# EFFECT OF PACLOBUTRAZOL, UNICONAZOLE AND FLURPRIMIDOL APPLIED AS A SUBSTRATE DRENCH OR BY SUBIRRIGATION ON GROWTH OF *MONARDA DIDYMA* AND *BUDDLEIA DAVIDII*

By

RACHAEL E. PEPIN

Bachelor of Science in Horticulture

Oklahoma State University

Stillwater, Oklahoma

2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2012

EFFECT OF PACLOBUTRAZOL, UNICONAZOLE AND FLURPRIMIDOL

APPLIED AS A SUBSTRATE DRENCH OR BY SUBIRRIGATION ON GROWTH OF

*MONARDA DIDYMA* AND *BUDDLEIA DAVIDII*

Thesis Approved:

Dr. Janet C. Cole

Thesis Adviser

Dr. Michael Smith

Dr. Thomas Hennessey

ACKNOWLEDGMENTS

There are several individuals and companies that were crucial to the development, implementation, and completion of this study of plant growth regulators, paclobutrazol, uniconazole, and flurprimidol on the growth of *Monarda didyma* ‘Marshall’s Delight’ and *Buddleia davidii* ‘Pink Delight’.

Appreciation is due to Laura Marquez and her colleagues at Greenleaf Nursery Company (Park Hill, OK) for their suggestions on perennial plants and plant growth regulators that they were interested in finding out more about. I would, also, like to thank Greenleaf Nursery Company for providing all rooted cuttings throughout the past two year’s studies and the growing media and containers for the Spring 2010 study. The help received from these individuals as a company was vital in the initial development of this project, and I am extremely thankful for all of their help.

The plant growth regulators provided by Todd Bunnell of Se Pro Corp. (flurprimidol, Topflor), Kevin Forney of Fine America (paclobutrazol, Piccolo), and Todd Mayhew of Valent Corp. (uniconazole, Sumagic) were critical to this study. I cannot express how much I appreciate the expertise provided by these men and the donation of the chemicals from their respective companies. Without the efforts of these groups, our project would have never been able to proceed past the planning stages. Thank you all for providing enough plant growth regulator for all of our studies.

It is always a great opportunity to work with individuals who have graced the halls of the Department of Horticulture and Landscape Architecture at Oklahoma State University and are aware of the needs of student researchers and the value of their project. Dr. Todd Cavins is such an individual. I would to thank Dr. Cavins for being a liaison between Dr. Janet Cole and myself and SunGro Media. The potting media provided by SunGro was essential to our Summer and Fall 2010 research studies. Their contribution is greatly appreciated.

Help is always most appreciated on the home front. I would like to thank Dr. Bruce Dunn for working with Dr. Cole and myself on providing greenhouse space, advice, and providing another pair of watchful eyes on our research crops. In association with Dr. Dunn, Stephen Stanphill has been of great assistance during all greenhouse studies conducted throughout this research project. He professionally applied all pesticides necessary during the greenhouse studies and has continued to provide information on all chemicals he applied for use in this document. Arjina Shrestha, Katie Fine, and John Pepin, my loving husband, have provided so much assistance in harvesting and caring for these crops, and have provided so much support during the development of this paper, I cannot thank them enough. Also, I would like to thank Dr. Cole's husband, William, for all of his help getting us to harvest and into the building during the historic 4 foot snowfall of 2011.

Behind every successful research project is a great committee. I appreciate the suggestions, support and assistance provided by Drs. Michael Smith and Thomas Hennessey. Most importantly, I would like to thank Dr. Smith for his invaluable guidance in statistical analysis of the data collected. I would, also, like to thank these men for being ever so patient with the length of time it has required to complete this thesis.

I would like to thank The Department of Horticulture and Landscape Architecture at Oklahoma State University for giving me the opportunity to study in the department. The academic, financial, and emotional support provided by everyone within the department has provided the encouragement and drive necessary to complete this project. I am so thankful to have been a representative of the great department, and I plan to make you all proud by upholding the integrity and reputation of our department.

Dr. Janet Cole, without her, I would have not returned to attend graduate school. She sought me out and encouraged me to pursue my master's degree in horticulture. Because of her grace and friendship, I reluctantly conceded. I am so glad that I did! Throughout the past two years, we have met with multiple challenges outside of academia in our respective lives, and Dr. Cole has been a pillar of strength and inspiration for me. I want to thank you for your guidance, support, and continued friendship. Thank you a million times over.

Disclaimer: Acknowledgements reflect the views of the author and are not endorsed by committee members or Oklahoma State University.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# CHAPTER I

## Introduction: Plant Growth Regulators in Nursery Production

Nursery production is a vital industry in Oklahoma. Advancements in production practices in Oklahoma may draw more industry to the state, increasing revenues and benefiting the entire local community. A better understanding of subsurface irrigation application of plant growth regulators (PGRs) will provide benefits to production practices in the nursery industry in Oklahoma as well as other states and countries. Plant growth regulators are commonly applied to commercially produced plants to regulate stem elongation and produce compact plants (Tayama et al., 1992). Communication with nursery producers in northeastern Oklahoma has revealed an interest in using PGRs to control growth of a variety of ornamental crops, but information on efficacy and appropriate application rates is needed.

The purpose of this study was to determine the effect of the plant growth regulators paclobutrazol ((2RS,3RS)-1-(4-chlorophenyl)-4,-4dimethyl-2-(1,2,4-trizol-1-yl)pentin-3-ol), uniconazole ((E)-1-(4-chlorophenyl)-4,-4-dimethyl-2-(1,2,4-trizol-1-yl)pentin-3-ol), and flurprimidol ((alpha-(1-methylethyl)-alpha-[4-(trifluoromethoxy)phenyl]-5-pyrimidine-methanol)) on commercially produced bee balm (*Monarda didyma* L.). One objective of this study was to compare subsurface and substrate drench methods of application for each plant growth regulator on plant growth and visual quality of *Monarda didyma*, and the effects of each plant growth regulator applied as a subsurface irrigation was compared for butterfly bush (*Buddleia davidii* Franch). A second objective compared application rates for each plant growth regulator on growth of *Monarda didyma*

The efficacy of these growth regulators as substrate drenches depends on the growth substrate composition (Barrett, 1982; Bonaminio and Larson, 1978; Million et al., 1998a; Newman and Tant, 1995). Paclobutrazol and uniconazole are relatively nonpolar molecules, that are adsorbed by organic substrate components (Barrett, 1982). Million et al. (1998a) reported that pine bark and peat reduced the efficacy of paclobutrazol, but pine bark decreased effectiveness more than peat. They also found that adsorption of paclobutrazol varied with particle size and degree of decomposition of the pine bark. Labels of paclobutrazol and uniconazole recommend growers using pine bark-based substrate may need to apply higher concentrations of the chemical drench than they would apply if using substrate without pine bark (Million et al., 1998b).

**<u>Plant Growth Regulators</u>**

Paclobutrazol is effective at reducing growth of many species of nursery crops, particularly herbaceous perennials and containerized nursery crops. Paclobutrazol is a triazole compound that controls plant height by inhibiting production of gibberellins, the primary natural plant hormones responsible for cell elongation (Latimer and Whipker, 2007). Wang et al. (1986) found that root-applied paclobutrazol was translocated throughout apple seedlings grown in a continuously aerated nutrient solution, but when paclobutrazol was applied to the foliage none translocated to the stems or roots. Translocation of paclobutrazol from root uptake has been assumed to occur primarily through the xylem, possibly resulting in better translocation from root applications than from foliar applications (Dalziol and Lawrence, 1984; Sterrett, 1985). Much less active ingredient is required when subirrigation is used to apply PGRs (Cox, 2003).

Application rates of chemicals used are important in determining the costs of a given application method. Million et al. (2002) found that plant size was reduced more when paclobutrazol was applied continuously through an ebb and flood system supported by a tank filled with a stock solution containing PGR than when the PGR was applied in a single application. For ‘Cocktail Gin’ begonias (*Begonia χ semperflorens-cultorum* hybrids), ‘Super

Elfin White' impatiens (*Impatiens wallerana* Hook.), 'Tara' chrysanthemum (*Dendranthema* χ *grandiflorum* (Ramat.) Kitamura), and 'Plum Crazy' petunia (*Petunia* χ *hybrida* Vilm.-Andr.) (Million et al. 2002), 2.1, 4.0, 5.4 and 3.0 times higher application rates, respectively, were required with a single application than with continuous application to obtain a similar reduction in growth.

The volume of subirrigate taken up by the plant is important in determining the appropriate application rate of paclobutrazol. Million et al. (2002) noted that the initial treatment volumes were 129, 96, 74 and 92 ml per pot for begonia, impatiens, chrysanthemum and petunia, respectively. The rates chosen were based on earlier research on subirrigation (Million et al., 1999) and relative crop sensitivities to drench applications. Plant growth was compared with various volumes and application methods, and lower rates with subirrigation reduced growth more than higher rates of drench.

Uniconazole has a similar chemical structure to paclobutrazol (Adriansen, 1997). It is a triazole compound, a bioregulator that suppresses stem elongation by inhibition of gibberellic acid (GA) biosynthesis. Early research indicated that uniconazole can be very persistent in retarding plant growth without causing phytotoxicity (Davis et al., 1988). Although the chemical structures are similar, in most species of ornamental plants, uniconazole reduces plant growth more than paclobutrazol when applied as a soil drench in equal amounts (Davis et al., 1987). On average, the amount of paclobutrazol required is four to ten times that of uniconazole, to obtain a similar effect on plant size (Barrett and Nell, 1989). Results of several studies have indicated that uniconazole is effective in controlling growth of woody landscape plants grown in containers (Keever et al., 1990; Frymire and Henderson-Cole, 1992; Frymire and Cole, 1992; Norcini and Knox, 1990; Warren, 1990). Henderson and Nichols (1991) found that uniconazole was effective in reducing height in firethorn (*Pyracantha coccinea* M.J. Roem. 'Kasan') when applied as a substrate drench, and uniconazole-treated plants had desirable, compact growth and darker green foliage than plants not treated with the growth regulator. Also, it has been suggested that uniconazole drenches may affect cell elongation or cell division during flower development to a lesser extent than foliar applications, resulting in faster flowering in some species (Barrett, 2001; Starman, 1991). Keever and West (1992) reported that thorny elaeagnus (*Elaeagnus pungens* Thunb. 'Fruitlandii') shoot dry weights decreased with increasing rates of uniconazole applied as a substrate drench at the end of the second season, or the season following treatment. Sterrett (1988) and Numbere et al. (1989) showed that only a small portion of uniconazole moves through the xylem once in the plant. In addition, uniconazole has little or no effect on rooted cuttings taken from parent plants that have previously been treated with uniconazole by substrate drench (Wang and Gregg, 1989).

Flurprimidol is a plant growth regulator used on a wide range of ornamental crops, including very vigorous plant species. Flurprimidol is a nitrogen-containing heterocycle compound of the pyrimidine chemical class that inhibits enzyme catalyzing steps in the GA biosynthesis pathway that involves oxidation of ent-kaurene to ent-kaurenoic acid, a GA precursor. Flurprimidol is a relatively new plant growth regulator in the United States that has a similar chemical structure and mode of action to paclobutrazol and uniconazole, and it is effective as a substrate drench (Krug et al., 2005a, 2005b, 2006). Flurprimidol is commonly used to control shoot growth in trees, like *Fraxinus americana* L. (Premachandra, 1997). A caladium, (*Caladium bicolor* Vent.), tuber study showed that substrate drench of flurprimidol provided acceptable height control for vigorous 'Red Flash' caladiums, and the efficacy of flurprimidol was comparable to equal concentrations of paclobutrazol when applied by drench (Krug et al., 2007). Krug et al. (2005a) also reported height control with flurprimidol on 'Star Gazer' oriental lilies (*Lilium* hybrids).

**Methods of Application**

Substrate drench has been a popular method of applying plant growth regulators. Several studies have reported substrate drench application of plant growth regulators to be effective methods of controlling stem elongation in poinsettias (Barrett and Nell, 1982; Barrett et al., 1994; Currey and Lopez, 2011; Faust et al., 2001; Newman and Tant, 1995; Nui et al., 2002; Wilfret, 1978, 1993, 1996). When compared with foliar spray applications, substrate drench applications provide more uniform height control over a longer period of time (Boldt, 2008; Ecke et al, 2004; Gent and McAvoy, 2000). Effectiveness of uniconazole in controlling vegetative growth of elaeagnus was greater with substrate drench applications than foliar applications (Keever and West, 1992). Currey and Lopez (2011) reported that flurprimidol drenches were effective in suppressing final height of poinsettia without adversely affecting time to anthesis or aesthetic quality.

The high efficacy of flurprimidol substrate drenches along with split applications could provide height control with more uniform internode length (Krug et al., 2005a). Results of this study also suggested that, similar to the recommendations for ancymidol, multiple applications of flurprimidol as a substrate drench should be explored with concentrations less than 0.5 mg/container to effectively regulate height of 'Star Gazer' Lily (DeHertogh, 1996; Hamrick, 2003; Krug et al., 2005a; Wilkins and Grueber, 1983).

Site of application of plant growth regulators determines the effectiveness on growth suppression. Differences in growth suppression with different application sites have been attributed to the difference in root and foliar uptake or differences in the ability of plant growth regulators (paclobutrazol and uniconazole) to translocate in the xylem and phloem (Keever et al., 1990; Quinlan and Richardson, 1986; Warren, 1990). Root-applied plant growth regulators are acropetally transported to the leaves and shoot apex primarily through the xylem (Richardson and Quinlan, 1986). Transpiration is necessary to initiate movement of the chemical into the leaves and shoots via the xylem. Roots have fewer barriers to prevent entry of plant growth regulators than leaves. Foliar-applied plant growth regulators must first accumulate in the leaves, enter into the phloem of the stem, and eventually translocate into the xylem before being effective (Barrett and Bartuska, 1982). Quinlan and Richardson (1986) and Wang et al. (1986) demonstrated that no foliar-applied triazole PGR was translocated to stems or roots. Soil applied triazole compounds are relatively immobile and are most efficiently taken up by plant roots when the plant growth regulator is localized within the root zone (Lever, 1986).

Alternative application methods are being investigated for several plant growth regulators. Subirrigation is a method in which the plant growth regulator is added to a stock tank mix of water and/or fertilizer and is delivered to the plant by ebb and flood techniques or by adding the solution to a saucer under the plant. Application of a plant growth regulator by subirrigation is expected to be more effective than a foliar spray application. Cox (2003) found that less active ingredient was required to decrease plant size of geranium when plant growth regulators were applied by subirrigation than by foliar application. This greater effectiveness may be attributed to more rapid uptake of the plant growth regulator by the root system than foliar absorption since translocation of growth regulators primarily occurs through the xylem (Dalziol and Lawrence 1984; Sterrett 1985). Uniconazole and paclobutrazol have limited movement in plants once absorbed into the translocation system (Early and Martin, 1988). In the same study, paclobutrazol remained in lower regions of peach stems after being absorbed by roots.

The labels for paclobutrazol, uniconazole, and flurprimidol list guidelines for substrate drench application methods and suggested rates of application. A study on potted kalanchoë (*Kalanchoë blossfeldiana* v. Poelln.) showed several times more plant growth regulator is required for foliar spray applications than for substrate surface drenches with paclobutrazol and uniconazole to obtain the same growth reduction (Adriansen, 1989).

## **<u>Crop Information</u>**

*Monarda didyma* 'Marshall's Delight' is marketed as an attractive herbaceous perennial for hummingbird and butterfly gardens. It has traditionally been produced in 10.2 to 11.4 cm diameter containers or 3.7 L pots. *Monarda didyma* grows to a mature height of 70 to 120 cm with 6 to 14 cm long ovate, deltoid to ovate-lanceolate, serrate, or hirsute leaves, and glomerules are 2 to 4 cm across with red tinged bracts, it is hardy to zone 4 (Griffiths, 1994). Plants can become top heavy as the substrate dries and loses weight. As a result, plants and containers may fall over leading to mechanical damage to the plant caused by equipment or human traffic crushing or stepping on leaves and stems, or lack of irrigation caused by the substrate not being accessible to irrigation. By reducing plant height during production, nursery growers can provide consumers with a more attractive plant with fewer labor costs for pruning and other cultural practices and reduce shipping costs.

*Buddleia davidii* 'Pink Delight' is a popular woody perennial produced in Oklahoma. It has a desirable floral display and is attractive to pollinators. This deciduous perennial grows to 3 m tall with subquadrangular branchlets. Leaves grow to 20 cm long with dark green upper surfaces, felted beneath, lanceolate, acuminate, finely toothed. Panicles extend to 30 cm long, are terminate, cymose, tapering, and bear fragrant flowers. *Buddleia davidii* 'Pink Delight' flowers are bright pink on long panicles (Griffiths, 1994). Buddleia may grow 0.9 to 1.5 meters in height in a single season; depending on how much the plant was sheared in the preceding year. In some locations, buddleia is maintained as a herbaceous perennial due to its abundant tender vegetative growth during a single season. Top-heaviness when produced in containers results in lodging of plants which may result in plant damage or misplacement of weighted drip tube irrigation emitters during production.

**Factors Associated with Quality**

Determining plant saleability requires an understanding of plant characteristics. Based on the guidelines set forth in the Judging Manual for the J. Benton Storey Undergraduate Judging

Competition (1999), four main criteria exist for evaluating a crop's quality: symmetry, uniformity, proportion, and showiness. Symmetry is the equal distribution of the plant's entire structure around a central point of a geometric form when viewed from above. Uniformity is the similarity of individual plants within a crop with regard to size, shape, and color. Proportionality refers to the ratio of plant size to container size. Showiness is the overall visual appeal of the crop (Needham, 1996).

Additional factors considered in this study were uniformity of foliage, color, plant size, and plant form. Cultural perfection refers to the overall plant quality in respect to growth and development, healthy stems and foliage, lack of blemishes, nutritional deficiency, and damage. Uniformity is the balanced placement of foliage of similar size for similar stages of development throughout the plant with no gaps or bare spaces along the stems. The color of the plant should be true-to-type, uniform throughout, and intense. Plant size is crucial in relation to the pot and determines plant form, which is the evaluation of the plant's size (over or undersized) and the habit in which the plant grows. For example, a plant with all of its branches and leaves on one side of the plant is one-sided, and considered very poor quality.

**Objectives of Research**

The objectives of this research were to determine the effect of 1) the plant growth regulators paclobutrazol, uniconazole, and flurprimidol on commercially produced *Monarda didyma* and *Buddleia davidii* subsurface and substrate drench application of each plant growth regulator on plant growth and quality of *Monarda didyma*, and subsurface applications on *Buddleia davidii,* and 2) application rates for each plant growth regulator on growth of *Monarda didyma*.

**Literature Cited**

Adriansen, E. 1989. Growth and flowering of pot plants soaked with plant growth regulator solutions in ebb and flood benches. Acta Hort. 251:319-327.

Adriansen, E. 1997. Residues of paclobutrazol and uniconazole in nutrient solutions from ebb and flood irrigation of pot plants. Sci. Hort. 69:73-83.

Barrett, J.E. 1982. Chrysanthemum height control by ancymidol, PP333, and EL-500 dependent on medium composition. HortScience 17:896-897.

Barrett, J.E. 2001. Mechanisms of action, p. 32-47. In: M.L. Gaston (ed.). Tips on regulating growth of floriculture crops. Ball Publishing, Batavia, IL.

Barrett, J.E and C.A. Bartuska. 1982. PP333 effects on stem elongation dependent on site of application. HortScience 17:737-738.

Barrett, J.E., C.A. Bartuska, and T.A Nell. 1994. Comparison of paclobutrazol drench and spike applications for height control of potted floriculture crops. HortTechnology 29:180-182.

Barrett, J.E. and T.A. Nell. 1982. Irrigation interval and growth retardants affect poinsettia development. Proc. Fla. State Hort. Soc. 95:167-169.

Barrett, J.E. and T.A. Nell. 1989. Comparison of paclobutrazol and uniconazole on floriculture crops. Acta Hort. 251:275-280.

Boldt, J.L. 2008. Whole plant response of chrysanthemum to paclobutrazol, chlormequat chloride, and (s)-abscisic acid as a function of exposure time using a split-root system. MS Thesis, Univ. of Fla., Gainesville.

Bonaminio, V.P. and R.A. Larson. 1978. Influence of potting media, temperature, and concentration of ancymidol on growth of *Chrysanthemum morifolium* Ramat. J. Amer. Soc. Hort. Sci. 103:752-756.

Cox, D.A. 2003. Subirrigating seed geraniums with Bonzi. University of Massachusetts, Amherst. Department of Plant and Soil Sciences www.umass.edu/umext/floriculture/fact_sheets/specific_crops/bonzi_geranseed.html. UMass Extension. Accessed 12 November 2009.

Currey, C.J. and R.G. Lopez. 2011. Early flurprimidol drench applications suppress final height of four poinsettia cultivars. HortTechnology 21:35-40.

Dalziol, J. and D.K. Lawrence 1984. Biochemical and biological effects of kaurene oxidase inhibitors, such as paclobutrazol. In: R. Menhenett, D.K. Lawrence, (eds.). Biochemical Aspects of Synthetic and Naturally Occurring Plant Growth Regulators, Monograph 11. British Plant Growth Regulation Group, Wantage, England, pp 43-57.

Davis. T.D., G.L. Steffens, and N. Sankhla. 1988. Triazole plant growth regulators. Hort. Rev. 10:63-105.

Davis, T.D., H.S. Gehlot, C.F. Williams, and N. Sankhla. 1987. Comparative shoot growth retarding activities of paclobutrazol and XE-1019. Proc. Plant Growth Regulat. Soc. Amer. 14:121-124.

DeHertogh, A. 1996. *Lilium* (asiatic and oriental hybrids)---Potted plants, p. C109-C121. Holland bulb forcer's guide. Intl. Flower Bulb Ctr., Hillegom, The Netherlands.

Early, J.D. and G.C. Martin. 1988. Translocation and breakdown of C-labelled paclobutrazol in 'Nemaguard' peach seedlings. HortScience 23:196-200.

Ecke, P., III, J.E. Faust, J. Wiggins, and A. Higgins. 2004. Height control, p. 51-72. In: The Ecke poinsettia manual. Ball Publishing, Batavia, IL.

Faust, J.E., P.C. Korczynski, and R. Klein. 2001. Effects of paclobutrazol drench application date on poinsettia height and flowering. HortTechnology 11:557-560.

Frymire, R.M. and J.C. Cole. 1992. Uniconazole effect on growth and chlorophyll content of pyracantha, photinia, and dwarf Burford holly. J. Plant Growth Regulat. 11:143-148.

Frymire, R.M. and J.C. Henderson-Cole. 1992. Effect of uniconazole and limited water on growth, water relations, and mineral nutrition of 'Lalandei' pyracantha. J. Plant Growth Regulat. 11:227-231.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture, p. 89-146. In: A.S. Basara (ed.). Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton, NY.

Griffiths, M. 1994. The new royal horticultural society dictionary: Index of garden plants. Timber Press, Portland, OR.

Hamrick, D. 2003. *Lilium* (asiatic and oriental hybrids). Vol. 2. Ball Publishing, Batavia, IL.

Henderson, J.C. and T.H. Nichols. 1991. *Pyracantha coccinea* 'Kasan' and 'Lalandei' response to uniconazole and chlormequat chloride. HortScience 26:877-880.

Judging Manual for the J. Benton Storey Undergraduate Judging Contest. Southern Region, American Society of Horticultural Science, Association of Collegiate Branches. Revised 12 July 1999.

Keever, G.J., W.J. Foster, and J.C. Stephenson. 1990. Paclobutrazol inhibits growth of woody landscape plants. J. Environ. Hort. 8:41-47.

Keever, G.J. and M.S. West. 1992. Response of established landscape plants to uniconazole. HortTechnology 2:465-468.

Krug, B.A., B.E. Whipker, and I. McCall. 2005a. Flurprimidol is effective at controlling height of ‘Star Gazer’ oriental lily. HortTechnology 15:373-376.

Krug, B.A., B.E. Whipker, and I. McCall. 2007. Caladium growth control with flurprimidol, paclobutrazol, and uniconazole. HortTechnology 17:368-370.

Krug, B.A., B.E. Whipker, I. McCall, and J.M. Dole. 2005b. Comparison of flurprimidol to ancymidol, paclobutrazol, and uniconazole for tulip height control. HortTechnology 15:371-373.

Krug, B.A., B.E. Whipker, I. McCall, and J.M. Dole. 2006. Narcissus response to plant growth regulators. HortTechnology 16:129-132.

Latimer, J. and B.Whipker. 2007. Using piccolo with herbaceous perennials. Edited by Fine America, Inc.

Lever, B.G. 1986. Cultar-A technical overview. Acta Hort. 179:459-466.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998a. Influence of media components on efficacy of paclobutrazol in inhibiting growth of broccoli and petunia. HortScience 33:852-856.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998b. Influence of pine bark on efficacy of different growth retardants applied as a drench. HortScience 33:1030-1031.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1999. Inhibiting growth of flowering crops with ancymidol and paclobutrazol in subirrigation water. HortScience 34:1103-1105.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 2002. One-time vs. continuous application of paclobutrazol in subirrigation water for the production of bedding plants. HortScience 37:345-347.

Needham, D.C. 1996. Horticulture Crop Judging. Oklahoma State University, Cooperative Extension Service, 4-H Circ. 702.

Newman, S.E. and J.S. Tant. 1995. Root-zone medium influences growth of poinsettias treated with paclobutrazol-impregnated spikes and drenches. HortScience 30:1403-1405.

Norcini, J.G. and G.W. Knox. 1990. Effect of pruning on the growth inhibition activity of Sumagic (uniconazole). J. Environ. Hort. 8:199-204.

Nui, G., R. Heins, and W. Carlson. 2002. Using paclobutrazol to control height of poinsettia ‘Freedom’. HortTechnology 12:232-236.

Numbere, T.E., F.D. Morrison, R.W. Campbell, and H. Moser. 1989. Uptake, translocation, and metabolism of XE-1019 in apple trees. HortScience 24:113 (Abstr.).

Premachandra, G.S, W.R. Chaney, and H.A. Holt. 1997. Gas exchange and water relations of *Fraxinus americana* affected by flurprimidol. Tree Physiol. 17:97-103.

Quinlan, J.D. and P.J. Richardson. 1986. Uptake and translocation of paclobutrazol and implications for orchard use. Acta Hort. 179:443-451.

Richardson, P.J. and J.D. Quinlan. 1986. Uptake and translocation of paclobutrazol by shoots of M.26 apple rootstock. Plant Growth Regulat. 4:347-356.

Starman, T.W. 1991. Lisianthus growth and flowering responses to uniconazole. HortScience 26:150-152.

Sterrett, J.P. 1985. Paclobutrazol: a promising growth inhibitor for injection into woody plants. J. Amer. Soc. Hort. Sci. 110:4-8.

Sterrett, J.P. 1988. XE-1019: Plant response, translocation, and metabolism. J. Plant Growth Regulat. 7:19-26.

Tayama, H.K., R.A. Larson, P.A. Hammer, and T.J. Rolls. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assn., Columbus, OH.

Wang, Y.T. and L.L. Gregg. 1989. Uniconazole affects vegetative growth, flowering, and stem anatomy of hibiscus. J. Amer. Soc. Hort. Sci. 114:927-932.

Wang, Y.T., T. Sun, and M. Faust. 1986. Translocation of paclobutrazol, a gibberellin biosynthesis inhibitor, in apple seedlings. Plant Physiol. 82:11-14.

Warren, S.L. 1990. Growth response of 13 container-grown landscape plants to uniconazole. J. Environ. Hort. 8:151-153.

Wilfret, G.J. 1978. Height regulation of poinsettia with a growth regulator incorporated into the soil medium. Proc. Fla. State Hort. Soc. 91:220-222.

Wilfret, G.J. 1993. Comparative effect of growth regulators on poinsettia. Proc. Fla. State Hort. Soc. 106:294-297.

Wilfret, G.J. 1996. Response of seventeen poinsettia cultivars to growth regulators. Proc. Fla. State Hort. Soc. 109:5-7.

Wilkins, H.F. and K.L. Grueber. 1983. Lily-height control: Drenches, sprays, dips. Florists' Rev. 173:50-53.

CHAPTER II

# Growth Inhibition of *Monarda didyma* When Paclobutrazol, Uniconazole, or Flurprimidol are Applied at Various Rates as a Substrate Drench or Through Subirrigation

Rachael E. Pepin and Janet C. Cole

**ADDITIONAL INDEX WORDS.** herbaceous perennials, plant growth regulator

**SUMMARY.** The Spring study examined the control of growth of *Monarda didyma* 'Marshall's Delight' by paclobutrazol, uniconazole, or flurprimidol applied to the substrate by subirrigation delivered via saucer. Application rates for each chemical were the recommended label rate for herbaceous perennials listed on the product label applied in 4 equal applications (1/4 recommended label rate) 4 days per week for each plant growth regulator (PGR). The Summer and Fall studies investigated the control of growth of *Monarda didyma* 'Marshall's Delight' by paclobutrazol, uniconazole, or flurprimidol applied to the substrate as a surface drench or through subirrigation delivered via saucer. Application rates for each chemical were 0.5, 1.0, 1.5, and 2.0 times the recommended label rate for herbaceous perennials listed on the product label for each PGR. Plant dry weights of leaves and stems decreased curvilinearly and linearly, respectively, as paclobutrazol rate increased and linearly as uniconazole or flurprimidol rates increased. Height decreased as paclobutrazol and flurprimidol rate increased.

**Introduction.**

Several PGRs are labeled for use on ornamental crops; however, their effectiveness is often species or cultivar dependent (Barrett, 2001; Chamberlayne and Banko, 2003; Keever and Olive, 1994; Kim et al., 1999; Latimer et al., 2001). In addition to the variety of PGRs available, alternative application methods are being developed and added to product labels. Subirrigation is a method in which the PGR is added to a tank mix of water and fertilizer and then is delivered to the plants by ebb and flood irrigation or by adding the solution to a saucer under the plant. Effectiveness of the PGR in reducing plant growth should be increased with subirrigation, since the PGR is taken up by the roots of the plant more readily than by leaves using a foliar application. Wang et al (1986) found that root-applied paclobutrazol was translocated throughout apple seedlings grown in a continuously aerated nutrient solution, but when paclobutrazol was applied to the foliage none translocated to the stems or roots. Translocation of paclobutrazol from root uptake has been assumed to occur primarily through the xylem and it may be less mobile in the phloem (Dalziol and Lawrence, 1984; Sterrett, 1985). Much less active ingredient is required when PGRs are applied by subirrigation than when they are applied as a foliar spray (Cox 2003). Acropetal transport from roots to other plant parts is more efficient than basipetal transport from leaves. Acropetal (upward only) transport in the xylem from roots to the shoots and leaves is driven by transpiration creating a negative water potential in aerial portions of the plant. Water, nutrients, and PGRs move toward the lowest (most negative) water potential (Nobel 2009).

Chemical application rates are important in determining monetary costs of a given application. Million et al. (2002) noted that plant size was reduced more when paclobutrazol was applied continuously through an ebb and flood system supported by a tank filled with a stock solution containing paclobutrazol than when applied as a single application. For *Begonia* x *semperflorens-cultorum* hybrids 'Cocktail Gin', *Impatiens wallerana* Hook. 'Super Elfin White', *Dendranthema* x *grandiflorum* (Ramat.) Kitamura 'Tara', and *Petunia* x *hybrida* Vilm.-Andr. 'Plum Crazy' (Million et al. 2002), 2.1, 4.0, 5.4 and 3.0 times higher application rates, respectively, were required with a single application than with continuous application.

The subirrigate volume absorbed by the plant is important in determining the appropriate application rate of PGR. Million et al. (2002) noted that the initial treatment volumes for paclobutrazol treatments were 129, 96, 74 and 92 ml per pot for begonia, impatiens, chrysanthemum, and petunia, respectively. Compared to volumes typically used for substrate drench applications, rates were lower in subirrigation treatments. Uniconazole and paclobutrazol have limited redistribution in plants once deposited from the xylem (Early and Martin, 1988). In the same study, paclobutrazol remained in lower regions of peach stems after being absorbed by roots. Flurprimidol is a relatively new plant growth regulator in the United States that has a similar chemical structure and mode of action to paclobutrazol and uniconazole, and it is effective as a substrate drench (Krug et al., 2005a, 2005b, 2006). However, information on flurprimidol applied through subirrigation is limited.

The objectives of this research were to determine (1) the effects of each PGR on plant growth when applied through subirrigation, (2) the effects of substrate drench application versus subirrigation on plant growth, and (3) the effect of rate of application on plant growth for each method of application and growth regulator.

**Materials and methods**

***Spring 2010 Greenhouse Study.*** Commercially produced (Greenleaf Nursery, Co., Park Hill, OK) rooted cuttings of *Monarda didyma* L. were planted in 3.7 L containers. Each cubic yard of substrate included: 12 oz of dolomitic lime, 4 oz urea, 8 oz 0N-20P-0K (0N-46 $P_2O_5$-0 $K_2O$), 7 oz 0N-0P-50K (0N-0 $P_2O_5$-60 $K_2O$, potassium chloride), 2 lbs Micromax (The Scotts Co., Marysville,OH), 12 lbs 22N-2P-8K controlled release fertilizer (22N-5 $P_2O_5$ -10 $K_2O$, 12-14 month formulation, Osmocote, The Scotts Co.) 4:2:1 (by vol.) coarse pine bark (63-65% by volume of particles greater than 2.4 mm): fine pine bark (48-50% by volume of particles greater than 2.4 mm): and sand (Greenleaf Nursery Co., Park Hill, OK). Plants were allowed to establish for four weeks, and the study was conducted in a polycarbonate-covered greenhouse with an average daily high/low temperature of 21/15 $^oC$ with a maximum photosynthetic photon flux (PPF) of 1340 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at the Oklahoma State University Research Greenhouses at Stillwater, OK. No supplemental lighting was provided. The experiment began 9 February 2010 and was terminated 22 April 2010.

Paclobutrazol (Piccolo, Fine America, Walnut Creek, CA), uniconazole (Sumagic, Valent Corp., Walnut Creek, CA), or flurprimidol (Topflor, Se Pro Corp., Carmel, IN) was applied through subsurface irrigation via a 20-cm-diameter saucer placed under each container based on the recommended label rate for drench applications on herbaceous perennial plants in 3.7 L containers (Table 2.1). Solutions of 300 mL per pot were applied at each irrigation with ¼ of the recommended rate (the full recommended rate was distributed over a week's time) of each PGR which were 1 ppm (material, not a.i.) paclobutrazol, 0.25 ppm uniconazole, 0.25 ppm flurprimidol, or no PGR (tap water control) to all plants through subirrigation. On cloudy days or when the potting media was relatively moist, less irrigation was given and 150 mL of solution was applied. This was determined using indicator plants grown in similar environmental conditions and irrigated with tap water on the same days as the plants in the experiment. If the indicator plants did not take up 150 mL of solution, then only 150 mL was applied to the experimental plants; if the indicator plants absorbed more than 150 ml, then 300 mL was applied to the experimental plants.

All plants were treated with TriStar (Acetamiprid, Cleary Chemical Corporation, Dayton, NJ) at the label rate of 1/3 teaspoon per 3 gallon (0.012 oz. ai/gallon) as a foliar spray on 11 March 2010 for fungus gnat control. Spider mites were treated on 7 April 2010 with Floramite (Bifenazate, Olympic Horticultural Products (OHP), Inc., Mainland, PA) at the label rate of 1/4 teaspoon per quart (1.0 oz. ai/quart) as a foliar spray.

Plant height from the substrate surface to the highest growing point and width (average of width measured at the widest part and perpendicular to the widest part), leaf length of the longest leaf, and leaf width of the widest leaf per plant were measured at planting. Plant height and width were measured bi-weekly. At harvest, plant height, width, shoot (including leaves), and root dry weights were determined.

The experiment was arranged in a completely randomized design with three growth regulators and twelve replications. Data were analyzed using PROC GLM in SAS (SAS Institute, Cary, NC) and means were separated using protected LSD.

***Summer 2010 Outdoor Study.*** Commercially produced (Greenleaf Nursery, Co., Park Hill, OK) rooted cuttings of *Monarda didyma* were planted in 3.7 L containers with SunGro Professional Growing Mix peat-based substrate (Sungro LC1, Sungro, Bellevue, WA). Plants were allowed to establish for four weeks outdoors under full sun (1890 $\mu mol \bullet m^{-2} \bullet s^{-1}$) at Claremore, OK. Daily high temperatures averaged 36 $^{o}C$. The experiment began on 14 May 2010 and was terminated on 18 August 2010.

Paclobutrazol, uniconazole, or flurprimidol was applied as a substrate drench or through subsurface irrigation. Subsurface applications were poured into a 20 cm diameter plastic saucer placed under each container. Growth regulators were applied at 0 (control), 0.5x rate (2 ppm paclobutrazol (material, not a.i.) or 0.5 ppm uniconazole or flurprimidol), recommended label rate (4 ppm paclobutrazol or 1 ppm uniconazole or flurprimidol), 1.5x rate (6 ppm paclobutrazol or 1.5 ppm uniconazole or flurprimidol), or 2x rate (8 ppm paclobutrazol or 2 ppm uniconazole or flurprimidol). Solutions of 296 mL for the control and paclobutrazol applications and 177 mL of solution for uniconazole and flurprimidol applications (based on suggested drench solution rates on the product labels) were applied to each pot (Table 2.2). On days when no PGRs were applied 300 mL of tap water was applied to all plants as a substrate drench or as subirrigation based on their treatment application method.

Soluble fertilizer was applied every other week at 1/2 tablespoon per gallon of water 22N-2P-13K (Jack's Professional 22N-5 $P_2O_5$-16 $K_2O$, Allentown, PA). Soluble trace elements mix (STEM, Peter's Professional, Marysville, OH ) was applied monthly at ½ tablespoon per gallon of water. All plants received 300 ml of fertilizer solution at each application. Bonide Systemic Granules Insect Control (Acephate, Bonide Products Inc., Oriskany, NY) was applied 22 June 2010 at a rate of 3 tablespoons (44.4 ml) per gallon for grasshopper control.

Plant measurements were as described for the 2010 Spring Greenhouse study except only height and width were measured. Plant quality (damage) was rated on a scale of one to four with four being a dead plant and one being a high quality, salable plant two weeks prior to market date on about 4 August 2010. At harvest, plant height, width, leaf area, and shoot, leaf, and root dry weights were determined.

A randomized complete block design with three growth regulators, at five application rates, two methods of application, and ten replications was used. Data were analyzed using PROC GLM in SAS 9.1 (SAS Institute, Cary, NC) by plant growth regulator. For significant method by rate interactions, trend analyses were conducted for rates within each application method.

***Fall 2010 Greenhouse Study.*** The Summer 2010 study was repeated except plants were grown in a polycarbonate-covered greenhouse with an average daily high/low temperature of 21/15 $^{o}$C and average PPF of 1450 μmol• $m^{-2}$•$s^{-1}$ within the greenhouse at the Oklahoma State University Research Greenhouses at Stillwater, OK. Supplemental lighting (lamps with 400W high-pressure sodium bulbs) was added on 22 October 2010 to extend the day length from 1800 to 2200 HR. The experiment began on 1 October 2010 and was terminated on 31 January 2011.

In addition to the plant measurements described above, number of leaves per plant was counted at harvest. Leaf area per leaf was calculated using to following equation:

Leaf area/Leaf = (leaf area/plant)/(number of leaves/ plant)

**Results**

***Spring 2010 Greenhouse Study.*** The change in initial height and height at harvest was the only measured variable that differed among treatments. Plants not receiving a plant growth regulator were taller than those treated with plant growth regulators (Table 2.3).

***Summer 2010 Outdoor Study.*** No interaction existed between application method and rate for paclobutrazol for plant width (data not presented). The change in initial plant width and width at harvest was greater with subsurface application than substrate drench (Table 2.4). Plant width decreased linearly as paclobutrazol application rate increased. Paclobutrazol application method interacted with rate for plant height and stem and leaf dry weight (Table 2.5). The change in initial height and height at harvest, and stem and leaf dry weight of plants receiving substrate drenches decreased linearly as paclobutrazol rate increased. Stem and leaf dry weights decreased curvilinearly as paclobutrazol rate increased with subirrigation.

No interaction occurred between uniconazole application method and application rate for change in plant width (data not presented). Neither uniconazole application method nor rate affected plant width (Table 2.6). Uniconazole application method interacted with rate for stem dry weight. With the substrate drench, stem dry weight decreased linearly as uniconazole rate increased, but rate did not affect stem dry weight with the subsurface application (Table 2.7).

Application method did not interact with rate for flurprimidol (data not presented). Main effects of application method and rate also did not affect plant growth (Table 2.8). Flurprimidol application method interacted with rate for change in height and stem dry weight. Change in height and stem dry weight decreased linearly as rate increased with the substrate drench but not with subsurface application (Table 2.9). Heights and stem dry weights were greater for subirrigated plants than drench applications at similar rates (Tables 2.9).

***Fall 2010 Greenhouse Study.*** Paclobutrazol application method did not interact with rate for change in plant width (data not presented). Plants receiving the subsurface application were wider than those receiving the substrate drench (Table 2.4). Paclobutrazol application method interacted with rate for stem and leaf dry weight (Table 2.5). Substrate drench did not affect stem or leaf dry weight, but the subsurface application resulted in a decreasing curvilinear response for stem and leaf dry weights.

Uniconazole application method did not interact with rate for plant leaf dry weight (data not presented). Plants receiving the subsurface application had greater changes in plant widths than those receiving the substrate drench (Table 2.6). Subsurface application did not affect the change in initial height and height at harvest, the change in initial width and width at harvest, or stem, leaf or root dry weight, but the substrate drench application resulted in a decreasing curvilinear response for leaf dry weight (Table 2.7).

Flurprimidol application method and rate were not significant for plant width (Table 2.8). The change in initial height and height at harvest and stem dry weights did not differ for methods or rates of application (Table 2.9).

Leaf area was calculated by dividing leaf area per leaf by number of leaves per plant. Leaf area was determined using a Li-Cor 3100 light meter (Li-Cor, Lincoln, NE). There were no significant differences for leaf area per leaf among all treatments and variables (Table 2.10).

**Discussion**

***Spring 2010 Greenhouse Study.*** The effectiveness of the PGRs in reducing plant growth was increased with subirrigation when compared to plants that did not receive PGR during subirrigation (Table 2.3). These observations are similar to when Million et al. (2002) noted that plant size was reduced more when paclobutrazol was applied continuously through an ebb and flood system supported by a tank filled with a stock solution containing paclobutrazol than when applied as a single application. The quality of the plants was not significantly different for control, paclobutrazol, and flurprimidol. Uniconazole treated plants had the poorest quality.

Pine bark is commonly used in nursery substrate. The first greenhouse trial with *Monarda didyma* (Griffiths, 1994) used potting substrate containing pine bark. Bhat and Tayama (1990) concluded that the reduced effectiveness of ancymidol in bark-based media was due to an increase in leaching loss associated with the physical change imparted by the bark. Barrett (1982) stated that paclobutrazol and uniconazole are relatively nonpolar molecules, which are adsorbed by organic media components. Million et al. (1998) reported that pine bark reduced efficacy of paclobutrazol and that the amount of adsorption of paclobutrazol varied with pine bark particle size and degree of decomposition.

Based on the results of this trial, paclobutrazol applied by subirrigation gives the best height control while preserving the quality of the plant throughout production. This may be due to larger leaf surfaces in paclobutrazol treated plants and greater root dry weights.

***Summer Outdoor and Fall Greenhouse Studies.*** Overall, the trend among all chemicals was a gradual decrease in the change from initial height and width to height and width at harvest for plants treated with substrate drench or subirrigation methods of application. During the summer trial substrate drench treated plants were significantly different in respect to height change, and stem and leaf dry weights and subirrigated plants were significantly different in respect to leaf dry weight for paclobtrazol (Table 2.5); substrate drench was significant for stem dry weight for uniconazole (Table 2.7); and substrate drench was significant for height change and stem dry weight for flurprimidol (Table 2.9). The fall trial showed a significant difference in stem and leaf dry weights of subirrigated plants for paclobutrazole (Table 2.5), and substrate drench treated plants showed a significant change in leaf dry weight for uniconazole (Table 2.7). Results indicate that paclobutrazol (Piccolo) caused the most significant changes in both substrate drench and subirrigate treated plants during the summer and fall trials.

Similar observations were made during the summer and fall trials associated with plant quality, overall visual quality of the plants declined as the trials progressed. The observation of plant quality suggests that the PGRs are effective earlier in production, but as the plants mature and/or the environment changes (primarily temperature) the plants begin to decline. Therefore, it may be suggested that PGR be applied to *Monarda didyma* 'Marshall's Delight' no later than the third week in May in preparation for a June 1 market date in Oklahoma, USA.

**Literature Cited**

Barrett, J.E. 1982. Chrysanthemum height control by ancymidol, PP333, and EL-500 dependent on medium composition. HortScience 17:896-897.

Barrett, J. 2001. Mechanisms of action, p. 32-47. In: M.L. Gaston (ed.). Tips on regulating growth of floriculture crops. Ball Publishing, Batavia, IL.

Bhat, N.R. and H.K. Tayama. 1990. Retention and distribution of ancymidol in bark-based container growing media. Plant Growth Reg. Soc. Amer. 18:147-154.

Chamberlayne, C.L. and T.J. Banko. 2003. Growth response of container grown herbaceous perennials to ethephon, daminozide, paclobutrazol, and uniconazole. Proc. Southern Nursery Assn. Res. Conf. 48:267-271.

Cox, D.A. 2003. Subirrigating Seed Geraniums with Bonzi. University of Massachusetts, Amherst. Department of Plant and Soil Sciences www.umass.edu/umext/floriculture/fact_sheets/specific_crops/bonzi_geranseed.html. UMass Extension. Accessed 12 November 2009.

Dalziol J. and D.K. Lawrence 1984. Biochemical and biological effects of kaurene oxidase inhibitors, such as paclobutrazol. In R. Menhenett, and D.K. Lawrence, eds. Biochemical Aspects of Synthetic and Naturally Occurring Plant Growth Regulators, Monograph 11. British Plant Growth Regulation Group, Wantage, England, pp 43-57.

Early, J.D. and G.C. Martin. 1988. Translocation and breakdown of C-labelled paclobutrazol in ‘Nemaguard’ peach seedlings. HortScience 23:196-200.

Griffiths, M. 1994. The new royal horticultural society dictionary: Index of garden plants. Timber Press, Inc. Portland, OR. pp.173, 754-755.

Hilger, K.R., C. Haynes, and W.R. Graves. 2005. Chemical height control of containerized seashore mallow. HortTechnology 15:330-332.

Keever, G.J. and J.W. Olive. 1994. Response of ‘Prize’ azaleas to sumagic applied at several stages of shoot apex development. J. Environ. Hort. 12:12-15.

Kim, S., A.A. DeHertogh, and P.V. Nelson. 1999. Effects of plant growth regulators applied as sprays or media drenches on forcing of Dutch-grown bleeding heart as a flowering potted plant. HortTechnology 9:629-633.

Krug, B.A., B.E. Whipker, and I. McCall. 2005a. Flurprimidol is effective at controlling height of ‘Star Gazer’ oriental lily. HortTechnology 15:373-376.

Krug, B.A., B.E. Whipker, I. McCall, and J.M. Dole. 2005b. Comparison of flurprimidol to ancymidol, paclobutrazol, and uniconazole for tulip height control. HortTechnology 15:371-373.

Krug, B.A., B.E. Whipker, I. McCall, and J.M. Dole. 2006. Narcissus response to plant growth regulators. HortTechnology 16:129-132.

Latimer, J.G., T.J. Banko, and V. Groover. 2001 Using PGRs to hold containerized perennials in the nursery. Proc. Southern Nursery Assn. Res.Conf. 46:336-338.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998. Influence of media components on efficacy of paclobutrazol in inhibiting growth of broccoli and petunia. HortScience 30: 1403-1405.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 2002. One-time vs. continuous application of paclobutrazol in subirrigation water for the production of bedding plants. HortScience 37:345-347.

Nobel, P.S., 2009. Physicochemical and Environmental Plant Physiology. 4th Edition. Elsevier Inc. Burlington, MA 01803, USA.

Sterrett J.P. 1985. Paclobutrazol: a promising growth inhibitor for injection into woody plants. J. Amer. Soc. Hort. Sci. 110:4-8

Wang S.Y., T. Sun, and M. Faust. 1986. Translocation of paclobutrazol, a gibberellin biosynthesis inhibitor, in apple seedlings. Plant Physiol. 82:11-14.

**Table 2.1. Rates of application for paclobutrazol, uniconazole, and flurprimidol on monarda during bi-weekly application through substrate drench or by subirrigation (based on label recommendations for repeat individual treatments for 7 to 21 day intervals) during Spring 2010 Greenhouse Study.**

| PGR Applied | Rate of Application[z] | ppm[y] | µl /pot | |
|---|---|---|---|---|
| **Paclobutrazol** | 0 | 0 | 0 | 300 mL/pot |
| | 0.5 | 2 | 158.52 | |
| | 1.0 | 4 | 317.04 | |
| | 1.5 | 6 | 475.56 | |
| | 2.0 | 8 | 634.08 | |
| **Uniconazole or Flurprimidol** | 0 | 0 | 0 | 178 mL/pot |
| | 0.5 | 0.5 | 23.51 | |
| | 1.0 | 1 | 47.03 | |
| | 1.5 | 1.5 | 70.54 | |
| | 2.0 | 2 | 94.05 | |

**[z]The recommended rate of application listed on the product label is represented by 1.0.**
**[y]ppm= parts per million**

**Table 2.2. Rates of application of three plant growth regulators (PGR) listed in ppm and mL of chemical per gallon of solution applied to *Monarda didyma* during Summer 2010 Outdoor study.**

| PGR | Rate of Application[z] | ppm[y] | mL/gallon of solution |
|---|---|---|---|
| Paclobutrazol | 0 | 0 | 0 |
| | 0.5 | 2 | 3.43 |
| | 1.0 | 4 | 6.86 |
| | 1.5 | 6 | 10.29 |
| | 2.0 | 8 | 13.72 |
| Uniconazole | 0 | 0 | 0 |
| | 0.5 | 0.5 | 0.52 |
| | 1.0 | 1 | 1.04 |
| | 1.5 | 1.5 | 1.56 |
| | 2.0 | 2 | 2.08 |
| Flurprimidol | 0 | 0 | 0 |
| | 0.5 | 0.5 | 0.52 |
| | 1.0 | 1 | 1.04 |
| | 1.5 | 1.5 | 1.56 |
| | 2.0 | 2 | 2.08 |

**[z]The recommended rate of application listed on the product label is represented by 1.0.**
**[y]ppm= parts per million**

**Table 2.3 Plant height and width, leaf width and length, visual quality and dry weights of shoots and roots of *Monarda didyma* treated with three growth regulators or tap water (control) as a subsurface application during Spring 2010 Greenhouse study. n= 12**

| Plant growth regulator | Height (cm) | Width (cm) | Leaf width (mm) | Leaf length (mm) | Visual quality ranking | Shoot dry weight (g) | Root dry weight (g) |
|---|---|---|---|---|---|---|---|
| None (control) | 6.6a[z] | 17.9 | 15.5 | 27.9 | 2.5 | 9.6 | 12.6 |
| Paclobutrazol | 4.9b | 15.8 | 15.3 | 27.9 | 2.8 | 9.0 | 12.2 |
| Uniconazole | 4.7b | 16.5 | 12.2 | 22.9 | 3.0 | 8.2 | 9.8 |
| Flurprimidol | 5.0b | 16.3 | 12.1 | 23.9 | 2.6 | 9.8 | 10.3 |
| Significance | 2.0 | NS | NS | NS | NS | NS | NS |

[z] Means followed by the same letter are not significantly different P≤. 0.05. Mean separation by Protected LSD.

Not Significant (NS)

**Table 2.4. Plant width of *Monarda didyma* treated with several rates of paclobutrazol as a substrate drench or subsurface application outdoors in the summer of 2010, n=11, or in the greenhouse in the fall of 2010, n=7.**

| Treatment | Width (cm) | |
|---|---|---|
| | Summer | Fall |
| *Application Method* | | |
| Substrate Drench | 6.5 | 1.4 |
| Subsurface | 10.4 | 3.4 |
| Significance (Ftest) | * | * |
| *Paclobutrazol Rate* | | |
| 0 | 10.8 | 4.8 |
| 0.5 | 8.5 | 2.5 |
| 1.0 | 9.6 | 2.4 |
| 1.5 | 7.0 | 1.1 |
| 2.0 | 6.4 | 1.2 |
| Linear | * | * |
| Quadratic | NS | NS |
| Cubic | NS | NS |

**Not significant (NS) or significant at $P \leq 0.05$ (*).**

**Table 2.5. Chamge in height and stem and leaf dry weights for *Monarda didyma* treated with paclobutrazol at various rates as a substrate drench or subsurface application outdoors in the summer of 2010, n=12, or in the greenhouse in the fall of 2010, n= 7.**

| Application Method | Rate (ppm active ingredient) | Height (cm) | | Dry Weight (g) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Stem | | Leaf | | Root | |
| | | Summer | Fall | Summer | Fall | Summer | Fall | Summer | Fall |
| Substrate Drench | 0 | 22.2 | 0.4 | 4.2 | 0.4 | 4.7 | 0.8 | 4.9 | 1.1 |
| | 0.5 | 20.6 | 0 | 3.4 | 0.3 | 4.7 | 0.4 | 5.8 | 0.8 |
| | 1.0 | 15.0 | 0 | 2.2 | 0.3 | 3.7 | 0.9 | 4.5 | 1.8 |
| | 1.5 | 14.3 | 0 | 2.1 | 0.3 | 4.3 | 0.5 | 5.9 | 1.3 |
| | 2.0 | 9.6 | 0.3 | 1.3 | 0.4 | 2.7 | 0.8 | 3.2 | 1.8 |
| | Linear | ** | NS | ** | NS | * | NS | NS | NS |
| | Quadratic | NS | NS | NS | NS | NS | NS | NS | NS |
| | Cubic | NS | NS | NS | NS | NS | NS | NS | NS |
| Subsurface | 0 | 21.9 | 1.3 | 4.3 | 0.4 | 5.9 | 1.2 | 4.9 | 1.6 |
| | 0.5 | 17.0 | 2.4 | 3.0 | 0.7 | 4.8 | 2.1 | 3.8 | 2.4 |
| | 1.0 | 21.8 | 0.6 | 3.0 | 0.4 | 3.8 | 1.0 | 2.7 | 1.0 |
| | 1.5 | 19.8 | 0 | 3.5 | 0.3 | 4.4 | 0.8 | 4.7 | 1.4 |
| | 2.0 | 22.5 | 0.6 | 4.4 | 0.4 | 5.9 | 1.1 | 4.8 | 2.4 |
| | Linear | NS | NS | NS | NS | NS | NS | NS | NS |
| | Quadratic | NS | NS | ** | NS | ** | NS | NS | NS |
| | Cubic | NS | NS | NS | ** | NS | ** | NS | NS |

**Not significant (NS) or significant at $P \leq 0.05$ (*) or 0.01(**).**

**Table 2.6. Plant width of *Monarda didyma* treated with several rates of uniconazole as a substrate drench or subsurface application outdoors in the summer of 2010, n=12, or in the greenhouse in the fall of 2010, n=7.**

| Treatment | Width (cm) | |
|---|---|---|
| | Summer | Fall |
| *Application Method* | | |
| Substrate Drench | 7.9 | 2.4 |
| Subsurface | 11.4 | 4.9 |
| Significance (F test) | NS | NS |
| *Flurprimidol Rate* | | |
| 0 | 10.7 | 4.8 |
| 0.5 | 10.5 | 2.9 |
| 1.0 | 9.6 | 5.7 |
| 1.5 | 9.1 | 3.6 |
| 2.0 | 8.3 | 1.8 |
| Linear | NS | NS |
| Quadratic | NS | NS |
| Cubic | NS | NS |

**Not significant (NS)**

**Table 2.7. Change in height, change in width and stem and leaf dry weights for *Monarda didyma* treated with uniconazole at various rates as a substrate drench or subsurface application outdoors in the summer of 2010, n=12, or in the greenhouse in the fall of 2010, n=7.**

| Application Method | Rate (ppm active ingredient) | Height (cm) | | Width (cm) | | Dry Weight (g) Stem | | Leaf | | Roots | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Summer | Fall | Summer | Fall | Summer | Fall | Summer | Fall | Summer | Fall |
| Substrate Drench | 0 | 22.2 | 0.4 | 10.1 | 4.8 | 4.2 | 0.4 | 4.7 | 0.8 | 4.9 | 1.1 |
| | 0.5 | 21.9 | 0.7 | 9.4 | 1.7 | 4.1 | 0.3 | 5.1 | 0.7 | 5.6 | 1.5 |
| | 1.0 | 23.8 | 0.2 | 5.7 | 3.2 | 3.9 | 0.5 | 4.8 | 0.8 | 6.0 | 1.8 |
| | 1.5 | 19.5 | 0.8 | 8.0 | 2.0 | 2.9 | 0.3 | 4.3 | 0.6 | 4.3 | 1.1 |
| | 2.0 | 22.5 | 0.7 | 6.5 | 1.1 | 3.3 | 0.5 | 5.0 | 1.1 | 5.2 | 1.8 |
| | Linear | NS | NS | NS | NS | * | NS | NS | NS | NS | NS |
| | Quadratic | NS | NS | NS | NS | NS | NS | NS | * | NS | NS |
| | Cubic | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Subsurface | 0 | 21.9 | 1.3 | 11.5 | 4.7 | 4.3 | 0.4 | 5.9 | 1.2 | 4.9 | 1.6 |
| | 0.5 | 22.4 | 0 | 11.7 | 4.0 | 3.3 | 0.5 | 4.3 | 1.1 | 2.9 | 1.4 |
| | 1.0 | 24.5 | 2.3 | 13..5 | 8.2 | 4.3 | 0.6 | 5.9 | 1.7 | 5.6 | 1.8 |
| | 1.5 | 23.1 | 0.1 | 10.4 | 5.0 | 4.1 | 0.5 | 5.3 | 1.3 | 5.9 | 1.6 |
| | 2.0 | 23.9 | 2.3 | 10.0 | 2.7 | 4.5 | 0.4 | 6.1 | 0.8 | 6.0 | 1.6 |
| | Linear | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | Quadratic | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | Cubic | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

**Not significant (NS) or significant at $P \leq 0.05$ (*).**

**Table 2.8. Plant width of *Monarda didyma* treated with several rates of flurprimidol as a substrate drench or subsurface application outdoors in the summer of 2010 or in the greenhouse in the fall of 2010. n= 2 for application method and n= 5 for rate.**

| Treatment | Width (cm) | |
|---|---|---|
| | Summer | Fall |
| *Application Method* | | |
| Substrate Drench | 5.9 | 0.7 |
| Subsurface | 8.6 | 3.9 |
| Significance (F test) | NS | NS |
| *Flurprimidol Rate* | | |
| 0 | 10.8 | 4.8 |
| 0.5 | 8.2 | 4.5 |
| 1.0 | 7.9 | 0 |
| 1.5 | 5.9 | 2.6 |
| 2.0 | 3.3 | 0.4 |
| Linear | NS | NS |
| Quadratic | NS | NS |
| Cubic | NS | NS |

**Not significant (NS)**

**Table 2.9. Change in height and stem dry weights for *Monarda didyma* treated with flurprimidol at various rates as a substrate drench or subsurface application outdoors in the summer of 2010, n=12, or in the greenhouse in the fall of 2010, n=7.**

| Application Method | Rate (ppm active ingredient) | Height (cm) | | Dry Weight (g) Stem | | Dry Weight (g) Roots | |
|---|---|---|---|---|---|---|---|
| | | Summer | Fall | Summer | Fall | Summer | Fall |
| Substrate Drench | 0 | 22.2 | 0.4 | 4.2 | 0.4 | 4.9 | 1.1 |
| | 0.5 | 18.1 | 0.6 | 2.7 | 0.3 | 4.7 | 1.3 |
| | 1.0 | 13.6 | -1.3 | 2.1 | 0.3 | 4.9 | 1.5 |
| | 1.5 | 12.1 | -0.4 | 1.5 | 0.4 | 4.0 | 1.8 |
| | 2.0 | 7.5 | -0.9 | 1.3 | 0.3 | 3.8 | 1.5 |
| | Linear | ** | NS | ** | NS | NS | NS |
| | Quadratic | NS | NS | NS | NS | NS | NS |
| | Cubic | NS | NS | NS | NS | NS | NS |
| Subsurface | 0 | 21.9 | 1.3 | 4.3 | 0.4 | 4.9 | 1.6 |
| | 0.5 | 24.6 | 0.4 | 4.3 | 0.4 | 5.7 | 1.3 |
| | 1.0 | 19.5 | 0.7 | 3.7 | 0.5 | 4.0 | 2.4 |
| | 1.5 | 20.6 | 0 | 4.0 | 0.5 | 4.8 | 1.9 |
| | 2.0 | 19.2 | 0.7 | 3.4 | 0.3 | 3.7 | 1.4 |
| | Linear | NS | NS | NS | NS | NS | NS |
| | Quadratic | NS | NS | NS | NS | NS | NS |
| | Cubic | NS | NS | NS | NS | NS | NS |

**Not significant (NS) or significant at $P \leq 0.01$ (**).**

**Table 2.10. Leaf area per leaf for *Monarda didyma* treated with three different plant growth regulators, paclobutrazol, uniconazole, and flurprimidol, or a tapwater control during a greenhouse trial during the fall of 2010, n=7.**

| Application Method | Rate (ppm active ingredient) | Leaf area per leaf | | |
|---|---|---|---|---|
| | | Paclobutrazol | Uniconazole | Flurprimidol |
| Substrate Drench | 0 | 1.4 | 1.4 | 1.4 |
| | 0.5 | 0.7 | 1.2 | 1.0 |
| | 1.0 | 1.0 | 1.4 | 1.5 |
| | 1.5 | 0.8 | 1.1 | 1.3 |
| | 2.0 | 1.0 | 1.1 | 1.1 |
| | Linear | NS | NS | NS |
| | Quadratic | NS | NS | NS |
| | Cubic | NS | NS | NS |
| Subsurface | 0 | 1.4 | 1.4 | 1.4 |
| | 0.5 | 1.6 | 1.1 | 1.3 |
| | 1.0 | 1.2 | 1.3 | 1.4 |
| | 1.5 | 1.2 | 1.1 | 1.1 |
| | 2.0 | 1.1 | 1.1 | 0.7 |
| | Linear | NS | NS | NS |
| | Quadratic | NS | NS | NS |
| | Cubic | NS | NS | NS |

**Not significant (NS)**

CHAPTER III

# Effects of Paclobutrazol, Uniconazole or Flurprimidol Applied as a Substrate Drench or by Subirrigation on *Buddleia davidii*

Rachael E. Pepin and Janet C. Cole

**ADDITIONAL INDEX WORDS.** Application rates, herbaceous perennials, plant growth regulator, woody perennial, ebb and flood, pine bark

**SUMMARY.** *Buddleia davidii* 'Pink Delight' exhibits an aggressive rate of growth in commercial production. There are limited recommendations for drench application and no recommendations for subirrigation methods of application for paclobutrazol, uniconazole, and flurprimidol for controlling *Buddleia davidii* growth. This trial examined the possibility of applying these PGRs as a continuous substrate drench or subirrigation, similar to an ebb and flood type production system. No differences occurred among PGRs.

Buddleia's aggressive growth during commercial production requires controlling plant size. Vigorous shoot and poor root growth are common characteristics of container-grown butterfly-bush (*Buddleia davidii* Franch. 'Dubonnet') (Ruter, 1992). Many growers and chemical labels list *Buddleia* spp. as an herbaceous perennial. Since some species of *Buddleia* may grow three to five feet (0.9 to 1.5 meters) in a single season it is important to control the height of container grown plants to produce a marketable product that is not top-heavy or out of proportion to its container. No recommended rates are listed on the labels for paclobutrazol or uniconazole for *Buddleia* spp. Flurprimidol has a recommended foliar spray application of 20-80 ppm (active ingredient) for *Buddleia sp.*, but no recommendations for drench application.

Paclobutrazol retards growth of woody landscape plants (Keever et al., 1990) and enhances flowering (Bailey et al., 1986; Keever et al., 1990; Wilkinson and Richards, 1991). Ruter (1992) found that paclobutrazol formulation influenced several plant characteristics of *Buddleia davidii* Franch. ‘Dubonnet'. Application rate influenced all but the number of panicles, but the interaction between application rate and formulation of paclobutrazol (either granular or liquid) was significant only for root dry weight. The growth index was reduced 50% by granular formulation at 10 mg a.i./pot, yet liquid drench applications required double a.i/pot to achieve equivalent reductions in growth. In this same study, a greater response among shoot compared to root dry weights resulted in increased root to shoot ratio among plants treated with paclobutrazol. Keever et al. (1990) showed that growth suppression of other woody landscape plant species were greater when paclobutrazol was applied by substrate drench instead of foliar application. Although uniconazole is chemically similar to paclobutrazol, a study conducted by Davis et al. (1987) suggested that for most species the retarding effect of uniconazole was greater than paclobutrazol when applied as a substrate drench and equal rates are used. On average the amount of paclobutrazol needed is four to ten times greater than that required of uniconazole to achieve similar effects on plant size (Barrett and Nell, 1989).

Limited research has been conducted on the use of flurprimidol on *Buddleia davidii*. Keever and Gilliam (1995) observed that the rank shoot growth of *Buddleia davidii* during container production required multiple prunings to develop a well-branched, marketable plant, and most growth inhibitors were either not economical or caused undesirable side effects. Their research showed that flurprimidol effectively retarded shoot elongation of *Buddleia davidii* and had minimal effects of flower development at low rates of application.

The objective of this study was to determine if paclobutrazol, uniconazole, or fluriprimidol could control growth of *Buddleia davidii* when applied through subirrigation. The growth regulators were applied by subirrigation through a saucer placed under each plant based on the recommended trial rates for herbaceous perennials listed on the label of each chemical.

**Materials and methods**

Commercially produced (Greenleaf Nursery, Co., Park Hill, OK) rooted cuttings of *Buddleia davidii* 'Pink Delight' were planted in 3.7 L containers. Each cubic yard of substrate included: 12 oz of dolomitic lime, 4 oz urea, 8 oz 0N-20P-0K (0N-46 $P_2O_5$-0 $K_2O$), 7 oz 0N-0P-50K (0N-0 $P_2O_5$-60 $K_2O$, potassium chloride), 2 lbs Micromax (The Scotts Co., Marysville,OH), 12 lbs 22N-2P-8K controlled release fertilizer (22N-5 $P_2O_5$ -10 $K_2O$ 12-14 month formulation, Osmocote, The Scotts Co.) 4:2:1 (by vol.) coarse pine bark (63-65% by volume of particles greater than 2.4 mm): fine pine bark (48-50% by volume of particles greater than 2.4 mm): and sand (Greenleaf Nursery Co., Park Hill, OK). Liners were transplanted to containers and established for four weeks before treatment. Plants were grown in a polycarbonate-covered greenhouse with an average daily high/low temperature of 21/15$^{o}$C under seasonal light conditions (1340 µmol. $m^{-2}.s^{-1}$) at the Oklahoma State University Research Greenhouses at Stillwater, OK. No supplemental lighting was provided. The experiment began on 9 February 2010 and was terminated on 22 April 2010. Plants were treated with paclobutrazol, uniconazole, or flurprimidol mixed with water using rates listed in Table 3.1. The variation in rates between everyday applications and every other day applications is to account for cooler spring temperatures than summer and a decrease in water uptake by the plants; therefore, an adjustment was made to the rate of application to ensure the plants received consistent weekly amounts of PGR. No additional fertilizer was applied.

Paclobutrazol, uniconazole, or flurprimidol were applied as a subsurface irrigation via a saucer placed under each container based on the recommended label rate for *Buddleia davidii* or similar perennial plants potted in 3.7 L containers. Solutions of 300 mL per pot were applied at every irrigation with 1 ppm paclobutrazol, 0.25 ppm uniconazole, 0.25 ppm flurprimidol, or no

PGR as a clear water control to all plants as a substrate drench or by subirrigation. On days when less irrigation was needed 150 mL of solution was applied.

All plants were treated with TriStar (Acetamiprid, Cleary Chemical Corporation, Dayton, NJ) at the label rate of 1/3 teaspoon per 3 gallons (0.012 oz. ai/gallon) as a foliar spray on 11 March 2010 for fungus gnat control. Spider mites were treated on 7 April 2010 with Floramite (Bifenazate, Olympic Horticultural Products (OHP), Inc., Mainland, PA) at the label rate of 1/4 teaspoon per quart (1.0 oz. ai/quart) as a foliar spray.

Plant height from the substrate surface to the highest growing point and width (average of width measured at the widest part and perpendicular to the widest part), leaf length of the longest leaf, and leaf width of the widest leaf per plant were measured at planting. Plant height and width were measured bi-weekly. Plant damage was rated on a scale of one to four with four being a dead plant and one being a high quality, salable plant four weeks prior to market date on 18 March and 8 April 2010. At harvest, plant height, width, shoot (including leaves), and root dry weights were determined.

The experiment was arranged in a completely randomized design within species with four growth regulator treatments and twelve replications. Data were analyzed using PROC GLM in SAS (SAS Institute, Cary, NC). Means were separated using a protected LSD.

**Results**

Among growth regulators, no differences were detected in plant width, leaf width, leaf length, visual quality rating, or shoot or root dry weights (Table 3.2). The change from initial height to height at harvest was greatest among control plants with uniconazole, paclobutrazol, and flurprimidol gradually decreasing in plant height (Table 3.2).

**Discussion**

These PGRs applied as a continuous treatment through substrate drench or by subirrigation are statistically significant by height for *Buddleia davidii* ‘Pink Delight’. Higher rates of application are needed to control growth using previously mentioned methods of application.  Pine bark in the media may be a reason for higher rates of application.  Bhat and Tayama (1990) concluded that the reduced effectiveness of ancymidol in bark-based media was due to an increase in leaching loss associated with the bark component.  Barrett (1982) stated that paclobutrazol and uniconazole are relatively nonpolar molecules, which are adsorbed by organic media components.  Million et al. (1998) reported that pine bark reduced efficacy of paclobutrazol and that the amount of adsorption of paclobutrazol varied with pine bark particle size and degree of decomposition.

**Literature Cited**


Bailey, D.A., T.C. Weiler, and T.I. Kirk. 1986. Chemical stimulation of floral initiation in florist hydrangea. HortScience 21:555-557.

Barrett, J.E. 1982. Chrysanthemum height control by ancymidol, PP333, and EL-500 dependent on medium composition. HortScience 17:896-897.

Barrett, J.E. and T.A. Nell. 1989. Comparison of paclobutrazol and uniconazole on floriculture crops. Acta Hortic. 251:275-280.

Bhat, N.R. and H.K. Tayama. 1990. Retention and distribution of ancymidol in bark-based container growing media. Plant Growth Reg. Soc. Amer. 18:147-154.

Davis, T.D., H.S. Gehlot, C.F. Williams, and N. Sankhla. 1987. Comparative shoot growth retarding activities of paclobutrazol and XE-1019. Proc. Plant Growth Regulat. Soc. Amer. 14:121-124.

Keever, G.J. and C.H. Gilliam. 1995. Growth and flowering response of butterfly-bush to Cutless. Alabama Agricultural Experiment Station Ornamental Research Report. 34-35.

Keever, G.J., W.J. Foster, and J.C. Stephenson. 1990. Paclobutrazol inhibits growth of woody landscape plants. J. Environ. Hort. 84:41-47.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998. Influence of media components on efficacy of paclobutrazol in inhibiting growth of broccoli and petunia. HortScience 30: 1403-1405.

Ruter, J.M. 1992. Growth and flowering response of butterfly-bush to paclobutrazol formulation and rate of application. HortScience 27:929.

Wilkinson, R.I. and D. Richards. 1991. Influence of paclobutrazol on growth and flowering of *Rhododendron* ‘Sir Robert Peel’. HortScience 26:282-284.

**Table 3.1. Rates of application for paclobutrazol, uniconazole, and flurprimidol on buddleia cultivars during continuous application through substrate drench or by subirrigation (based on label recommendations for repeat individual treatments for 7 to 21 day intervals).**

| | Rate of Application | Total Solution |
|---|---|---|
| **Applied Every Other Day**[z] | | |
| **Paclobutrazol** | 1ppm [y]<br>1.0mL /3.7 L | 300mL/pot |
| **Uniconazole** | 1ppm<br>8mL/3.7 L | 300mL/pot |
| **Flurprimidol** | 1ppm<br>0.96mL/3.7 L | 300mL/pot |
| **Applied Every Day** | | |
| **Paclobutrazol** | 0.5ppm<br>0.5mL/3.7 L | 300mL/pot |
| **Uniconazole** | 0.5ppm<br>4mL/3.7 L | 300mL/pot |
| **Flurprimidol** | 0.5ppm<br>0.48mL/3.7 L | 300mL/pot |

[z]Treatments applied every other day were applied on Monday, Wednesday, Friday, and Sunday
[y]PGR was administered in ppm of active ingredient or mL of product, both are listed above

**Table 3.2 Mean separation of plant height and width, leaf width and length, visual quality and dry weights of shoots and roots of *Buddleia davidii* treated with three growth regulators or tap water (control) as a subsurface application during Spring 2010 Greenhouse study. n= 12**

| Plant Growth Regulator | Height (cm) | Width (cm) | Leaf width (mm) | Leaf length (mm) | Visual quality Ranking | Shoot dry weight (g) | Root dry weight (g) |
|---|---|---|---|---|---|---|---|
| None (control) | 19.4a | 23.2 | 10.5 | 48.3 | 2.5 | 16.8 | 8.5 |
| Paclobutrazol | 16.3ab | 23.8 | 8.1 | 43.8 | 2.2 | 17.0 | 8.8 |
| Uniconazole | 18.3a | 25.7 | 8.6 | 48.3 | 2.2 | 15.8 | 9.9 |
| Flurprimidol | 14.5b | 21.7 | 7.5 | 46.8 | 2.7 | 14.7 | 9.0 |
| Significance | 2.0 | NS | NS | NS | NS | NS | NS |

[z] Means followed by the same letter are not significantly different at P≤ 0.05. Mean separation by Protected LSD.
Not Significant (NS)

REFERENCES


Adriansen, E. 1989. Growth and flowering of pot plants soaked with plant growth regulator solutions in ebb and flood benches. Acta Hort. 251:319-327.

Adriansen, E. 1997. Residues of paclobutrazol and uniconazole in nutrient solutions from ebb and flood irrigation of pot plants. Scientia Hort. 69:73-83.

Bailey, D.A., T.C. Weiler, and T.I. Kirk. 1986. Chemical stimulation of floral initiation in florist hydrangea. HortScience 21:555-557.

Barrett, J.E. 1982. Chrysanthemum height control by ancymidol, PP333, and EL-500 dependent on medium composition. HortScience 17:896-897.

Barrett, J.E. 2001. Mechanisms of action, p. 32-47. In: M.L. Gaston (ed.). Tips on regulating growth of floriculture crops. Ball Publishing, Batavia, IL.

Barrett, J.E and C.A. Bartuska. 1982. PP333 effects on stem elongation dependent on site of application. HortScience 17:737-738.

Barrett, J.E., C.A. Bartuska, and T.A Nell. 1994. Comparison of paclobutrazol drench and spike applications for height control of potted floriculture crops. HortTechnology 29:180-182.

Barrett, J.E. and T.A Nell. 1982. Irrigation interval and growth retardants affect poinsettia development. Proc. Fla. State Hort. Soc. 95:167-169.

Barrett, J.E. and T.A Nell. 1989. Comparison of paclobutrazol and uniconazole on floriculture crops. Acta Hort. 251:275-280.

Barrett, J.E. 1982. Chrysanthemum height control by ancymidol, PP333, and EL-500 dependent on medium composition. HortScience 17:896-897.

Barrett, J.E. and T.A. Nell. 1989. Comparison of paclobutrazol and uniconazole on floriculture crops. Acta Hortic. 251:275-280.

Bhat, N.R. and H.K. Tayama. 1990. Retention and distribution of ancymidol in bark-based container growing media. Plant Growth Reg. Soc. Amer. 18:147-154.

Boldt, J.L. 2008. Whole plant response of chrysanthemum to paclobutrazol, chlormequat chloride, and (s)-abscisic acid as a function of exposure time using a split-root system. Univ. Florida, Gainesville, MS Thesis.

Bonaminio, V.P. and R.A. Larson. 1978. Influence of potting media, temperature, and concentration of ancymidol on growth of *Chrysanthemum morifolium*. Ramat. J. Amer. Soc. Hort. Sci. 103:752-756.

Chamberlayne, C.L. and T.J. Banko. 2003. Growth response of container grown herbaceous perennials to ethephon, daminozide, paclobutrazol, and uniconazole. Southern Nursery Assn. Res. Conf. Proc. 48:267-271.

Cox, D.A. June 2003. Subirrigating seed geraniums with Bonzi. University of Massachusetts, Amherst. Department of Plant and Soil Sciences www.umass.edu/umext/floriculture/fact_sheets/specific_crops/bonzi_geranseed.html. UMass Extension. Accessed 12 November 2009.

Currey, C.J. and R.G. Lopez. 2011. Early flurprimidol drench applications suppress final height of four poinsettia cultivars. HortTechnology 21:35-40.

Dalziol, J. and D.K. Lawrence 1984. Biochemical and biological effects of kaurene oxidase inhibitors, such as paclobutrazol. In R. Menhenett, D.K. Lawrence, eds. Biochemical Aspects of Synthetic and Naturally Occurring Plant Growth Regulators, Monograph 11. British Plant Growth Regulation Group, Wantage, England, pp 43-57.

Davis. T.D., G.L. Steffens, and N. Sankhla. 1988. Triazole plant growth regulators. Hort. Rev. 10:63-105.

Davis, T.D, H.S. Gehlot, C.F. Williams, and N. Sankhla. 1987. Comparative shoot growth retarding activities of paclobutrazol and XE-1019. Proc. Plant Growth Regulat. Soc. Amer. 14:121-124.

DeHertogh, A. 1996. *Lilium* (asiatic and oriental hybrids)---Potted plants, p. C109-C121. Holland bulb forcer's guide. Intl. Flower Bulb Ctr., Hillegom, The Netherlands.

Early, J.D. and G.C. Martin. 1988. Translocation and breakdown of C-labelled paclobutrazol in 'Nemaguard' peach seedlings. HortScience 23:196-200.

Ecke, P., III, J.E. Faust, J. Wiggins, and A. Higgins. 2004. Height control, p. 51-72. In: The Ecke poinsettia manual. Ball Publishing, Batavia, IL.

Faust , J. E., P.C. Korczynski, and R. Klein. 2001. Effects of paclobutrazol drench application date on poinsettia height and flowering. HortTechnology 11:557-560.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture, p. 89-146. In: A.S. Basara (ed.). Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton, NY.

Griffiths, M. 1994. The new royal horticultural society dictionary: Index of garden plants. Timer Press, Inc. Portland, Oregon. pp.173, 754-755.

Hamrick, D. 2003. *Lilium* (asiatic and oriental hybrids). Vol. 2. Ball Publishing, Batavia, IL.

Henderson, J.C. and T.H. Nichols. 1991. *Pyracantha coccinea* 'Kasan' and Lalandei' response to uniconazole and chlormequat chloride. HortScience 26:877-880

Hilger, K.R., C. Haynes, and W.R. Graves. 2005. Chemical height control of containerized seashore mallow. HortTechnology 15:330-332.

Judging Manual for the J. Benton Storey Undergraduate Judging Contest. Southern Region, American Society of Horticultural Science, Association of Collegiate Branches. Revised 12 July 1999. 3-4.

Keever, G.J. and J.W. Olive. 1994. Response of 'Prize' azaleas to Sumagic applied at several stages of shoot apex development. J. Environ. Hort. 12:12-15.

Keever, G.J., W.J. Foster, and J.C. Stephenson. 1990. Paclobutrazol inhibits growth of woody landscape plants, J. Environ. Hort. 8:41-47.

Keever, G.J. and M.S. West. 1992. Response of established landscape plants to uniconazole. HortTechnology 2:465-468.

Keever, G.J. and C.H. Gilliam. 1995. Growth and flowering response of butterfly-bush to Cutless. Alabama Agricultural Experiment Station Ornamental Research Report. 34-35

Kim, S., A.A. DeHertogh, and P.V. Nelson. 1999. Effects of plant growth regulators applied as sprays or media drenches on forcing of Dutch-grown bleeding heart as a flowering potted plant. Horttechnology 9:629-633.

Krug, B.A., B.E. Whipker, and I. McCall. 2005a. Flurprimidol is effective at controlling height of 'Star Gazer' oriental lily. HortTechnology 15: 373-376.

Krug, B.A., B.E. Whipker, and I. McCall. 2007. Caladium growth control with flurprimidol, paclobutrazol, and uniconazole. HortTechnology 17: 368-370.

Krug, B.A., B.E. Whipker, I. McCall, and J.M. Dole. 2005b. Comparison of flurprimidol to ancymidol, paclobutrazol, and uniconazole for tulip height control. HortTechnology 15:371-373.

Krug, B.A., B.E. Whipker, I. McCall, and J.M. Dole. 2006. Narcissus response to plant growth regulators. HortTechnology 16:129-132.

Latimer, J. and B.Whipker. 2007. Using piccolo with herbaceous perennials. Edited by Fine America, Inc.

Latimer, J.G., T.J. Banko, and V. Groover. 2001 Using PGRs to hold containerized perennials in the nursery. Southern Nursery Assn. Res.Conf. Proc. 46:336-338.

Lever, B.G. 1986. Cultar-A technical overview. Acta Hort. 179:459-466.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998a. Influence of media components on efficacy of paclobutrazol in inhibiting growth of broccoli and petunia. HortScience 33:852-856.

Million, J.B., J.E. Barrett, T.A. Nell, and D.G. Clark. 1998b. Influence of pine bark on efficacy of different growth retardants applied as a drench. HortScience 33:1030-1031.

Million, J.B., J.E. Barrett, T.A. Nell, D.G. Clark. 1999. Inhibiting growth of flowering crops with ancymidol and paclobutrazol in subirrigation water. HortScience 34:1103-1105.

Million, J.B., J.E. Barrett, T.A. Nell, D.G. Clark. 2002. One-time vs. continuous application of paclobutrazol in subirrigation water for the production of bedding plants. HortScience 37:345-347.

Needham, D.C. 1996. Horticulture Crop Judging. Oklahoma State University, Cooperative Extension Service, 4-H Circ. 702.

Newman, S.E. and J.S. Tant. 1995. Root-zone medium influences growth of poinsettias treated with paclobutrazol-impregnated spikes and drenches. HortScience 30:1403-1405.

Nobel, P.S., 2009. Physicochemical and Environmental Plant Physiology. 4th Edition. Elsevier Inc. Burlington, MA 01803, USA.

Norcini, J.G. and G.W. Knox. 1990. Effect of pruning on the growth inhibition activity of Sumagic (uniconazole). J. Environ. Hort. 8:199-204.

Nui, G., R. Heins, and W. Carlson. 2002. Using paclobutrazol to control height of poinsettia 'Freedom'. HortTechnology 12:232-236.

Numbere, T.E., F.D. Morrison, R.W. Campbell, and H. Moser. 1989. Uptake, translocation, and metabolism of XE-1019 in apple trees. Hort Science 24:113. (abstr.).

Premachandra, G.S, W.R. Chaney and H.A. Holt. 1997. Gas exchange and water relations of *Fraxinus americana* affected by flurprimidol. Tree Physiol. 17:97-103.

Quinlan, J.D. and P.J. Richardson. 1986. Uptake and translocation of paclobutrazol and implications for orchard use. Acta Hort. 179:443-451.

Richardson, P.J. and J.D. Quinlan. 1986. Uptake and translocation of paclobutrazol by shoots of M.26 apple rootstock. Plant Growth Regulat. 4:347-356.

Starman, T.W. 1991. Lisianthus growth and flowering responses to uniconazole. HortScience 26:150-152.

Ruter, J.M. 1992. Growth and flowering response of butterfly-bush to paclobutrazol formulation and rate of application. HortScience 27:929.

Sterrett, J.P. 1985. Paclobutrazol: a promising growth inhibitor for injection into woody plants. J. Amer. Soc. Hort. Sci. 110:4-8.

Sterrett, J.P. 1988. XE-1019: Plant response, translocation, and metabolism. J. Plant Growth Regulat. 7:19-26.

Tayama, H.K., R.A. Larson, P.A. Hammer, and T.J. Rolls. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assn., Columbus, OH.

Wang, Y.T. and L.L. Gregg. 1989. Uniconazole affects vegetative growth, flowering, and stem anatomy of hibiscus. J. Amer. Soc. Hort. Sci. 114:927-932.

Wang, Y.T., T. Sun, and M. Faust. 1986. Translocation of paclobutrazol, a gibberellin biosynthesis inhibitor, in apple seedlings. Plant Physiol. 82:11-14.

Warren, S.L. 1990. Growth response of 13 container-grown landscape plants to uniconazole. J. Environ. Hort. 8:151-153.

Wilfret, G.J. 1978. Height regulation of poinsettia with a growth regulator incorporated into the soil medium. Proc. Fla. State Hort. Soc. 91:220-222.

Wilfret, G.J. 1993. Comparative effect of growth regulators on poinsettia. Proc. Fla. State Hort. Soc. 106:294-297.

Wilfret, G.J. 1996. Response of seventeen poinsettia cultivars to growth regulators. Proc. Fla. State Hort. Soc. 109:5-7.

Wilkins, H.F. and K.L. Grueber. 1983. Lily-height control: Drenches, sprays, dips. Florists' Rev. 173(1):50-53.

Wilkinson, R.I., and D. Richards. 1991. Influence of paclobutrazol on growth and flowering of *Rhododendron* 'Sir Robert Peel'. HortScience 26:282-284.

APPPENDIX A

**Fig A.1 Summer 2010 study randomized complete block layout for *Monarda didyma* 'Marshall's Delight' at Claremore, Oklahoma.**

**Fig A.2 Example of desired plant qualities for *Monarda didyma* 'Marshall's Delight' during summer 2010 outdoor study, *(large leaves, good color, uniform leaf shape, and free from blemish)***

**Fig A.3 Visual observation of growth regulation and quality within a single replication of *Monarda* during summer 2010 outdoor study.  A) Flurprimidol and uniconazole treated plants (front center) had deeper green leaves and expressed greater height reduction.  B) Drench applications showed more short stems closer to substrate surface.**

**A.**

**B.**

**Fig A.4 Early stage of tip necrosis of *Monarda didyma* 'Marshall's Delight' during summer 2010 outdoor trial.**

**Fig. A.5. Visual comparison between PGRs applied by subirrigation at half the recommended label rate during summer 2010 outdoor study on *Monarda didyma* 'Marshall's Delight'. From left to right: flurprimidol, control, uniconazole, and paclobutrazol treated plants.**

**Fig. A.6. Visual comparison between PGRs applied as a substrate drench at the recommended label rate during summer 2010 outdoor study on *Monarda didyma* 'Marshall's Delight'. From left to right: paclobutrazol, flurprimidol, and uniconazole treated plants.**

VITA

Rachael Elizabeth Pepin

Candidate for the Degree of

Master of Science

**Thesis:** EFFECT OF PACLOBUTRAZOL, UNICONAZOLE AND FLURPRIMIDOL APPLIED AS A SUBSTRATE DRENCH OR BY SUBIRRIGATION ON GROWTH OF *MONARDA DIDYMA* AND *BUDDLEIA DAVIDII*

**Major Field**: Horticulture

**Biographical:**

**Education:**

Completed the requirements for the Master of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in December, 2012.

Completed the requirements for the Bachelor of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in December 2006.

**Experience:**

| | | |
|---|---|---|
| Self-employed | Fiore Bouquets and Botanicals | Claremore,OK<br>July 2007 to Present |
| Teaching Assitantship | Oklahoma State University | Stillwater, OK<br>August 2009 to May 2011 |
| Landscape Manager | Stonebridge Garden Center | Claremore, OK<br>July 2007 to August 2008 |
| Floral Design | Oasis Garden Center | Stillwater, OK<br>February 2005 to July 2007 |
| Public Garden Mgmt | Oklahoma Gardening | Stillwater, OK<br>May 2005 to August 2005 |
| Nursery Experience | Sanders Nursery | Broken Arrow, OK<br>April 2003 to July 2003 |

Name: Rachael E. Pepin Date of Degree: December, 2012

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EFFECT OF PACLOBUTRAZOL, UNICONAZOLE AND FLURPRIMIDOL APPLIED AS A SUBSTRATE DRENCH OR BY SUBIRRIGATION ON GROWTH OF MONARDA *DIDYMA* AND *BUDDLEIA DAVIDII*

Pages in Study: 50 Candidate for the Degree of Master of Science

Major Field: Horticulture

Scope and Method of Study:
Plant growth regulator use in nursery production of Bee Balm (*Monarda didyma* 'Marshall's Delight') and Butterfly Bush (*Buddleia davidii* 'Pink Delight') was the focus of this study. paclobutrazol ((2RS,3RS)-1-(4-chlorophenyl)-4,-4dimethyl-2-(1,2,4-trizol-1-yl)pentin-3-ol), uniconazole ((E)-1-(4-chlorophenyl)-4,-4-dimethyl-2-(1,2,4-trizol-1-yl)pentin-3-ol), and flurprimidol ((alpha-(1-methylethyl)-alpha-[4-(trifluoromethoxy)phenyl]-5-pyrimidine-methanol)) were applied as a substrate drench applied or through subsurface irrigation applied in a saucer placed under each plant to control plant growth. Three trials were conducted.

Findings and Conclusions:
The spring greenhouse *Monarda didyma* study showed height was the only measured variable that differed among treatments. The effectiveness of the PGRs in reducing plant growth was increased with subirrigation compared to plants that received no PGR during subirrigation. Plants that received no plant growth regulator were taller than those receiving any of the three plant growth regulators. The quality of the plants did not differ among control, paclobutrazol, and flurprimidol treatments. Plants treated with uniconazole had the poorest quality. The results of the spring trial showed paclobutrazol applied by subirrigation gave the best height and width control while preserving plant quality throughout production.
The summer outdoor and fall greenhouse *Monarda didyma* studies showed that among the three chemicals there was a gradual decrease among height and width of the plants as the rate of application increased for both substrate drench and subirrigation methods of application.
During the spring study the PGRs applied as a continuous treatment through substrate drench or by subirrigation were statistically significant by height for *Buddleia davidii* 'Pink Delight'.

ADVISER'S APPROVAL: Dr. Janet C. Cole