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Hydroponic Tomato Yield Affected by Chlormequat Chloride, Seeding Time, and Transplant Maturity

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Abstract. **The addition of chlormequat chloride to tomato (*Lycopersicon esculentum* Mill.) transplants decreased fruit yield, number, and size. Flowering was accelerated both by chlormequat chloride and by transplanting at a more advanced stage of development. By transplanting a more mature plant without chlormequat chloride, yield was increased over the first 3 weeks of harvest. Although it is difficult to manage a "leggy" transplant, typical of flowering hydroponic tomato transplants grown under low light levels and close spacing, increased yield was sufficient to justify this management practice. Chemical name used: 2-chloro-*N,N,N*-trimethylethanaminium chloride (chlormequat chloride).**

In Indiana, a high price for hydroponic tomatoes is obtainable only until local outdoor-grown tomatoes become available in July. Since production during the low light levels of winter months is unprofitable, the grower must strive for early production of a spring crop to maximize return on investment. Early production can be obtained by early seeding and transplanting in the greenhouse. Delay of transplanting would reduce greenhouse heating costs because transplants occupy less greenhouse space during cold months, but result in "leggy" plants. In ground bed culture, transplants are grown in small pots to control growth rate by restricting root growth (8), whereas transplants for nutrient film technique (NFT) hydroponics are grown in porous cubes (which do not restrict root growth), making control of the associated top growth rate difficult.

Plant growth retardants are used in floriculture to decrease plant height and increase plant compactness and, consequently, aesthetic appeal. The objective of this study was to use chlormequat chloride, a plant growth retardant, to eliminate rapid stem elongation associated with tomato transplants grown in close spacing. Transplanting of resulting compact plants, which would be more advanced in development, should achieve early production and minimize heating costs.

Materials and Methods

On 1 Dec. and 1 Jan., 3 'Jumbo' tomato seeds were sown per rockwool cube ($3.81 cm^2$ grodan rockwool cubes, Agro Dynamics, Brooklyn, N.Y.), germinated at 25°C under an 18-hr photoperiod, and kept moist with deionized water. After germination, the seedlings were watered, until experiment termination, with a nutrient solution with the following composition: 4 mM $Ca(NO_3)_2$, 4 mM KNO_3, 2 mM KH_2PO_4, 2 mM K_2SO_4, and 2.5 mM $MgSO_4$. The micronutrients were applied as follows: Fe as $FeSO_4$ ($2.5 mg\cdot liter^{-1}$) and DTPA ($2.5 mg\cdot liter^{-1}$), B as H_3BO_3 ($0.5 mg\cdot liter^{-1}$), Mn as $MnSO_4$ ($1.0 mg\cdot liter^{-1}$), Zn as $ZnSO_4$ ($0.05 mg\cdot liter^{-1}$), Cu as $CuSO_4$ ($0.02 mg\cdot liter^{-1}$), and Mo as H_2MoO_4 ($0.01 mg\cdot liter^{-1}$).

Transplant system. When the cotyledons were fully expanded (8 days after seeding), seedlings were transferred to a recirculating nutrient solution system (4) in a greenhouse. Tomato seedlings were arranged in a split-split-plot design (one replication only) with seeding date (1 Dec. or 1 Jan.) as main-plot treatments, chlormequat chloride (Cycocel formulation, 11.8% a.i., American Cyanamid, Princeton, N.J.) application as subplot treatments and stage of development at transplanting as sub-subplots. Plant spacing was 15 cm within the trough and 30 cm between troughs. When seedlings reached the three-leaf stage, chlormequat chloride was added to the nutrient solution to establish a concentration of 10^{-4} M. This concentration was reestablished in the recirculating solution at 3 and 5 weeks after treatment initiation. This concentration was slightly high for the 1 Jan.-seeded plants, as indicated by leaf chlorosis. Chlormequat chloride at 10^{-4} M during winter months gave plant height reduction comparable to 10^{-5} M chlormequat chloride in summer months. This probably resulted from increased uptake of chlormequat chloride because of higher transpiration during the summer experiment.

Production system. Transplants were set into a NFT system as described by Wilcox (18) from the recirculating nutrient solution system (4) at two stages of development. The first stage

Table 1. Effect of chlormequat chloride and transplant development on time to flower from full cotyledon expansion stage.

Chlormequat chloride concn	Time to flower (days)		
	Transplanting stage		
	Bud^z	Flower^y	Mean^x
	Seeded 1 Dec.		
0	58.6	55.4	57.0
10^{-4} M	56.1	53.2	54.7*
Mean^v	57.4	54.3	---
	Seeded 1 Jan.		
0	47.5 a^w	44.5 c	46.0
10^{-4} M	46.1 b	41.4 d	43.7*
Mean^v	46.8	42.9	---

^{z}Tomato transplants set into NFT system 1 week after flower buds became visible.

^{y}Tomato transplants set into NFT system when 50% of the chlormequat chloride-treated plants had an open blossom.

^{x}*Significant from 0 rate, $P = 5\%$.

^{w}Mean separation within rows and columns for each seeding time by Newman–Keuls' multiple range test, 5% level, when interaction is significant.

^{v}Means of bud and flower different, $P = 1\%$.

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Table 2. Effect of chlormequat chloride and transplant development on plant height, leaf number, and cluster development.

Chlormequat chloride concn	Transplant stage	Bud stage^{z} Plant ht	Bud stage^{z} Leaf no.	Flower stage^{y} Plant ht	Flower stage^{y} Leaf no.	Height to first cluster	Total ht (cm)^{x}	No. clusters^{x}
0				*Seeded 1 Dec.*				
	Bud^{z}	21.0 a^{w}	10.9 a	33.0 b	14.2 a	35.0 b	136.0 a	6.2 a
	Flower^{y}	21.0 a	10.9 a	52.0 a	13.9 a	48.0 a	139.0 a	6.1 a
10^{-4} M								
	Bud	14.0 b	10.7 a	27.0 c	14.1 a	29.0 c	116.0 b	5.9 a
	Flower	14.0 b	10.7 a	25.0 d	13.9 a	28.0 c	103.0 c	5.3 b
0				*Seeded 1 Jan.*				
	Bud	17.0 a	9.9 a	32.0 b	13.0 a	40.0 b	100.0 a	4.1 a
	Flower	17.0 a	9.9 a	38.0 a	12.5 b	48.0 a	98.0 a	4.1 a
10^{-4} M								
	Bud	10.0 b	9.3 a	22.0 c	12.3 bc	30.0 c	78.0 b	3.9 a
	Flower	10.0 b	9.3 a	22.0 c	12.1 c	27.0 d	74.0 c	3.6 b

[z] Tomato transplants set into NFT system 1 week after flower buds became visible.

[y] Tomato transplants set into NFT system when 50% of the chlormequat chloride-treated plants had an open blossom.

[x] Measurement taken on 15 Mar.

[w] Mean separation within columns for each seeding time by Newman–Keuls' multiple range test, 5% level.

was 1 week after the flower buds became visible. The 2nd stage was when 50% of the chlormequat chloride-treated plants had an open blossom. The NFT system had a 160-plant capacity with four beds, treated as blocks, each having two troughs. The beds were on 1.4-m centers with 46 cm between troughs and 36 cm between plants within a trough.

The factorial experiment was arranged in a split-plot design with seeding time (1 Dec. or 1 Jan.) as the main-plot treatments assigned to troughs, and the treatment combination of chlormequat chloride application (with or without 10^{-4} M chlormequat chloride) and stage of development (bud or flower) as subplot treatments completely randomized within a trough.

The solution pH was adjusted to 6.0 with HNO_3 and nutrient solution composition maintained by monitoring solution electrical conductivity. The nutrient solution was pumped out every 2 weeks and renewed using deionized water as the source of water.

Tomato harvest started 25 Mar. and 11 Apr. for 1 Dec.- and 1 Jan.-seeded plants, respectively. Tomatoes were harvested twice weekly for 9 weeks, and yields were summed over 3-week periods. Individual fruits were separated by weight into two categories: those $\geq$170 g and those $<$170 g (fresh weight).

Results and Discussion

Flowering was accelerated by both chlormequat chloride and transplanting at more advanced development (Table 1). Early flowering (3–5 days) of mature transplants probably resulted from two different factors: a) increased rate of stem elongation of transplants not treated with chlormequat chloride, and b) increased dry matter partitioning into inflorescence of transplants treated with chlormequat chloride. Under a vegetative canopy, the red : far-red ratio (R:FR) and light intensity are always lower than in direct sunlight (11, 15). The stem elongation rate increases as R:FR (15) and light intensity (6, 14) decrease. As the tomato transplants in our experiment grew, their leaves began to overlap. As leaf overlap increased, less direct sunlight reached the plant. Therefore, more of the light reaching the plants was altered by the vegetative canopy (i.e., lower R:FR and light intensity). These changes in light quality and quantity produced elongated tomato transplants when not treated with chlormequat chloride. In an experiment with wheat, Friend et al. (5) hastened flowering by decreasing the R:FR. They concluded that the early flowering was the result of an increase in rate of stem elongation and floral development rather than by early flower initiation. Chlormequat chloride may accelerate flowering because it alters dry matter partitioning, i.e., inflorescence dry weight increases while shoot dry weight decreases (12). Dry matter partitioning becomes critical under light-limiting conditions when carbohydrate production is limited and vegetative growth is favored over fruit production. In preliminary studies, rate of flowering was the same as controls when tomato plants were treated with chlormequat chloride during the summer (data not shown). Accelerating flowering by chlormequat chloride has not been observed consistently. Consistency of response appears to be related to light level during application of chlormequat chloride. Under low light levels, chlormequat chloride was shown to hasten flower initiation from 2–6 days (2, 10, 17, 19), whereas, when light was not limiting, time to flowering was similar between chlormequat chloride-treated and control plants (1, 13).

Plant growth variables were affected similarly over seeding time and transplanting stage. Plant height and height of first cluster were decreased by chlormequat chloride (Table 2) and by transplanting a very young plant without chlormequat chloride before plant-to-plant light competition caused stem elongation associated with between-plant shading. However, total height on 15 Mar. was decreased only by chlormequat chloride. The number of clusters was decreased only by prolonged exposure to chlormequat chloride. Leaf number was unaffected by chlormequat chloride, except for the 1 Jan.-seeded transplants transplanted at flowering. Generally, leaf number has been reported not to be significantly affected (10).

Fruit weight. Chlormequat chloride decreased yield of large fruit ($\geq$170 g) over the 9-week harvest in both 1 Dec.- and 1 Jan.-seeded transplants (Table 3). Over the first 3 weeks of harvest, large fruit yield of 1 Dec.-seeded transplants was in-

Table 3. Effect of chlormequat chloride and transplant development on tomato fruit yield and number after 9 weeks of harvest.

Chlormequat chloride concn	Yield and no. of tomato fruit[z] Transplanting stage Bud[y]	 Flower[x]	 Mean[w]
	Large fruit wt (g)		
0	3118	3451	3285
10^{-4} M	2344	2014	2179 **
Mean (NS)[v]	2731	2732	---
	Small fruit wt (g)		
0	1301	1112	1207
10^{-4} M	1404	1267	1335 ***
Mean (*)	1352	1190	---
	Total fruit wt (g)		
0	4419	4563	4491
10^{-4} M	3747	3281	3514 **
Mean (NS)	4083	3922	---
	No. large fruit		
0	13.7	14.6	14.1
10^{-4} M	10.7	9.6	10.1**
Mean (NS)	12.2	12.1	
	No. small fruit		
0	11.0	9.0	10.0
10^{-4} M	11.1	9.7	10.4
Mean (**)	11.1	9.3	---
	Total no. of fruit		
0	24.7	23.6	24.1
10^{-4} M	21.8	19.2	20.5**
Mean (***)	23.2	21.4	---

[z] Average per plant over 1 Dec. and 1 Jan. seeding dates.

[y] Tomato transplants set into NFT system 1 week after flower buds became visible.

[x] Tomato transplants set into NFT system when 50% of the chlormequat chloride-treated plants had an open blossom.

[w] *, **, ***Significantly different from 0 rate at $P = 5\%$, 1%, or 10%, respectively.

[v] NS, *, **, ***Means of bud and flower stage not significant or different at $P = 5\%$, 1%, or 10%, respectively.

Table 4. Effect of chlormequat chloride and transplant development on yield of large fruit after first 3 weeks of harvest.

Chlormequat chloride concn	Yield of large fruit[z] Transplanting stage Bud[y]	 Flower[x]	 Mean[w]
	Seeded 1 Dec.		
0	172	283	227
10^{-4} M	124	165	144*
Mean (*)[v]	148	224	---
	Seeded 1 Jan.		
0	266	305	286
10^{-4} M	139	165	152*
Mean (NS)[v]	202	235	---

[z] Average yield per week within 3-week period.

[y] Tomato transplants set into NFT system 1 week after flower buds became visible.

[x] Tomato transplants set into NFT system when 50% of the chlormequat chloride-treated plants had an open blossom.

[w] *Significantly different from 0 rate within seeding date, $P = 5\%$.

[v] *, NSSignificantly different between bud and flower stage, $P = 5\%$ or not significant, respectively.

Table 5. Effect of chlormequat chloride and transplant development on fruit number after first 3 weeks of harvest.

Chlormequat chloride concn	No. of fruit[z] Transplanting stage Bud[y]	 Flower[x]	 Mean[w]
	No. large fruit seeded 1 Dec.		
0	0.8	1.2	1.0
10^{-4} M	0.6	0.8	0.7***
Mean (*)[v]	0.7	1.0	---
	Seeded 1 Jan.		
0	1.2	1.4	1.3
10^{-4} M	0.7	0.8	0.8*
Mean (NS)	0.9	1.1	---
	No. small fruit seeded 1 Dec.		
0	0.3	0.2	0.2
10^{-4} M	0.9	1.1	1.0**
Mean (NS)	0.6	0.6	---
	Seeded 1 Jan.		
0	0.3	0.7	0.5
10^{-4} M	0.9	0.8	0.8***
Mean (NS)	0.6	0.7	---

[z] Average per plant per week within 3-week period.

[y] Tomato transplants set into NFT system 1 week after flower buds became visible.

[x] Tomato transplants set into NFT system when 50% of the chlormequat chloride-treated plants had an open blossom.

[w] *, **, ***Significant from 0 rate at $P = 5\%$, 1%, or 10%, respectively.

[v] NS,*Means for bud and flower stage not significant or significant at $P = 5\%$, respectively.

creased both by a lack of chlormequat chloride and by transplanting plants in flower (Table 4). This increase is probably because fruit set reduces excessive vegetative growth typical of tomato plants grown under low light conditions. The light conditions were improved when the 1 Jan.-seeded transplants were setting fruit. Therefore, the yield was not affected by the stage of transplant development. Small fruit (<170 g) yield was increased both by chlormequat chloride and by transplanting before flowering (Table 3). The total yield of tomatoes was decreased only by chlormequat chloride.

Fruit number. The number of large fruit ($\geq$170 g) was decreased by chlormequat chloride (Table 3). A transplant started 1 Dec. had more large fruit over the first 3 weeks of harvest when transplanted in flower than if it was transplanted before flowering (Table 5). Fruit set is a typical problem when tomatoes are grown under low light levels (7). Under low light, transplants become excessively vegetative if transplanted without flowers or some other means of reducing vegetative growth. Transplants without chlormequat chloride had fewer small fruit (<170 g) over the first 3 weeks of harvest than transplants treated with chlormequat chloride (Table 5). However, after 9 weeks of harvest, number of small fruit was decreased only by transplanting plants in flower (Table 4). The total number of fruit was reduced both by chlormequat chloride and transplanting plants in flower.

Fruit size. Chlormequat chloride decreased the average size

Table 6. Effect of chlormequat chloride and transplant development on tomato fruit size after 9 weeks of harvest.

Chlormequat chloride concn	Transplanting stage		
	Bud[z]	Flower[y]	Mean[x]
	Average large fruit wt (g)		
0	228 a[w]	235 a	232
10^{-4} M	219 ab	207 b	213 **
Mean (NS)[v]	224	221	---
	Average small fruit wt (g)		
0	118	124	121
10^{-4} M	127	132	129**
Mean (**)	122	128	---
	Average total fruit wt (g)		
0	179 b[x]	192 a	185
10^{-4} M	172 b	170 b	171**
Mean (NS)	175	181	---

[z] Tomato transplants set into NFT system 1 week after flower buds became visible.

[y] Tomato transplants set into NFT system when 50% of the chlormequat chloride-treated plants had an open blossom.

[w] Mean separation within rows and columns for each fruit variable by Newman–Keuls' multiple range test, 5% level, when interaction is significant.

[x] **Significant from 0 rate at $P = 1\%$.

[v] NS, **Means of bud and flower stages not significant or significant at $P = 1\%$, respectively.

of large fruit (≥170 g) (Table 6); whereas chlormequat chloride and transplanting plants in flower increased the average size of small fruit (<170g). Overall fruit size was decreased by chlormequat chloride.

The effect of chlormequat chloride on tomato yield has been variable. Some researchers have observed yields of chlormequat chloride-treated plants comparable to controls (10), while others have seen fruit yield, number, and size decrease (17). This difference in response may be attributable to application dose, as some have noticed a decrease in yield only at increased chlormequat chloride concentrations (13). Dosage is not only the concentration but also the duration of exposure.

Growth retardants affect the partitioning of dry matter. A change in the partitioning of dry matter has been demonstrated by an increase in root : shoot ratio in radish (16), an increase in bud size (3) and no. 1 grade spears of asparagus (9), and an increase growth of tomato inflorescence (12). Although tomato fruit growth was accelerated initially on plants treated with chlormequat chloride, the prolonged affect of chlormequat chloride on plant growth was a decrease in yield.

Although chlormequat chloride decreased fruit yield, number, and size, flowering was accelerated both by chlormequat chloride and transplanting larger plants. In this experiment, chlormequat chloride depressed yields too much to be considered as a means to control plant morphology. If the transplants had been treated with GA when set into the NFT system, normal growth may have been resumed soon enough so that fruit set would not excessively stunt plant growth and decrease yield. This experiment reconfirmed the value of using fruit set to control "excessive" vegetative growth and increase yield under low light levels. By transplanting a more mature transplant without chlormequat chloride, a 111 g per plant per week yield increase was obtained over the first 3 weeks of harvest. Therefore, although it is difficult to manage a leggy transplant (typical of flowering hydroponic tomato transplants grown under low light levels and close spacing), the increase in yield makes transplanting tomato plants in flower a profitable management practice.

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