variable in their research.

Leaf greenness index exhibited statistically significant differences (P<0.01) in relation to the frequency of application at 120 DAS, treatments involving the application of mepiquat chloride (MC) in two and three separate periods, differed significantly from the treatment where MC was applied in a single instance. These treatments demonstrated higher mean values of the greenness index, measuring 55.81 and 55.01, respectively (Table 3). Furthermore, a significant disparity was observed in the comparison of groups (P<0.01) at 120 DAS. Plants treated with the growth regulator (MC) exhibited a notably higher leaf greenness index value of 54.19, in contrast to the control group without MC, which registered a value of 46.84 (Figure 1E).

The observed difference of 7.35 units in favor of plants treated with mepiquat chloride (MC) confirms the positive impact of these substances on chlorophyll production, thereby enhancing the photosynthesis process. These findings are consistent with Morales *et al.* (2004), who explored the effect of MC on photosynthesis in cotton noted that chlorophyll indices did not show significant value until 80 days after emergence (DDE), suggesting that until that specific period, MC did not exert any influence on the total chlorophyll concentration. This is according to Rosolem *et al.* (2013), that found with MC increased chlorophyll contents (SPAD) in cotton leaves.

The total number of branches per plant was significantly influenced by the growth regulator (MC), at 91 days after DAS (Table 4). The treatment where MC was applied only once (at 50 DAS) resulted in the highest total number of branches per plant. This was significantly different from the other two treatments where MC was applied in two or three periods, both of which showed a lower total number of branches per plant. However, the treatments did not have a significant influence, in the total number of flower buds (Table 4; Figure 2A). In the comparison between the factorial treatments and the control group (without MC), plants treated with MC exhibited significantly lowest total number of branches per plant (Figure 1F). This outcome can be attributed to the reduced height of these plants.

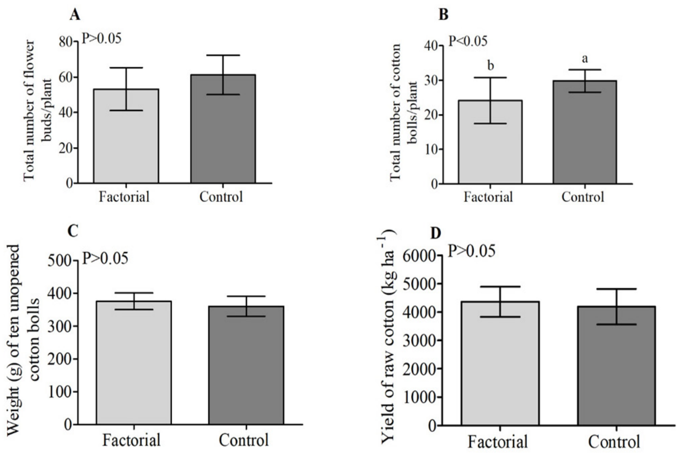

Figure 2: *Comparative analysis between treatments with growth regulator vs. control (no growth regulator), in total number of flower buds/plant (A), total number of cotton bolls/plant (B), weight (g) of ten unopened cotton bolls (C), and yield of raw cotton (kg ha^{-1}) (D) in the Coker cotton variety.*

In weight (g) of ten unopened cotton bolls per plot were observed significant differences (p<0.05) when varying growth regulator doses were applied (Table 4). In the comparison between the factorial treatments and the control group (without MC) there are not significant differences in cotton boll weight (Figure 2C). The 600 mL dose resulted in the highest boll weight at 387.67 g, while the 300 mL dose displayed the lowest weight at 359.83 g (Table 4). These findings

Table 4: *Average values of application frequency and dosage of mepiquat chloride as a growth regulator on productive traits in the Coker cotton variety, Teodomira, Santa Ana.*

Factors	Total number branches/plant	Total number of flower buds/plant	Total number of cotton bolls/plant	Weight (g) of ten unopened cotton bolls	Yield of raw cotton (kg ha^{-1})
Application frequency (A)	P<0.05	P>0.05	P<0.05	P>0.05	P<0.05
50 DAS	17.44 a	56.46	26.83 a	385.25	4641.60 a
50 –70 DAS	15.88 b	52.38	23.35 ab	369.50	4172.22 b
50 –70 –80 DAS	16.20 b	50.76	22.34 b	372.63	4279.17 ab
Dosage - mL ha^{-1} (B)	P>0.05	P>0.05	P>0.05	P<0.05	P<0.05
300 mL	16.57	55.32	26.53	359.83 b	4612.67 a
600 mL	16.73	52.40	24.20	387.67 a	4503.79 ab
900 mL	16.48	52.08	23.83	384.67 ab	4307.95 ab
1200 mL	16.23	53.00	22.12	371.00 ab	4032.91 b
Interaction AxB	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05
Mean	16.50	53.20	24.17	375.79	4364.33
CV (%)	8.54	20.97	20.37	6.24	10.15

Means followed by the same letter did not differ statistically from each other according to Tukey's test (P<0.05). DAS = days after sowing.

are consistent with those of McCarty and Hedin (1994), who reported increased boll weight and cotton boll height with the application of RCP, particularly on lower branches. In contrast, studies by Cadena *et al*. (2002) and Morales *et al*. (2004) indicated that the application of MC had no significant effect on cotton boll weight.

The application of MC in the agronomic traits of cotton plants could be influenced by other factors such as plant density, fertilization with N, temperature exposure (Leal *et al*., 2020; Rosolem *et al*., 2013; Yuan *et al*., 2021). Leal *et al*. (2020) suggested that the best results for fiber quality and yield occurred with the application of 76.8 mL ha^{-1} of mepiquat chloride to the cotton crop when the N dose was greater than 80 kg ha^{-1}. Rosolem *et al*. (2013) evaluated cotton plants grown under different temperature regimes and found that the higher temperatures increased plant height, reproductive branches, fruit number and abscission, and photosynthesis per unit area, but decreased leaf area and chlorophyll. The largest effect of MC on plant height was observed when the daily temperature was 32 °C, with nights of 22 °C, which was also best for plant growth. High temperatures not only decreased the effectiveness of MC on plant height control, but also caused lower dry matter and fruit number per plant. Low temperatures (25/15 °C) decreased cotton growth and fruit retention, but a higher concentration of MC was required per unit of growth reduction as compared with 32/22 °C.

Yield of raw cotton (kg ha^{-1}), showed significant differences (P<0.05) for frequency of application and dosage of MC (Table 4). In the comparison between the factorial treatments and the control group (without MC), there are not significant differences in yield of raw cotton (Figure 2D). The highest yield was obtained when the MC regulator was applied in a single period (50 DAS), which obtained a total yield of raw cotton of 4642 kg ha^{-1}, very different from when the MC regulator was applied in two periods (50 and 70 DAS), which reported significantly the lowest cotton yield (4172 kg ha^{-1}). This result was consistent with the study by Leal *et al*. (2020), who found that MC increased yield up to a dose of 76.8 mL ha^{-1} and that higher doses were detrimental to the crop; this decline could be caused by the excessive reduction of GA levels in the plant. Murtza *et al*. (2002) demonstrated that single foliar application of mepiquat chloride 5SL pre-defined crop times (50, 60 and 70 DAS) and MC application at 50 DAS decreased the rampant vegetative growth of cotton but did not increase the yield and yield related attributes. Contrarily, the late application of MC (70 DAS) reduced the days to flowering significantly, while increasing the yield and yield-related traits.

Based on the Marginal Analysis of Non-Dominated Treatments, the optimal economic choice is determined to be the application of the growth regulator (mepiquat chloride) at the lowest dosage of 300 mL per hectare, administered as a single application at 50 days after DAS. This specific treatment

Table 5: *Marginal analysis of non-dominated treatments in the application frequency and dosage of mepiquat chloride as a growth regulator on productive traits in the Coker cotton variety, Teodomira, Santa Ana.*

Treatments	NB (USD./ha)	VC (USD./ha)	MRBN (USD./ha)	MRVC (USD./ha)	MRR (%)	RRR
1	1798,8	271.38	69.36	104.48	66.39	50%
13	1729.44	166.9				

NB = Net benefit, VC = Variable Cost, MRNB = Marginal revenue of net benefit, MRVC= Marginal revenue of Variable Cost, MRR= Marginal Rate of Return, RRR = Required Rate of Return.

achieved the highest Marginal Rate of Return (MRR) at 66.39%, surpassing the Minimum Rate of Return (RRR) threshold set at 50%. It stood out as the sole treatment exceeding the RRR requirement, as outlined in Table 5. This result was consistent with the study of Yuan *et al*. (2021), that found the highest seed cotton yield (3423.1 to 3885.2 kg ha^{-1}) with the application of 270 g ha^{-1} MC on the cultivar CRRI50, a high yielding commercial short-season upland cotton cultivar.

Application of the growth regulator (mepiquat chloride) at the minimum rate of 300ml/ha, as a single application at 50 DAS, results in a reduced amount of product in the field, this not only helps to prevent chemical contamination, but also reduces the accumulation of high residual levels that could otherwise increase the possibility of mammalian toxicity.

Conclusions and Recommendations

Multiple applications of growth regulator (MC) reduced the plant height, number, and length of internodes per plant, total number of branches in the plant, and total number of cotton bolls, as well as yield. However, the leaf greenness index showed an inverse relationship. Increasing the growth regulator dosage also reduced the yield. Applying the MC regulator once (50 DAS) at the lowest dosage (300 mL per hectare) demonstrates the highest Marginal Rate of Return in production the Coker cotton variety.

Acknowledgements

The authors wish to express their gratitude for the GCP/RLA/199/BRA Trilateral South-South Cooperation project Fortalecimiento del Sector Algodonero por medio de la Cooperación Sur-Sur, also known as Proyecto + Algodón, signed by the Government of Brazil, through the Brazilian Cooperation Agency of the Ministry of Foreign Affairs (ABC/MRE), the Brazilian Cotton Institute (IBA) and the FAO Regional Office for Latin America and the Caribbean (FAO RLC), for providing the funds for this research.

Novelty Statement

With respect to the conditions of Santa Ana, Manabí, Ecuador, only one application of mepiquat chloride at 50 das is necessary, with the 300 mL ha^{-1} dose, to reduce the plant height in the cotton Coker variety.

Author's Contribution

Luis Fernando Díaz-Toral, Carlos Eddy Alvarado-Zamora and Gilmar Jesús Cañarte-Cañarte: Conducted the experiment and the data collection.
Ernesto Gonzalo Cañarte-Bermúdez: Conceived the study idea, designed and supervised the experiment, and helped in the writing and reviewing the manuscript.
Fernando David Sánchez-Mora: Contributed during writing up and editing of the manuscript.
José Bernardo Navarrete-Cedeño: Helped in the conducted the experiment and did data analysis and wrote-up of manuscript.

Conflict of interest
The authors declare that there is no conflict of interest.

References

Brubaker, C., F. Bourland and J. Wendel. 1999. The origin and domestication off Cotton. In: Smith C.W. and, J.T. Cothren. Cotton Origin, History, Technology, and Production. Wiley Series in Crop Science. New York. Chapter 1. pp. 23-32.

Cadena, J., W. Morales, H. Mosquera and A. Jarma. 2002. Efecto de cuatro dosis de Cloruro de Mepiquat sobre la concentración de clorofila y la fotosíntesis en el algodonero (*Gossypium hirsutum*). Agrosavia, pp. 69-74.

Cañarte-Bermúdez, E., R. Sotelo-Proaño and

B. Navarrete-Cedeño. 2020. Generación de tecnologías para incrementar la productividad del algodón *Gossypium hirsutum* L. en Manabí, Ecuador. Revista Ciencia Unemi, 13(33): 85-95. https://doi.org/10.29076/issn.2528-7737vol13iss33.2020pp85-95p

Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). 1988. La formulación de recomendaciones a partir de datos agronómicos: Un manual metodológico de evaluación económica. Programa de Economía: 1st ed. CIMMYT, México.

Cordeiro, C.F.S., I.F. Santos, P.R. Mello and F.R. Echer. 2021. Cotton root growth response to mepiquat chloride application in early reproductive stages are cultivar dependent. Crop Sci., 61(3): 1987-1995. https://doi.org/10.1002/csc2.20478

Dunne, R., D. Desai, R. Sadiku and J. Jayaramudu. 2016. A review of natural fibres, their sustainability and automotive applications. J. Reinforced Plastics Composit., 35(13): 1041-1050. https://doi.org/10.1177/0731684416633898

Environmental Protection Agency (EPA). 1997. Fact Sheet for Mepiquat chloride. (https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-109101_1-Mar-97.pdf)

Espinosa, M.G.C. and D. Suárez-Duque. 2019. El sector algodonero en Ecuador: Desafíosy oportunidades de la cadena de valor. Rev. Anales, 1(377): 91-101.

Gahan, H. and J. Zavala. 1999. Importancia y Manejo de los Reguladores de Crecimiento en el Rendimiento del Cultivo de Algodón. Revista de la Facultad de Agronomía, 19(3): 267-274.

García L.D.R. and O.J.M. Carnero. 1991. El Algodón. Madrid: Ediciones Mundi-Prensa.

Hake, K., T. Burch, L. Harvey, T. Kerby and J. Supak. 1991. Plant population. Physiol. Today, 2(4): 1-4.

Leal, A.J.F., G.L. Piati, R.C. Leite, M.S. Zanella, C.R.W.S. Osorio and S.F. Lima. 2020. Nitrogen and mepiquat chloride can affect fiber quality and cotton yield. Rev. Brasil. Engenharia Agrícola e Ambiental, 24(4): 238-243. https://doi.org/10.1590/1807-1929/agriambi.v24n4p238-243

Li, W.X., M. Chen, W.T. Chen, C.K. Qiao, M.H. Li and L.J. Han. 2012. Determination of mepiquat chloride in cotton crops and soil and its dissipation rates. Ecotoxicol. Environ. Saf., 85: 137-143. https://doi.org/10.1016/j.ecoenv.2012.08.015

McCarty, J.C. and P. Hedin. 1994. Effects of 1, l-Dimethylpiperidinium chloride on the yields, agronomic traits, and allelochemicals of cotton (*Gossypium hirsutum* L.), a nine year study. J. Agric. Food Chem., 42(10): 2302–2304. https://doi.org/10.1021/jf00046a041

Morales, W.R., H. Mosquera, A.J.Y. Jarma. 2004. Efectos del cloruro de mepiquat en la fotosíntesis y parámetros del rendimiento en algodón (*Gossypium hirsutum* L.) var Gossica MC23. Temas Agrarios, 9(2): 5-12. https://doi.org/10.21897/rta.v9i2.622

Murtza, K., M. Ishfaq, N. Akbar, S. Hussain, S.A. Anjum, N.A. Bukhari, A.M. AlGarawi and A.A. Hatamleh, 2022. Effect of mepiquat chloride on phenology, yield and quality of cotton as a function of application time using different sowing techniques. Agronomy, 12: 1200. https://doi.org/10.3390/agronomy12051200

Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). 2017. El estado de arte del sector algodonero en países del Mercosur y asociados. https://www.fao.org/3/i7740s/i7740s.pdf.

Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). 2018. Estudio nichos de mercados del algodón. https://www.fao.org/3/I8813ES/i8813es.pdf.

Pereira, J., W. Araujo, G. Carvalho, F. de Lima and S. de Sousa Junior. 2008. Modos de aplicação do cloreto de mepiquat em duas cultivares de algodoeiro herbáceo. Embrapa Algodão. Ministério da Agricultura, Pecuaria e Abastecimento. Comunicado técnico pp. 356.

Poquiviqui, L.G.V., 1999. Comportamiento de dos variedades de algodón (*Gossypiunt hirsutum* L.) sembradas a tres densidades con el uso de un regulador de crecimiento en el Zamorano, Honduras. Ceiba, 40(1): 131.

R Studio Team, 2019. R studio: Integrated development for R, version 3.6., Boston, MA.

Reddy, V.R., D.N. Baker and H.F. Hodges. 1990. Temperature and mepiquat chloride effects on cotton canopy architecture. Agron. J., 82: 190-195. https://doi.org/10.2134/agronj1990.00021962008200020004x

Reyes, P.M.M., 2014. El-Algodón Pima Peruano: Cultivo y Manejo Agronómico. Fondo Editorial de la Universidad Nacional de Piura: 1ra ed. Chiclayo, Perú.

Rosolem, C.A., D.M. Oosterhuis and F.S. de Souza. 2013. Cotton response to mepiquat chloride and temperature. Sci. Agricola, 70: 82–87. https://doi.org/10.1590/S0103-90162013000200004

Schott, P. and R. Heydendorff. 1981. Pix: Un biorregulador para el algodón. BASF reporte agrícola. Edición especial.

Sion, M.F., 1992. Manual del cultivo del algodón. Ecuador: INIAP, Estación Experimental Portoviejo.

Wang, C., C. An, N. Li, C. Sun, Y. Shen, S. Zhan, X. Li and Y. Wang. 2023. Long-lasting growth regulation on cotton using mepiquat chloride adsorbed layered double hydroxide. Adv. Agrochem., https://doi.org/10.1016/j.aac.2023.08.003

Wang, L., C. Mu, M. Du, Y. Chen, X. Tian, M. Zhang and Z. Li. 2014. The effect of mepiquat chloride on elongation of cotton (*Gossypium hirsutum* L.) internode is associated with low concentration of gibberellic acid. Plant Sci., 225: 15-23. https://doi.org/10.1016/j.plantsci.2014.05.005

Wang, L., Y. Yin, L.F. Wang, M. Wang, M. Zhao, Y. Tian and Y. Li. 2020. Transcriptome profiling of the elongating internode of cotton (*Gossypium hirsutum* L.) seedlings in response to mepiquat chloride. Front. Plant Sci., 10: 1-18. https://doi.org/10.3389/fpls.2019.01751

Weaver, R., 1982. Reguladores del crecimiento de las plantas en la agricultura. 2da ed. México: Trillas SA.

Yuan, C., L. Zhen-yu, H. Li, L.I.M. Tambel, Z. Xiang, C. Yuan and C. De-hua. 2021. Effects of plant density and mepiquat chloride application on cotton boll setting in wheat–cotton double cropping system. J. Integr. Agric., 20(9): 2372–2381. https://doi.org/10.1016/S2095-3119(20)63286-5