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Cotton root and shoot growth as affected by application of mepiquat chloride to cotton seeds

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ABSTRACT. The effects of mepiquat chloride (MC) application to cotton seeds on the initial growth of the plant roots and shoots were studied in a greenhouse experiment. Glass-front containers with 27 L of soil were used in the experiment. Cotton seeds of the cultivar FM 993 were sprayed with MC at five different doses of active ingredient (a.i.): 0, 3, 6, 9 and 12 g kg⁻¹ seed. The shoot and root dry matter, leaf area, shoot:root ratio, leaf area: root growth ratio, and shoot length were evaluated 21 days after sowing. The root growth was evaluated every three days up to 18 days. The application of MC to cotton seeds decreased the shoot length but had no significant effect on the dry matter production, root length, shoot:root ratio or leaf area: root length ratio. Thus, the application of MC to cotton seeds is not expected to have a deleterious effect on plant water acquisition.

Keywords: plant regulator, *Gossypium hirsutum*, decrease.

Crescimento radicular e da copa do algodoeiro em função da aplicação de cloreto de mepiquat às sementes

RESUMO. Estudou-se o efeito do tratamento de sementes de algodão com cloreto de mepiquat sobre o crescimento inicial de raízes e parte aérea. O experimento, realizado em casa de vegetação, utilizou vasos de PVC adaptados com uma parede frontal de vidro e os tratamentos foram constituídos por cinco doses do cloreto de mepiquat (CM) do ingrediente ativo (i.a.): 0, 3, 6, 9 e 12 g kg⁻¹ de sementes, pulverizado sobre as sementes, e a cultivar FM 993. Massa de matéria seca da parte aérea (folhas, pecíolos e haste), massa de matéria seca da raiz, área foliar, relação parte aérea:raiz, relação área foliar:crescimento radicular, o comprimento da parte aérea foram avaliados aos 21 dias após a semeadura. Crescimento radicular foi avaliado a cada três dias até os 18 dias. O CM aplicado às sementes do algodão promove redução da altura da planta e da área foliar, sem, contudo, afetar produção de massa de matéria seca da parte aérea e raiz, relação parte aérea:raiz, relação área foliar:crescimento radicular e comprimento total de raízes do algodoeiro. Assim, no presente experimento não foi observado efeito negativo do CM aplicado às sementes do algodoeiro na absorção de água pela planta.

Palavras-chave: regulador vegetal, *Gossypium hirsutum*, decréscimo.

Introduction

Manipulation of cotton (*Gossypium hirsutum* L.) plant architecture using growth regulators can be an agronomic strategy for obtaining high yields. Plant growth regulators (PGRs) are used at concentrations that are sufficient to reduce plant height, which allows more efficient interception of sunlight, but low enough to avoid phytotoxic effects (ROSOLEM, 2007). The use of these compounds to reduce plant height in cotton results in earlier maturity and, under some circumstances, increased yield. These products inhibit gibberellin biosynthesis, which implies that they cause growth reduction by decreasing cell elongation (TAIZ; ZEIGER, 2009).

The inhibitors of gibberellin synthesis act within the plant body, reducing the natural production of this hormone, modifying plant morphology and resulting in shorter plants. PGRs has been reported to affect the formation of cells and the elongation of the internodes below the meristem (TAIZ; ZEIGER, 2009). The shrinkage of the internodes is caused by the inhibitory effects of PGRs on the division and elongation of the sub-apical meristem without restricting the function of the apical meristem, which is responsible for stem growth and extension.

Obtaining cotton plants with an adequate height for growing with smaller between-row spacings and at higher population densities than usual is important for the success of the crop, particularly

when it is planted during non-ideal periods (NAGASHIMA et al., 2005).

Mepiquat chloride, 1,1-dimethylpiperidin chloride (MC), is a synthetic growth retardant used to control plant height in cereals and other crops, especially in cotton (McCARTY; HEDIN, 1994). In cotton, the smaller plants have better flower bud and boll retention on the lower reproductive branches, a shorter life cycle and quicker ripening and harvest.

MC modifies the rooting pattern because acts in the partition of biomass, inhibiting the growth certain parts and increasing other, this way cotton crop can be more efficient and improve water stress resistance (LAMAS et al., 2000), and Nagashima et al. (2005) have confirmed this finding under Brazilian conditions by applying MC to cotton seeds to reduce plant height from emergence. This application reduced plant shoot and root growth, but despite being advantageous from an operational point of view, soaking the seeds could lead to a decrease in the root growth rate, which would result in plants more susceptible to water deficit in their initial growth stages. Thus, it is important to study the effect of this substance on cotton root growth as related to shoot growth.

Therefore, the objective of the present experiment was to study the effects of MC applied to cotton seeds on the initial growth of plants and the shoot root⁻¹ ratio.

Material and methods

The experiment was carried out in a greenhouse at the College of Agricultural Sciences, São Paulo State University at Botucatu, 22°51' S, 48°26' W and 786 meters above sea level between October and December 2008. Glass-walled pots were built from PVC tubes 60 cm high and 30 cm in internal diameter cut in half longitudinally, with a 5-mm thick glass inserted in the cutting plane to allow the roots to be seen. Each pot was filled with 27 L of soil that had been limed and fertilized in the field.

According to Embrapa (2006), the soil is classified as Red Nitisol (Alfisol). The glass wall was covered with a wooden sliding cover to allow normal growth.

For all treatments, The FiberMax 993 (FM 993) cultivar was used. The MC was applied to the seeds at the following doses of active ingredient (a.i.): 0, 3, 6, 9 and 12 g kg⁻¹ of seed.

The cotton seeds were placed in a plastic tray, and MC was sprayed directly over them. Then, they were manually shaken for one minute to achieve uniform distribution and placed in Petri dishes to promote product absorption. After 30 minutes, four seeds were placed near the glass wall of each pot, and after emergence, they were thinned to one plantlet per pot. Water was added to maintain the soil within 80% of water retention capacity by weighing 10% of the pots every day to estimate water loss.

Root growth was determined at six evaluation points (every three days up to 18 days) by drawing the visible roots on a transparent plastic sheet placed over the glass of the pots. At the end of the experiment, the plastic sheets were placed over a 0.5 x 0.5-cm grid, and root length was determined for each period using the Tennant (1975) intersection method. To determine the length of the roots, the values obtained by counting the intersections were used in the following equation:

$$R = \frac{11}{14} \times N \times G$$

where:

R = root length (cm);

N = number of intersections;

G = mesh unit (cm).

The following characteristics were evaluated 21 days after sowing (DAS): shoot and root dry matter, leaf area, shoot root⁻¹ ratio, leaf area root⁻¹ length ratio, shoot length and root growth. The leaf area was determined using a bench-top leaf area integrator (LICOR 3100), and the shoots and roots were dried in a forced-air oven at 65°C for 72 hours to determine the dry matter weight.

A complete randomized block experimental design was employed, and four replicates were performed. The results were submitted to analysis of variance (ANOVA), regression analysis was carried out by F test ($p < 0.05$) for variables that presented significant differences among treatments. The equations were adjusted for root growth and the significant model with the greatest determination coefficient was chosen.

Results and discussion

No significant differences due to the treatments were observed for the shoot and root dry matter yields, shoot root⁻¹ ratio, leaf area root length⁻¹ ratio, root length or root growth (Tables 1 and 2).

Table 1. Summary of the ANOVA (mean squares) results on the effects of mepiquat chloride applied to cotton seeds on plant shoot length, shoot dry matter yield, root dry matter yield, shoot-to-root ratio, leaf area, root growth and leaf-to-root-growth ratio.

VF	DF	MS						
		Shoot length	Stem dry matter	Root dry matter	Leaf area	Root growth	Shoot:Root ratio	Leaf area: Root growth ratio
Treatments	4	4.18*	0.06 ^{ns}	0.02 ^{ns}	0.000**	315.18 ^{ns}	0.79 ^{ns}	0.001 ^{ns}
Block	3	1.20 ^{ns}	0.02 ^{ns}	0.01 ^{ns}	0.0001 ^{ns}	1109.06 ^{ns}	0.42 ^{ns}	0.002 ^{ns}
Error	12	1.61	0.07	0.02	0.0001	1621.52	0.70	0.003
VC (%)		10.64	26.52	31.55	1.91	18.78	36.78	20.91
General mean		11.91	0.09	0.47	0.52	214.56	2.28	0.25

ns = not significant, *and **are significant at $p < 0.05$ and $p < 0.01$ respectively. VF = Variation font, DF = Degree of freedom, MS = Mean squares, VC = Variation coefficient.

Table 2. Summary of the ANOVA (mean squares) results on the effects of mepiquat chloride applied to cotton seeds on root growth for each evaluation (1st, 2nd, 3rd, 4th, 5th and 6th evaluations)¹. Results are not cumulative.

VF	DF	MS					
		1 st	2 nd	3 rd	4 th	5 th	6 th
Treatments	4	4.17 ^{ns}	106.53 ^{ns}	133.22 ^{ns}	28.87 ^{ns}	128.93 ^{ns}	225.44 ^{ns}
Block	3	10.75 ^{ns}	101.78 ^{ns}	161.72 ^{ns}	26.08 ^{ns}	136.56 ^{ns}	77.59 ^{ns}
Error	12	5.22	263.69	277.19	42.03	117.69	31.19
VC (%)		20.45	31.28	31.84	17.80	28.16	23.04
General mean		11.17	51.92	52.29	36.42	38.52	24.24

ns = not significant, *and **are significant at $p < 0.05$ and $p < 0.01$ respectively. VF = Variation font, LD = Degree of freedom, MS = Mean squares, VC = Variation coefficient. ^{1st} = first evaluation of root growth; ^{2nd} = second evaluation of root growth; ^{3rd} = third evaluation of root growth; ^{4th} = fourth evaluation of root growth; ^{5th} = fifth evaluation of root growth; ^{6th} = sixth evaluation of root growth.

Iqbal et al. (2005) reported increasing on cotton dry matter and observed significant effects when applied MC to the seeds at a high dose (2000 mL L⁻¹), but Nagashima et al. (2007) observed no effects when they applied MC to a cotton cultivar IPR 120, through seeds and leaf pulverization (17 and 32 days after emergence). However, in other studies, MC applied to seeds has caused a decrease in the cotton leaf dry matter yield, with no significant effect on the root dry matter yield (NAGASHIMA et al., 2010). When the cotton plant is treated with MC, the leaf, stem and root dry matter may also be decreased (ZHANG et al., 1990) with increasing doses of the regulator. Thus, the response of cotton to MC seems to be highly variable and depends not only on the way in which this growth regulator is applied (either to the seed or leaf pulverization), but it also depend on the concentration at which it is applied.

The main objective of the use of a plant growth retardant with MC is the inhibition of gibberellin synthesis, hence the effects on dry matter yields might be related to carbohydrate transport because cotton growth and development are closely related to favorable weather conditions and adequate water and nutrient availability (ELKOCA; KANTAR, 2006; HAQUE et al., 2007; TAIZ; ZEIGER, 2009; TARI, 2004). The use of MC as a plant growth retardant can help in attaining an adequate balance between shoot and root growth, therefore increasing the transport of metabolites to organs that favor greater yield (for instance, to fruits). However, if any physiological alteration in the pathway occurs, these metabolites can be directed to other parts of the plant.

Shoot length was significantly affected by MC, with a linear decline and a total decrease of 79.5% when compared with the control (Figure 1). Nagashima et al. (2005) found similar results when cotton seeds were soaked in MC, and this effect was observed until 49 days after emergence. In later work, Nagashima et al. (2007) observed that soaking cotton seeds in an MC solution resulted in a linear reduction in plant height in the first weeks of growth (26.1% less than the control at a dose of 7.5%). Athayde and Lamas (1999) also reported a decrease in cotton height and a result similar to that of Zhao and Oosterhuis (2000) was observed until 21 days after sowing even though MC was sprayed on cotton leaves rather than seeds, as in the present study. Teixeira et al. (2008) also reported significant differences in cotton plant height, cultivar FMX 986, when MC was used in the leaves, and according to the authors, this effect could be attributed to the anti-gibberellin effect of the product. Yeates et al. (2005) also observed shorter plant when the seed surfaces were treated with MC.

In the present experiment, a quadratic model $\hat{y} = 0,001x^2 - 0,016x + 0,568$ ($R^2 = 0.8173$) was fitted to the leaf area results, and treatment with MC resulted in a 14.1 % decrease compared to the control treatment (Figure 2). Similar results were obtained by Nagashima et al. (2005, 2010), who found that MC reduced the shoot length and leaf area. The authors explained that this compound inhibits leaf expansion, consequently lending plants a more compact architecture. Souza and Rosolem (2007) also observed a decrease in cotton leaf area when plants were treated with this growth regulator.

In an experiment carried out by Reddy et al. (1996), plants treated with MC presented a leaf area 16% smaller than the control treatment. Reduced leaf area was found by many authors that used MC, and although cotton plants of cv. FM 993 presented similar results, the shoot and root dry matter production were not significantly influenced by the product when it was applied directly to the seeds.

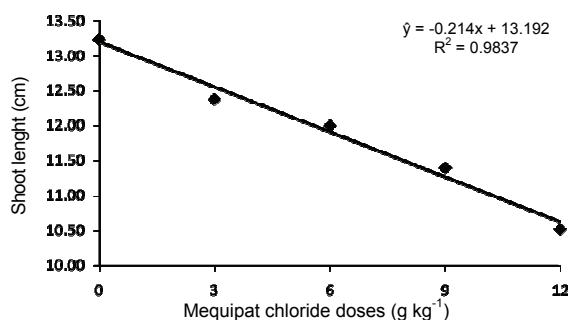


Figure 1. Cotton shoot length as affected by mepiquat chloride applied to seeds.

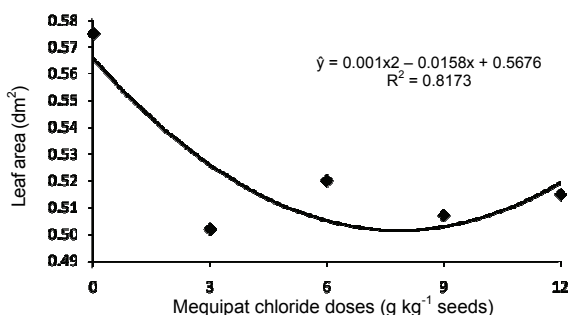


Figure 2. Cotton leaf area as affected by mepiquat chloride applied to seeds.

Even though no significant differences were observed in cotton root lengths until day 15, the growth over time can be observed in Figure 3. At day 18, which corresponds to the sixth evaluation, the larger dose used in this work (12 g kg⁻¹ of MC) caused a decrease in root length (Table 2). Xu and Taylor (1992) did not observe root growth until 12 DAS in cotton seeds treated with 500 mg kg⁻¹ MC, but after 18 DAS, seedlings treated with this PGR grew faster than others. Similarly, Iqbal et al. (2005) found that root length increased with increasing doses of MC. According to Taiz and Zeiger (2009), gibberellins as well as auxins and cytokinins are important for root growth. Though MC inhibits gibberellin synthesis, in the present experiment, the hormonal imbalance did not significantly influence this variable.

However, Fernández et al. (1991) noticed that MC did not influence plant dry matter yields but

did affect the distribution this growth regulator both by inhibiting leaf expansion and branch growth as well as by increasing the growth of thin roots. According to that study the combination of these effects can lead to a greater capacity of plants to withstand water deficits because plants with smaller leaf area and more compact architecture lose less water by transpiration. In the present work, the lack of MC-induced effects on the initial growth of cotton roots suggests that this practice would not impair water acquisition by plants.

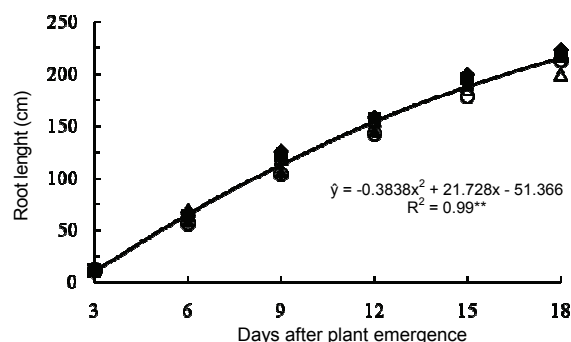


Figure 3. Cotton root growth over time. There were no significant differences observed at any MC concentration, so the line shows data averaged across five concentrations of MC (symbols).

In the present experiment, no significant differences were observed in shoot root⁻¹ ratios and leaf area root length⁻¹ ratios due to the application of MC to cotton seeds. Cotton root growth behaved similarly among the treatments. Though a greater dose of the product resulted in a slight (non-significant) decrease in length at 18 days after emergence, all values were similar to the control during the experiment.

The shoot root⁻¹ ratio is determined by a functional balance between water absorption by the roots and photosynthesis, meaning that the shoot will continue to grow until the water absorption by roots is reduced (TAIZ; ZEIGER, 2009). Therefore, the root shoot⁻¹ ratio and the leaf area root length⁻¹ ratio are developmentally correlated, and they express how root growth can affect the shoots and vice-versa (CARSON, 1974). When a reduction in leaf area occurs (which reduces carbon and energy consumption) a greater proportion of plant assimilates may be transported to the underground system to foster and sustain continuous root growth (TAIZ; ZEIGER, 2009). In this experiment, although the leaf area was decreased, no increase or decrease in root growth occurred under any treatment, including the control, which did not receive MC.

Conclusion

The application of MC to cotton seeds results in shorter plants, with no effects on shoot and root dry matter production, shoot root⁻¹ ratio or leaf area root length⁻¹ ratio. MC applied to the seeds decreases the cotton leaf area even without producing a significant effect on dry matter yields.

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