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Persistent Effects of Plant Growth Regulators on Landscape Performance of Seed Geraniums[1]

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Abstract

In 1988, spray applications of 3.5 or 7 ppm paclobutrazol, 1500 ppm chlormequat, or 200 ppm ancymidol were applied to seed geraniums (*Pelargonium* x *hortorum* L. H. Bailey 'Ringo White' and 'Ringo Rose') to determine effects on growth in the greenhouse and the subsequent growth and performance of treated plants in the landscape. All growth retardants reduced stem length and shoot dry weight as well as time required for flowering, while branching was increased relative to the untreated plants. Flowering in the landscape was increased by all growth regulator treatments at 4 weeks after planting but was generally not different from the untreated plants at 6 weeks after planting. Plant height and width were reduced by all treatments for both cultivars, relative to untreated plants, at 4 weeks after planting. However, only 7 ppm paclobutrazol reduced height and width of 'Ringo White' plants at 6 weeks after planting. Plant height, but not width, was reduced by all treatments for 'Ringo Rose' at 6 weeks after planting.

In 1989, seedlings of 'Ringo Rose' were treated with 3.5, 7, 16, 40, or 80 ppm paclobutrazol or 1500 ppm chlormequat or 200 ppm ancymidol. Seedling growth was excessively reduced by 40 or 80 ppm paclobutrazol. Time required for flowering was not reduced by growth regulators in 1989. Landscape performance under conditions of excess rain was not improved by plant growth regulators and the height of plants treated with 16, 40 or 80 ppm paclobutrazol was still less than that of the untreated plants at 12 weeks after planting. Only chlormequat controlled plant growth in the greenhouse without delaying the resumption of growth in the landscape.

Index words: growth retardant, Bonzi, paclobutrazol, A-Rest, ancymidol, Cycocel, chlormequat chloride.

Growth regulators used in this study: Bonzi (paclobutrazol), ß-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol; A-Rest (ancymidol), α-cyclopropyl-α-(4-methoxyphenyl)-5-pyrimidinemethanol; Cycocel (chlormequat chloride), 2-chloro-*N,N,N*-trimethylethanaminium chloride).

Species used in this study: 'Ringo White' and 'Ringo Rose' geranium (*Pelargonium* x *hortorum* L. H. Bailey 'Ringo White' and 'Ringo Rose').

Significance to the Nursery Industry

Chemical growth retardants are generally applied to seed geraniums during bedding plant production to enhance branching and early flowering and to reduce plant height. However, persistent effects of growth retardants in plants planted in the landscape affect resumption of growth and ultimate size of the plants. This is particularly true of the new generation of growth regulators including paclobutrazol. Growth retardant rates must be selected based on both growth responses during production as well as persistence in the landscape to produce plants that meet size requirements for complete fill of landscape beds. Chlormequat or very low rates (3.5 ppm) of paclobutrazol provide growth regulation of seed geraniums in the greenhouse while permitting unchecked growth in the landscape.

Introduction

Plant growth regulators are commonly used in the production of bedding plants to control plant growth and habit during production and to improve plant appearance and quality during marketing. A-Rest (ancymidol) and Cycocel (chlormequat) have been commonly used on geraniums for many years and generally increase number of lateral breaks and inflorescenses per plant and hasten flowering (9). Optimum rates may vary with geranium cultivar, or environmental or growing conditions (2, 4).

Once transplanted to the landscape, influence of the growth regulators should diminish due to new soil conditions and time, but residual effects have been observed. Residual effects of chlormequat in the landscape included early flowering and shorter plants throughout the season (11). Triazole compounds, such as paclobutrazol, are active in plants for a longer period of time than older growth retardants such as ancymidol (6) and their persistent effects may be even more important. Marigold plants drenched with paclobutrazol during production remained shorter in the landscape 138 days after treatment compared to control plants, but spray treatments resulted in no differences (8). Spray applications of paclobutrazol to seed geranium reduced growth linearly over the 10 to 80 ppm range, but persistence of growth reduction in the landscape was not reported (5). Drench treatments of paclobutrazol strongly retarded growth of five cultivars of seed geranium, with the three highest rates (0.25, 0.50, or 1.0 mg a.i. per plant) almost totally inhibiting stem elongation in the garden until late summer (10).

This research was established to determine if different rates of paclobutrazol applied as a spray in the greenhouse during plant production affect subsequent performance of seed geraniums after they are transplanted to a landscape setting. All treatments were compared to ancymidol, chlormequat and an untreated control.

Materials and Methods

In February 1988, seeds of 'Ringo White' or 'Ringo Rose' were sown in seedling flats filled with Pro-Gro 200 seedling medium (Pro-Gro Products, Inc., Elizabeth City, NC) and

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transplanted 24 days after sowing (DAS) to 804 cell-packs (root cell volume 160 cm^3) filled with the same medium. Treatments consisting of 3.5 or 7 ppm paclobutrazol, 1500 ppm chlormequat or 200 ppm ancymidol plus an untreated control were applied at 28 DAS at which time the plants had about six true leaves. Greenhouse temperatures averaged 30°C day/14°C night (86°F/57°F) and photosynthetic photon flux (PPF) averaged 19.9 mol/m^2/day.

The experiment was repeated in March 1989 using only 'Ringo Rose' since seeds of 'Ringo White' were unavailable. Seedlings were transplanted 22 DAS, and treatments were applied 33 DAS which corresponded to five to six true leaves per plant. Treatments in 1989 consisted of 3.5, 7, 16, 40 or 80 ppm paclobutrazol, 1500 ppm chlormequat or 200 ppm ancymidol plus an untreated control. Greenhouse temperatures averaged 28°C day/15°C night (82°F/59°F) and PPF averaged 20.5 mol/m^2/day.

Chlormequat and ancymidol rates were those recommended by Carlson (4) and Armitage (1), and palcobutrazol spray rates were selected from those previously reported for geranium, which range from 3.5 ppm (3) to 80 ppm (5). Freshly prepared solutions were applied as directed sprays at 1.0 ml/plant using a hand-held spray bottle. The volume applied thoroughly covered seedlings, but allowed little or no run-off onto the medium. All seedlings were fertilized once weekly before transplanting and twice weekly thereafter with 200 ppm N of 20N-8.7P-16.6K (Peters General Purpose 20-20-20, Grace-Sierra Horticultural Products, Cambridge, MA.). Each experiment used a randomized complete block design with four replications of one flat of 32 plants for each treatment.

At completion of the greenhouse experiment, 9 weeks after treatment (due to wet field conditions) in 1988 or 6 weeks after treatment in 1989, six plants per treatment were randomly selected from each of the four replications for measurement of growth (n = 24). Data included dry weights (72 hr at 70°C (158°F) in a forced-air oven) of leaves, stems, and roots (handwashed from medium), leaf area in 1989 (LI-COR 3000 leaf area meter), stem length (measured from the root/shoot interface of the stem to the bottom of the terminal bud of the main stem, no lateral shoots were included) and number of lateral branches over 0.5 cm (0.2 in) in length on each plant. Days required for the first flower to open were noted for each treatment.

On the day following greenhouse growth measurements, the remaining plants were transplanted to the field to assess effects of greenhouse treatments on subsequent growth and performance. Four replications were planted in a randomized complete block design. No additional treatments were imposed in the field. Geraniums were set one plant per 0.2 m^2 (2.2 ft^2) in full sun in a field fertilized once with 896 kg/ha (800 lb/A) of 13N-5.8P-11K (13-13-13). Plants were irrigated by overhead sprinklers and mulched with hardwood chips.

At 4 and 6 weeks after planting (WAP) in 1988 and at 4, 6, 8, 10 and 12 WAP in 1989, plant height and width were measured and number of inflorescences in each plot counted. Plant width consisted of the average of the width of the plant taken at its widest point plus the width of the plant perpendicular to the widest point. In 1989, a plant quality rating (subjective rating of plant appearance) was taken on five representative plants from each treatment in each block to evaluate landscape performance at 4, 6, 8, 10 and 12 WAP. The quality rating was based on plant habit and branching (8 = excellent mounded shape with many branches to 0 = irregularly shaped with few branches). The ratings were subjected to arcsin transformation for analysis and presentation, resulting in a scale of 0 = poor to 90 = excellent. All data were subjected to analysis of variance using the general linear models procedure of SAS (7). Means were separated using a protected least significant difference (LSD) test at $P < 0.05$.

Results and Discussion

Production-1988. In 1988, local conditions delayed field transplanting for about 3 weeks. Therefore, plants were somewhat overgrown in the greenhouse at the time of landscape planting, 9 weeks after treatment application. Most plants flowered in the greenhouse. All growth regulator treatments hastened flowering; paclobutrazol and ancymidol by 10 days, and chlormequat by 4 days for 'Ringo White' (Table 1). Flowering of 'Ringo Rose' was hastened 11 days by ancymidol, 10 days by 7 ppm paclobutrazol but only 4 days by 3.5 ppm paclobutrazol and 8 days by chlormequat. Stem length of 'Ringo White' was reduced 17% and 33% by 3.5 and 7 ppm paclobutrazol, respectively, and 20% by ancymidol or chlormequat. 'Ringo Rose' was less responsive to

Table 1. Effect of plant growth regulators applied at 28 days after sowing (DAS) on days to flower, plant growth and number of branches of 'Ringo White' and 'Ringo Rose' geraniums at 9 weeks after treatment (91 DAS) in 1988.

Treatment	Conc (ppm)	Days to flower	Stem length (cm)	Shoot dry wt (g)	Branches per plant	Root dry wt (g)
Ringo White						
Untreated	—	96 a[z]	10.2 a	3.6 a	0.8 b	0.45 a
Paclobutrazol	3.5	86 c	8.5 b	2.9 b	2.0 a	0.33 b
	7	86 c	6.8 c	2.0 d	1.6 a	0.27 c
Ancymidol	200	86 c	8.2 b	2.4 c	1.9 a	0.30 bc
Chlormequat	1500	92 b	8.1 b	2.7 bc	1.6 a	0.32 b
Ringo Rose						
Untreated	—	96 a	9.9 a	3.5 a	0.1 d	0.52 a
Paclobutrazol	3.5	92 b	9.4 a	2.5 b	1.1 c	0.39 b
	7	86 c	7.6 b	2.1 c	1.3 bc	0.35 c
Ancymidol	200	85 c	7.3 b	2.3 bc	2.1 a	0.36 bc
Chlormequat	1500	88 bc	7.1 b	2.3 bc	1.8 ab	0.38 bc

[z]Mean separation within cultivar and column by LSD, $P < 0.05$.

Table 2. Effect of plant growth regulators on subsequent growth and flowering of 'Ringo White' and 'Ringo Rose' geraniums at 4 and 6 weeks after planting (WAP) in 1988.

Treatment[z]	Conc (ppm)	4 WAP Plant height (cm)	4 WAP Plant width (cm)[y]	4 WAP Flowers per plant	6 WAP Plant height (cm)	6 WAP Plant width (cm)	6 WAP Flowers per plant
Ringo White							
Untreated	—	27.8 a[x]	26.0 a	1.9 c	27.0 a	28.4 a	3.0 c
Paclobutrazol	3.5	22.4 b	20.8 c	2.6 ab	25.9 ab	27.4 ab	3.7 ab
	7	19.7 c	18.6 d	2.9 a	22.6 c	25.6 b	4.2 a
Ancymidol	200	22.2 b	22.3 b	2.4 b	24.7 b	28.2 a	3.2 bc
Chlormequat	1500	23.4 b	23.0 b	2.4 b	26.0 ab	27.7 a	3.2 bc
Ringo Rose							
Untreated	—	25.3 a	27.5 a	1.8 b	26.8 a	31.2 a	4.0 a
Paclobutrazol	3.5	22.7 b	24.2 b	2.6 a	23.4 b	31.2 a	4.2 a
	7	19.6 c	22.7 c	2.7 a	21.7 c	30.8 a	4.1 a
Ancymidol	200	20.0 c	24.1 bc	2.6 a	22.1 bc	31.1 a	4.2 a
Chlormequat	1500	20.6 c	24.4 b	2.5 a	22.7 bc	31.2 a	4.6 a

[z]Treatments applied at 28 days after sowing. Plants were transplanted to landscape 9 weeks after treatment.

[y]Average of width at widest point + width perpendicular to widest point.

[x]Mean separation within cultivar and column by LSD, $P < 0.05$.

paclobutrazol but slightly more reponsive to ancymidol or chlormequat. 'Ringo Rose' was reported less sensitive to paclobutrazol than 'Ringo White' (10). All growth retardant treatments reduced shoot and root dry weights, but increased branching of both cultivars.

Landscape evaluation-1988. Although none of the growth regulator treatments resulted in excessively stunted plants at time of field planting, plant height and width of 'Ringo White' or 'Ringo Rose' were reduced by all treatments at 4 weeks after planting (WAP) (Table 2). Height of 'Ringo White' plants treated with 7 ppm paclobutrazol or 200 ppm ancymidol was still less than that of controls at 6 WAP while width was reduced only by 7 ppm paclobutrazol. Height, but not width, of 'Ringo Rose' was reduced by all growth regulator treatments at 6 WAP. However, the number of flower inflorescenses on 'Ringo White' plants treated with any growth regulator was greater than that of the untreated plants at 4 WAP, but was improved only by paclobutrazol at 6 WAP. The number of flowers on 'Ringo Rose' plants was increased by all growth regulator treatments at 4 WAP, but the differences were no longer present at 6 WAP. These data are consistent with the increased early flowering of plants treated with chlormequat reported by Schwartz et al. (11). The higher sensitivity of 'Ringo White' to growth regulators (10) is not supported by these data. Use of higher rates of paclobutrazol may have delineated the cultivar differences.

Production-1989. Plants of 'Ringo Rose' were more responsive to paclobutrazol in this experiment than in 1988. For example, stem length of plants treated with 7 ppm paclobutrazol was reduced 37% in 1989 (Table 3) versus only 23% in 1988 (Table 1). Perhaps the additional 3 weeks between time of treatment and measurement in 1988 permitted more resumption of growth than was evident in 1989. Even 3.5 ppm paclobutrazol reduced stem length (13%) in 1989 (Table 3). Stem length was further decreased by increasing rates of paclobutrazol with 80 ppm paclobutrazol causing a 75% reduction in stem elongation at 6 weeks after treatment. Ancymidol and chlormequat resulted in about 20% reductions in stem growth. Leaf area was reduced by about the same percentages as stem length. Plant growth retardants generally have the greatest effects on expanding or elongating cells where inhibition of gibberellin synthesis rapidly causes reductions in stem elongation and leaf expansion (12). Final shoot dry weight also decreased with increasing rates of paclobutrazol to a maximum of 54% at 80 ppm. Ancymidol and chlormequat reduced shoot dry weight 25%. Root dry weight of untreated plants was 0.38 g/plant and exhibited almost the exact same percent reductions in response to plant growth retardant treatments as seen in shoot dry weight (data not shown). Branching was improved by the lower rates of paclobutrazol (3.5, 7, or 16 ppm) and even more so by ancymidol or chlormequat. The meaurement of fewer branches in 1989 was probably due to the stage of plant development at the end of greenhouse production; plants in the 1989 experiment were 3 weeks younger than in 1988.

Landscape evaluation-1989. Time required for untreated 'Ringo Rose' geranium to flower in 1989 was 10 days shorter than in the previous experiment and was further reduced by

Table 3. Effect of plant growth regulators applied at 33 days after sowing (DAS) on growth and branching of 'Ringo Rose' geranium at 6 weeks after treatment in 1989.

Treatment	Conc (ppm)	Stem length (cm)	Leaf area (cm^2)	Shoot dry wt (g)	Branches per plant
Untreated	—	10.7 a[z]	521 a	2.8 a	0.0 c
Paclobutrazol	3.5	9.3 b	406 b	2.3 b	0.5 b
	7	6.7 d	315 c	2.0 c	0.5 b
	16	4.8 e	228 d	1.6 d	0.5 b
	40	3.4 f	169 e	1.5 de	0.1 c
	80	2.7 f	114 f	1.3 e	0.0 c
Ancymidol	200	8.4 c	420 b	2.1 bc	1.0 a
Chlormequat	1500	8.2 c	430 b	2.1 bc	0.9 a

[z]Mean separation within column by LSD, $P < 0.05$.

Table 4. Landscape flowering and growth of 'Ringo Rose' geranium treated with plant growth regulators at 33 days after sowing (DAS) and planted in the landscape 6 weeks later (75 DAS). Plant heights and widths were measured at 4, 8 and 12 weeks after planting (WAP) in 1989.

Treatment	Conc (ppm)	Days to flower	Plant height (cm)			Plant width (cm)[z]		
			4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
Untreated	—	86 bc	19.2 a[y]	26.5 a	32.4 a	18.4 a	24.5 a	32.6 a
Paclobutrazol	3.5	84 bcd	17.8 a	23.4 bc	30.8 a	16.1 bc	22.9 ab	32.7 a
	7	85 bcd	17.0 a	21.0 c	29.0 ab	14.3 c	20.6 b	30.6 a
	16	83 bcd	14.0 b	17.2 d	25.6 b	12.5 d	16.6 c	27.6 a
	40	82 d	11.0 c	11.6 e	20.1 c	9.7 e	12.5 d	21.6 b
	80	84 bcd	6.8 d	5.3 f	10.4 d	6.9 f	7.2 e	13.5 c
Ancymidol	200	90 a	19.0 a	22.0 bc	29.2 ab	15.5 bc	21.0 ab	31.0 a
Chlormequat	1500	86 bc	17.8 a	24.1 ab	31.2 a	17.0 ab	22.6 ab	31.8 a

[z]Average of width at widest point + width perpendicular to widest point.

[y]Mean separation within column by LSD, $P < 0.05$.

40 ppm paclobutrazol; however, it was slightly increased by ancymidol (Table 4).

Plant growth in the landscape was hindered by frequent and excessive rainfall, totalling 25 cm (9.8 inches) during the 12-week measurement period. Plants that were severely stunted by 80 ppm paclobutrazol suffered greater establishment problems than other treatments, with 78% plant loss at 4 WAP compared to 34% plant loss for untreated or 30% to 36% for the other growth regulator treatments. Plant height in the landscape was reduced by 16, 40, or 80 ppm paclobutrazol at 4 WAP with similar reductions measured at 12 WAP (Table 4). Plant width was reduced by all rates of paclobutrazol and by ancymidol at 4 WAP, but, by 12 WAP, only plants treated with 40 or 80 ppm paclobutrazol were still smaller than untreated plants. Only plants treated with chlormequat resumed growth quickly enough to show no persistent growth retardation in the landscape.

Norremark and Andersen (10) reported that plants excessively stunted by paclobutrazol drenches did not resume growth in the landscape from existing stems, but developed new branches at the soil line which developed their own root systems. We did not observe this type of development in our test.

Flowering was not improved by treatment with plant growth regulators at any time during the 12-week measurement period and was reduced by the higher rates of paclobutrazol at all measurement dates (Table 5). The quality rating of 37 for the untreated plants at 4 WAP was lower than we expected. Only plants treated with 3.5 ppm paclobutrazol or 1500 ppm chlormequat had a quality rating equal to the untreated plants at each measurement period throughout the study. All other treatments reduced the overall landscape quality of 'Ringo Rose' at all evaluation dates. Excessive rainfall reduced plant performance in the landscape, and treatment with plant growth regulators prior to transplanting did not improve plant tolerance to wet soil conditions.

Although plant growth retardants, in many cases, are essential for the production of high quality seed geranium plants, growth retardants may not subsequently improve plant quality in the landscape. Only chlormequat controlled plant growth in the greenhouse without negatively affecting plant development in the landscape. Plants treated with ancymidol attained the same size as untreated plants in the landscape, but did not attain the same quality rating over the 12-week measurement period. With respect to paclobutrazol, only 3.5 ppm gave moderate growth regulation of 'Ringo Rose' in the greenhouse while permitting normal growth, flowering and quality under landscape conditions. Recommendations for growth retardant rates on geranium should include consideration of the long-term effects of the chemical on landscape performance.

(*Ed. note*: This paper reports the results of research only and does not imply registration of a pesticide and/or growth regulant under amended FIFRA. Before using any of the products mentioned in this research report, be certain of their registration by appropriate state and/or federal authorities.)

Table 5. Landscape performance of 'Ringo Rose' geranium treated with plant growth regulators at 33 days after sowing (DAS) and planted in the landscape 6 weeks later (75 DAS). Flowering and quality were evaluated at 4, 8 and 12 weeks after planting (WAP) in 1989.

Treatment	Conc (ppm)	Flowers per plant			Quality rating[z]		
		4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
Untreated	—	0.7 a[y]	1.7 a	3.7 a	37 a	62 a	55 a
Paclobutrazol	3.5	0.8 a	1.5 ab	3.7 a	32 abc	58 ab	54 a
	7	0.6 ab	1.0 abc	2.6 b	27 cd	49 b	43 c
	16	0.4 bc	0.8 bc	2.1 b	21 d	36 c	40 cd
	40	0.3 cd	0.6 c	1.7 bc	11 e	24 d	32 d
	80	0.2 d	0.4 c	0.8 c	0 f	4 e	12 e
Ancymidol	200	0.6 ab	1.4 ab	2.7 b	28 bcd	49 b	44 bc
Chlormequat	1500	0.6 ab	1.6 a	4.1 a	36 ab	58 ab	52 ab

[z]Quality rating: 0 = poor to 8 = excellent; data subjected to arcsin transformation for analysis and presentation with resulting scale 0 = poor to 90 = excellent.

[y]Mean separation within column by LSD, $P < 0.05$.

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