

Effects of mepiquat chloride applications on non-oilseed sunflower

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Abstract: Non-oilseed sunflower plants can be exposed to lodging in some production regions due to higher plant height and larger heads, which is further exacerbated by heavily rainfall and strong winds. In this context, plant growth regulators such as mepiquat chloride (MC) can be considered as an alternative approach in reducing plant height and lodging. This study was conducted to determine the effect of MC application on the growth, yield, and yield components of non-oilseed sunflowers at different growth stages (V4, R1, R2, and R3) and rates (0, 30, 60, and 90 g a.i. ha⁻¹) in Erzurum Province, eastern Anatolia, Turkey, in the 2012 and 2013 growing seasons. In general, the MC applications had significant effects on the plant parameters investigated. In comparison with the control treatment, the MC application of 60 g a.i. ha⁻¹ decreased plant height by 5.38% and increased stem diameter, head diameter, seed filling percentage, ratio of dehulled/hulled seed weight, 1000-achene weight, and seed yield by 14.01%, 3.78%, 1.61%, 4.20%, 5.94%, and 5.26%, respectively. Similarly, the applications of MC at different growth stages also significantly affected seed yield and other characteristics such as plant height, stem diameter, and head diameter. The application of MC at the early growth stage (V4) was more effective compared to the later growth stages (R1, R2, and R3). The results of this study suggest that the mepiquat application rate of 60 g a.i. ha⁻¹ in the early growth stage (V4) was more effective on the plant characteristics and that MC application could be effectively used as a means of reducing plant height and the risk of lodging in non-oilseed sunflower production.

Key words: Sunflower, *Helianthus annuus* L., growth stage, plant growth regulator

1. Introduction

Turkey is one of the few countries in the world that is largely self-sufficient in terms of food. The country's fertile soil, access to sufficient water, suitable climate, and hard-working farmers all make for a successful agricultural sector. In addition, a broad range of crops can be raised because of the variety of different climates throughout the land. This has allowed Turkey to become the largest producer and exporter of agricultural products in the Near East and North African regions (Açar et al., 2016; Bozokalfa et al., 2016; İpek et al., 2016). However, despite all efforts to increase oilseed crop production, Turkey continues to be import-dependent for oilseeds and products.

Sunflower is the most important oilseed crop of Turkey, with the production of approximately 650,000 ha annually (<http://www.fao.org/faostat/en/>). Most of the sunflower production areas in Turkey are devoted to oilseed sunflower types, and non-oilseed sunflower production is estimated to be practiced on about 100,000 ha, which corresponds to roughly one-sixth of the total harvested area. Eastern Anatolia is the largest geographical region of Turkey, where non-oilseed sunflower acreage accounts for

approximately 90% of the total harvested area (<http://www.fao.org/faostat/en/>). Sunflower is mainly grown for two principal marketing objectives: oilseed and non-oilseed (confectionery). Non-oilseed sunflower production, although a small, specialized market in comparison with oilseed sunflower, is nevertheless constantly growing in size and importance due to the increasing demand for sunflower seeds in the health-food, confectionary, and snack trades.

Plant growth regulators (PGRs) are natural or synthetic organic compounds that control or modify one or more physiological events in plants. These synthetic compounds are widely used in plants, especially in cereals, in reducing plant height. The most commonly used and known PGR group is the gibberellins. Gibberellins affect many physiological functions in plants. They are essentially responsible for controlling cell elongation and shoot and stem growth (Spitzer et al., 2011). When gibberellins are applied to plants, internodes become shorter and leaves become thicker and greener, increasing both drought resistance and net photosynthesis (Arteca, 1995). Mepiquat chloride (MC), which is a gibberellin acid

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inhibitor, inhibits cell elongation and limits overgrowth in plants. It also decreases the length of internodes and partially leaf area in plants and increases the concentration of chlorophyll in plant leaves, thus yielding increases of up to nearly 20% in plants treated with MC (York, 1983). The use of growth regulators such as MC to decrease plant height alters plant morphology and can alter assimilate partitioning in favor of seed growth by increasing radiation utilization efficiency. On the other hand, many PGR substances are also widely utilized in cereals and oilseed crops to facilitate harvesting and increase yield and quality. For this reason, they are thought to have high potential in many plants (Daniels et al., 1982). Sunflower grown under irrigated conditions is usually more productive but tends to have taller plants, causing plants to lodge. This is particularly true for non-oilseed sunflower types, with higher plant heights and larger heads. Resistance to lodging differs considerably among genotypes due to the differences in plant height and root development. In fact, reduced plant height is a desirable trait for improving machine harvest efficiency and facilitating pesticide applications against diseases and pests (Weiss, 2000; Koutroubas et al., 2004). This was achieved with oilseed sunflower by breeding studies, but unfortunately this is not the case for non-oilseed types. Nowadays, most genotypes of non-oilseed sunflower have higher plant heights and heavier heads. This situation poses a problem or may be a concern in non-oilseed sunflower production areas such as eastern Anatolia, which is characterized by stronger winds. Therefore, the application of PGRs seems to have important potential in reducing plant height and the risk of lodging of non-oilseed sunflower genotypes. However, there has been limited study on this subject. Wanderley et al. (2007) showed that paclobutrazol application decreased head diameter and plant height in sunflower. Spitzer et al. (2011) reported that the application of chlormequat chloride treatments combined with ethephon reduced plant height by 63 cm, while the application of ethephon

only reduced plant height by 35 cm. In another study, Koutroubas et al. (2014) also found that paclobutrazol and MC applications did not have a significant effect on the seed yield of non-oilseed sunflower but did cause plant height to decrease by 11.1% and 11.7%, respectively.

The response of plants to PGR applications can differ with plant growth stage, rates of application, and environmental conditions during the applications (Kim et al., 2003). Therefore, studies should be undertaken to determine the responses of non-oilseed sunflower to PGRs. The objective of this study was to determine the effects of MC applied at various rates and growth stages on the growth, yield, and yield components of non-oilseed sunflower.

2. Materials and methods

The field experiments were conducted at the experimental farm of Atatürk University in Erzurum in East Anatolia (29°55'N, 41°16'E; altitude of 1850 m), during the 2012 and 2013 growing seasons. The experimental field received 80 kg P₂O₅ ha⁻¹ in triple superphosphate form and 100 kg N ha⁻¹ in ammonium sulfate at sowing in both years. The experimental design was a randomized complete block design with three replications in each year. Treatments consisted of combinations of MC rates (0, 30, 60, and 90 g a.i. ha⁻¹) and four application stages. The growth stages were defined as follows (Schneiter and Miller, 1981): V4- this stage is counting the number of true leaves at least 4 cm in length, R1- the terminal bud forms a miniature floral head rather than a cluster of leaves and when viewed from directly above the immature bracts form a many-pointed star-like appearance, R2- the immature bud elongates 0.5 to 2 cm above the nearest leaf attached to the stem and leaves attached directly to the back of the bud are disregarded, R3- the immature bud elongates more than 2.0 cm above the nearest leaf. MC (Megahix, 50 g a.i. L⁻¹ Hektaş, Kocaeli, Turkey) was applied with a hand-pressurized knapsack sprayer fitted with a single flat-fan nozzle at 300 L ha⁻¹ application volume. Details of application times are presented in Table 1.

Table 1. Details of mepiquat chloride application times during growth seasons of sunflower in 2012 and 2013.

Application times				
	2012 growing season		2013 growing season	
Growth stage of crop	Date	DAS	Date	DAS
Vegetative stage (V4)	18 June	38	23 June	53
Reproductive stage (R1)	30 June	50	7 July	67
Reproductive stage (R2)	17 July	67	16 July	76
Reproductive stage (R3)	24 July	74	25 July	85

DAS, Days after sowing.

Air temperatures and precipitation values were collected from a meteorological station about 2 km north of the test site and are presented in Figure 1. The total amount of precipitation during the growing season of 2012 and 2013 was 133.6 mm and 81.9 mm, respectively. The average monthly temperature (16.2 °C) during 2012 and the 83-year average were above the average monthly temperature of the 2013 growing season (15.7 °C) (Figure 1). Preplanting soil samples were taken from a depth of 0 to 0.30 m and analyzed for residual nutrient levels. The soil at the experimental site was loamy with an organic matter content of 0.80% to 0.93% and a pH of 7.7 to 7.6. Available P_2O_5 of 41.7 and 39.6 kg ha⁻¹ and available K_2O of 1549 and 1494 kg ha⁻¹, respectively, were determined for the growing seasons of 2012 and 2013. Sowings were done on 11 May 2012 and 1 May 2013, respectively. The plots were 2.8 m wide and 5 m long and consisted of four rows spaced 0.7 m apart. Three seeds were sown on each hill, and the plots were hand-thinned to one plant per hill when the plants were at the four- to six-leaf stage. Weeds in the rows were removed by hand. All plots were furrow-irrigated regularly to avoid drought stress. A total of 4 irrigations each year were applied. The sunflower plants were hand-harvested at the stage of physiological maturation when the back of the head had turned from green to yellow and the bracts were turning brown. At harvest, 15 plants from each plot were selected to determine plant height, head diameter, stem diameter, seed filling percentage, ratio of dehulled/hulled seed weight, and 1000-achene weight. At maturity, head samples for yield were harvested from the two center rows on 27 September 2012 and 23 September 2013.

Data were analyzed by analysis of variance and means were separated by Fisher's protected LSD procedure (P

< 0.05) using the SAS computer program (SAS Institute, 2001). Regression models were calculated to determine the association of plant height and seed yield with MC rates.

3. Results and discussion

In this research, significant differences ($P < 0.01$) were found in the characteristics investigated between the study years, except for seed filling percentage (Table 2). The lower values were recorded in seed yield and yield components in the second growth season for the average of MC application rates and growth stages. The 2013 growing season was drier and cooler than the 2012 season, and the total amount of precipitation during the growth period was 133.6 and 81.9 mm in 2012 and 2013, respectively (Figure 1). The lower seed yield in the second year was probably due to the low rainfall during the seed filling stage of sunflower, which corresponded to July and August. It has been reported in many studies conducted in sunflower that low temperature and drought stress, especially during the seed filling period, significantly reduced seed yield (Botella Miralles et al., 1997; De la Vega and Hall, 2002; Özer et al., 2003; Montemurro et al., 2007; Nasim et al., 2012; Ozturk et al., 2017). Weather conditions during and after the applications, and especially winds and precipitation, can decrease the effect of MC (Barrabé et al., 2007). In our study, in fact, precipitations that occurred immediately after MC application (about 6–12 h later) during growth stages V4 and R1 in both years of our study seem to have decreased the effect of MC applications.

In this study conducted for 2 years, the effects of MC rates and the interaction of MC × growth stage on plant height were significant ($P < 0.01$). The application rates of 30, 60, and 90 g a.i. ha⁻¹ reduced plant height by 3.75%,

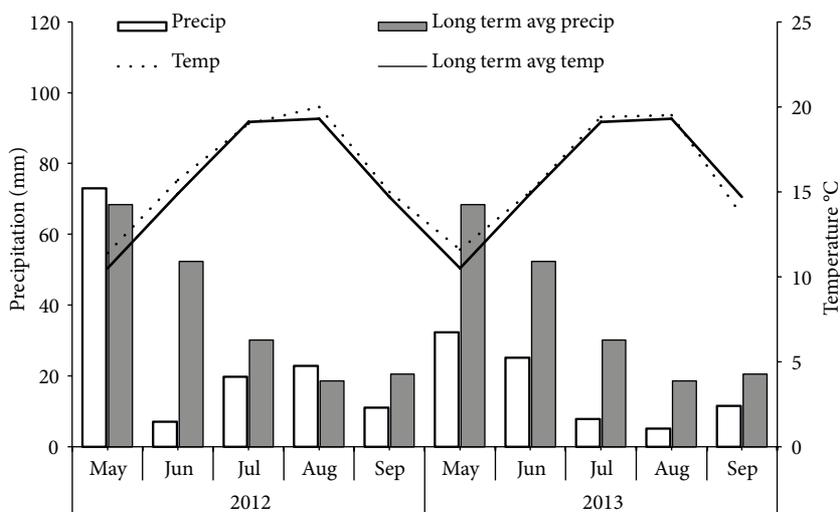


Figure 1. Monthly mean air temperature and precipitation during the growing season for each year of the study and the 83-year average for Erzurum, Turkey.

Table 2. The effects of mepiquat chloride rates and growth stages on plant height, stem diameter, head diameter, seed filling percentage, ratio of dehulled/hulled seed weight, 1000-achene weight, and seed yield of non-oilseed sunflower in Erzurum, Turkey, during 2012 and 2013.

Treatments		Plant height (cm)	Stem diameter (cm)	Head diameter (cm)	Seed filling percentage (%)	Ratio of dehulled/hulled seed weight (%)	1000-achene weight (g)	Seed yield (kg ha ⁻¹)
Years (Y)	2012	179.1 a	2.29 a	19.3 a	93.9	54.2 a	109.0 a	3437.2 a
	2013	178.3 b	2.27 b	18.6 b	93.8	53.1 b	101.9 b	3106.9 b
Rates (R)	0	183.8 a	2.14 d	18.5 bc	93.0 b	52.3 b	99.3 c	3035.5 c
	30	176.9 c	2.31 b	18.2 c	93.9 a	52.6 b	100.3 c	3090.3 b
	60	173.9 d	2.44 a	19.2 a	94.5 a	54.5 a	105.2 a	3195.2 a
	90	178.8 b	2.19 c	18.6 b	93.8 ab	53.0 b	102.6 b	3106.6 b
Growth stages (S)	V4	176.2 c	2.41 a	19.1 a	94.2	52.6	102.1	3149.2 a
	R1	178.1 b	2.26 b	18.3 b	93.5	52.9	101.6	3133.0 a
	R2	178.7 b	2.20 c	18.6 b	93.8	53.5	101.6	3074.4 b
	R3	180.4 a	2.21 c	18.5 b	93.6	53.4	102.1	3070.8 b
	df							
Source								
Y	1	**	**	**	ns	**	**	**
R	3	**	**	**	**	*	**	**
S	3	**	**	**	ns	ns	ns	**
Y × R	3	ns	ns	**	ns	ns	**	ns
Y × S	3	ns	ns	ns	ns	ns	**	ns
R × S	9	**	**	ns	ns	ns	**	**
Y × R × S	9	ns	ns	**	ns	*	**	**

*, **: Significant at the 0.05 and 0.01 levels, respectively. For each main effect, values within columns followed by the same letter are not significantly at $P = 0.05$. ns, Nonsignificant.

5.38%, and 2.72%, respectively, compared to control plots. The lowest plant height was 176.2 cm at the V4 stage, and among the growth stages the highest plant height was obtained at the R3 growth stage, with 180.4 cm (Table 2; Figures 2 and 3a). This difference among growth stages was found statistically significant ($P < 0.01$). These results indicate that plant heights differed according to MC rates and growth stages. It is well known that it is effective in reducing plant height. Decreasing gibberellin can affect the movement among cells due to decreased cell wall relaxation, decreased cell wall plasticity, and increased cell wall stiffness, thus inhibiting cell elongation and replication. This causes reduced plant height (Biles and Cothren, 2001; Gencsoylu, 2009). PGRs such as MC, a gibberellic acid inhibitor, can inhibit increases in plant

height, leading to thicker stems. It has also been reported by many researchers that plant height has been reduced by PGRs in different plants (Lamas et al., 2000; Iqbal et al., 2004; Balodis and Gaile, 2009; Espindula et al., 2009; Gencsoylu, 2009). It was found in a study by Spitzer et al. (2011) that the plant height of sunflower was reduced by 63 cm with application of chlormequat chloride plus ethephon and by 35 cm with only the application of ethephon. A study by Koutroubas et al. (2014) also demonstrated that different PGR applications or combinations reduced plant height in sunflower. A similar situation was also observed in our study. The effect of growth regulators on plant height in sunflower can vary depending on the active ingredients, types of growth regulator, and application time (Weiss, 2000). In our study, the heights of sunflower plants differed

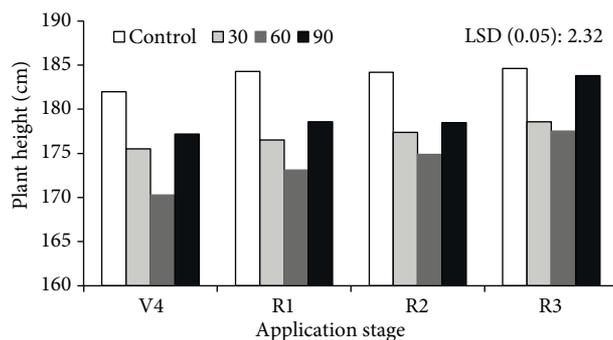


Figure 2. Effect on plant height of application rate and growth stage of mepiquat chloride as an average of both years.

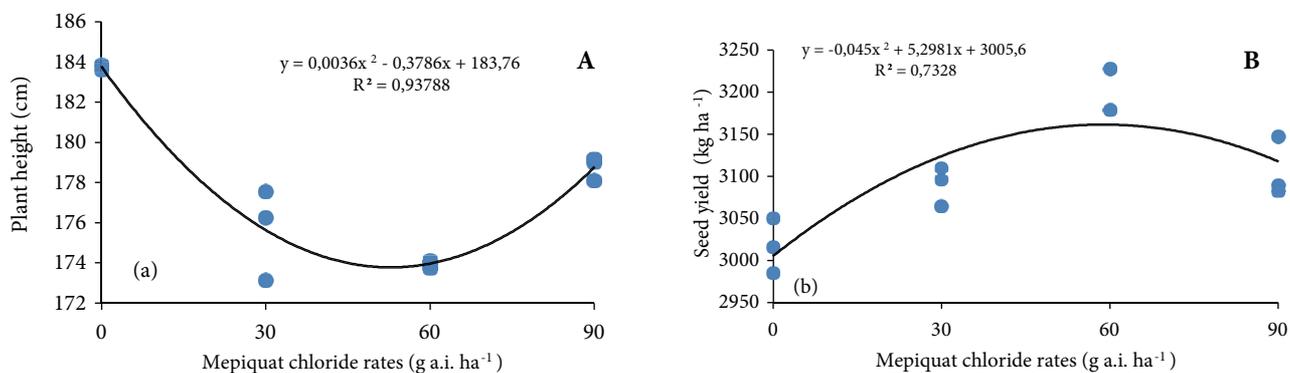


Figure 3. Relationship between mepiquat chloride rates for (a) plant height and (b) seed yield in non-oilseed sunflower for the 2-year data. Each point is the mean of three replications for treatment combinations.

according to growth stage. Previous research showed that treatment at an early growth stage (2 visibly extended internodes) was more effective on plant heights than at a late growth stage (bud in axil of the upper leaves 2–3 cm in diameter) (Spitzer et al., 2011). In our study, the plant heights observed at the early growth stage (V4) were lower than those in the other growth stages. The plant height values from our study were lower than those reported by other researchers (Spitzer et al., 2011; Koutroubas et al., 2014), who found that the differences could have resulted from the plant regulators used and agronomic practices and climate conditions.

MC application rates, growth stages, and application rate \times growth stage interaction had significant effects ($P < 0.01$) on stem diameter (Table 2). The MC applications led to an increase in stem diameter compared to control plots; the highest increase (12.30%) was obtained from the MC application of 60 g a.i. ha⁻¹. Stem diameter decreased with the proceeding growth stages, with the highest value from the first growth stage (V4). PGRs can cause thickened stems by inhibiting the increase in plant height. A similar situation occurred in our study, in which stem thickness increased with MC application. It is thought that the

increase in stem thickness may likely be due to reduced plant height. The study by Koutroubas et al. (2014) reported that there was no significant difference in stem diameter among the various growth stages, while paclobutrazol, MC, and chlormequat chloride applications increased stem thickness. Similarly, in another study on sunflower, Lovett and Campbell (1973) showed that chlormequat chloride applications increased stem diameter. In our study, the rates of MC also proved to be effective in increasing stem thickness and this effect was more prominent in the V4 vegetative period.

The head diameter is one of the important yield components in sunflower. Therefore, larger head diameter is a desired property by producers. Application rate, growth stage, year \times application rate, and year \times application rate \times growth stage interactions ($P < 0.01$) had significant effects on head diameter. The largest head diameter among MC applications was obtained from the rate of 60 g a.i. ha⁻¹. No significant change was observed among R1, R2, and R3 head diameter values with the advancing stages of growth; the head diameter was larger at the first growth stage (V4) (Table 2). Spitzer et al. (2011) found that different PGR applications, including chlormequat chloride, ethephon,

trinexapac-ethyl, and their combinations, did not cause any significant change in head diameter. The authors also reported that head diameter was affected by the growth stage and that growth regulators applied at the early growth stage (2 visibly extended internodes) were found to be more effective than those applied at a later growth stage (bud in axil of the upper leaves 2–3 cm in diameter).

As seen in Table 2, MC application had a significant effect ($P < 0.01$) on seed filling percentage, and the highest seed filling percentage was obtained from the MC application rate of 60 g a.i. ha⁻¹. The seed filling percentage at this rate was 1.61% higher than in the control plots. Although growth stages did not respond significantly to MC applications, the seed filling percentage was higher in the V4 growth stage. The increase in the amount of photoassimilates from outside of the sunflower head inwards via different PGR applications, as seen in previous studies (Beltrano et al., 1994), may cause a decrease in the percentage of empty achenes in the middle of the sunflower. This photoassimilate partitioning can increase the number of filled achenes. A similar result was obtained in our study and an increase in seed filling percentage occurred. In another PGR study conducted in sunflower, an increase was observed in seed filling percentages compared to the control plots (Koutroubas et al., 2014).

The effect of MC application rate and year × MC application rate × growth stage interaction for the ratio of dehulled/hulled seed weight was significant (Table 2). A change was observed in the ratio of dehulled/hulled seed weight of the sunflower depending on the MC application rate. The lowest value (52.3%) for ratio of dehulled/hulled seed weight was obtained from the control plots, and the highest one was obtained from the MC application of 60 g a.i. ha⁻¹ (54.5%) (Table 2). There was no considerable change among the growth stages in respect to the ratio of dehulled/hulled seed weight. Anitha et al. (2007) reported that in sunflower MC application increased the ratio of dehulled/hulled seed weight by 11.1% compared to control plots. A similar trend was found in our study, and MC

applications positively affected the ratio of dehulled/hulled seed weight.

The results of variance analysis for 1000-achene weight revealed significant differences for year, mepiquat chloride rates, and all interactions, except for growth stages (Table 2). Among the MC application rates, the lowest 1000-achene weight was obtained from the control plots (99.3 g) and the highest 1000-achene weight (105.2 g) was obtained from the MC rate of 60 g a.i. ha⁻¹ (Table 2). These results indicated that MC application positively affected 1000-achene weight. The MC applied during different growth stages had no significant effect on 1000-achene weight. As seen for head diameter, the number of seeds in a head also affects seed yield positively (Yasin and Singh, 2010). Since large seeds are preferred by consumers, seed size is an important trait in non-oilseed sunflower. Anitha et al. (2007) reported that different PGRs in sunflower, including salicylic acid, brassinosteroid, triiodobenzoic acid, and MC, increased 1000-achene weight, and the highest increase in 1000-achene weight was obtained from salicylic acid (6.30 g) and MC (5.25 g) applications relative to the control plots (3.72 g). It was reported in a similar study by Koutroubas et al. (2014) that in sunflower PGR applications (paclobutrazol, MC, and chlormequat chloride) had a negative effect on 1000-achene weight.

All factors and interactions except year × MC rate and year × growth stage were found to be significant for seed yield (Table 2). In this study, the MC rates applied during different growth stages had a positive effect on the seed yield. The MC application rates (30, 60, and 90 g a.i. ha⁻¹) increased seed yield by 1.81%, 5.26%, and 2.34%, respectively, compared to control plots, and the highest increase (5.26%) was observed with the MC application of 60 g a.i. ha⁻¹. It was observed during the study that the MC applications performed in the early growth stages of sunflower (V4 and R1) were more efficient than those performed in the later growth stages (R2 and R3) (Table 2; Figures 3b and 4). Among the current MC applications, the highest seed yield (3149.2 kg ha⁻¹) was obtained in the

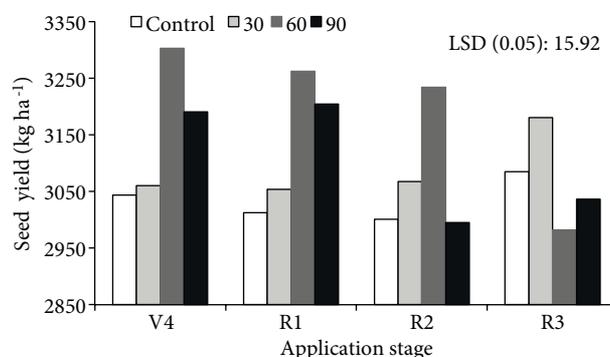


Figure 4. Effect on seed yield of application rate and growth stage of mepiquat chloride as an average of both years.

early growth stage (V4). Based on the results of this study, it can be said that it would be more appropriate to perform MC application for the seed yield of sunflower during the early growth stages. In this study, the positive effect of MC application on seed yield may be attributed to the increased head diameter, seed filling percentage, ratio of dehulled/hulled seed weight, and 1000-achene weight. It has been reported that the application of PGRs in the early growth stages of sunflower is more favorable in respect to the seed yield and yield components (Spitzer et al., 2011). It was emphasized in another study (Koutroubas et al., 2004) that PGRs are more efficient in the early growth stages (flowering and maturation) of sunflower, and the applications should be applied at the earlier growth stages of sunflower in order to obtain conclusive results from these applications. Similarly, there are many studies reporting beneficial effects of MC on plants such as peas, cotton, barley, and canola (Biles and Cothren, 2001; Sawan et al., 2001; Iqbal et al., 2004; Elkoca and Kantar, 2006). MC application has an effect on yield likely due to the fact that it promotes the physiological process in many plants, because of an increase in carbon dioxide uptake and fixation by plant leaves. MC applications may expand xylem transmission ducts in plant stems. This could possibly increase water and nutrient element uptake of

plants (Gausmann et al., 1980). The beneficial effect of MC and another PGRs on plants may be related to increased photosynthesis activity due to increased leaf area, dry substance ratio, net assimilation ratio, and leaf chlorophyll concentration by increasing photosynthesis activity in sunflower (Anitha et al., 2007).

In conclusion, in this study, the application of MC decreased plant height in non-oilseed sunflower but increased the stem and head diameter, seed filling percentage, ratio of dehulled/hulled seed weight, 1000-achene weight, and seed yield. It was observed that the mepiquat chloride rate of 60 g a.i. ha⁻¹, compared to the other rates of MC, produced more efficient results. These increases may be due to the effect of the MC on the morphological and physiological characteristics of sunflower plants. MC applied in the different growth stages had significant effects on plant height, stem diameter, head diameter, and seed yield. The best results were obtained from the vegetative growth stage (V4). These results showed that the MC application of 60 g a.i. ha⁻¹ performed in the early growth stage (V4) provided better results in non-oilseed sunflower. However, further studies are needed to investigate the responses of non-oilseed sunflower to MC under various climate conditions with different genotypes

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