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Applying Plant Growth Retardants for Height Control

EXPERT REVIEWED

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Controlling plant size is one of the most important aspects of greenhouse crop production. Growers can control crop height genetically, environmentally, culturally, or chemically. Genetic control of plant height is primarily achieved by selecting shorter cultivars. Environmental control involves manipulating light (increasing light intensity, minimizing far-red light, and photoperiod) or temperature (reducing the difference between the day and night temperatures, or DIF). Cultural control includes moisture management (stress) and phosphorus or nitrogen deprivation.

These techniques can be effective height-suppressing strategies for some crops, but when growers are faced with greenhouses containing large varieties of genera, species, or cultivars, these techniques may not work equally well for each crop under a common environment. An alternative, effective strategy for controlling plant height is to use chemical plant growth retardants (PGRs).

Plant growth retardants are an incredibly useful tool. Growers can achieve crop-specific height control by selecting the proper PGRs, using the optimal application technique, and using the right solution strength for individual crops. There are numerous chemicals available in a variety of commercial formulations, as well as multiple strategies for applying PGRs. That means growers need to take special care before applying these products.

Table 1. *Common plant growth retardant active ingredients, trade names, manufacturers, and re-entry intervals (REI).*

Active Ingredient	Trade Name	Manufacturer	REI (hours)
ancymidol	A-Rest®	SePRO Corp.	12
	Abide®	Fine Americas, Inc.	12
chlormequat chloride	Chlormequat E-Pro®	Etigra, LLC	12
	Citadel®	Fine Americas, Inc.	12
	Cycocel®	OHP, Inc.	12
daminozide	B-Nine®	OHP, Inc.	24
	Dazide®	Fine Americas, Inc.	24
ethephon	Florel®	Monterey Lawn and Garden Products, Inc.	48
flurprimidol	Topflor®	SePRO Corp.	12
paclobutrazol	Bonzi®	Syngenta Crop Protection	12
	Downsize®	Greenleaf Chemical, LLC	12
	Paczol®	OHP, Inc.	12
	Piccolo®	Fine Americas, Inc.	12
uniconazole	Concise®	Fine Americas, Inc.	12
	Sumagic®	Valent USA Corp.	12

Adapted from R. Lopez, M. Blanchard, and E. Runkle (2008, Comparing PGRs).

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Table 2. Plant growth retardant active ingredients and their characteristics.

Active Ingredient	Relative Activity	Difficulty of Use	Absorption Site(s)	Application Method(s)	Shelf Life (years)
ancymidol	Medium	Medium	Leaves, roots	Spray, dip, drench	3
chlormequat chloride	Low	Low	Leaves, roots	Spray	3
daminozide	Low	Low	Leaves	Spray	2
ethephon	Medium	Low	Leaves	Spray	Indefinite
flurprimidol	High	High	Stems, roots	Spray, dip, drench	2
paclobutrazol	High	High	Stems, roots	Spray, dip, drench	4
uniconazole	High	High	Stems, roots	Spray, dip, drench	2

Adapted from J. Barrett (2001, Mechanisms of Action) and A. Hammer (2001, Calculations).

The goals of this publication are to identify the PGRs currently available for height control, discuss application techniques for these chemicals, and give some guidance for selecting and mixing chemicals so you can optimize applications.

Active Ingredients

Before selecting a PGR, you need to understand the active ingredient (AI) in each chemical. The AI is the compound in the product that suppresses stem elongation (Tables 1 and 2). Although all PGRs control stem elongation, the mode of action is not the same for all PGRs.

Gibberellins (GAs) are plant hormones responsible for stem elongation. Most PGRs inhibit different steps during the production (biosynthesis) of GA in plants. Thus, PGRs suppress stem elongation by blocking GA production within plants. However, as we discuss in the case of ethephon below, not every PGR works this way.

In addition to their modes of action, AIs differ in relative activity, difficulty of use, site of absorption, application methods, and shelf life (Table 2).

Daminozide

Daminozide (commonly known as B-Nine® or Dazide®) is one of the most common PGRs used in the floriculture industry. At the end of the GA production process daminozide renders a key enzyme for GA production useless, thus reducing GA levels.

Daminozide has the lowest level of activity compared to other AIs (Table 2). The relatively high concentrations necessary to suppress crop heights (compared to other chemicals) reflects the forgiving nature of daminozide. The water-soluble granular formulation is mixed in solution for foliar sprays. Applying daminozide solutions to the substrate is ineffective.

Chlormequat Chloride

Chlormequat chloride (commonly known as Cycocel®, Citadel®, or Chlormequat E-Pro®) is another very popular PGR. Unlike daminozide, chlormequat chloride inhibits GA production early in the process.

Chlormequat chloride has activity when applied to both the leaves and the roots (Table 2), but it is primarily applied as a foliar spray due to the higher concentrations required for adequate control when applied as a drench. Applicators frequently tank mix chlormequat chloride with daminozide. Because the two products have different sites of inhibition in the GA production process, such a mix can be highly effective at suppressing elongation.

Ancymidol, Flurprimidol, Paclobutrazol, and Uniconazole

Ancymidol (A-Rest® or Abide®), flurprimidol (Topflor®), paclobutrazol (Bonzi®, Downsize®, Paczol®, or Piccolo®), and uniconazole (Concise® or Sumagic®) are all listed together due to their similar chemical structures. They all inhibit GA production at similar sites in the GA production process.

Generally speaking, these PGRs have the strongest efficacy relative to other AIs, so applicators typically apply lower concentrations. All of these chemicals can be applied to the shoots or roots, which allows a broad range of application choices including foliar sprays, substrate drenches, liner dips, and media sprays.

Ethephon

Unlike other PGRs, ethephon (Florel®) does not inhibit GA production. Plants take up ethephon through the leaves where it is converted to ethylene in plant cells. The increased ethylene causes cells to limit elongation and increase in width instead.

Ethephon's mode of action can offer benefits other than height suppression. The release of ethylene reduces apical dominance, which can increase axillary branching. However, if the application is made close to flowering, the ethylene can result in flower abortion and delayed flowering.

Application Methods

Just as there are a variety of AIs to choose from, there are also several methods for applying PGRs. In addition to spraying and drenching (the most common methods of application) PGRs can also be applied by "sprenches" (high-volume sprays where the solution is applied to both the foliage and the growing substrate); liner dips; and bulb, tuber, and rhizome soaks or dips.

Sprays

Foliar sprays are the most common PGR application method. Many growers are attracted to the perceived ease of applying foliar sprays on their crops. However, there are several factors to consider when applying PGRs in this manner.

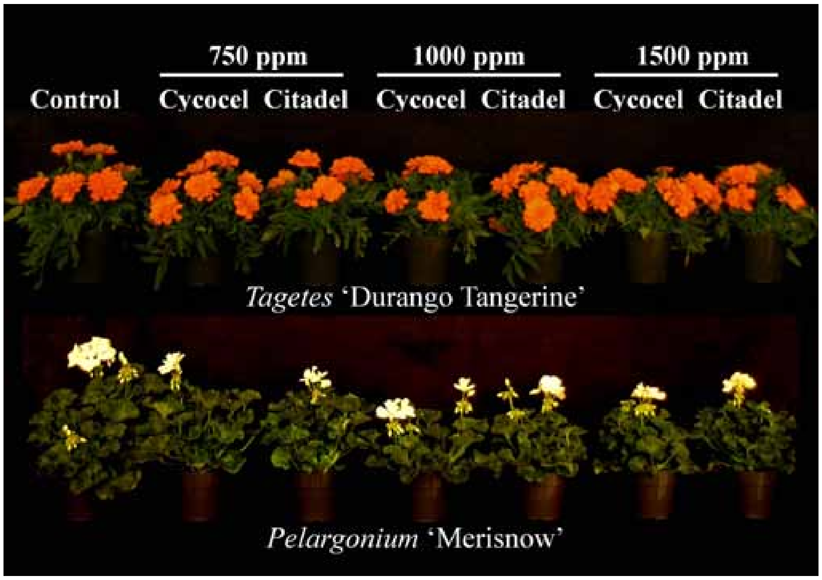

Figure 1. *'Durango Tangerine' marigold plants and 'Merisnow' geranium plants five weeks after being sprayed with Citadel® or Cycocel® (both chlormequat chloride) at 750, 1,000, or 1,500 ppm or left untreated (control).*

First, the volume of solution to apply determines how much active ingredient is applied to the crop. Without careful consideration of application volume, spray volume can vary considerably among different personnel and can decrease uniformity among and between crops.

Applicators often spray PGR solutions to "runoff," or until leaves look saturated. While this may be adequate, a better strategy is to apply a specific volume of the chemical over a specified area. Two quarts of spray solution per 100 square feet is a commonly recommended rate (although less may be required for smaller plants, and more required for larger plants, depending on coverage).

When an excess volume of PGR spray and runoff reaches the substrate, this can result in additional height control through substrate activity, depending on the AI used. Intentionally doing this can be an application strategy, which is referred to as sprenching.

Other factors also influence the effectiveness of PGR sprays. The application environment can affect PGR performance. For example, plants take up ancymidol, flurprimidol, paclobutrazol, and uniconazole relatively quickly, but plants require more time to take up chlormequat chloride, daminozide, and ethephon.

To improve the effectiveness of these slow-uptake AIs, it makes sense to apply them in an environment that allows for longer drying times. There are several ways to do this.

First, apply these products early in the morning, in the evening, or on cloudy days.

Second, in the greenhouse, increase humidity and turn off horizontal airflow fans to minimize air movement.

Third, avoid overhead irrigation before foliar PGR applications have dried — the irrigation water can wash off the AI and reduce its efficacy.

Finally, add an adjuvant or spreader-sticker to the PGR solution to decrease surface tension and increase application uniformity — always refer to product labels before mixing anything; adjuvants and spreader-stickers are not recommended with all AIs.

Drenches

Drenching (applying solutions to the growing substrate) is another popular PGR application method (Figure 2). However, not all PGRs are effective as drenches.

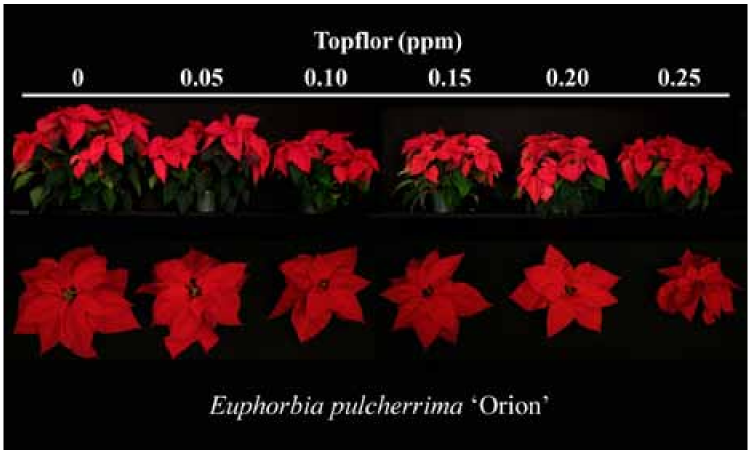

Figure 2. *The final heights of 'Orion' poinsettia plants drenched with 4-fluid-ouce solutions containing 0, 0.05, 0.10, 0.15, 0.20, or 0.25 ppm of Topflor® (flurprimidol) two weeks after pinching. Photos taken at flowering.*

Compared to foliar sprays, drenches are more uniform and provide increased efficacy at lower concentrations. Factors affecting the efficacy of drenches include AIs, solution volume, substrate moisture content at application, and substrate components.

As with all application methods, the solution's AI concentration will affect height control. Just as the volume of solution applied over a specific area affects foliar sprays, the volume of solution applied to individual containers will affect the total amount of AI applied.

For instance, while 2 fl. oz. is adequate for 4-inch containers, 4 fl. oz. is necessary for 6-inch containers (Table 3). In addition to ensuring an adequate solution volume, be sure the root substrate is dry enough to minimize the amount of solution leaching at application.

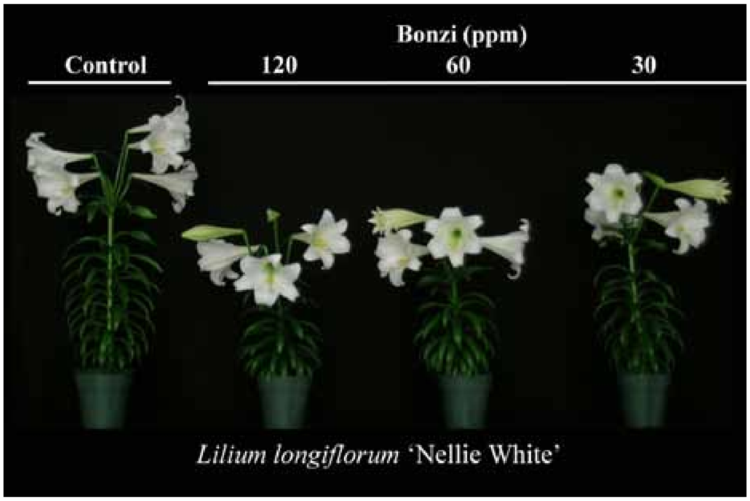

Figure 3. *'Nellie White' Easter lily plants forced from bulbs soaked in clear water (control) or dipped for 15 minutes in solutions containing 120, 60, or 30 ppm of Bonzi® (paclobutrazol) before planting. Photo taken at flowering.*

Substrate composition can also affect the effectiveness of PGR drenches. It is well-established that pine bark, when included in substrate, reduces the effectiveness of PGR drenches. Therefore, if you are drenching plants in substrates that contain pine bark, you may need to increase the AI concentration by as much as 25 percent to achieve better height control.

Bulb, Tuber, and Rhizome Soaks

Bulb soaks are a preventative strategy of growth regulation because PGRs are applied before stem elongation really begins (Figure 3).

Bulb soaks can be economical because many bulbs can be treated with much less solution than spray or drench applications require. Additionally, the same PGR solution can be reused with each successive dip without adversely affecting height control. When finished, the solution can be disposed of by applying it as a drench to another crop.

The time the bulbs should be submerged in the PGR solution generally ranges between 2 and 40 minutes, depending on the AI and plant species. Make sure the PGR solution is at least 46°F, as cooler solution temperatures may reduce PGR uptake and subsequent activity.

Bulb soaks also make application timing flexible. Bulb soaks may be performed up to seven days before planting.

Bulb soaks are performed before bulb forcing begins. This can make selecting appropriate rates difficult since PGRs are applied without knowing how plants will grow in the upcoming season. To minimize potential over-application, consider using a solution with a low PGR concentration, and then make an application of some other type during the forcing period, if necessary.

Liner Dips

Liner dips are another economical and preventative PGR application method that provides early control of vigorous crops. Liner dips involve partially submerging a tray of rooted liners in a PGR solution (Figure 4).

The factors that affect liner dips are similar to those that affect drenches; however, there are additional

Table 3. *Container size and appropriate volumes per container for drench applications.*

Container Diameter (inches)	Drench Volume	
	fl oz/container	mL/container
4	2	60
5	3	90
6	4	120
8	10	300
10	25	750
12	40	1,200

Adapted from J.G. Latimer (2009, Selecting and Using Plant Growth Regulators on Floricultural Crops).

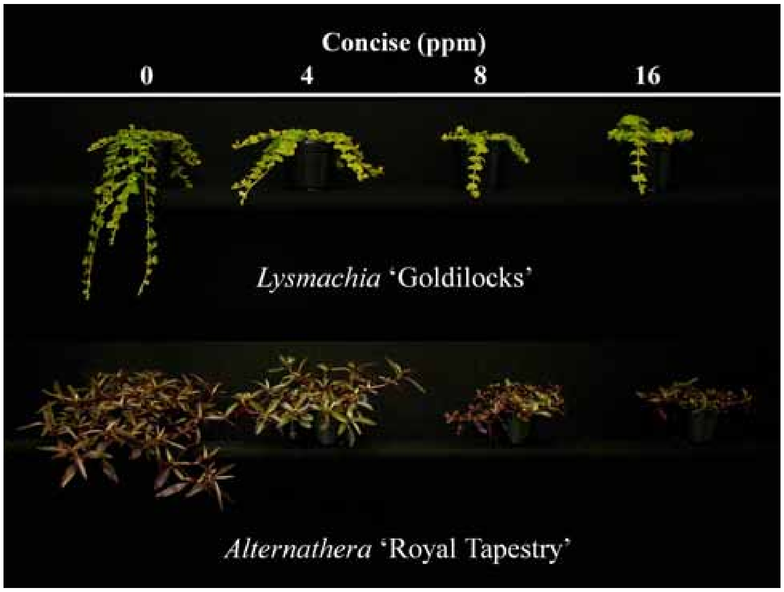

Figure 4. *'Goldilocks' lysmachia plants and 'Royal Tapestry' alternanthera plants that were grown from liners that were dipped for 30 seconds in solutions containing 0, 4, 8, or 16 ppm of Concise® (uniconazole) before planting. Photos were taken six weeks after treatment.*

considerations as PGRs are being applied to the substrate.

The substrate's moisture content will affect the amount of solution that each cell in the tray absorbs. To ensure that the PGR is absorbed uniformly, apply it when the substrate is at the point that it is ready to be irrigated. Depending on the environment, you can probably do this by watering well-rooted liners the day before application.

In addition to substrate moisture content, the length of time that plugs or liners are allowed to soak in the solution will affect how much PGR the substrate absorbs. Generally, you should dip plugs and liners between 30 seconds and two minutes.

Growers will also need to consider the sizes of the plugs or liner tray cells they are starting with and the containers the transplant will be finished in. For instance, New Guinea impatiens from a 50-cell tray liner that will be finished in 4-inch containers will need more growth regulator than plants from a 72-cell tray. Alternatively, marigolds from a 128-cell tray finished in an 804 pack will need less PGR than the same plug size planted in a 1206 pack.

Recommendations for Specific Crops

To determine which PGR to use, consult reputable resources for guidance on which AIs and application techniques are most suitable for the plants you want to treat.

The variation among genera, species, and cultivar responses to AIs, application methods, and rates are endless. Therefore, it is beyond the scope of this publication to provide crop-specific PGR application recommendations for height control. However, there are numerous resources that provide such recommendations.

Consult product labels first for crop recommendations.

For height control of annuals and perennials, see Michigan State University's Plant Growth Regulator Research website (it has information about and PGR recommendations for numerous species of the northern United States) — www.hrt.msu.edu/floraoe/PGRinfo.

Greenhouse Product News has a searchable database that includes research results of PGR applications to herbaceous perennials — www.gpnmag.com.

Height Control for Commercial Greenhouse Flowers (North Carolina State Cooperative Extension Horticulture Information Leaflet 528) contains many crop-specific recommendations for potted plants, annuals, and perennials — www.ces.ncsu.edu/depts/hort/hil/hil-528.html.

Table 4. Amounts of chemical necessary for making ancymidol, chlormequat chloride, ethephon, flurprimidol, paclobutrazol, and uniconazole solutions for sprays or drenches.

Chemical (% AI)	Concentration (ppm)	mL/L	fl oz/gal
ancymidol (0.264)	2.5	9.47	1.21
	5	18.94	2.42
	10	37.88	4.85
	20	75.76	9.70
	40	151.51	19.39
chlormequat chloride (11.8)	750	6.36	0.81
	1,500	12.71	1.63
	3,000	25.42	3.25
ethephon (3.9)	250	6.41	0.82
	500	12.82	1.64
	750	19.23	2.46
	1,000	25.64	3.28
flurprimidol (0.38)	1	0.26	0.03
	2.5	0.66	0.08
	5	1.32	0.17
	10	2.63	0.34
	20	5.26	0.67
paclobutrazol (0.4)	1	0.25	0.03
	2.5	0.62	0.08
	5	1.25	0.16
	10	2.50	0.32
	20	5.00	0.64
uniconazole (0.055)	1	1.82	0.23
	2.5	4.55	0.58
	5	9.09	1.16
	10	18.18	2.33

Table 5. Amount of water-soluble granular material necessary for making daminozide spray solutions.

Chemical (% AI)	Concentration (ppm)	g/L	oz/gal
daminozide (85)	1,250	1.47	0.19
	2,500	2.94	0.38
	5,000	5.88	0.75

Mixing Chemicals

After you have identified the crop(s) you will be treating and have selected an appropriate chemical, AI concentration, and application method, the first step in mixing PGRs is determining how much area will be treated for sprays or how many bulbs, trays, or containers will be treated for bulb soaks, liner dips, or drenches.

Next, using the area to be sprayed or the number of units to be treated, determine the volume of PGR solution that will be necessary. Finally, using the concentration of AI you want to apply, you will know how much chemical will be necessary for mixing your PGR solution. Most PGRs will have mixing tables on the label. We also have included tables for mixing PGR solutions at common concentrations for all the retardants (Tables 4 and 5).

PGRCALC is a user-friendly software program from the University of New Hampshire and North Carolina State University that can save you time and minimize calculation errors — extension.unh.edu/Agric/AGGHFL/Plantgrowthregulatorcalculator.cfm.

PGRCALC is a Microsoft Excel-based application that calculates the amount of solution needed for spray and drench applications, the amount of AI needed to make the solution, and the average cost of PGR applications per unit or area treated.

When mixing PGR solutions, you must aim for precision and accuracy. A calculation or measuring error could result in under-regulation or, even worse, over-regulation. Good tools to keep on hand are graduated cylinders and pipettes (for measuring liquid PGRs) and balances (for measuring water-soluble granular PGRs).

Conclusions

Growers are fortunate to have a wide range of PRGs available that have diverse modes of action, sites of absorption, and activity. Additionally, there are a number of techniques to successfully apply PRG solutions to plant material. While greenhouse growers are faced with an incredible variety of plant materials to grow, the number of PGR products and application techniques means there should be a chemical PGR height control solution for nearly every situation.

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