Use of Plant Growth Regulators to Improve Branching of Herbaceous Perennial Liners

Mara C. Grossman

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Horticulture

Joyce G. Latimer, Chair

Holly L. Scoggins, Committee Member

Erik H. Ervin, Committee Member

May, 1, 2012

Blacksburg, VA

Keywords: PGR, benzyladenine (BA), dikegulac sodium, ethephon

Use of Plant Growth Regulators to Improve Branching of Herbaceous Perennial Liners

Mara C. Grossman

ABSTRACT

The objective of this study is to evaluate the efficacy of PGRs to improve branching during production of herbaceous perennial liners and finished plants. The effects of benzyladenine (BA) on the branching and root and shoot growth of *Agastache* Clayt. Ex Gronov. 'Purple Haze', *Gaura lindheimeri* Engelm. & A. Gray 'Siskiyou Pink', *Lavandula* ×*intermedia* Emeric ex Loisel. 'Provence', *Leucanthemum* ×*superbum* (Bergmans ex J.W. Ingram) Bergmans ex Kent. 'Snowcap', and *Salvia* ×*sylvestris* L. (pro sp.) 'May Night' was tested. Root dry weight was found to be highly correlated to root volume and root surface area. In liners, all taxa except *Salvia* had increased branching while all except *Gaura* had reduced rooting. Increased branching was not evident in most taxa as finished plants. The effects of BA on *Aster* 'Professor Anton Kippenberg' (*Symphyotrichum novi-belgii* L.'Professor Anton Kippenburg'), *Campanula punctata* Lam. 'Cherry Bells,' *Cosmos atrosanguineus* (Hook) Voss., *Verbena bonariensis* L. 'Lollipop,' *Rosmarinus officinalis* L.'Hill Hardy' and *Veronica spicata* L. 'Goodness Grows.' was tested. BA increased branching of three taxa as liners while roots were not affected. The addition of IBA did not improve root growth in BA-treated plants. Dikegulac sodium and ethephon were evaluated as branching enhancers in the same six perennials. Dikegulac increased branching of all except *Campanula* while ethephon increased branching in *Veronica* and *Verbena*. The effects of application time of BA on the branching of *Agastache* Clayton ex Gronov. 'Tutti Frutti' and *Verbena bonariensis* 'Lollipop' was evaluated with application of BA at 0, 7, 14, 17, 20 and 21 days after sticking (DAS); however growth was reduced in plants treated before rooting had occurred. *Agastache* finished plants treated at 14 DAS had increased branching whereas branching was not affected in *Verbena* liners or finished plants. The effects of single or multiple applications of BA and dikegulac sodium on *Sedum spectabile* Boreau 'Autumn Joy,' *Gaillardia aristata* Pursh 'Gallo Red,' *Phlox paniculata* L. 'Bright Eyes,' *Nepeta racemosa* Lam. 'Walker's Low,' *Delosperma* NE Br. 'Table Mountain,' and *Achillea* L. 'Moonshine' were evaluated. Two applications of PGR was most effective at increasing branching in finished plants. High rates of dikegulac sodium reduced growth in most plants studied while BA increased branches without negatively affecting plant growth.

ACKNOWLEDGEMENTS

I would like to express my appreciation to a number of people who have provided me with direction and assistance throughout my graduate studies. I would like to thank Joyce Latimer for her guidance and encouragement. Thank you to Holly Scoggins for sharing her knowledge and advice. I would like to thank John Freeborn for his technical support, worldview and patience in helping me reach my goals. I am thankful for the support of Jeff Burr, John James and Velva Groover. Thank you to the team of students whose cooperation and teamwork aided me in completing my research and whose friendship made the process enjoyable: Shawn Appling, Kevin Harris, Carly Reynolds, and J.B. Snelson.

Photo credits: all photos were taken by the author.

Table of Contents

List of Tables

List of Figures

Chapter 1. Literature Review

Introduction

Commercial production of ornamental plants is an important business, both in Virginia and the United States as a whole. According to the USDA Floriculture Crops 2010 Summary, sales of floriculture crops in the U.S. totaled 4.13 billion dollars in 2010, with potted herbaceous perennials accounting for 553 million dollars in sales (USDA, 2011). Young plants are a significant segment of the industry, with sales of liners and plug seedlings over 448 million dollars (USDA, 2009). According to a survey conducted by *Greenhouse Grower*, production of young plants was down about 10% in 2011, and while more plant material is currently being produced by seed (47%) than cuttings (43%), the gap between the two is smaller than in the past (Yanik, 2011). This survey also describes the trend of increasing demand for production of larger size plugs and liners.

Commercial growers of herbaceous perennials must produce plants that are aesthetically pleasing and ready to ship at appropriate times to market. In order to meet these production challenges, growers control plant growth by using cultural controls, including plant nutrition, light and temperature, as well as chemical controls, i.e. plant growth regulators (PGRs) (Albrecht and Tayama, 1992; Whipker et al., 2006). However, using PGRs can be challenging, because plants respond in different ways to PGRs depending on species, cultivar, growing conditions, and the PGR utilized (Gent and McAvoy, 2000). New varieties and cultivars are continually being developed; ongoing research is needed to keep PGR guidelines up to date. New PGRs on the market have not been evaluated for use in many crops, but growers want to take advantage of their use. Research is necessary to determine the correct use of PGRs in managing different crops.

Currently many growers treat with PGRs after transplant, however treating before transplant can have significant benefits for growers. Reduced time of application and reduced chemical cost in treating plug flats will result in a more cost effective method of controlling plant growth (Whitman and Runkle, 2003). Additionally, if treating plants earlier in their lifecycle results in quicker production times, even more savings could be realized. For producers who sell plants as liners to be finished by other growers, producing fuller liners more rapidly could be important to sales and profitability.

Traditionally, PGRs have been applied after transplant, when plants are in active growth and have started to expand. Foliar applications should be made when plants are turgid, well irrigated with dry foliage, and temperatures should be below 75°F (Albrecht and Tayama, 1992). Whitman and Runkle (2003) researched the effects of using paclobutrazol, a plant growth retardant, on bedding plants during plug production, with PGR applications between 3 and 33 days after seed sowing. The effectiveness in reducing height varied with species: in dianthus 'Rosemarie Fire' height was reduced 45% to 50%, in petunia 'Ultra Lilac' height was reduced 40% to 60%, in salvia 'Salsa Scarlet Bicolor' height was reduced 27% to 40%, and in marigold 'Janie Flame' height was reduced 15% to 19%. Some delays in flowering were noted: in marigold 2 to 3 days, in petunia 3 to 9 days, and in dianthus between 3 days and two weeks (Whitman and Runkle, 2003). This study shows the benefit of applying PGRs to very young plants, in this case plugs produced from seed; similarly PGRs may be applied to vegetative cuttings during liner production (Whipker et al., 2006).

Dole and Hamrick (2006) divided the process of liner production into five stages: Stage 0, prior to arrival or harvest of cuttings; Stage 1, cutting arrival or harvest and sticking; stage 2, callusing; stage 3 root development; and stage 4 toning the rooted cutting. During stage 4 the roots are grown enough so that the root ball will hold together when pulled from the plug tray. PGR applications may be made during late stage 3 or stage 4 (Dole and Hamrick, 2006). Herbaceous perennials can be produced by cutting propagation with material from stock plants or purchased as unrooted cuttings (Scoggins, 2006). According to the Green Leaf Plants Technical Guide Handling Unrooted Perennials (2010), cuttings should be stuck immediately upon arrival, after treatment with rooting hormone (this requirement varies with species), and placed under mist. Cell size varies depending on the size of the cutting; tray size of 54 to 76 cells is common (Scoggins, 2006). Most varieties root within 2 to 3 weeks; total production time for most perennial liners is between 6 and 8 weeks (Adam, 2005).

Plant Growth Regulator Branching Agents

Benzyladenine

One of the newer PGRs on the market is Configure from Fine Americas, Inc. (Walnut Creek, CA) which is a benzyladenine (BA) plant growth regulator. Benzyladenine is a synthetic cytokinin; cytokinins are plant hormones which promote cell division in tissue culture (Miller et al., 1955). Early studies in *Pisum sativum* L. describe the effects of cytokinin in releasing inhibition of bud initiation caused by auxin (Sorokin and Thimann, 1964). The application of exogenous cytokinins in many species increases the ratio of cytokinin to auxin in the plant, disrupting apical dominance which controls branching patterns and plant form, and promotes lateral bud out growth (Cline, 1991).

Benzyladenine has been studied on herbaceous plants with the objective of increasing offsets on slow to reproduce plants (Amling et al., 2007; Carey et al., 2009; Keever, 1994; Leclerc et al., 2006; Lubbell et al., 2005). Keever (1994) studied the effects of BA on shoot development (offsets) in blue hosta (*Hosta sieboldiana* (Lodd.) Engl.). Foliar application rates of 125 to 4000 $mg \cdot L^{-1}$ BA and drench rates of 5 to 120 mg a.i. BA/0.8 L (5 in.) pot were tested. All BA treatments increased offsets; the optimal foliar application rates were 2000 to 3000 $mg \cdot L^{-1}$ and the optimal drench rates were 20 to 40 mg a.i./pot. Foliar application of BA did not affect growth indices, while growth decreased with increasing rates of drench application (Keever, 1994). Phytotoxicity was found to be transient. Garner et al. (1997) found that response to BA is dependent on cultivar in hostas. Of ten *Hosta* Tratt (Funkia K. Spreng; Niobe Salisb.) cultivars treated with a single foliar application of 1250 to 3750 $mg \cdot L^{-1}$ BA, five cultivars had an increased number of offsets. No phytotoxicity was noted, and growth was either not affected or was increased by BA treatment. In subsequent studies, multiple foliar applications of 3000 $mg \cdot L^{-1}$ BA were tested in 30 day intervals and resulted in a linear increase in offset production (Garner et al., 1998). Hosta is responsive to various application methods of BA including crown drenches, crown spray, crown and foliar spray, root immersion and crown immersion (Keever and Warr, 2005; Warr and Keever, 2004). Although Leclerc et al. (2006) found no increase in offsets in field grown *Hosta* ‘Gold Standard’ when BA was applied as a foliar spray at the rates of 1250, 2500, or 3750 $mg \cdot L^{-1}$; the application of 2500 $mg \cdot L^{-1}$ BA increased the number of divisions per plant in *Hemerocallis* ‘Happy Returns’ compared to controls. Amling et al. (2007) also found that BA application of 2500 or 5000 $mg \cdot L^{-1}$ increased offset production in

Hemerocallis, although the response was cultivar dependent. While a single foliar application of BA resulted in few significant differences in number of buds in *Epimedium* x *rubrum* Morren, four monthly applications of 40 to 60 ml of 3000 mg·L^{-1} BA resulted in double the number of buds compared to controls (Lubbell et al., 2005). Similar results were achieved with multiple applications of 60 to 80 ml of 3000 mg·L^{-1} BA on *Helleborus* x *hybridus* L., but foliar phytotoxicity was noted in both *Epimedium* and *Helleborus* (Lubbell et al., 2005). A single foliar spray of 50 to 400 mg·L^{-1} BA increased offsets in *Echeveria setosa* and two cultivars of *Sempervivum*, with the number of offsets increasing with increasing concentration of BA (Carey et al., 2009).

Benzyladenine produced well branched perennials and potted plants (Blanchard and Runkle, 2008; Carpenter and Carlson, 1972; Kamínek et. al., 1987; Latimer and Freeborn, 2008; Padhye and Groninger, 2009). Spraying chrysanthemums (*Chrysanthemum* L.) with 400 mg·L^{-1} BA increased branching and reduced stem length (Carpenter and Carlson, 1972). In their study the application of BA to chrysanthemum stock plants delayed or prevented rooting in cuttings taken 0 to 4 weeks after treatment. Number of branches doubled in *Echinacea* 'White Swan' and 'Double Decker' treated with foliar sprays of 300 to 600 mg·L^{-1} BA (Latimer and Freeborn, 2008). A single foliar spray at a volume of 0.2 L·m^{-2} of BA and gibberellins A_4+A_7 was effective in increasing height and promoting bract expansion in poinsettia (*Euphorbia pulcherrima* Willd. Ex Klotz) 'Freedom Red' (Blanchard and Runkle, 2008). Five repeated applications of 22.5 mg·L^{-1} BA increased branching in the poinsettia cultivar Annette Hegg Lady (Kamínek et al., 1987). BA also reduced bract necrosis in poinsettia: a single foliar spray of 100 mg·L^{-1} BA applied to 'Supjibi Red' and 'Annette Hegg Dark Red' arrested development of bract necrosis (McAvoy and Bible, 1998). Padhye and Groninger (2009) tested the effects of two applications of 500 or 1000 mg·L^{-1} BA on the height and tiller production of six ornamental grasses. In their test BA increased tillers in only *Carex flagellifera* 'Toffee Twist' at 2 and 4 weeks after initial treatment (WAIT), but this effect was diminished by 8 WAIT. However, BA suppressed the height of four of the grasses by <15% compared to untreated controls (Padhye and Groninger, 2009).

Benzyladenine increased the number of offshoots in stock plants (Farris et al., 2009; Kamínek et al., 1987; Martin and Singletary, 1999; Pogroszewska and Sadkowska, 2008; Svenson, 1991). Of 18 juvenile perennials treated with BA as a foliar spray at rates of 1000, 2000, or 4000 mg·L^{-1}, 89% had an increase in the number of lateral branches although no additional branching was seen in the higher two rates as compared to 1000 mg·L^{-1} (Martin and Singletary, 1999). In their study, plants treated with higher rates were more compact and had decreased leaf size; treatment with BA at temperatures over 30˚C caused leaf burn. Two foliar applications of 400 mg·L^{-1} BA was effective in increasing branching in *Campanula persicifolia* L. (Pogroszewska and Sadkowska, 2008). Drench or foliar application of BA at rates from 250 to 2000 mg·L^{-1} increased vegetative shoots, reproductive shoots and flower buds in *Coreopsis verticillata* L. 'Moonbeam'; however plants treated with 1000 or 2000 mg·L^{-1} BA had persistent symptoms of phytoxicity and a 19 day delay in flowering as compared with only transient phytotoxicity and a 7 day delay in flowering in plants treated with 250 or 500 mg·L^{-1} BA (Farris et al., 2009). Benzyladenine was applied to *Verbena* cuttings (*Verbena* x *hybrids* Voss) in order to determine the effects of BA on adventitious root formation and lateral bud elongation (Svenson, 1991). Low concentrations of BA, either 30 or 100 mg·L^{-1}, applied as foliar sprays immediately or 12 hours after sticking increased root dry weight in *Verbena* cuttings whereas 300 mg·L^{-1} BA reduced root dry weight when compared to untreated controls. Lateral bud elongation was increased by 20% and 49% in subsequently rooted shoots treated with 10 or 30 $mg \cdot L^{-1}$ BA, respectively (Svenson, 1991).

Benzyladenine produced more fully branched annuals, bedding plants and tender perennials (Carey et al., 2008; Higaki and Rasmussen, 1979; Khosh-Khui et al., 1978; Pilon, 2010). A single foliar application of 400 to 1200 $mg \cdot L^{-1}$ BA increased branching in four cultivars of coleus (*Solenostemon scutellarioides* (L.) Codd) (Khosh-Khui et al., 1978). In their study, root fresh and dry weights were unaffected; shoot dry weight was decreased in plants treated with 1200 $mg \cdot L^{-1}$ BA. One or two foliar sprays of 80 to 160 $mg \cdot L^{-1}$ BA produced more compact petunias (*Petunia* Juss) with increased numbers of branches and flowers; results varied depending on cultivar (Carey et al., 2008). A single foliar spray of 300 $mg \cdot L^{-1}$ BA increased branching in calibrachoa (*Calibrachoa* Llave & Lex) (Pilon, 2010). Lateral shoots of *Anthurium andreanum* Andre were increased by a single foliar application of 100 to 1500 $mg \cdot L^{-1}$ BA, with maximum shoot formation produced with 1000 $mg \cdot L^{-1}$ BA (Higaki and Rasmussen, 1979).

In woody plants, BA has been used to increase branching as an alternative to mechanical pruning (Abdelgadir et al., 2009; Keever and Morrison, 2003; Kender and Carpenter, 1972; Oates et al., 2005; Sansberro et al., 2006). Multiple foliar applications of 100 to 500 $mg \cdot L^{-1}$ BA on actively growing shoots of two cultivars of apple (*Malus* Mill.) increased the number of lateral shoots (Kender and Carpenter, 1972). In *Ilex paraguariensis* St. Hil. (yerba mate), a single foliar spray of 8.8 $mmol \cdot L^{-1}$ BA increased the number of branches per stem, with eight branches in treated plants compared to one branch in control plants (Sansberro et al., 2006). A single foliar application of 12 mM significantly increased branches in physic nut, *Jatropha curcas* L., a potential biofuel crop, in both containers and field production (Abdelgadir et al., 2009). Shoot counts increased in *Nandina domestica* Thunb. as the number of weekly foliar applications of

2500 to 5000 mg·L^{-1} BA increased (Keever and Morrison, 2003). In their study shoot counts increased linearly with the application rate of BA; phytotoxicity in plants treated with 5 weekly applications was transient.

Mechanisms of shoot development

While exogenously applied BA increases branching in plants, it is not well understood how BA affects changes in plant growth. Does the application of BA, a synthetic cytokinin, affect endogenous levels of cytokinins in the plant, thus acting in opposition to auxin to disrupt apical dominance? Auer et al. (1992) showed that two different *Petunia hybrida* Vilm lines differed in their cellular response to exogenous BA; St40 had a shorter shoot induction period which led to greater BA metabolism than TLV1. Cytokinin levels of the same two *Petunia* lines were later assessed with and without BA present in the culture medium; St40 cytokinin levels increased in plants grown with or without BA in the culture medium whereas TLV1 cytokinin levels only increased with the addition of BA (Auer et al., 1999). Klems et al. (2011) found low initial levels of endogenous cytokinins present in *Nicotiana tabacum* L. explants during in vitro induction of shoot organogenesis, with levels of cytokinins rapidly increasing within the first 8 hours of cultivation. Results of this study indicate organogenic capacity is closely connected to the uptake of exogenous and metabolism of endogenous cytokinins.

Levels of cytokinins have been studied in intact plants as a response to application of BA. Kuiper et al. (1989) studied cytokinin levels in *Plantago major* L.ssp. *pleiosperma* (Pilger) in response to BA treatment and mineral nutrition and found that levels of zeatin and zeatin riboside (Z and ZR), the predominant cytokinins present, dropped within 24 hours of decreased nutrition; but this affect was retarded by the addition of BA to the nutrient solution. Chen et al. (1997) examining the change in endogenous levels of plant hormones in *Rhododendron* x*obtusum* Planch found that a single foliar spray of 1000 mg·L^{-1} BA increased the level of endogenous cytokinins in the terminal bud and the shoot and decreased the level of endogenous IAA in the terminal bud.

Measurement of Cytokinins

Levels of endogenous cytokinins have been measured in different plant organs in intact plants at different stages of development and following treatment with exogenous cytokinins (Chen et al., 1997; Dielman et al., 1996; Emery et al., 1998; Kuiper et al., 1988; Xu and Huang , 2009). Auxin, cytokinins, and abscisic acid were measured in different regions of *Lupinus angustifolius* L. (cv. Merrit) and at different developmental stages; levels of auxins were high in slow growing branches and low in strongly growing branches, while cytokinins showed the opposite concentrations (Emery et al., 1998). Cytokinin concentration was measured in different regions of *Rosa hybrid* L. at different developmental stages: mature tissues were found to be primarily zeatin riboside (ZR) cytokinins, in young leaves iso-pentenyl (IPA) cytokinins were 50% of the totals cytokinins, in older leaves and roots an unidentified form of a cytokinin like substance was found which might be a storage form of cytokinin (Dielman et al., 1996). Chen et al. (1997) measured cytokinins and other plant hormones in azalea ‘Siji’ (*Rhododendron obtusum* L.) after treatment with 1000 mg·L^{-1} BA; results showed that BA caused an increase in cytokinins in the shoot segment and the terminal bud and a decrease in auxin in the shoot segment and an increase in auxin in the terminal bud. In this study, hormone measurements were taken at 0, 4, 8, 12, 24, and 48 hours after treatment (Chen et al., 1997). Xu and Huang (2009) found that treatment with exogenous ZR resulted in an increase in endogenous cytokinins at 7 days after treatment four times greater than the initial levels in creeping brentgrass (*Agrostis stolonifera* L.). Kuiper et al. (1988) examined cytokinin levels in *Plantago major* L. *ssp. Pleiosperma* after treatment with BA and in relation to mineral nutrition: levels of cytokinins were similar in plants treated with BA and plants grown in a high mineral solution.

Dikegulac sodium

Augeo, by OHP Inc., is another new PGR available for use by growers. Based on the active ingredient dikegulac sodium, Augeo has been used as a chemical pinch to decrease apical dominance and stimulate bud formation. Previously labeled as Atrimmec or Atrinal, it was primarily used to reduce shoot elongation and increase branching in woody plants (Banko and Stefani, 1995; Bell et al., 1997; Bruner et al., 2002; Porter and Shaw, 1983; Sachs et al., 1975). Early research demonstrated the usefulness of dikegulac sodium as a growth inhibitor for woody plants. Foliar application of 0.1% to 1% dikegulac sodium inhibited shoot elongation and increased lateral shoots in *Xylosma congestum* (Lour.), *Pyracantha coccinea* (Roem.), *Callistemon citrinus* (Curt.), *Cotoneaster pannosa* (Franch.) and *Nerium oleander* L (Sachs et al., 1975). In this study phytoxicity was slight except in *Nerium* which had chlorosis in young leaves and leaf tip necrosis. Banko and Stefani (1995) assessed the use of dikegulac on container grown woody ornamentals. Of nine species they studied, dikegulac effectively controlled growth in five: the application of 1480 $mg \cdot L^{-1}$ dikegulac to glossy abelia *(Abelia* x *grandiflora* (Andre) Rehd.) and 4440 $mg \cdot L^{-1}$ dikegulac to bearberry cotoneaster *(Cotoneaster dammeri* C.K.Schneid. 'Coral Beauty'), Manhattan euonymus *(Euonymus kiautschovicus* Loes. 'Manhattan'), Foster holly *(Ilex* x *attenuata* Ashe 'Fosteri'), or Fraser photinia *(Photinia* x *fraseri* Dress) produced compact plants which appeared more fully branched. Bell et al. (1997) looked at the effects of dikegulac sodium, BA and GA_{4+7} , alone and in combination, on florist azaleas, *Rhododendron* L. cultivars Gloria and Prize. In this study, dikegulac sodium at the rate of 3900 $mg \cdot L^{-1}$ was the only treatment effective in increasing lateral branching, while treatments of 1000 $mg \cdot L^{-1}$ GA_{4+7}, 1000 mg·L^{-1} BA, 1000 + 1000 mg·L^{-1} BA + GA_{4+7} , or 3900 + 1000 mg·L^{-1} dikegulac + GA_{4+7} did not significantly increase branches compared to untreated controls. In addition, the combination of dikegulac sodium with GA_{4+7} was more phytotoxic than dikegulac alone (Bell et al., 1997). Foliar sprays of 2340 or 4680 mg·L^{-1} dikegulac to *Lonicera* x *heckrottii* Rehder [×americana × sempervirens] 'Goldflame' suppressed shoot length and increased shoot number in both unpruned shoots treated in April and pruned and unpruned shoots treated in June (Bruner et al., 2002). When three year old field-grown *Lavandula* × *intermedia* Emeric ex Loisel.'Twickle Purple' plants were treated with 0.5%, 1.0%, or 2.0% Atrinal (containing 20% dikegulac sodium), the number of vegetative shoots, inflorescences, and oil yield increased significantly compared to untreated plants (Porter and Shaw, 1983).

Little research has been conducted on the responses of herbaceous plants to Augeo; however it shows promise as a branching agent. When seedlings of *Zinnia* L. 'Scarlet Flame,' *Helianthus annuus* L. 'Peredovic,' and rooted cuttings of *Chrysanthemum morifolium* Ramat. (pro sp.) 'Escapade' were treated with dikegulac sodium in the range of 100 to 750 mg·L^{-1} as foliar sprays, dikegulac inhibited the elongation of internodes and stimulated the elongation of axillary branches in all three species (Arzee et al., 1977). Chlorosis and distorted leaves were noted but found to be a transient effect of treatment. When used on Boston fern (*Nephrolepsis exaltata* (L.) Schott `Compacta'), 250, 500, or 750 mg·L^{-1} dikegulac sodium significantly increased shoot count, whereas 50, 100 or 150 mg·L^{-1} BA did not (Carter et al., 1996). *Kalanchoe* Adans. X spp treated with foliar sprays of 750 to 2250 mg·L^{-1} dikegulac sodium had an increased number of inflorescences and decreased height (Nightingale et al., 1985). Branching of *Gaillardia aristata* Pursh. 'Gallo Yellow' was increased by foliar sprays of 400 or 800 mg·L^{-1} dikegulac sodium whereas drench applications of 40 to 160 mg·L^{-1} at 300 ml per pot did not affect branching and higher spray rates of 1600 or 3200 mg·L^{-1} dikegulac sodium caused stunting and phytotoxicity (Latimer and Freeborn, 2010).

Florel

Florel (Monterey Chemical) is a plant growth regulator which is labeled for increasing lateral branching, delaying flowering, and inhibiting internode elongation on floricultural crops. In plant tissue, ethephon transforms into the plant hormone ethylene (Gent and McAvoy, 2000). Although the role of ethylene in regards to apical dominance is not well understood, ethephon is used as a pinching agent which inhibits terminal buds and releases outgrowth of axillary buds (Cline, 1991). Foley and Keever (1992) assessed the effect of ethephon, BA, BA + GA_{4+7} , and pyranyl benzyladenine (PBA, Accel) on increasing axillary shoots of geranium (*Pelargonium* x *hortorum* L.H. Bailey 'Hollywood Star') stock plants. In their study, a single application of 500 mg·L^{-1} ethephon increased axillary shoots by 93%, while BA + GA_{4+7} and PBA increased axillary shoots by 19% compared to untreated controls. When tested on 27 cultivars of vegetative annuals with spreading and trailing growth habits, foliar sprays of either 500 or 1000 mg·L^{-1} ethephon reduced height and width indexes of 81% of plants studied (Starman et al., 2004). Three foliar sprays of 1000 mg·L^{-1} ethephon reduced height in five of eight herbaceous perennials tested (*Achillea millefolium* L. 'West River Sandstone,' *Echinacea purpurea* Moench 'Bravado', *Leucanthemum x superbum* Bergmans ex. J. Ingram 'Thomas Killen', *Monarda didyama* L. 'Blue Stocking,' and *Physostegia virginiana* Bentham 'Summer Snow'); ethephon did not affect the number of shoots per pot in seven species and reduced the number of shoots in *Leucanthemum* (Hayashi et al., 2001). Two applications of 500 mg·L^{-1} ethephon reduced height on *Salvia* x *sylvestris* L. 'May Night' ('Mainacht'), and *Scabiosa columbaria* L. 'Butterfly Blue'; numbers of inflorescences were increased in *Salvia* but not *Scabiosa* (Banko et al., 2001).

Table 1.1 Taxa Studied

Plants chosen for this study are listed in the following table. Selection criteria included: herbaceous perennials popularly grown in the industry, plants that are typically grown as liners, and plants that could benefit from additional branching in the liner stage. Plant popularity was judged based on a list of top 50 perennials sold as unrooted cuttings by Green Leaf Plants (personal communication).

Name	Family	Hardi-ness zone	Form	Origin
Achillea L. 'Moonshine' yarrow	Asteraceae	3-8	Clump forming perennial with dissected foliage, basal branching	(species northern temperate regions)
Agastache Clayt. Ex Gronov. 'Purple Haze' anise hyssop, purple haze hyssop, giant hyssop, Mexican hyssop	Lamiaceae	6-9	Upright perennial	N. America, China and Japan
Agastache 'Tutti Frutti'	Lamiaceae	6-10	Upright perennial	N. America
Aster 'Professor Kippenburg' *Symphyotrichum novi-belgii* L.'Professor Anton Kippenburg' michaelmas daisy	Asteraceae	4-8	Clump forming, mounded perennial	N. America
Campanula punctata Lam. 'Cherry Bells' spotted bellflower	Campanulaceae	5-7	Upright perennial with large bell shaped flowers	Asia
Cosmos atrosanguineus (Hook) Voss. chocolate cosmos	Asteraceae	7-9	Erect perennial, oblong leaves, radiate flowers on long stalks	Mexico
Delosperma NE Br.'Table Mountain' iceplant	Aizoaceae	6-8	Succulent, mat-forming perennial	Africa, Middle East

Gaillardia aristata Pursh ‘Gallo Red’ blanketflower	Asteraceae	3-8	Clump forming perennial	N. America
Gaura lindheimeri Engelm. & A. Gray 'Siskiyou Pink' gaura, butterfly gaura	Onagraceae	5-8	Perennial, leaves mostly basal, flowers on a leafless spike	Texas, Louisiana
Lavandula ×intermedia Emeric ex Loisel. 'Provence' Lavender	Lamiaceae	5-8	Subshrub, erect or spreading, oblong leaves	Mediterra nean
Leucanthemum ×superbum (Bergmans ex J.W. Ingram) Bergmans ex Kent. 'Snowcap' Shasta daisy	Asteraceae	5-9	Upright perennial, lanceolate leaves, radiate	(Species Europe, N. Asia) Garden origin
Nepeta racemosa Lam. ‘Walker’s Low’ catmint	Lamiaceae	4-8	Decumbent or erect stems with many flower spikes, 2-3 ft tall	Caucasus , Iran
Phlox paniculata L. ‘Bright Eyes’ garden phlox	Polemoniaceae	4-8	upright perennial	N. America
Rosmarinus officinalis L.'Hill Hardy' rosemary	Lamiaceae	8-10	Upright, evergreen shrub, linear leaves	S. Europe, N. Africa
Salvia ×sylvestris L. (pro sp.) 'May Night' wood sage	Lamiaceae	4-8	Clump forming perennial with lanceolate leaves and upright flower spikes.	Uncertain origin
Sedum spectabile Boreau 'Autumn Joy‘ stonecrop	Crassulaceae	3-9	Clump forming perennial, inflorescence a dense cyme	Europe, N. America, Asia
Verbena bonariensis L. ‘Lollipop’	Verbenaceae	7-11	Upright annual or perennial, lanceolate leaves, flowers in short spikes	S. America
Veronica L. Goodness Grows speedwell	Scrophulariaceae	3-8	Compact, erect bushy perennial with flower spikes	Europe

Literature Cited

Abdelgadir, H.A., S.D. Johnson and J. Van Staden. 2009. Promoting branching of a biofuel crop *Jatropha curcas* L. by foliar application of plant growth regulators. Plant Growth Regul. 58:287–295.

Adam, Jr., S. 2005. Grower 101: Propagating herbaceous perennials. Greenhouse Product News 15(3):58-59.

Albrecht, M.L. and H.K. Tayama. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assoc., Columbus, Ohio.

Amling, J.W., G.J. Keever, J.R.J. Kessler, and D.J. Eakes. 2007. Benzyladenine (BA) promotes ramet formation in *Hemerocallis*. J. Environ. Hort. 25(1):9-12.

Arzee, T., H. Langenauer and J. Gressel. 1977. Effect of dikegulac, a new growth regulator, on apical growth and development of three Compositae. Bot. Gaz. 138(1):18–28.

Auer, C.A., J.D. Cohen, M. Lalue, and T.J. Cooke. 1992. Comparison of benzyl adenine metabolism in two Petunia hybrid lines differing during shoot organogenesis. Plant Physiol. 98:1035-1041.

Auer, C.A., V. Motyka, A. Brezinova, and M. Kaminek. 1999. Endogenous cytokinin accumulation and cytokinin oxidase activity during shoot organogenesis of Petunia hybrid. Physiol. Plant. 105:141-147.

Banko, T.J. and M.A. Stefani. 1995. Cutless and Atrimmec for controlling growth of woody landscape plants in containers. J. Environ. Hort. 13(1):22-26.

Banko, T.J., M.A. Stefani, and M.S. Dills. 2001. Growth and flowering response of 'May Night' *Salvia* and 'Butterfly Blue' *Scabiosa* to growth retardants. J. Environ. Hort. 19(3):145-149.

Bell, M.L., R.A. Larson, and D.A. Bailey. 1997. Vegetative growth responses of florist azaleas to dikegulac, GA_{4+7}, and 6-benzylamino purine. HortScience 32(4):690-693.

Blanchard, M.G. and E.S. Runkle. 2008. Increasing stem elongation and bract size of poinsettia 'Freedom Red' with gibberellins and benzyladenine. Acta Hort. 774:209–215.

Bruner, L.L., G.J. Keever, J.R. Kessler, Jr., and C.H. Gilliam. 2002. Atrimmec suppresses shoot length and promotes branching of *Lonicera* x *heckrottii* 'Goldflame' (Goldflame honeysuckle). J. Environ. Hort. 20(2):3-76.

Carey, D., B. Whipker, I. McCall, and W. Buhler. 2008. Cytokinin based PGR affects growth of vegetative petunia. Proc. Plant Growth Regulat. Soc. Amer. 35:85-89.

Carey, D., W. Buhler, and B. Whipker. 2009. Stimulating plant growth. Greenhouse Product News 9(5):20, 22, 24.

Carey, D., B. Whipker, I. McCall, W. Buhler. 2009. Benzyladenine foliar sprays increase offsets in Sempervivum and Echeveria. Proc. Plant Growth Regulat. Soc. Amer. 36:169-172.

Carpenter, W.J. and W.H. Carlson. 1972. The effect of growth regulators on chrysanthemum. HortScience 97(3):349-351.

Carter, J., B.P. Singh and W. Whitehead. 1996. Dikegulac, but not benzyladenine, enhances the aesthetic quality of Boston fern. HortScience 31:978-980.

Chen J.G., H.Y. Zhao, X. Zhou, L.S. Mao, X.X. Chen. 1997. Fluctuation in levels of endogenous hormones in azalea after decapitation and 6-benzyl amino purine treatment, and their relationship to apical dominance. Scientia Hort. 71:49–58.

Cline, M.G. 1991. Apical dominance. Bot. Rev. 57:318-358.

Dielman, J.A., F.W.A. Verstappen, B. Nicander, D. Kuiper, E. Tillberg, and J. Tromp. 1997. Cytokinins in *Rosa hybrida* in relation to bud break. Physiol. Plant. 99:456-464.

Dole, J. M. and D.J. Hamrick. 2006. Propagation basics, p. 3-16. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Early, J.D. and G.C. Martin. 1988. Sensitivity of peach seedling vegetative growth to paclobutrazol. J. Amer. Soc. Hort. Sci. 113(1):23-27.

Emery, R.J.N., N.E. Longnecker, and C.A. Atkins. 1998. Branch development in *Lupinus angustifolius* L. relationship with endogenous ABA, IAA, and cytokinins in axiallry and main stem buds. J. Expt. Bot. 49(320): 555-562.

Farris, M.E., G.J. Keever, J.R. Kessler, and J.W. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of *Coreopsis verticillata* 'Moonbeam'. J. Environ. Hort. 27(3):176-182.

Foley, J.T. and G.J. Keever. 1992. Chemical promotion of axillary shoot development of geranium stock plants. J. Environ. Hort. 10(2):90-94.

Garner, J.M., G.J. Keever, D.J. Eakes, and J.R. Kessler. 1997. Benzyladenine-induced offset formation in hosta dependent on cultivar. HortScience 32(1):91-93.

Garner, J.M., G.J. Keever, D.J. Eakes, and J.R.J. Kessler. 1998. Sequential BA applications enhance offset formation in *Hosta*. HortScience 33 (4):707-709.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture: a critical appraisal, p. 89-130. In Basra, A.S. (ed.) Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton.

Green Leaf Plants. 2010. Technical guide handling unrooted perennials. Green Leaf Plants™, A Division of Aris Horticulture, Inc. Lancaster, PA.

Hayashi, T., R.D. Heins, A.C. Cameron, and W.H. Carlson. 2001. Ethephon influences flowering, height, and branching of several herbaceous perennials. Scientia Hort. 91:305-323.

Higaki, T. and H.P. Rasmussen. 1979. Chemical induction of adventitious shoots in anthurium. HortScience 14(1):64-65.

Kamínek, M., T. Vaněk, A. Kalendová-Kulasová, J. Pilař. 1987. The effect of two cytokinins on production of stem cuttings by stock plants of *Euphorbia pulcherrima* Willd. and *Gerbera jamesonii* Hook. Scientia Hort. 33:281-289.

Keever, G.J. 1994. BA-induced offset formation in *Hosta*. J. Environ. Hort. 12(1):36-39.

Keever, G.J. 2003. Plant growth regulation in ornamental nurseries – unrealized opportunities. Proc. 30th Annu. Plant Growth Regulat. Soc. Amer. Vancouver, 3-6 Aug. 2003.

Keever, G.J. and T.A. Morrison. 2003. Multiple benzyladenine applications increase new shoot formation in *Nandina*. J. Environ. Hort. 21:144–147.

Keever, G.J., and J.C. Warr. 2005. Response of *Hosta* to method and time of BA application. Plant Growth Regulat. Soc. of Amer. Qrtly 33 (1):4-11.

Kender, W.J. and S. Carpenter. 1972. Stimulation of lateral bud growth of apple trees by 6-benzylamino purine. HortScience 97(3):377-380.

Khosh-Khui, M., I. Rouhani, and B. Shaybany. 1978. Axillary shoot stimulation and plant development of coleus treated with certain plant growth regulators. Can. J. Plant Sci. 58:971-976.

Klemš, M., Z. Slámová, V. Motyka, J. Malbeck, A. Trávníčková, I. Macháčková, J. Holík and S. Procházka. 2011. Changes in cytokinin levels and metabolism in tobacco (*Nicotiana tabacum* L.) explants during in vitro shoot organogenesis induced by *trans*-zeatin and dihydrozeatin. Plant Growth Regul. 65 (3):427-437.

Kuiper, D., P.J.C. Kuiper, H. Lambers, J. Schuit, and M. Staal. 1989. Cytokinin concentration in relation to mineral nutrition and benzyladenine treatment in *Plantago major* ssp. *pleiosperma*. Physiol. Plant. 75(4):511–517.

Latimer, J. and J. Freeborn. 2008. Enhance branching of *Echinacea* with PGRs. Greenhouse Product News 18(4):24–28.

Latimer, J.G. and J. Freeborn. 2010. Branching enhancers, Configure (6-BA) and Augeo (dikegulac sodium), affect branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 37:148-152.

Latimer, J.G., Scoggins, H.L. and Banko, T.J. 2003. Persistence of plant growth regulator effects on perennial plants in the nursery. Acta Hort. 624:229-232

Leclerc, M., C.D. Caldwell, and R.R. Lada. 2006. Effect of plant growth regulators on propagule formation in *Hemerocallis* spp. and *Hosta* spp. HortScience 41(3):651-653.

Lubbell, J.D., D.M. Thompson, and M.H. Brand. 2005. Foliar sprays of benzyladenine increase bud and propagule production in *Epimedium* x*rubrum* Morren and *Helleborus* x*hybridus* L. Prop. Ornamental Plants 5(1):19-22.

Martin, S. and S. Singletary. 1999. N-6 Benzyladenine increases lateral offshoots in a number of perennial species. Proc. Intl. Plant Prop. Soc. 49:329-334.

McAvoy, R.J., and B.B. Bible. 1998. Poinsettia bract necrosis is affected by scion/rootstock combinations and arrested by a benzyladenine spray. HortScience 33(2):242-246.

Nightingale, A.E., S.E. Cross and M.T. Longnecker. 1985. Dikegulac alters growth and flowering of Kalanchoe. HortScience 20:722-724.

Oates, J.M, G.J. Keever, and J.R. Kessler, Jr. 2005. BA application frequency and concentration effects on two Indian Hawthorn cultivars. J. Environ. Hort. 23(1):37-41.

Padhye, S.R. and J.K. Groninger. 2009. Influence of benyladenine, trinexapac-ethyl, or uniconazole applications on height and tillering of six ornamental grasses. HortTechnology 19(4):737-742.

Pilon, P. 2010. Calibrachoa – using Configure to promote lateral branching, p. 8-9. In: Latimer, J.G. and B. Whipker (eds.). Configure Product Information and University Trial Results. Fine Americas, Walnut Creek, CA.

Pogroszewska, E. and P. Sadkowska. 2008. The effect of benzyladenine on the flowering of *Campanula persicifolia* L. 'Alba' cultivated in an unheated plastic tunnel and in the field. Acta Sci. Pol., Hortorum Cultus 7(3):57-63.

Porter, N.G. and M.L. Shaw. 1983. Increasing growing points and oil yield in lavender by growth regulator sprays. J. Plant Growth Regul. 2:151-158.

Sansberro, P., L. Mroginski, and R. Bottini. 2006. Stimulation of lateral branch formation on *Ilex paraguariensis* (Aquifoliaceae) seedlings. Austral. J. Expt. Agr. 46:707-710.

Sachs, R.M., H. Hield, and J. DeBie. 1975. Dikegulac: A promising new foliar-applied growth regulator for woody species. HortScience 10(4):367-369.

Scoggins, H.L. 2006. Cutting propagation of herbaceous perennials, p. 173-186. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Sorokin, H.P. and K.V. Thimann. 1964. The histological basis for inhibition of axillary buds in *Pisum sativum* and the effects of auxins and kinetins on xylem development. Protoplasma 59:326-350.

Starman, T.W., M.C. Robinson, and K.L. Eixmann. 2004. Efficacy of ethephon on vegetative annuals. HortTechnology 14 (1):83-87.

Svenson, S.E. 1991. Rooting and lateral shoot elongation of verbena following benzylaminopurine application. HortScience 26(4):391-392.

USDA 2011. Floriculture Crops 2010 Summary. Cited November 17, 2011. <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1072>

USDA 2009. Census of Horticultural Specialties.Cited November 17, 2011. <http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Census_of_Horticulture/HORTIC.pdf>

Warr, J.C., and G.J. Keever. 2004. Response of *Hosta* to BA crown drenches applied at division and establishment. J. Environ. Hort. 22(3):129-132.

Whipker, B.E., J.L. Gibson, and C.B. Cerveny. 2006. Rooting hormones and plant growth regulators, p. 89-100. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Whitman, C. and E. Runkle. 2003. PGR rates and timing for plug production. Greenhouse Product News 13(12):38-43.

Xu, Y. and B. Huang. 2009. Effects of foliar-applied ethylene inhibitor and synthetic cytokinin on creeping bentgrass to enhance heat tolerance. Crop Sci. 49:1876-1884.

Yanik, K. 2011. How plug and liner operations are overcoming the decline. Posted on 13 September 2011. Accessed on 27 October 2011. <http://www.greenhousegrower.com>.

Chapter 2. Benzyladenine Increases Branching but Reduces Root Growth of Herbaceous Perennial Liners

Mara Grossman, John Freeborn, Holly Scoggins, and Joyce Latimer[1]

Department of Horticulture, Virginia Tech, Blacksburg, Virginia, 24061

Received for publication ___________

Funding for this project was provided by Fine Americas, Inc. and the Virginia Nursery and Landscape Association. We also thank Conrad Fafard, Inc., and Aris Horticulture, Inc. for their support of floriculture research at Virginia Tech.

Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by Virginia Tech and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

[1] To whom reprint requests should be addressed. E-mail address: jlatime@vt.edu

Subject category: Reports – Growth regulators

Benzyladenine Increases Branching but Reduces Root Growth of Herbaceous Perennial Liners

Additional index words. BA, Configure, plant growth regulators, *Agastache*, *Gaura lindheimeri, Lavandula* x *intermedia*, *Leucanthemum* x *superbum*, *Salvia* x *sylvestris*, WinRhizo, root surface area, root volume

Abstract.

The objective of this study is to evaluate the branching effect of benzyladenine (BA) on herbaceous perennial plants during the production of rooted cuttings (liners) and to examine and quantify the root growth of these liners using multiple methods of root evaluation. Five perennials were studied: *Agastache* Clayt. Ex Gronov. 'Purple Haze', *Gaura lindheimeri* Engelm. & A. Gray 'Siskiyou Pink', *Lavandula ×intermedia* Emeric ex Loisel. 'Provence', *Leucanthemum ×superbum* (Bergmans ex J.W. Ingram) Bergmans ex Kent. 'Snowcap', and *Salvia ×sylvestris* L. (pro sp.) 'May Night'. After rooting but prior to transplant, BA was applied to rooted cuttings as four treatments: controls (0 mg L^{-1}), one application of 300 mg·L^{-1}, two applications of 300 mg·L^{-1}, or one application of 600 mg·L^{-1}. Results varied by species; all except *Salvia* had increased branching as measured as either increased lateral or basal branches and/or increased leaders at 3 to 4 weeks after initial treatment. Four species showed reduced root growth while *Gaura* was unaffected. Root dry weight was found to be highly correlated with root surface area

and root volume. After transplant and growing out, branching of the finished plants was increased in *Gaura* and *Lavandula*, unaffected in *Salvia* and *Leucanthemum* and decreased in *Agastache*. Treating rooted cuttings with BA prior to transplant increased branching but the effects were not long lasting which suggests that additional applications at or after transplant may improve finished plant quality. Reductions in root growth noted in rooted cuttings did not affect the growth of finished plants.

Chemical names. N-(phenylmethyl)-1H-purine-6-amine (benzyladenine, BA).

In order to meet the challenges of producing plants for sale, growers frequently use plant growth regulators (PGRs) to control plant height, branching, and flowering. Benzyladenine (BA) is a PGR which increases branching in floriculture crops when sprayed on containerized plants (Carey et al., 2009; Farris et al., 2009; Martin and Singletary, 1999). The addition of BA, a synthetic cytokinin, increases the ratio of cytokinin to auxin in the plant, disrupting apical dominance (Cline, 1991). This results in more basal and/or lateral branching and fuller plants. The effects of BA vary with cultivar: of ten *Hosta* Tratt (Funkia K. Spreng; Niobe Salisb.) cultivars treated with 1250 to 3750 mg L^{-1} foliar sprays of BA, five cultivars had an increased number of offsets (Garner et al., 1997).

Chemical PGRs are often used during plug and rooted cutting (liner) production but must be used with care for efficacy and to prevent unwanted effects such as phytotoxicity or delayed flowering. These PGR applications are typically made about 2 to 4 weeks after liners have been transplanted, when plants are established and in active growth (Albrecht and Tayama, 1992). However, we are interested in testing the use of BA at an earlier stage of plant production, on liners prior to transplant. Because liners are still in smaller cells, they are easier to treat with

PGRs than plants that have already been transplanted into larger containers and less chemical is required per plant, so growers can save money by spraying earlier in the plant production cycle. Some commercial producers of liners have reported reduced root mass in plants treated with BA (personal communications). BA has been shown to reduce root growth *in vitro Arabidopsis* seedlings (Auer, 1996). Sedum leaf cuttings treated with BA at concentrations for 8 to 500 $mg \cdot L^{-1}$ exhibited reduced root growth and increased shoot growth at all concentrations (Boe et al., 1972). Other research has shown BA has no effect on the root growth of treated plants (Khosh-Kui et al., 1978; Leclerc et al., 2006; Richards and Wilkinson, 1984). However, application of BA to unrooted cuttings of *Verbena* x *hybrids* Voss which had already initiated adventitious root formation had no effect on root growth whereas low rates of BA (30 $mg \cdot L^{-1}$) applied to cuttings prior to initiation of adventitious root formation increased root dry weight of liners at 12 days after treatment (Svenson, 1991).

The process of liner production has been divided into five stages: Stage 0, prior to arrival or harvest of cuttings; Stage 1, cutting arrival or harvest and sticking; stage 2, callusing; stage 3 root development; and stage 4 toning the rooted cutting. During stage 4 the roots are grown enough so that the root ball will hold together when pulled from the plug tray (Dole and Hamrick, 2006). The objective of this study is to evaluate the effects of the application of BA to herbaceous perennial plants during liner production, specifically during stage 3, on root growth and shoot branching of the finished liners (stage 4).

Materials and Methods

Five plant species were studied: *Agastache* 'Purple Haze', *Gaura lindheimeri* 'Siskiyou Pink', *Lavandula* x *intermedia* 'Provence', *Leucanthemum* x *superbum* 'Snowcap', and *Salvia* x *sylvestris* 'May Night'. Plants arrived as unrooted cuttings, which were dipped for ten seconds in 1500 mg·L-^{1} IBA rooting hormone (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp, New York, NY) as a basal treatment and stuck into 72 size (height 5.71 cm, volume 35.4 ml) trays filled with a peat moss media with pine bark, perlite and vermiculite (45%, 25%, 15%, and 15%, respectively; Fafard 3B, Conrad Fafard, Inc. Agawam, MA). Cuttings were allowed to root under mist with bottom heat at 22°C (72°F). Twenty-seven to 34 days after sticking, depending on species, plants were removed from mist and bottom heat. Cuttings received clear water under mist, but after removal from mist received 100 mg·L^{-1} N with each irrigation using 20N-4.4P-16.6K Peters Professional General Purpose fertilizer (The Scotts Co. LLC, Marysville OH).

Benzyladenine (BA, Configure, Fine Americas, Inc., Walnut Creek, CA) was applied to liners at least 8 hours after removal from mist. This was considered the week 0 treatment. The BA treatments included: control (0 mg·L^{-1}), one application of 300 mg·L^{-1}, two applications of 300 mg·L^{-1} (one application at week 0 and the second application 2 weeks later), or one application of 600 mg·L^{-1}. Treatments were applied when roots from cuttings were evident on all four sides of the root ball, but liners were not fully rooted and ready for transplant. Treatments were applied as foliar sprays of BA with a CO_2 backpack sprayer (R&D Sprayers, Inc., Opelousas, LA) applying 210 ml per m^2. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W) from January through April, 2010. Greenhouse light levels averaged 17.8 mol·m^{-2}·d^{-1} and temperatures averaged 20.2°C. The experimental setup was a completely randomized design with each plant species conducted as a separate experiment. Experimental units consisted of six plants in a single six-cell pack with four replications of the experimental unit per treatment for each of three destructive harvests for each species. An additional set of replications was included for evaluation of how the liners grow out as described below.

Data were collected at 0, 2, and 4 weeks after initial treatment (WAIT) on individual plants in each experimental unit (except at 0, 2, and 3 WAIT on *Agastache* due to vigorous growth). At 3 to 4 WAIT liners were finished and ready to be transplanted. Measurements included plant height measured from the top of the container, average width which was the average of the width measured at the widest point of the plant and again perpendicular to this point, number of branches, number of plants in flower, and phytotoxicity. Branches were counted if they were 2 mm long or longer. Based on growth habit, branches counted in *Leucanthemum* and *Salvia* were basal branches which had no secondary laterals and in *Agastache*, *Gaura* and *Lavandula*, leaders (primary branches with secondary lateral branches) and secondary lateral branches were counted.

For root measurements and root and shoot dry weights, all six plants from the experimental unit (cell pack) were pooled. Media was washed off of roots by hand, using a screen to prevent loss of roots. Roots were washed randomly by experimental unit. In order to better understand BA's effects on root growth and development, roots were scanned at each harvest using WinRhizo (Regent Instruments Inc., Quebec, Canada) and analyzed to determine root surface area and root volume. Root surface area and volume were determined by first washing all media off roots by hand and then scanning roots using WinRhizo. Root and shoot dry weights were determined after drying roots and shoots at 66°C (150°F) for 48 hours. Root:shoot dry weight ratio was calculated on an experimental unit basis using total shoot dry weight (shoot plus flowers, when present). Although the WinRhizo allowed detailed measurement of root growth characteristics, the process was very time consuming. To facilitate future research, we evaluated the correlation between root dry weight and the root surface area and root volume data from the WinRhizo analysis. Root dry weights of BA treated and untreated plants at all times of measurement (0, 2, and 3-4 WAIT) were compared to root volume and root surface area for each species studied.

After data were collected at 3-4 WAIT, eight plants of each treatment were randomly selected from the remaining replications, potted into quart sized plastic pots (1.1 liter) filled with Fafard 3B medium and grown out for a period of four additional weeks to assess liner treatment effects on the finished plant. These plants were arranged as single plant replications in a completely randomized design for each taxa. On finished plants, data measurements included height, width, and numbers of leaders and lateral or basal branches as applicable, and the number of plants flowering.

Data were analyzed by ANOVA and subjected to LSD means separation ($P \leq 0.05$) using SAS Version 9.2 by SAS Institute Inc. (Cary, NC) and JMP®9.0 ©2010 SAS Institute Inc. Correlation of root dry weight to root volume and surface area was performed by bivariate analysis and linear regression in JMP®9.0.

Results

In all plants, measurements were taken at 0 weeks after initial treatment (WAIT) to ensure uniformity. At this time, there were no significant differences between control plants and plants treated with BA in plant height, width, numbers of leaders and lateral branches or basal branches, root or shoot dry weights, root surface area, root volume, or root shoot ratio (data not presented). None of the cuttings were flowering. No significant phytotoxicity was noted in plants at any data collection times.

Agastache 'Purple Haze.' At 2 WAIT, all plants treated with BA showed significant increases in the number of lateral branches as compared to control plants (8.8 to 12.4 versus 2.5), although there were no significant differences in height, width, the number of leaders or shoot dry weight (Appendix 2.A.1). Root surface area and volume measurements were lower than control plants only in plants treated with one application of 300 $mg \cdot L^{-1}$ while plants assigned to the two applications of 300 $mg \cdot L^{-1}$ BA had greater root volume than controls. Since these plants had not yet been treated the second time, this suggests significant variability in the root growth response. There were no significant differences in root dry weights but the root:shoot ratio was significantly lower than controls in plants treated with one application of either 300 or 600 $mg \cdot L^{-1}$ BA (Appendix 2.A1).

At 3 WAIT, although plant height, width and number of leaders were not affected, all BA-treated *Agastache* liners showed an increase in the number of lateral branches as compared to control plants (Table 2.1). Although shoot dry weight was not affected, all BA-treated plants had less root dry weight, root surface area and root volume than control plants, resulting in lower root:shoot ratios relative to control plants. Root growth of *Agastache* liners treated with two applications of 300 $mg \cdot L^{-1}$ or one application of 600 $mg \cdot L^{-1}$ had the greatest reductions in root growth.

On finished plants, height and width of BA-treated plants were not different from control plants but plants treated at the higher BA concentrations (two applications of 300 $mg \cdot L^{-1}$ or one application of 600 $mg \cdot L^{-1}$) had fewer leaders and lateral branches than control plants or those treated with a single application of 300 $mg \cdot L^{-1}$ BA (Table 2.2). There were no differences between BA-treated and untreated plants in the number of plants flowering (data not presented).

Agastache liners treated with BA showed increased lateral branches and decreased root growth at 3 WAIT; however finished plants treated with the higher treatment concentrations in the liner stage had fewer lateral branches.

Gaura lindheimeri 'Siskiyou Pink.' At 2 WAIT BA-treated *Gaura* liners showed no significant differences in height or numbers of leaders or lateral branches as compared to controls (Appendix Table 2.A.1). Shoot dry weight increased in liners treated with two applications of 300 $mg \cdot L^{-1}$ BA or one application of 600 $mg \cdot L^{-1}$ BA when compared to control liners (Appendix Table 2.A.1). Root dry weight, surface area and volume were greater than controls in plants treated with one application of 300 $mg \cdot L^{-1}$ BA (Appendix Table 2.A.1). Root:shoot ratio was greater than controls in plants treated with one or two applications of 300 $mg \cdot L^{-1}$ BA. Again, since the second application of the 300 $mg \cdot L^{-1}$ BA had not yet been applied, there is some variability in liner response to the 300 $mg \cdot L^{-1}$ BA treatment.

At 4 WAIT BA-treated *Gaura* liners showed no significant differences in plant height or width as compared to the control plants (Table 2.1). However, all *Gaura* liners treated with BA had more leaders than the untreated control plants; the number of lateral branches on these shoots at this time was not different from control plants. Shoot dry weight was greater in BA-treated plants than in control plants (Table 2.1). Root growth was not affected by BA treatment as there were no significant differences in root dry weight, root surface area, root volume, or root:shoot ratio compared to control plants. In *Gaura* liners, treatment with BA resulted in more shoot growth at 4 WAIT without significantly affecting root growth.

In finished *Gaura* plants, there were no significant treatment effects on plant height or width (Table 2.2). However all plants treated with BA had significant increases in the numbers of leaders and lateral branches relative to the untreated control plants. The branching effects of BA in *Gaura* liners were persistent in the finished plants. There were no differences in the number of plants in flower between BA-treated and untreated plants (data not presented).

Lavandula x intermedia 'Provence.' For *Lavandula* at 2 WAIT, there were no significant differences in BA treated plants in plant height, width, number of leaders, number of lateral branches, or shoot dry weight as compared to control plants (Appendix Table 2.A.1). All liners treated with BA had significant reductions in root dry weight, root surface area, root volume, and root:shoot ratio at 2 WAIT as compared to control liners (Appendix Table 2.A.1).

At 4 WAIT *Lavandula* liners treated with two applications of 300 $mg \cdot L^{-1}$ or one application of 600 $mg \cdot L^{-1}$ BA were significantly taller than untreated controls (Table 2.1). Width was significantly increased only with two applications of 300 $mg \cdot L^{-1}$ BA. Only liners treated with one application of 600 $mg \cdot L^{-1}$ BA had increased numbers of leaders and lateral branches as compared to control plants. Shoot dry weight increased with all BA treatments as compared to control liners. Root surface area, volume, and root:shoot ratio were reduced in all BA-treated *Lavandula* liners relative to controls at 4 WAIT, although root dry weight was significantly reduced only with two applications of 300 $mg \cdot L^{-1}$ BA.

Finished *Lavandula* plants treated with multiple applications of BA were taller than control plants, but two applications of 300 $mg \cdot L^{-1}$ or a single application of 600 $mg \cdot L^{-1}$ BA reduced plant width as compared to control plants (Table 2.2). Plants treated with two applications of 300 $mg \cdot L\text{-}^{1}$ BA had greater numbers of leaders and lateral branches than control plants. *Lavandula* did not flower during this study.

At 4 WAIT, BA treated *Lavandula* liners showed increased numbers of leaders and lateral branches at the highest BA concentration and decreased root growth with all BA treatments; however, only plants treated with two applications of 300 mg·L^{-1} showed persistent increases in branching in finished plants.

Leucanthemum x superbum 'Snowcap.' At 2 WAIT, *Leucanthemum* liners treated with BA were not significantly different from controls in the shoot measurements of plant height, width, number of basal branches, or shoot dry weight (Appendix Table 2.A.1). However, root dry weight, root surface area, and root volume were significantly less in plants treated with BA as compared to controls (Appendix Table 2.A.1). Liners treated with one application of either 300 mg·L^{-1} BA or 600 mg·L^{-1} BA had significantly lower root:shoot ratios as compared to control liners (Appendix Table 2.A.1).

At 4 WAIT, *Leucanthemum* liners treated with BA showed no significant differences in plant height, width, or number of leaders relative to controls (Table 2.1). However, the number of basal branches was significantly increased with all BA treatments as compared to control liners. Shoot dry weight was significantly increased only with two applications of 300 mg·L^{-1} BA. Root growth was significantly affected by BA; root dry weight, root surface area, root volume, and root:shoot ratio were significantly decreased in all BA treated liners as compared to controls.

Finished *Leucanthemum* plants treated with BA showed no significant differences in plant height but plants treated with one application of 600 mg·L^{-1} had a 14% reduction in width relative to control plants (Table 2.2). The number of basal branches on finished plants was not affected by BA treatments as compared to control plants. *Leucanthemum* did not flower during this study.

Leucanthemum liners treated with BA had significantly greater basal branching and decreased root growth at 4 weeks after initial treatment when compared to controls although this branching improvement was no longer evident in the finished plants.

Salvia x *sylvestris 'May Night.'* At 2 WAIT BA-treated *Salvia* liners showed no significant differences in plant height, width, number of basal branches or shoot dry weight when compared to control plants (Appendix Table 2.A.1). Root dry weight, surface area, and volume were significantly reduced in all BA treated liners as compared to controls. There was no significant difference in root:shoot ratio in BA-treated liners relative to control plants (Appendix Table 2.A.1).

At 4 WAIT, BA-treated *Salvia* liners had no significant differences in plant height, width, number of basal branches, or shoot or root dry weight relative to control liners (Table 2.1). However, root surface area and root volume were significantly reduced in liners treated with a single application of 300 $mg \cdot L^{-1}$ or 600 $mg \cdot L^{-1}$ BA as compared to those of control liners.

Finished *Salvia* plants treated with BA showed no significant differences in plant height, width or number of basal branches when compared to control plants (Table 2.2). *Salvia* did not flower during this study.

At 4 WAIT BA treatment did not significantly increase branching of *Salvia* liners although root surface area and volume decreased with one application of 300 or 600 $mg \cdot L^{-1}$ BA. After transplant and grow out, there were no differences in the finished *Salvia* plants.

Correlations of Root Measurements. Root growth of liners is important to growers because adequate roots are necessary to ensure plant establishment after transplant. Since our liners had reasonable root initiation (stage 3) prior to BA treatment, we wanted to assess the impact of BA on root growth. We found that root surface area and root volume were each highly correlated ($p < 0.0001$) with root dry weight for all five species (Figure 1). Coefficients of determination (r^2) of root dry weight to root surface area ranged from 0.7342 for *Gaura* to 0.876 for *Lavandula*. Coefficients of determination (r^2) of root dry weight to root volume ranged from 0.7444 for *Gaura* to 0.9496 for *Lavandula.* Although the WinRhizo scans allowed measurement of root surface area and root volume, which would have been extremely difficult to collect by hand, the scanning process was very time consuming. Since the data in this study were highly correlated, roots scans did not provide significantly more information than provided by root dry weight alone.

Discussion

Treating perennial plant liners with BA before the transplant stage changed the plants' growth habits, although the results varied by species, as expected (Basra, 2000). Treatment effects were most noticeable at 4 weeks after initial treatment. At this time, lateral or basal branches and/or leaders, which are measures of a plant's fullness, showed significant increases in BA-treated liners of all taxa studied except *Salvia*, compared to untreated plants. The branching results are similar to those of Martin and Singletary (1999) where 18 herbaceous perennials were screened for response to 1000, 2000, or 4000 $mg \cdot L^{-1}$ BA applied as a foliar spray after transplant; the majority (89%) of the BA-treated plants developed significantly more offshoots than untreated controls but root growth was not assessed. In their study no additional branching was seen in the higher two concentrations as compared to 1000 $mg \cdot L^{-1}$ BA (Martin and Singletary, 1999), and later studies have used lower concentrations with good success (Carey et al., 2008; Farris et al., 2009). Drench or foliar application of BA at concentrations from 250 to 2000 $mg \cdot L^{-1}$ increased vegetative shoots, reproductive shoots and flower buds in *Coreopsis verticillata* L. 'Moonbeam';

however plants treated with 1000 or 2000 mg·L^{-1} BA had persistent symptoms of phytoxicity and a 19-day delay in flowering as compared with only transient phytotoxicity and a 7-day delay in flowering in plants treated with 250 or 500 mg·L^{-1} BA (Farris et al., 2009).

After growing out for 4 weeks, only finished plants of *Gaura* and *Lavandula* showed persistent improvements in branching as a result of the BA treatment. Finished *Salvia* and *Leucanthemum* plants showed no significant branching effects after growing out, while *Agastache* plants showed less branching at two treatment concentrations. The persistence of the branching effect of BA varied with species, as seen in results by Latimer and Freeborn (2009) in which the increases in branching in herbaceous perennials treated with foliar sprays of 600 mg·L^{-1} BA after transplant to quart size pots ranged from 2 weeks in *Leucanthemum* x 'Alaska' to 6 weeks in *Euphorbia* 'Chameleon.' Plants metabolize BA at differing rates, even different cultivars of the same species are different (Auer et al. 1992). Since plants metabolize BA quickly, in about 10 days (Carey, 2009), multiple applications over the production cycle may be more effective than a single application.

Plant growth regulators affect root growth as well as shoot growth in plants (Basra, 2000). Low concentrations of BA, 30 mg·L^{-1}, applied to unrooted cuttings as foliar sprays immediately or 12 hours after sticking, increased root dry weight in *Verbena* evaluated 12 days later when compared to untreated controls whereas 300 mg L^{-1} BA tended to reduce root dry weight (Svenson, 1991). The multiple applications and higher rate used in our studies had greater effects on root dry weight. Furthermore, Svenson (1991) found that BA applications later than 48 hr after sticking had no effect on the cuttings. BA at 400, 800, or 1200 mg L^{-1} applied to seedlings of four cultivars of *Coleus blumei* benth after transplant increased the number of branches but did not affect root growth (Khosh-Kui et al., 1978). Similarly, in BA-treated *Hemerocallis*

‘Happy Returns’ the number of divisions per plant was increased while root fresh weight was unaffected (Leclerc et al., 2006). In their review of the role of cytokinins in adventitious root formation, Van Staden and Harty (1988) concluded that root initiation and root elongation are affected differently by exogenous cytokinins in that root initiation is more sensitive to inhibition by high levels of cytokinins than is root elongation. In our studies, BA was applied during root elongation. Root measurements showed significant reductions in BA-treated *Agastache*, *Lavandula*, *Leucanthemum*, and *Salvia* liners at 4 WAIT (3 WAIT for *Agastache*). However these plants did not show any reduced shoot measurements at this time. Thus, these reductions in root growth did not appear to affect shoot growth. Root:shoot ratio decreased in BA-treated *Agastache*, *Lavandula*, and *Leucanthemum* liners at 4 WAIT (3 WAIT for *Agastache*). In our studies, BA seemed to encourage shoot growth at the expense of root growth.

Root surface area and volume measurements were highly correlated with root dry weight. These results are similar to those of McPhee (2005) in a study of *Pisum sativum* L. seedlings in which root dry weight was highly correlated with root volume and root length. Because the intent of our study was to study the effects of BA on the root and shoot growth of liners, root and shoot dry weight measurements were not taken for plants after transplant and growing out for an additional 4 weeks; however, these measurements would be helpful in future studies in understanding the effects of BA on plants as they grow to marketable size.

Treating plants with BA as liners prior to transplant resulted in more branching which produced a liner that appeared fuller at an earlier stage of growth. However, in most of the crops tested, branching of the untreated liners eventually matched that of plants treated with BA, suggesting that multiple applications of BA may be beneficial. Root growth of liners of some crops was reduced by BA treatments but this reduction did not seem to influence the overall growth of the finished plants. In summary, herbaceous perennial plant liner producers may use BA to increase liner size and branching without major impact on subsequent plant establishment. Finished plant producers should consider applying BA again on responsive plants either in the flat prior to transplanting or in the finishing container shortly after transplanting.

Literature Cited

Albrecht, M.L. and H.K. Tayama. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assoc., Columbus, OH.

Auer, C.A., J.D. Cohen, M. Laloue, and T.J. Cooke. 1992. Comparison of benzyl adenine metabolism in two *Petunia hybrida* lines differing in shoot organogenesis. Plant Physiol. 96:1035-1041.

Auer, C.A. 1996. Cytokinin inhibition of *Arabidopsis* root growth: an examination of genotype, cytokinin activity, and N^6-benzyladenine metabolism. J. Plant Growth Regulat. 15:201-206.

Basra, A.S. 2000. Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton.

Boe, A.A., R.B. Stewart, and T.J. Banko. 1972. Effects of growth regulators on root and shoot development on sedum leaf cuttings. HortScience 7(4):404-405.

Carey, D., B. Whipker, I. McCall, and W. Buhler. 2008. Cytokinin based PGR affects growth of vegetative petunia. Proc. Plant Growth Regulat. Soc. Amer. 35: 85-89.

Carey, D., W. Buhler, and B. Whipker. 2009. Stimulating plant growth. Greenhouse Product News 9(5):20, 22, 24.

Cline, M.G. 1991. Apical dominance. Bot. Review. 57:318-358.

Dole J.M. and D.J. Hamrick. 2006. Propagation basics, p. 9. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Farris, M.E., G.J. Keever, J.R. Kessler, and J.W. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of *Coreopsis verticillata* 'Moonbeam'. J. Environ. Hort. 27(3):176-182.

Garner, J.M., G.J. Keever, D.J. Eakes, and J.R. Kessler. 1997. Benzyladenine-induced offset formation in hosta dependent on cultivar. HortScience 32(1):91-93.

Khosh-Khui, M., I. Rouhani, and B. Shaybany. 1978. Axillary shoot stimulation and plant development of coleus treated with certain plant growth regulators. Can. J. Plant Sci. 58:971-976.

Latimer, J.G. and J. Freeborn. 2009. New uses of PGRs in ornamentals: Configure (6-BA) increases branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 36:88-93.

Leclerc, M., C.D. Caldwell, and R.R. Lada. 2006. Effect of plant growth regulators on propagule formation in *Hemerocallis* spp. and *Hosta* spp. HortScience 41(3):651-653.

Martin, S. and S. Singletary. 1999. N-6 Benzyladenine increases lateral offshoots in a number of perennial species. Proc. Intl. Plant Prop. Soc. 49:329-334.

McPhee, K. 2005. Variation for seedling root architecture in the core collection of pea germplasm. Crop Sci. 45:1758-1763.

Richards, D., and R.I. Wilkinson. 1984. Effect of manual pinching, potting-on and cytokinins on branching and flowering of *Camellia*, *Rhododendron*, and *Rosa*. Scientia Hort. 23:75-83.

Svenson, S.E. 1991. Rooting and lateral shoot elongation of verbena following benzylaminopurine application. HortScience 26(4):391-392.

Van Staden, J. and A.R. Harty. 1988. Cytokinins and adventitious root formation, p. 185–201. In: T.D. Davis, B.E. Haissig, and N. Sankhla (eds.). Adventitious root formation in cuttings. Dioscorides, Portland, Ore.

Table 2.1. Liner root and shoot measurements of *Agastache* 'Purple Haze', *Gaura lindheimeri* 'Siskiyou Pink', *Lavandula x intermedia* 'Provence', *Leucanthemum x superbum* 'Snowcap', and *Salvia x sylvestris* 'May Night' at 4 weeks after initial treatment with benzyladenine (BA). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=4 based on 6 subsamples).

Taxon	Treatment: BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant height (cm)	Avg. plant width (cm)	Leaders	Lateral or basal branches[z]	Shoot dry weight (g)	Root dry weight (mg)	Root surface area (cm^2)	Root volume (cm^3)	Root: shoot ratio
Agastache[y]	0 x 1	13.9	10.5	1.5	11.6 b	2.16	982 a	69.0 a	2.94 a	0.47a
	300 x 1	14.1	10.4	1.8	16.1 a	2.40	820 b	64.5 a	2.52 b	0.35b
	300 x 2[x]	13.8	10.5	2.0	17.6 a	2.13	580 c	53.9 b	1.67 c	0.27b
	600 x 1	15.3	10.4	1.5	16.8 a	2.25	580 c	42.2 c	1.30 c	0.27b
	P value	0.5914	0.9812	0.2139	0.015	0.661	<0.0001	<0.0001	<0.0001	0.0017
	LSD	2.6	0.9	0.5	3.6	0.52	136	7.1	0.38	0.10
Gaura	0 x 1	6.5	8.2	1.0 c	7.5	1.51 b	403	51.8	1.93	0.18
	300 x 1	6.6	8.3	1.4 b	9.2	2.17 a	540	51.8	1.99	0.21
	300 x 2[x]	7.0	8.2	1.4 b	9.3	2.31 a	448	50.0	1.61	0.18
	600 x 1	6.6	8.5	1.8 a	8.5	2.31 a	543	51.0	1.94	0.20
	P value	0.9356	0.9479	0.0045	0.1323	<0.0001	0.1637	0.972	0.3549	0.6608
	LSD	1.8	1.2	0.3	1.7	0.24	151	8.3	0.47	0.06

Lavandula	0 x 1	7.6 c	6.0 b	1.8 b	13.4 b	2.21 b	695 a	71.7 a	2.99 a	0.32a
	300 x 1	8.2 bc	5.8 b	2.6 b	14.3 b	2.70 a	620 a	55.0 b	1.99 c	0.24b
	300 x 2[x]	8.9 ab	7.2 a	2.8 ab	15.6 ab	2.95 a	493 b	47.4 c	1.64 d	0.17c
	600 x 1	9.3 a	6.4 b	3.7 a	16.9a	3.08 a	643 a	59.2 b	2.43 b	0.21bc
	P value	0.0229	0.0425	0.0224	0.03	0.0057	0.0219	<0.0001	<0.0001	0.0015
	LSD	1.1	0.1	1.1	2.3	0.45	122	5.6	0.29	0.06
Leucanthemum	0 x 1	6.5	13.1	na	1.3b	3.48b	1220 a	74.0 a	2.41 a	0.35a
	300 x 1	6.6	13.4	na	2.5a	3.65b	730 b	55.9 b	1.74 b	0.20bc
	300 x 2[x]	6.5	13.7	na	2.9a	5.89a	905 b	62.2 b	1.88 b	0.16c
	600 x 1	6.2	12.9	na	2.5a	4.31b	903 b	60.7 b	1.86 b	0.21b
	P value	0.6506	0.3245	na	0.0023	0.0002	0.0284	0.0032	0.0028	<0.0001
	LSD	0.7	0.9	na	0.7	0.85	304	9.8	0.38	0.05
Salvia	0 x 1	4.3	14.1	na	3.0	2.89	1468	81.0 a	3.07 a	0.38
	300 x 1	4.2	13.0	na	4.2	3.81	1143	69.1 b	2.28 b	0.30
	300 x 2[x]	4.0	12.8	na	3.8	3.68	1285	75.1 ab	2.58 ab	0.35
	600 x 1	4.2	12.8	na	3.0	3.65	1125	67.2 b	2.23 b	0.31
	P value	0.9552	0.1646	na	0.0631	0.9243	0.3436	0.0244	0.0121	0.2496
	LSD	1.3	1.3	na	1.1	0.90	442	9.7	0.55	0.09

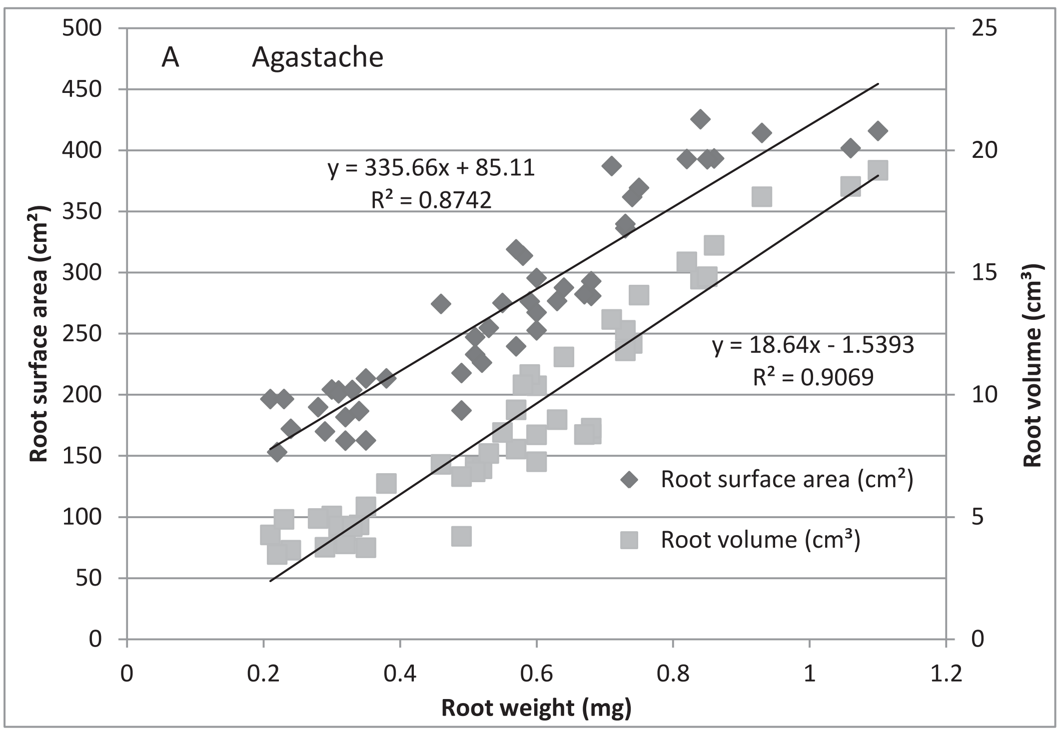
[z] Based on plant growth habit, basal branches were counted in Leucanthemum and Salvia; leaders and lateral branches were counted in Agastache, Gaura and Lavandula.
[y] Measurements were taken on Agastache at 3 weeks after initial treatment due to vigorous growth.
[x] The second application of 300 $mg \cdot L^{-1}$ BA was applied 2 weeks after the first treatment.

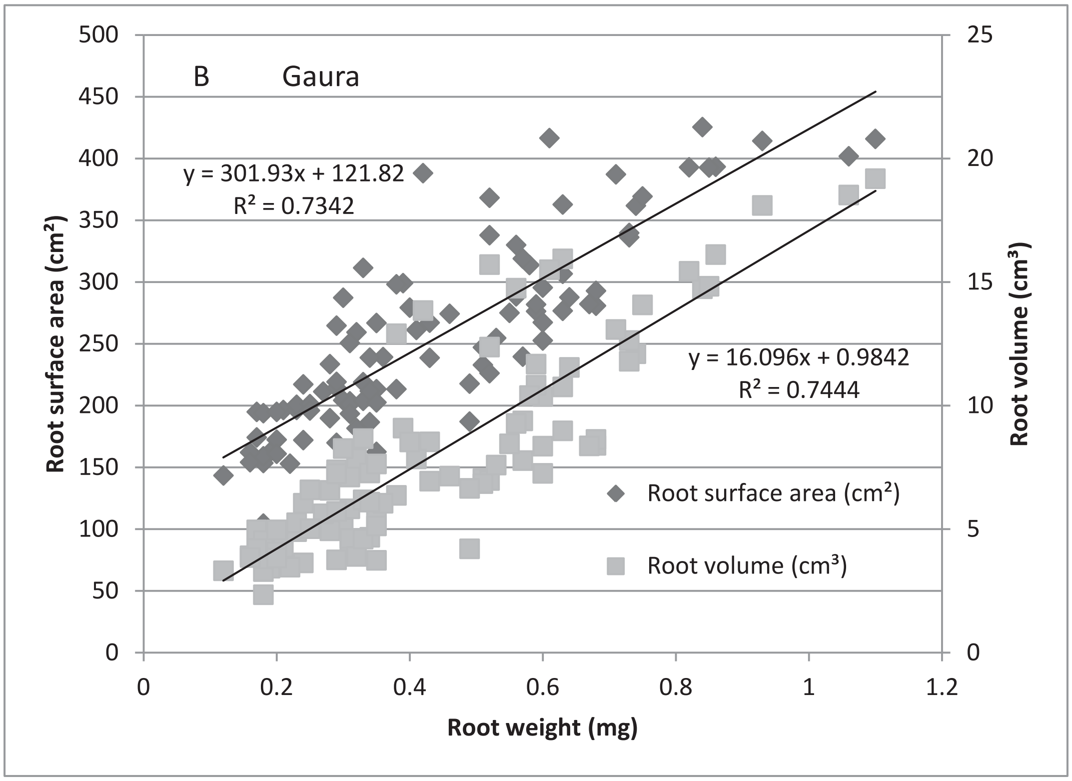
Table 2.2. Shoot measurements of Agastache 'Purple Haze', Gaura lindheimeri 'Siskiyou Pink', Lavandula x intermedia 'Provence', Leucanthemum x superbum 'Snowcap', and Salvia x sylvestris 'May Night' at 4 weeks after transplant, 8 weeks after initial treatment with benzyladenine (BA). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=8).

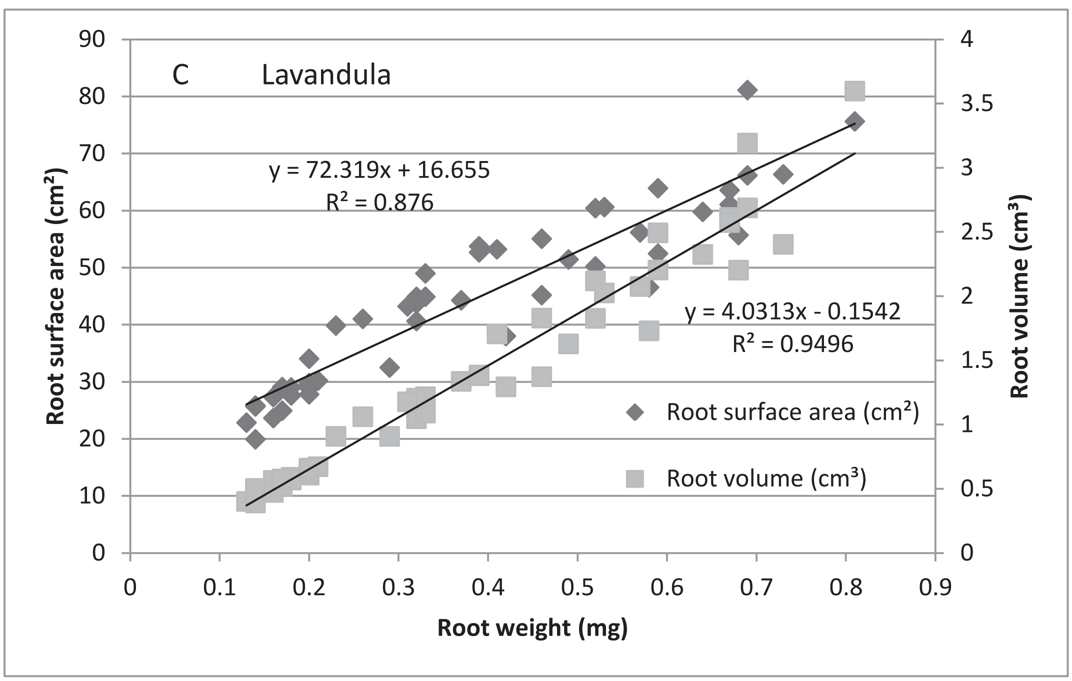
Taxon	Treatment: BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant height (cm)	Avg. plant width (cm)	Leaders	Lateral or basal branches[z]
Agastache	0 x 1	31.9 ab	20.1 a	9.4 a	44.6 a
	300 x 1	29.4 b	21.0 a	9.9 a	45.4 a
	300 x 2[x]	33.3 a	20.4 a	7.4 b	37.5 b
	600 x 1	28.8 b	15.8 b	7.0 b	31.8 b
	P value	0.0231	0.0097	0.0057	0.0009
	LSD	3.2	3.2	1.8	6.9
Gaura	0 x 1	4.5	27.9	1.8 c	11.1 b
	300 x 1	5.8	28.7	2.9 b	19.0 a
	300 x 2[x]	5.8	26.0	4.0 a	19.1 a
	600 x 1	6.3	27.8	3.5 ab	20.5 a
	P value	0.5864	0.4212	0.0085	0.0003
	LSD	2.7	3.3	1.0	5.7
Lavandula	0 x 1	10.2 b	11.6 a	3.6 a	24.8 b
	300 x 1	10.8 ab	11.4 ab	3.4 a	24.8 b
	300 x 2[x]	11.4 a	10.7 bc	6.0 b	45.8 a
	600 x 1	10.8 ab	9.8 c	3.0 a	27.8 b
	P value	0.0409	0.0008	<0.0001	0.0015
	LSD	0.8	0.851	1.5	5.9
Leucanthemum	0 x 1	4.4	19.0 a	na	15.5
	300 x 1	4.5	18.4 a	na	15.5
	300 x 2[x]	4.3	17.8 a	na	15.8
	600 x 1	4.3	16.4 b	na	16.3
	P value	0.9288	0.0012	na	0.9531
	LSD	0.9	1.2	na	3.1
Salvia	0 x 1	6.3	20.6	na	6.3
	300 x 1	5.9	19.0	na	5.9
	300 x 2[x]	6.4	20.1	na	6.4
	600 x 1	5.4	18.6	na	5.4
	P value	0.4006	0.17	na	0.7565
	LSD	1.4	2.0	na	1.4

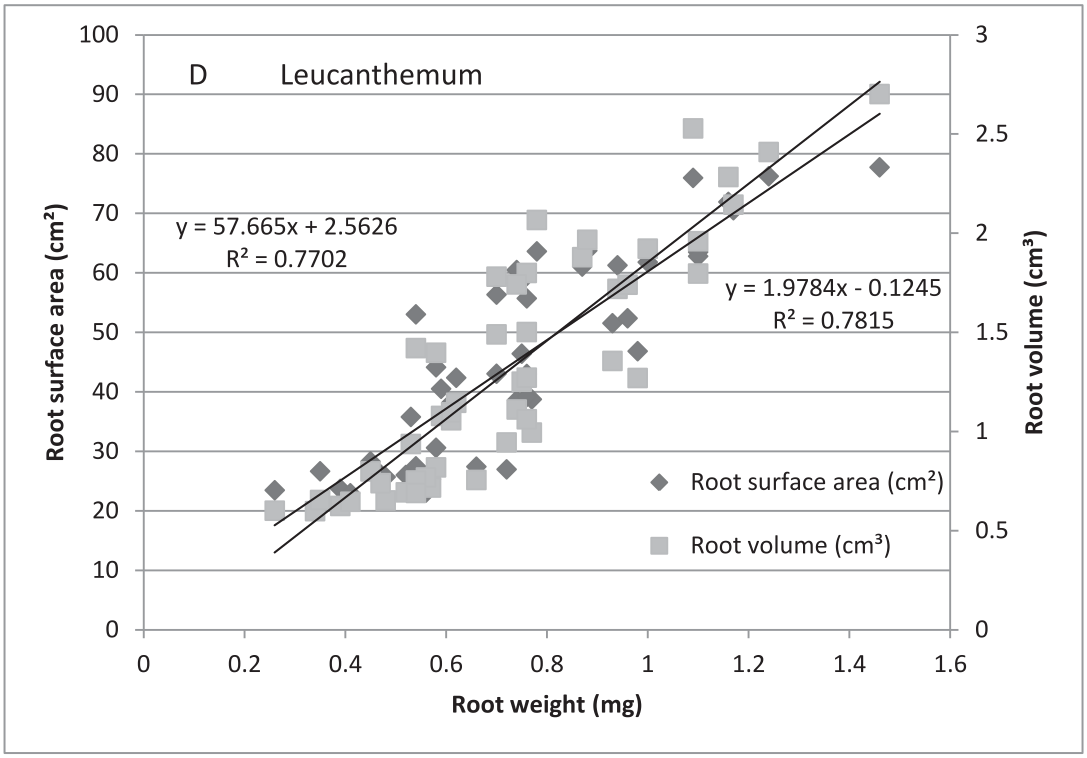
[z] Based on plant growth habit, basal branches were counted in Leucanthemum and Salvia; leaders and lateral branches were counted in Agastache, Gaura and Lavandula.
[y] The second application of 300 $mg \cdot L^{-1}$ BA was applied 2 weeks after the first treatment.

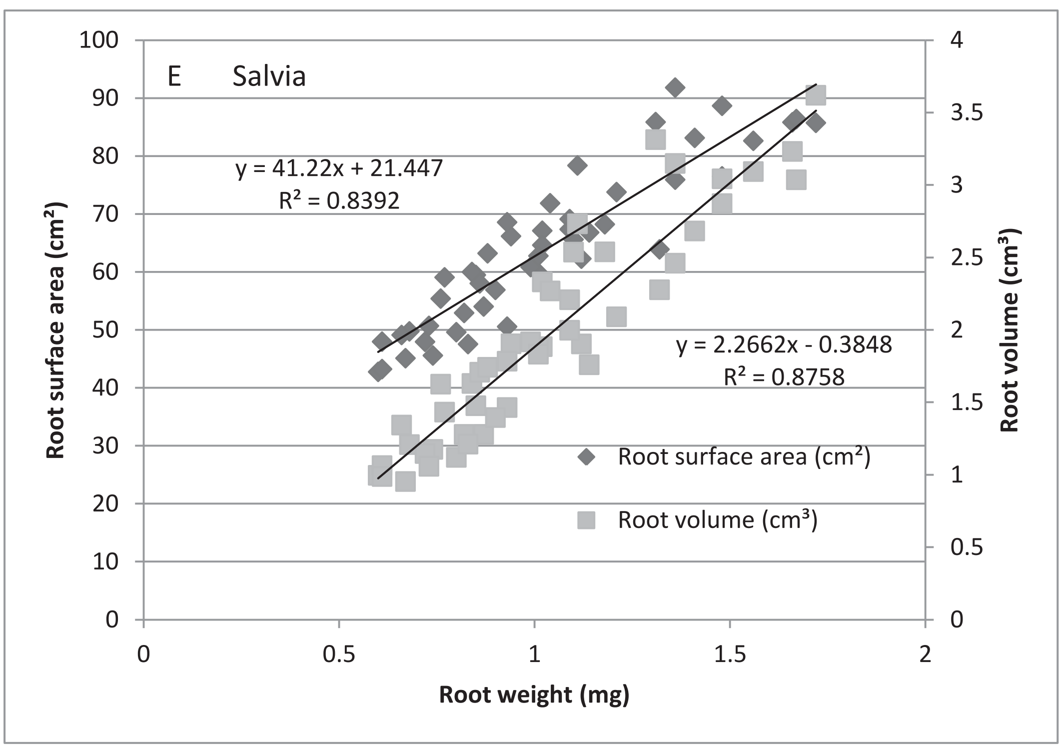
Figure 2.1. The correlation between root dry weight (mg, horizontal axis) and root surface area (cm^2, left axis) and between root dry weight and root volume (cm^3, right axis) at 0, 2 and 4 weeks after initial treatment (WAIT) (0, 2, and 3 WAIT for Agastache) of A) Agastache 'Purple Haze', B) Gaura lindheimeri 'Siskiyou Pink', C) Lavandula x intermedia 'Provence', D) Leucanthemum x superbum 'Snowcap', and E) Salvia x sylvestris 'May Night' along with the regression functions and coefficient of determination (r2), p <0.0001. Roots were analyzed using WinRhizo (Regent Instruments Inc., Quebec, Canada). Solid line represents linear regression.




B Gaura
y = 301.93x + 121.82
R² = 0.7342
y = 16.096x + 0.9842
R² = 0.7444
Root surface area (cm²)
Root volume (cm³)
Root weight (mg)
Root surface area (cm²)
Root volume (cm³)


C Lavandula
y = 72.319x + 16.655
R² = 0.876
y = 4.0313x - 0.1542
R² = 0.9496
Root surface area (cm²)
Root volume (cm³)
Root weight (mg)
Root surface area (cm²)
Root volume (cm³)


D Leucanthemum
y = 57.665x + 2.5626
R² = 0.7702
y = 1.9784x - 0.1245
R² = 0.7815
Root surface area (cm²)
Root volume (cm³)
Root weight (mg)
◆ Root surface area (cm²)
■ Root volume (cm³)


E Salvia
y = 41.22x + 21.447
R² = 0.8392
y = 2.2662x - 0.3848
R² = 0.8758
Root surface area (cm²)
Root volume (cm³)
Root weight (mg)
◆ Root surface area (cm²)
■ Root volume (cm³)

Appendix

Table 2.A.1. Liner root and shoot measurements of *Agastache* 'Purple Haze', *Gaura lindheimeri* 'Siskiyou Pink', *Lavandula x intermedia* 'Provence', *Leucanthemum x superbum* 'Snowcap', and *Salvia x sylvestris* 'May Night' at 2 weeks after initial treatment with benzyladenine (BA). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=4 based on 6 subsamples).

Taxon	Treatment: BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant height (cm)	Avg. plant width (cm)	Leaders	Lateral or basal branches[z]	Shoot dry weight (g)	Root dry weight (g)	Root surface area (cm^2)	Root volume (cm^3)	Root: shoot ratio
Agastache	0 x 1	9.5 b	9.9 b	1.0	2.5 b	1.53	0.65	48.7 ab	1.56 b	0.44a
	300 x 1[y]	9.6 b	9.6 b	1.0	8.8 a	1.64	0.52	41.5 c	1.22 c	0.32b
	300 x 2[x]	10.3 ab	9.9 b	1.0	12.0 a	1.69	0.66	51.6 a	1.85 a	0.39ab
	600 x 1	11.6 a	10.8 a	1.0	12.3 a	1.78	0.57	43.2 bc	1.50 cb	0.33b
	P value	0.011	0.0123	na	<0.0001	0.5893	0.1388	0.003	0.0005	0.0459
	LSD	1.4	0.7	na	1.7	0.38	0.14	5.9	0.29	0.09
Gaura	0 x 1	8.5	7.7 c	1.0 b	9.6	1.31 c	0.25b	36.4 bc	1.04 bc	0.16b
	300 x 1	8.2	8.1 bc	1.3 a	10.6	1.38 bc	0.31a	45.5 a	1.31 a	0.21a
	300 x 2[x]	8.9	8.6 ab	1.0 b	10.8	1.58 ab	0.35ab	41.7 ab	1.23 ab	0.21a
	600 x 1	8.5	8.7 a	1.1 b	11.7	1.71 a	0.32a	36.1 c	0.99 c	0.18ab
	P value	0.6764	0.001	0.0016	0.0755	0.0175	0.0015	0.0015	0.0044	0.0453
	LSD	1.2	0.5	0.2	1.6	0.25	5.40	5.4	0.20	0.04
Lavandula	0 x 1	6.9 ab	5.7	1.0	7.2	1.42	0.48 a	57.3 a	1.92 a	0.34a
	300 x 1	7.4 a	6.1	1.0	7.0	1.51	0.33 b	45.7 b	1.21 b	0.22b
	300 x 2[x]	6.8 b	6.0	1.0	6.8	1.50	0.33 b	43.0 b	1.17 b	0.22b
	600 x 1	7.3 a	5.8	1.0	7.3	1.49	0.31 b	43.8 b	1.09 b	0.21b
	P value	0.0471	0.1988	0.3966	0.6133	0.8211	0.002	<0.0001	<0.0001	0.0002
	LSD	0.4	0.4	0.1	0.8	0.24	0.08	5.2	0.17	0.05

Leucanthemum	0 x 1	5.1	9.0	na	1.2	2.54	0.88	55.9 a	1.67 a	0.34a
	300 x 1	5.3	10.0	na	1.4	3.24	0.74	43.2 b	1.15 b	0.23b
	300 x 2[x]	5.3	9.0	na	1.2	2.79	0.74	41.2 b	1.17 b	0.28ab
	600 x 1	5.3	9.5	na	1.3	3.14	0.68	40.0 b	1.08 b	0.22b
	P value	0.9336	0.0879	na	0.4469	0.299	0.3854	<.0001	<.0001	0.0076
	LSD	0.8	0.9	na	0.3	0.85	0.24	6.3	0.22	0.07
Salvia	0 x 1	3.6 ab	12.1	na	2.9	2.51	1.28	78.6 a	2.82 a	0.52
	300 x 1	4.1 a	12.1	na	2.4	2.51	1.03	67.0 b	1.97 b	0.41
	300 x 2[x]	3.3 b	12.3	na	2.6	2.78	0.97	65.1 b	1.80 b	0.35
	600 x 1	3.1 b	11.9	na	2.7	2.27	0.94	61.2 b	1.76 b	0.42
	P value	0.011	0.9056	na	0.2132	0.5296	0.1583	0.0068	<.0001	0.0937
	LSD	0.6	1.1	na	0.5	0.73	0.33	10.1	0.45	0.13

[z] Based on plant growth habit, basal branches were counted in Leucanthemum and Salvia; leaders and lateral branches were counted in Agastache, Gaura and Lavandula.
[y] The second application of 300 $mg \cdot L^{-1}$ BA was applied 2 weeks after the first treatment.

Chapter 3. IBA Does Not Impact the Root Growth of BA-Treated Plants

Growers of herbaceous perennials control plant growth by using both physical controls, including plant nutrition, light and temperature, as well as chemical controls, i.e. plant growth regulators (PGRs) (Albrecht and Tayama, 1992; Whipker et al., 2006). However, using PGRs can be challenging, because plants respond in different ways to PGRs depending on species, cultivar, growing conditions, and the PGR utilized (Gent and McAvoy, 2000). Treating rooted cuttings (liners) before transplant can have significant benefits for growers including reduced time of application and reduced chemical cost. PGRs can increase branching and improve plant architecture in plants by releasing apical dominance and allowing dormant later buds to expand which results in fuller, more well-branched plants (Cline, 1991).

Benzyladenine (BA), a synthetic cytokinin, is a PGR which increases branching when sprayed on ornamental plants (Latimer and Freeborn, 2008; Martin and Singletary, 1999). The number of branches doubled in *Echinacea* 'White Swan' and 'Double Decker' treated with foliar sprays of 300 to 600 $mg \cdot L^{-1}$ BA after transplant to quart size (1.1 L.) pots (Latimer and Freeborn, 2008). In using PGRs to increase branching in ornamental plants, the goal is to improve plant architecture and thus improve plant marketability.

However, improvements in branching could be negated if the PGR has a negative effect on root growth and subsequent growth after transplant. While some studies have shown that BA does not affect root growth (Khosh-Kui et al., 1978; Leclerc et al., 2006), others have found that BA reduces root growth in treated plants (Auer et. al., 1996; Boe et. al, 1972). BA-treated *Hemerocallis* 'Happy Returns' had an increase in the number of divisions per plant while root fresh weight was unaffected (Leclerc et al., 2006). In a previous study, BA increased branching of herbaceous perennials studied but reduced root growth in herbaceous perennials during liner production in which *Agastache* Clayt. Ex Gronov. 'Purple Haze', *Gaura lindheimeri* Engelm. & A. Gray 'Siskiyou Pink', *Lavandula ×intermedia* Emeric ex Loisel. 'Provence', and *Leucanthemum ×superbum* (Bergmans ex J.W. Ingram) Bergmans ex Kent. 'Snowcap', liners had increased branches or leaders at 3 to 4 weeks after initial treatment with BA while all except for *Gaura* had reduced root dry weight (Grossman et al., 2012).

The auxin indole-3-butyric acid (IBA), is a synthetic plant hormone, and is the active ingredient in many rooting compounds commonly used to encourage rooting during propagation (Dole and Wilkins, 2005). Our question is does the addition of IBA to BA treatment increase the root growth of treated plants?

The objective of this study is to further evaluate the effects of BA on branching and shoot growth of herbaceous perennials in order to improve plant architecture as well as investigate the effect of BA on root growth and the use of IBA to potentially improve root growth in BA-treated plants.

Materials and Methods

Experiment One (2010): Six herbaceous perennials were studied: *Aster* 'Professor Anton Kippenberg' (*Symphyotrichum novi-belgii* L.'Professor Anton Kippenburg'), *Campanula punctata* Lam. 'Cherry Bells,' *Cosmos atrosanguineus* (Hook) Voss., *Verbena bonariensis* L. 'Lollipop,' *Rosmarinus officinalis* L.'Hill Hardy' and *Veronica spicata* L. 'Goodness Grows.' Plants arrived as unrooted cuttings, which were dipped for ten seconds in 1500 $mg\cdot L^{-1}$ IBA rooting hormone (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp, New York, NY) as a basal treatment and stuck into 72 size cell (cell height 5.71 cm, volume 35.4 ml) trays filled with a peat and perlite based growing media (Canadian sphagnum peat moss ,70-75%/volume, Promix BX, Premier Tech Horticulture, Quakertown, PA), with 10% extra coarse perlite added (volume to volume). Cuttings were allowed to root under mist with bottom heat at 22°C for 2 to 3 weeks. Cuttings received clear water under mist, but after removal from mist received 100 $mg{\cdot}L^{-1}$ N with each irrigation using 20N-4.4P-16.6K Peters Professional General Purpose fertilizer (The Scotts Co. LLC, Marysville OH).

Benzyladenine (BA, Configure, Fine Americas, Inc., Walnut Creek, CA) was applied to liners at least 8 hours after removal from mist, between 13 and 28 days after sticking, as four treatments: control (0 $mg{\cdot}L^{-1}$), one application of 300 $mg{\cdot}L^{-1}$, two applications of 300 $mg{\cdot}L^{-1}$ (one application at week 0 and the second application 2 weeks later), or one application of 600 $mg{\cdot}L^{-1}$. Treatments were applied when roots from cuttings were evident on all four sides of the root ball, but liners were not fully rooted and ready for transplant. Treatments were applied as foliar sprays of BA with a CO_2 backpack sprayer (R&D Sprayers, Inc., Opelousas, LA) applying 210 ml per m^2. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W) from July through October, 2010. Greenhouse light levels averaged 17.1 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ and temperatures averaged 23.7°C. The experimental setup was a completely randomized design with each plant species conducted as a separate experiment. Experimental units consisted of six plants in a single six-cell pack with four replications of the experimental unit per treatment for each of two destructive harvests for each crop. An additional set of replications was included for evaluation of liner grow out as described below.

Data were collected at 0, and 3 to 4 weeks after initial treatment (WAIT) on individual plants in each experimental unit. At 3to 4 WAIT liners were finished and ready to be transplanted. Measurements included plant height measured from the top of the container, average width which was the average of the width measured at the widest point of the plant and again perpendicular to this point, numbers of branches, number of plants in flower, root and shoot dry weights, root to shoot ratio and phytotoxicity. Branches were counted if they were 2 mm long or longer. Based on growth habit, branches counted in *Campanula* were basal branches which had no secondary laterals and in *Aster*, *Cosmos, Verbena, Rosmarinus, and Veronica* leaders (primary branches with secondary lateral branches) and secondary lateral branches were counted. For root dry weights, media was washed off of roots by hand, using a screen to prevent loss of roots. Roots were washed randomly by experimental unit. Root and shoot dry weights were determined after drying roots and shoots at 66°C (150°F) for 48 hours.

After data were collected at 3 to 4 WAIT, eight plants of each treatment were randomly selected from the remaining replications, potted into quart sized plastic pots (1.1 liter) filled with Promix BX medium with 10% extra coarse perlite added (volume to volume) and grown out for a period of four additional weeks to assess liner treatment effects on the finished plant. These plants were arranged as single plant replications in a completely randomized design for each crop.

Experiment Two (2011): Four plant species were studied: *Agastache* 'Tutti Frutti,' *Leucanthemum* x *superbum* 'Snowcap,' *Rosmarinus* 'Hill Hardy,' and *Lavandula* x *intermedia* 'Provence.' These plants were chosen based the results of Grossman et al. (2012) in which *Agastache* 'Purple Haze,' *Leucanthemum* x *superbum* 'Snowcap,' and *Lavandula* x *intermedia* 'Provence' had reduced root dry weights after treatment with BA as well as results from experiment one in which BA-treated *Rosmarinus* 'Hill Hardy' had increased root dry weight. As in experiment one, plants arrived as unrooted cuttings which were dipped in IBA, stuck into 72 size flats filled with Pro-Mix BX with 10% extra coarse perlite added, and allowed to root under mist for 2 to 3 weeks.

Treatments were applied at least 8 hours after removal from mist and included: 0 $mg \cdot L^{-1}$ (control), 500 $mg \cdot L^{-1}$ BA, 1000 $mg \cdot L^{-1}$ IBA, and a tank mix of 500 $mg \cdot L^{-1}$ BA and 1000 $mg \cdot L^{-1}$ IBA. Treatments were applied as foliar sprays with a CO_2 backpack sprayer applying 210 ml per m^2. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W) from April through July, 2011. Greenhouse light levels averaged 21.9 $mol \cdot m^{-2} \cdot d^{-1}$ and temperatures averaged 23.1°C. The experimental setup was a completely randomized design with each plant species conducted as a separate experiment. Experimental units consisted of two plants in a two-cell pack with six replications of the experimental unit per treatment for each of two destructive harvests for each crop. An additional set of replications was included for evaluation of liner grow out. Data were collected as above at 0 and 2 to 3 WAIT when liners were finished and ready for transplant. Eight plants of each treatment were then transplanted into quart size pots and grown out for an additional four weeks before a final data collection.

In both experiments, data were analyzed by ANOVA and subjected to LSD means separation ($P \leq 0.05$) using SAS Version 9.2 by SAS Institute Inc. (Cary, NC) and JMP®9.0 ©2010 SAS Institute Inc.

Results

Experiment one (2010): in all plants, measurements were taken at 0 weeks after initial treatment (WAIT) to ensure uniformity. At this time, there were no significant differences between control plants and plants treated with BA in plant height, width, numbers of leaders and lateral branches or basal branches, root or shoot dry weights, or root shoot ratio (Appendix Table 3.A.1). None of the cuttings were flowering.

Aster 'Professor Anton Kippenberg': treatment with BA caused significant tip burn (Figure 3.1) which resulted in reduced height, number of branches, and shoot dry weight in liners at 4 WAIT (Table 3.1). At 8 WAIT finished plants treated with two applications of 300 mg·L^{-1} BA showed reduced growth in measurements of height, width, number of branches, number of leaders, shoot weight, root to shoot ratio, and reduced flowering as compared to untreated controls (Table 3.2). Treatment of *Aster* 'Professor Anton Kippenberg' with BA caused unacceptable phtotoxic damage in liners.

Campanula punctata 'Cherry Bells': *Campanula* liners (Table 3.3) and finished plants (Table 3.4) were not different than untreated controls in any plant growth measurements. *Campanula* was not responsive to BA treatment.

Cosmos atrosanguineus: Cosmos exhibited phytotoxicity in the form of twisted and distorted leaves at all times after 2 WAIT. Although treatments with BA resulted in increased number of branches with all treatments in liners at 3 WAIT (Table 3.5) and with one application of 300 or 600 mg·L^{-1} BA in finished plants (Table 6), the phytotoxic response reduced the quality of the finished plants (Figure 3.2). Flowering was not significantly affected by treatment with BA (Table 3.6).

Verbena bonariensis 'Lollipop': At 3 WAIT height was reduced in liners treated with two applications of 300 mg·L^{-1} BA whereas width, numbers of branches and leaders, shoot and root dry weight, and root: shoot ratio were not affected by treatment with BA (Table 3.7). In finished plants, height was no longer reduced in BA-treated plants; height was increased with one application of 300 mg·L^{-1} BA (Table 3.8). Shoot dry weight was reduced in plants treated with two applications of 300 mg·L^{-1} BA. Width, number of leaders, root dry weight, root to shoot ratio and number of plants flowering were not significantly different in finished plants compared to untreated controls. Treatment with BA did not increase branching in *Verbena* liners or finished plants.

Rosmarinus 'Hill Hardy': At 4 WAIT, height and width of *Rosmarinus* liners were not affected by BA treatment while liners treated with two applications of 300 $mg \cdot L^{-1}$ BA or one application of 600 $mg \cdot L^{-1}$ BA had increased numbers of branches and leaders (Table 3.9). At this time there was no significant difference in shoot dry weight, although plants treated with two applications of 300 $mg \cdot L^{-1}$ BA had increased root dry weight. Root to shoot ratio was increased in plants treated with one or two applications of 300 $mg \cdot L^{-1}$ BA. In finished plants, height was reduced only with two applications of 300 $mg \cdot L^{-1}$ BA , although width of *Rosmarinus* was not affected by BA treatment (Table 3.10). Finished plants no longer exhibited differences in numbers of branches or leaders at 8 WAIT. Plants treated with two applications of 300 $mg \cdot L^{-1}$ BA or one application of 600 $mg \cdot L^{-1}$ BA had reduced shoot dry weight and all BA treated plants had reduced root dry weights at 8 WAIT. Root: shoot ratio was decreased in plants with one or two applications of 300 $mg \cdot L^{-1}$ BA. BA increased branching in liners although the increase was no longer apparent in finished plants.

Veronica spicata ‘Goodness Grows’: While height was not affected by BA treatment, width was reduced in liners treated with 600 $mg \cdot L^{-1}$ BA at 4 WAIT (Table 3.11). The number of branches was significantly increased in all BA-treated liners and the number of leaders was increased in liners treated with 600 $mg \cdot L^{-1}$ BA. Shoot and root dry weights were not affected by BA treatment, although plants treated with two applications of 300 $mg \cdot L^{-1}$ BA had reduced root: shoot ratio. In finished *Veronica* plants there were no significant differences in height, width, or number of branches. Number of leaders was increased only with one application of 300 $mg \cdot L^{-1}$

BA. As in liners, shoot and root dry weights of BA-treated plants were not different from controls though root: shoot ratio was decreased in plants treated with two applications of 300 $mg \cdot L^{-1}$ BA. Treatment with BA increased branching in *Veronica* liners; finished plants treated with one application of 300 $mg \cdot L^{-1}$ BA had increased leaders. Height, width, root dry weight and shoot dry weight were not affected in *Veronica* by treatment with BA. *Veronica* did not flower during the study.

Experiment two (2011)

Agastache 'Tutti Frutti': While height was not different in plants treated with either BA or IBA compared to untreated controls, *Agastache* liners treated with the combination of BA and IBA had reduced height at 2 WAT (Table 3.13). Width, numbers of leaders and branches, and shoot dry weight were not affected by BA, IBA, or the BA and IBA combination treatment. Root dry weight was reduced in plants treated with the combination of BA and IBA. Height, width, and number of leaders were not different from controls in finished plants; however, plants treated with BA had significantly more branches (Table 3.14). Shoot and root dry weights were not affected.

Lavandula x *intermedia* 'Provence': at 3 WAT *Lavandula* liners treated with either BA or IBA alone were not different from controls in the measurement of height whereas the combination of BA and IBA reduced height (Table 3.15). Width was unaffected in treated plants compared to controls. BA increased the number of leaders although the number of branches was unaffected. Shoot dry weight was reduced with treatment by IBA or the BA and IBA combination. Root dry weight was unaffected. Height remained reduced in finished *Lavandula* plants treated with the BA and IBA combination at 7WAT (Table 3.16). At this time width, number of leaders, and number of branches were not different in treated plants compared to controls, although plants treated with BA had increased shoot dry weight. Root dry weight was reduced by the combination of BA and IBA.

Leucanthemum x *superbum* 'Snowcap': at 2 WAT heght, width, number of basal branches and shoot dry weight were not different in treated *Leucanthemum* liners compared to untreated controls (Table 3.17). Root dry weight was reduced in plants treated with BA or the BA and IBA combination. Finished *Leucanthemum* plants did not differ from controls in any measurement at 7 WAT, except plants treated with IBA had reduced root dry weight (Table 3.18).

Rosmarinus 'Hill Hardy': at 3 WAT, *Rosmarinus* liners treated with BA, IBA, or the BA and IBA combination were not different from controls in the measurements of height, width, or numbers of leaders (Table 3.19). Plants treated with BA had increased numbers of branches whereas shoot and root dry weights were unaffected by any treatment. In finished *Rosmarinus* plants at 7 WAT, plant height was not affected by BA, IBA, or the BA and IBA combination treatment. Plants treated with BA had reduced width and reduced numbers of leaders and branches. Shoot weight was reduced with all treatments, especially BA treatment. Root dry weight was not different in treated plants compared to controls.

Phytotoxicity: all BA and IBA treatments caused phytotoxicity in the form of tip dieback at 2 to 3 WAT in *Lavandula* and *Rosmarinus*; the combination of BA and IBA caused slight leaf twisting in *Agastache* at 2 WAT. No phytotoxicity was evident in finished plants.

Discussion

Foliar application of BA increased branching in *Verbena, Rosmarinus,* and *Verbena* liners although finished plants no longer exhibited increased numbers of branches. These results are similar to a previous study in which most but not all perennials tested exhibited an increase in branching as liners, and only some exhibited persistent increases in branching in finished plants (Grossman et al., 2012). Likewise, Martin and Singletary (1999) found that 89% of 18 herbaceous perennials treated after transplant with foliar sprays of 1000, 2000, or 4000 $mg \cdot L^{-1}$ BA responded by developing significantly more branches than untreated controls; however root response was not evaluated. BA caused a species specific response, as has been seen before with other PGRs (Basra, 2000).

The increased branching seen in *Verbena, Rosmarinus,* and *Verbena* was not accompanied by a reduction in root growth in liners. While reduced root dry weight was seen in three of five crops in the earlier study (Grossman et al., 2012), other studies have not shown reduced root weight with BA application (Khosh-Kui et al., 1978; Leclerc et al., 2006). The root response to treatment with BA seems to be species specific also. It is to be noted that in the second experiment root dry weight was not reduced in BA treated liners of *Agastache* or *Lavandula* although BA caused reductions in root dry weight in the previous study (Grossman et al., 2012). The addition of IBA to the BA treatment did not increase root dry weight in any treated liners; in fact the combination of BA and IBA reduced root dry weight in *Agastache* liners and *Lavandula* finished plants.

Literature Cited

Albrecht, M.L. and H.K. Tayama. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assoc., Columbus, Ohio.

Auer, C.A. 1996. Cytokinin inhibition of *Arabidopsis* root growth: an examination of genotype, cytokinin activity, and N^6-benzyladenine metabolism. J. Plant Growth Regulat. 15:201-206.

Basra, A.S. 2000. Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton.

Boe, A.A., R.B. Stewart, and T.J. Banko. 1972. Effects of growth regulators on root and shoot development on sedum leaf cuttings. HortScience 7(4):404-405.

Cline, M.G. 1991. Apical dominance. Bot. Rev. 57:318-358.

Dole, J.M. and H.F. Wilkins, 2005. Floriculture : principles and species. Pearson/Prentice Hall, Upper Saddle River, N.J.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture: a critical appraisal, p. 89-130. In Basra, A.S. (ed.) Plant growth regulators in agriculture and horticulture: their role and commercial uses. Food Products Press, Binghamton.

Grossman,M., J. Freeborn, H. Scoggins, and J. Latimer. 2012. Benzyladenine increases branching but reduces root growth of herbaceous perennial liners. HortScience (In press).

Khosh-Khui, M., I. Rouhani, and B. Shaybany. 1978. Axillary shoot stimulation and plant development of coleus treated with certain plant growth regulators. Can. J. Plant Sci. 58:971-976.

Latimer, J. and J. Freeborn. 2008. Enhance branching of *Echinacea* with PGRs. Greenhouse Product News 18(4):24–28.

Leclerc, M., C.D. Caldwell, and R.R. Lada. 2006. Effect of plant growth regulators on propagule formation in *Hemerocallis* spp. and *Hosta* spp. HortScience 41(3):651-653.

Martin, S. and S. Singletary. 1999. N-6 Benzyladenine increases lateral offshoots in a number of perennial species. Proc. Intl. Plant Prop. Soc. 49:329-334.

Whipker, B.E., J.L. Gibson, and C.B. Cerveny. 2006. Rooting hormones and plant growth regulators, p. 89-100. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Table 3.1. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Aster* 'Professor Anton Kippenberg' liners at 4 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Shoot Dry Weight (mg)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	10.2a	7.4	17.5a	3.0	316a	71.7	0.23
300 x 1	9.2a	6.9	4.9b	2.3	204b	70.8	0.37
300 x 2[z]	4.5b	6.8	3.8b	2.3	153c	61.3	0.42
600 x 1	9.6a	6.8	3.5b	2.3	202b	58.3	0.28
p value	<0.0001	0.3818	<0.0001	0.0559	<0.0001	0.5113	0.0523
LSD	1.9	0.8	3.1	0.6	0.04	23.0	0.14

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.2. Plant height, average plant width, number of branches, number of leaders, root dry weight, shoot dry weight, root: shoot ratio, percent of plants flowering of *Aster* 'Professor Anton Kippenberg' finished plants at 8 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of Branches	Number of Leaders	Shoot Dry Weight (g)	Root Dry Weight (mg)	Root: shoot ratio	Percent Flowering
0 x 1	8.5a	10.3a	19.0a	90.0a	1.58a	298	0.19b	100
300 x 1	11.5a	10.5a	19.7a	69.7a	1.53a	263	0.17b	100
300 x 2[z]	3.9b	6.8b	5.7b	21.8b	0.47b	163	0.61a	17
600 x 1	8.5a	12.0a	13.7a	57.5ab	1.44a	268	0.19b	100
p value	0.0038	<.0001	0.0038	0.0062	0.0002	0.0583	0.0008	0.0003
LSD	3.8	1.8	7.7	35.8	0.48	101	0.22	na[y]

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

[y]LSD not calculated in nominal linear regression

Table 3.3. Plant height, average plant width, number of basal branches, shoot dry weight, root dry weight, and root: shoot ratio of *Campanula punctata* 'Cherry Bells' liners at 4 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of basal branches	Shoot Dry Weight (mg)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	8.2	15.7	3.5	323	77	0.25
300 x 1	9.6	16.9	2.9	285	77	0.26
300 x 2[z]	10.5	18.0	3.5	374	87	0.22
600 x 1	9.4	16.3	3.0	297	62	0.20
p value	0.2694	0.5853	0.5956	0.2849	0.3345	0.1055
LSD	2.5	3.7	1.2	103	29	0.05

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.4. Plant height, average plant width, number of basal branches, shoot dry weight, root dry weight, and root: shoot ratio of *Campanula punctata* 'Cherry Bells' finished plants at 8 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of basal branches	Shoot Dry Weight (g)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	5.8	26.7	8.9	2.35	440	0.19
300 x 1	6.9	28.1	12.3	2.39	538	0.23
300 x 2[z]	7.0	29.3	10.8	2.61	548	0.21
600 x 1	5.5	28.7	11.5	2.17	430	0.20
p value	0.2124	0.0664	0.5025	0.6765	0.493	0.4514
LSD	1.8	2.0	5.9	0.75	199	0.05

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.5. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Cosmos atrosanguineus* liners at 3 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

BA concn ($mg·L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Shoot Dry Weight (mg)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	24.3a	9.4	4.8b	1.3	425	117	0.29a
300 x 1	18.3b	7.2	7.7a	1.5	403	83	0.20b
300 x 2[z]	17.9b	7.1	9.0a	2.2	402	63	0.16b
600 x 1	17.2b	8.0	8.8a	1.5	370	88	0.25ab
p value	<0.0001	0.3551	0.0009	0.1623	0.4215	0.0671	0.0337
LSD	2.3	3.0	1.8	0.8	0.69	39	0.09

[z]The second application of 300 $mg·L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.6. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Cosmos atrosanguineus* finished plants at 8 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

BA concn (mg•L-1) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of Branches	Number of Leaders	Shoot Dry Weight (g)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	7.1	26.6	11.3b	1.9	1.44	316	0.22a
300 x 1	9.0	24.3	18.7a	2.0	1.70	264	0.16b
300 x 2[z]	9.8	24.9	14.4ab	2.9	1.60	270	0.17b
600 x 1	8.9	24.7	18.0a	2.6	1.55	219	0.14b
p value	0.427	0.6622	0.0334	0.4009	0.5951	0.2561	0.0243
LSD	*	*	*	*		*	*

[z]The second application of 300 $mg·L^{-1}$ BA was applied two weeks after the first treatment.
[y] na, not available, LSD not calculated due to uneven data set.

Table 3.7. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Verbena bonariensis* 'Lollipop' liners at 3 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

BA concn ($mg{\cdot}L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Total Shoot Dry Weight (mg)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	21.2a	7.2	2.2	1.0	375	183	0.50
300 x 1	19.0a	6.9	3.5	1.2	309	154	0.50
300 x 2[z]	12.7b	6.7	5.3	1.3	350	176	0.50
600 x 1	21.0a	6.9	3.8	1.2	343	166	0.49
p value	0.0007	0.7207	0.1675	0.5145	0.3128	0.4811	0.9971
LSD	3.6	1.0	2.8	0.4	72	42	0.13

[z]The second application of 300 $mg{\cdot}L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.8. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, root: shoot ratio, and percent of plants flowering of *Verbena bonariensis* 'Lollipop' finished plants at 8 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

BA concn ($mg{\cdot}L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Total Shoot Dry Weight (g)	Root Dry Weight (mg)	Root: shoot ratio	% Flowering
0 x 1	33bc	31.0	21.1	3.5	3.06a	544	0.17	100
300 x 1	38.6a	33.3	23.1	3.4	3.23a	574	0.16	100
300 x 2[z]	29.5c	31.3	24.4	4.0	2.59b	463	0.17	88
600 x 1	36.8ab	30.6	22.5	2.6	2.97a	617	0.19	100
p value	0.0004	0.5455	0.5314	0.1334	0.0082	0.1428	0.5988	0.4062
LSD	4.0	4.1	1.2	6.0	na[y]	135	na[y]	na[x]

[z]The second application of 300 $mg{\cdot}L^{-1}$ BA was applied two weeks after the first treatment.
[y] na, not available, LSD not calculated due to uneven data set.
[x] na, not available, LSD not calculated in logistical regression

Table 3.9. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Rosmarinus* 'Hill Hardy' liners at 4 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Total Shoot Dry Weight (mg)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	10.5	5.1	16.9b	1.3c	228	30.4b	0.14c
300 x 1	11.2	5.0	20.4ab	2.2bc	253	43.8ab	0.18ab
300 x 2[z]	11.0	5.0	24.0a	3.8a	295	56.3a	0.20a
600 x 1	12.3	4.9	24.3a	3.6ab	312	47.5a	0.15bc
p value	0.2364	0.8851	0.0387	0.0074	0.1807	0.0348	0.0061
LSD	1.9	0.6	5.5	1.5	85.0	16.6	0.03

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.10. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Rosmarinus* 'Hill Hardy' finished plants at 8 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Total Shoot Dry Weight (g)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	19.3a	12.8	75.3	17.0	1.11a	236a	0.21a
300 x 1	19.5a	11.7	74.0	18.8	0.99ab	179b	0.19b
300 x 2[z]	15.0b	12.5	61.1	12.8	0.76b	138b	0.18b
600 x 1	17.8ab	11.3	62.0	14.8	0.83b	168b	0.2ab
p value	0.0161	0.3272	0.3025	0.0915	0.027	0.0025	0.0502
LSD	3.0	1.8	19.4	4.9	0.24	49	0.03

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.11. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Veronica spicata* 'Goodness Grows' liners at 4 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, n=4 based on 6 subsamples).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Total Shoot Dry Weight (mg)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	10.4	10.5a	2.3c	1.0b	445	166	0.38a
300 x 1	8.8	9.5ab	6.0b	1.0b	469	185	0.39a
300 x 2[z]	8.7	10.8a	9.3a	1.0b	566	163	0.28b
600 x 1	9.4	8.3b	5.0b	1.2a	525	188	0.36a
p value	0.3377	0.0059	0.0001	0.0097	0.08450	0.5516	0.0060
LSD	2.2	1.3	2.2	0.1	100	45	0.06

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.12. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Veronica spicata* 'Goodness Grows' finished plants at 8 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, n-8).

BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant Height (cm)	Average Width (cm)	Number of branches	Number of leaders	Total Shoot Dry Weight (g)	Root Dry Weight (mg)	Root: shoot ratio
0 x 1	9.9	15.6	18.3	1.0b	1.28	730ab	0.57a
300 x 1	10.3	14.4	19.0	2.1a	1.49	779a	0.52a
300 x 2[z]	11.7	13.9	16.1	1.1b	1.41	616b	0.44b
600 x 1	11.5	15.4	17.4	1.1b	1.51	790a	0.53a
p value	0.2171	0.1473	0.4653	0.0002	0.0536	0.0259	0.0063
LSD	2.0	1.7	3.8	0.5	0.18	121	0.07

[z]The second application of 300 $mg \cdot L^{-1}$ BA was applied two weeks after the first treatment.

Table 3.13. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, and root dry weight of *Agastache* 'Tutti Frutti' liners at 2 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on 2 subsamples).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Averag e Width (cm)	Number of leaders	Number of lateral branches	Shoot Dry Weight (mg)	Root Dry Weight (mg)
Control 0	18.0a	6.6	1.0	10.2	343	76.3ab
BA 500	15.5a	6.2	1.0	10.0	317	52.3bc
IBA 1000	18.6a	5.9	1.0	10.0	352	78.4a
BA 500 + IBA 1000	11.0b	6.4	1.1	8.8	274	44.2c
p-value	0.0003	0.3866	0.4133	0.3034	0.2700	0.0224
LSD	3.2	0.9	0.1	0.2	86.9	25.3

Table 3.14. Plant height, average plant width, number of leaders, number of branches, shoot dry weight, and root dry weight of *Agastache* 'Tutti Frutti' finished plants at 5 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of leaders	Number of lateral branches	Shoot Dry Weight (g)	Root Dry Weight (mg)
Control 0	37.6ab	24.6	7.88	32.0b	2.95	342
BA 500	42.0a	28.3	9.13	53.0a	2.60	315
IBA 1000	44.6a	30.6	8.75	30.4b	2.56	350
BA 500 + IBA 1000	29.3b	27.5	7.88	33.8b	1.97	272
p-value	0.0383	0.1104	0.4649	0.0001	0.0887	0.5366
LSD	10.9	4.9	2.0	8.4	0.75	118

Table 3.15. Plant height, average plant width, number of leaders, number of branches, shoot dry weight, and root dry weight of *Lavandula* x *intermedia* 'Provence' liners at 3 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on 2 subsamples).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of leaders	Number of lateral branches	Shoot Dry Weight (mg)	Root Dry Weight (mg)
Control 0	12.4a	0.1	1.0b	14.4	382a	62.6
BA 500	11.5a	7.9	1.9a	12.0	393a	52.6
IBA 1000	12.2a	7.6	1.0b	12.5	305b	61.4
BA 500 + IBA 1000	9.5b	7.5	1.0b	12.6	310b	48.8
p-value	0.0116	0.3531	<.0001	0.2283	0.0265	0.0729
LSD	1.8	0.7	0.4	2.5	70.4	12.0

Table 3.16. Plant height, average plant width, number of leaders, number of branches, shoot dry weight, and root dry weight of *Lavandula* x *intermedia* 'Provence' finished plants at 7 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of leaders	Number of lateral branches	Shoot Dry Weight (g)	Root Dry Weight (mg)
Control 0	18.4a	13.9	3.0	33.6	1.48b	194ab
BA 500	17.5ab	14.9	3.9	41.0	1.76a	220a
IBA 1000	18.5a	13.8	3.3	34.4	1.47b	183b
BA 500 + IBA 1000	15.75b	13.8	3.0	33.6	1.30b	147c
p-value	0.0168	0.3716	0.5098	0.0762	0.0006	0.0005
LSD	1.8	1.6	1.3	6.5	0.20	30.7

Table 3.17. Plant height, average plant width, number of basal branches, shoot dry weight, and root dry weight of *Leucanthemum* x *superbum* 'Snowcap' liners at 2 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on 2 subsamples).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of branches	Shoot Dry Weight (mg)	Root Dry Weight (mg)
Control 0	3.6	9.3	1.1	44.4	131a
BA 500	4.3	10.9	1.1	55.0	102b
IBA 1000	4.4	10.1	1.4	46.6	145a
BA 500 + IBA 1000	3.9	10.3	1.6	56.1	95.5b
p-value	0.23	0.1701	0.4585	0.1061	0.0051
LSD	0.9	1.5	0.8	11.4	28.6

Table 3.18. Plant height, average plant width, number of basal branches, shoot dry weight, and root dry weight of *Leucanthemum* x *superbum* 'Snowcap' finished plants at 7 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of branches	Shoot Dry Weight (g)	Root Dry Weight (g)
Control 0	5.8	25.2	13.9	3.96	1.13b
BA 500	5.8	24.4	14.0	3.52	1.01b
IBA 1000	6.4	25.5	14.9	4.18	1.36a
BA 500 + IBA 1000	6.3	25.1	13.5	4.28	0.977b
p-value	0.5328	0.7311	0.6571	0.1439	0.0014
LSD	1.1	2.0	2.3	0.71	0.19

Table 3.19. Plant height, average plant width, number of leaders, number of branches, shoot dry weight, and root dry weight of *Rosmarinus* ‘Hill Hardy’ liners at 3 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=6 based on 2 subsamples).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of leaders	Number of lateral branches	Shoot Dry Weight (mg)	Root Dry Weight (mg)
Control 0	13.2	6.3	5.2	27.8b	374	53.9
BA 500	12.2	6.3	6.2	36.2a	337	43.0
IBA 1000	10.6	5.9	4.1	23.1b	284	46.8
BA 500 + IBA 1000	11.3	5.4	5.6	29.9ab	293	40.5
p-value	0.1001	0.0703	0.2309	0.0115	0.1329	0.1459
LSD	2.1	0.8	2.1	7.3	85.1	12.1

Table 3.20. Plant height, average plant width, number of leaders, number of branches, shoot dry weight, and root dry weight of *Rosmarinus* ‘Hill Hardy’ finished plants at 7 weeks after treatment (WAT) with benzyladenine (BA), IBA, or the combination of the two. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n-8).

Treatment ($mg \cdot L^{-1}$)	Plant Height (cm)	Average Width (cm)	Number of leaders	Number of lateral branches	Shoot Dry Weight (g)	Root Dry Weight (mg)
Control 0	13.3	20.1a	23.0a	160a	2.23a	241
BA 500	11.6	15.8b	16.6b	115b	1.33c	166
IBA 1000	9.63	17.8ab	20.0ab	137ab	1.70b	188
BA 500 + IBA 1000	12.1	18.0ab	22.6a	156a	1.74b	169
p-value	0.4056	0.0185	0.0134	0.0156	<0.0001	0.0579
LSD	4.4	2.6	4.1	29.6	0.3002	60.0

Appendix

Table 3.A.1. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Aster* 'Professor Anton Kippenberg,' *Campanula punctata* 'Cherry Bells,' *Cosmos atrosanguineus, Verbena bonariensis 'Lollipop,' Rosmarinus 'Hill Hardy,' Veronica spicata 'Goodness Grows'* liners at 0 weeks after initial treatment (WAIT) with benzyladenine (BA). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Taxon	BA concn ($mg \cdot L^{-1}$) x no. of applications	Plant height (cm)	Average plant width (cm)	Number of branches	Number of leaders	Shoot dry weight (g)	Root dry weight (g)	Root: shoot ratio
Aster[z]	0 x 1	3.0	5.0	1.9	1.0	0.05	0.02	0.54
	300 x 1	3.1	4.7	2.7	1.0	0.07	0.03	0.43
	300 x 2 [y]	3.0	5.2	1.5	1.0	0.08	0.03	0.33
	600 x 1	3.3	4.9	2.4	1.1	0.07	0.03	0.42
	p value	0.7273	0.5471	0.2884	0.0728	0.3719	0.5198	0.3206
	LSD	0.7	0.8	1.3	0.1	0.29	0.01	0.24
Campanula	0 x 1	5.1	11.0	1.0	na	0.19	0.04	0.22
	300 x 1	6.3	10.8	1.1	na	0.18	0.05	0.29
	300 x 2	5.9	14.4	1.0	na	0.20	0.06	0.27
	600 x 1	5.5	10.5	1.0	na	0.19	0.05	0.24
	p value	0.6005	0.4199	0.0728		0.8241	0.2351	0.1151
	LSD	2.0	5.5	0.1		0.05	0.02	0.06
Cosmos	0 x 1	6.2	7.6	1.3	1.0	0.17	0.09	0.56
	300 x 1	6.9	7.7	1.7	1.0	0.20	0.09	0.45
	300 x 2	6.3	7.4	1.5	1.0	0.17	0.08	0.53
	600 x 1	8.2	6.7	1.8	1.0	0.17	0.08	0.52
	p value	0.3934	0.3278	0.5474	0.4262	0.465	0.8984	0.683
	LSD	2.7	1.2	0.8	0.1	0.05	0.03	0.19
Rosmarinus	0 x 1	2.9	4.8	6.5	1.0	0.10	0.03a	0.26a
	300 x 1	3.4	5.0	6.5	1.0	0.11	0.03a	0.25a
	300 x 2	3.1	4.8	5.7	1.0	0.11	0.03a	0.26a
	600 x 1	2.7	4.6	5.3	1.0	0.09	0.02b	0.20b
	p value	0.549	0.5568	0.4814		0.2205	0.043	0.0107

	LSD	1.1	0.6	2.0		0.02	0.01	0.04
Verbena	0 x 1	4.7	7.6	2.2	1.0	0.16	0.09	0.57
	300 x 1	4.7	7.6	1.6	1.0	0.14	0.09	0.61
	300 x 2	4.9	7.4	2.5	1.1	0.15	0.10	0.66
	600 x 1	4.5	7.7	1.5	1.0	0.14	0.10	0.69
	p value	0.7062	0.9208	0.4852	0.2476	0.4653	0.6503	0.1756
	LSD	0.8	1.0	1.7	0.1	0.35	0.02	0.12
Veronica	0 x 1	1.6	7.5	0.1	1.0	0.30	0.12	0.43
	300 x 1	1.8	8.4	0.3	1.0	0.33	0.10	0.32
	300 x 2	1.8	8.3	0.0	1.0	0.27	0.09	0.36
	600 x 1	2.1	7.5	0.0	1.0	0.32	0.08	0.27
	p value	0.2877	0.2722	0.2064	0.5885	0.16160	0.1987	0.1823
	LSD	0.6	1.2	0.3	0.9	0.06	0.03	0.15

[z] Based on plant growth habit, basal branches were counted in *Campanula*; leaders and lateral branches were counted in *Aster, Cosmos, Rosmarinus, Verbena, and Veronica.*
[y] The second application of 300 mg·L^{-1} BA was applied two weeks after the first treatment.

Figure 3.1. Phytotoxic effect of BA treatment on *Aster* 'Professor Anton Kippenberg' at 1 week after initial treatment. *Aster* treated with BA exhibited significant tip burn which reduced the growth of liners.

Figure 3.2. Phytotoxic response of *Cosmos atrosanguineus* finished plants to treatment with BA. Untreated control is pictured on the left, distorted leaves in plant treated with two applications of 300 mg·L^{-1} BA is on the right.

Chapter 4. Using Dikegulac Sodium or Ethephon to Improve Plant Architecture in Herbaceous Perennial Liners

Commercial growers of herbaceous perennials must produce and ship plants that are aesthetically pleasing and ready to ship at appropriate times to market. In order to meet these production challenges, growers control plant growth by using both cultural controls, including plant nutrition, light and temperature, as well as chemical controls, i.e. plant growth regulators (PGRs) (Albrecht and Tayama, 1992; Whipker et al., 2006). However, using PGRs can be challenging, because plants respond in different ways to PGRs depending on species, cultivar, growing conditions, and the PGR utilized (Gent and McAvoy, 2000).

PGRs can be used to increase branching in herbaceous perennials by reducing apical dominance. Dikegulac sodium is a chemical which represses apical dominance by preventing cell development and differentiation; it is used as a chemical pinching agent to increase branching in ornamental plants (Gent and McAvoy, 2000). Dikegulac sodium reduces shoot elongation and increases branching in woody plants (Banko and Stefani, 1995; Sachs et al., 1975). Banko and Stefani (1995) assessed the use of dikegulac sodium on container grown woody ornamentals; of nine species studied, dikegulac produced compact plants which appeared more fully branched in five. Little research has been conducted on the responses of herbaceous plants to dikegulac sodium; however it shows promise as a branching agent. Dikegulac sodium increased branches and reduced height in *Zinnia* L. 'Scarlet Flame,' *Helianthus annuus* L. 'Peredovic,' and *Chrysanthemum morifolium* Ramat. (pro sp.) 'Escapade' (Arzee et al., 1977). *Kalanchoe* Adans. X spp treated with foliar sprays of 750 to 2250 $mg\cdot L^{-1}$ dikegulac sodium had an increased number of inflorescences and decreased height (Nightingale et al., 1985).

Ethephon is used to delay flowering and reduce stem elongation in ornamentals; in plant tissue, ethephon transforms into the plant hormone ethylene (Gent and McAvoy, 2000). Although the role of ethylene in regards to apical dominance is not well understood, ethephon is used as a pinching agent which inhibits terminal buds and releases outgrowth of axillary buds (Cline, 1991). Foley and Keever (1992) assessed the effect of ethephon, benzyladenine (BA), BA + gibberellic acid $(GA)_{4+7}$, and pyranyl benzyladenine (PBA) on increasing axillary shoots of geranium (Pelargonium x *hortorum* L.H. Bailey 'Hollywood Star') stock plants. In this study, a single application of 500 $mg{\cdot}L^{-1}$ ethephon increased axillary shoots 93%, while BA + GA_{4+7} and PBA increased axillary shoots 19% compared to untreated controls.

Traditionally, PGRs have been applied 2 to 4 weeks after the transplant of liners (rooted cuttings) from the plug tray to larger size pots, when plants are in active growth and have started to expand (Albrecht and Tayama, 1992). However PGRs may be applied earlier in production, when liners are rooted well enough that the root ball will hold together when pulled from the plug tray (Whipker et al., 2006). The objective of this study is to evaluate the effects of the growth regulators dikegulac sodium and ethephon on branching as well as shoot and root growth of herbaceous perennial plants during liner production and on the finished plants after transplant and growing to marketable size.

Materials and Methods

Six herbaceous perennials were studied: *Aster* 'Professor Anton Kippenberg' (*Symphyotrichum novi-belgii* L.'Professor Anton Kippenburg'), *Campanula punctata* Lam. 'Cherry Bells,' *Cosmos atrosanguineus* (Hook) Voss., *Verbena bonariensis* L. 'Lollipop,' *Rosmarinus officinalis* L.'Hill Hardy' and *Veronica spicata* L. 'Goodness Grows.' Plants arrived as unrooted cuttings, which were dipped for ten seconds in 1500 mg·L-[1] IBA rooting hormone (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp, New York, NY) as a basal treatment and stuck into 72 size cell (cell height 5.71 cm, volume 35.4 ml) trays filled with a peat and perlite based growing media (Canadian sphagnum peat moss 70 to 75% by volume, Promix BX, Premier Tech Horticulture, Quakertown, PA), with 10% extra coarse perlite added (volume to volume). Cuttings were allowed to root under mist with bottom heat at 22°C (72°F) for 2 to 3 weeks. *Aster, Campanula,* and *Cosmos* were removed from mist at 22 days after sticking (DAS); *Verbena* was removed at 12 DAS, and *Rosmarinus* and *Veronica* were removed at 15 DAS. Cuttings received clear water under mist, but after removal from mist received 100 mg·L^{-1} N with each irrigation using 20N-4.4P-16.6K Peters Professional General Purpose fertilizer (The Scotts Co. LLC, Marysville OH).

Growth regulators were applied to liners at least 8 hours after removal from mist, between 14 and 30 days after sticking depending on the species: *Aster* was treated at 26 DAS, *Cosmos* at 27 DAS, *Campanula* at 30 DAS, *Verbena* at 14 DAS, *Rosmarinus* at 27 DAS, and *Veronica* at 28 DAS. Treatments were applies as foliar sprays: control (0 mg·L^{-1}), 400 mg·L^{-1} dikegulac sodium (Augeo, 18% dikegulac sodium, OHP, Inc, Mainland PA), 800 mg·L^{-1} dikegulac sodium, 1600 mg·L^{-1} dikegulac sodium, or 500 mg·L^{-1} ethephon (Florel, 3.9% ethephon, Monterey Lawn and Garden Products, Inc., Fresno, CA). *Rosmarinus* and *Veronica* received an additional treatment of ethephon as a drench of 500 mg·L^{-1}, applied via sub-irrigation until media was saturated. Treatments were applied when roots from cuttings were evident on all four sides of the root ball, but liners were not fully rooted and ready for transplant. Foliar sprays were applied with a CO_2 backpack sprayer (R&D Sprayers, Inc., Opelousas, LA) applying 210 ml per m^2. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42

W) from July through October, 2010. Greenhouse light levels averaged 17.1 $mol \cdot m^{-2} \cdot d^{-1}$ and temperatures averaged 23.6°C. The experimental setup was a completely randomized design with each plant species conducted as a separate experiment. Experimental units consisted of six plants in a single six-cell pack with four replications of the experimental unit per treatment for each of two destructive harvests for each crop. An additional set of replications was included for evaluation of liner grow out as described below.

Data were collected at 0 and 3 to 4 weeks after treatment (WAT) on individual plants in each experimental unit. At 3 to 4 WAT liners were finished and ready to be transplanted. Measurements included plant height measured from the top of the container, average width which was the average of the width measured at the widest point of the plant and again perpendicular to this point, numbers of leaders (primary branches with secondary lateral branches or primary branches which arise from the media) and lateral branches (secondary branches) or basal branches (which had no secondary branches), number of plants in flower, root and shoot dry weights, root to shoot ratio and phytotoxicity. Branches were counted if they were 2 mm long or longer. Based on growth habit, basal branches were counted in *Campanula*; leaders and lateral branches were counted in *Aster*, *Cosmos, Verbena, Rosmarinus, and Veronica*. For root dry weights, media was washed off of roots by hand, using a screen to prevent loss of roots. Roots were washed randomly by experimental unit. Root and shoot dry weights were determined after drying roots and shoots at 66°C (150°F) for 48 hours.

After data were collected at 3 to 4 WAT, eight plants of each treatment were randomly selected from the remaining replications, potted into quart sized plastic pots (1.1 liter) filled with Promix BX medium with 10% extra coarse perlite added (volume to volume) and grown out for a period of four additional weeks to assess liner treatment effects on the finished plant. These plants were arranged as single plant replications in a completely randomized design for each species.

Data were analyzed by ANOVA and subjected to LSD means separation ($P \leq 0.05$) using SAS Version 9.2 by SAS Institute Inc. (Cary, NC) and JMP®9.0 ©2010 SAS Institute Inc.

Results

In all plants, measurements were taken at 0 weeks after treatment (WAT) to ensure uniformity. At this time, there were no significant differences between control plants and plants treated with growth regulators in plant height, width, numbers of leaders and lateral or basal branches, root or shoot dry weights, or root: shoot ratio (Appendix Table 4.A.1). None of the liners were flowering.

Aster 'Professor Anton Kippenberg': at 3 WAT 1600 $mg \cdot L^{-1}$ dikegulac sodium reduced height and width (Table 4.1). Number of branches was not different in treated plants compared to controls, while the number of leaders was increased and shoot dry weight was reduced with 1600 $mg \cdot L^{-1}$ dikegulac sodium. At this time, number of branches, root dry weight and root: shoot ratio were not different in PGR-treated plants; plants were not flowering. At 8 WAT, finished plants treated with dikegulac sodium or ethephon did not differ from untreated plants in shoot or root measurements (Table 4.2).

Treatment with 1600 $mg \cdot L^{-1}$ dikegulac sodium increased leaders in *Aster* liners and reduced plant height, width and shoot dry weight. Treatment with lower concentrations of dikegulac sodium or ethephon did not affect the number of branches or leaders in *Aster* liners; none of the growth regulators had persistent effects on finished plants.

Campanula punctata 'Cherry Bells': at 3 WAT liners treated with 800 or 1600 mg·L^{-1} dikegulac sodium had reduced width compared to controls; at this time no other shoot and root measurements were significantly different (Table 4.3). Finished plants did not significantly differ from controls in any shoot or root measurements (Table 4.4). Campanula did not flower during the study. Neither dikegulac sodium nor ethephon increased the number of basal branches or significantly affected overall plant quality in *Campanula* liners or finished plants.

Cosmos atrosanguineus: at 3 WAT 1600 mg·L^{-1} dikegulac sodium reduced plant height and increased number of branches in liners (Table 4.5). Average width, number of leaders, shoot dry weight, and root dry weight were not affected by PGR treatment at this time. Root: shoot ratio was increased in liners treated with 1600 mg·L^{-1} dikegulac sodium or 500 mg·L^{-1} ethephon. Few plants were flowering as finished liners.

At 8 WAT, finished *Cosmos* plants treated with 800 or 1600 mg·L^{-1} dikegulac sodium or 500 mg·L^{-1} ethephon had reduced width although height was not different from control plants at this time (Table 4.6). Treatment with 1600 mg·L^{-1} dikegulac sodium increased the numbers of branches and leaders and reduced shoot dry weight compared to untreated controls. Flowering was not significantly affected by growth regulator treatments ; less than 25 % of plants were flowering at 8 WAT.

Treatment with 1600 mg·L^{-1} dikegulac sodium increased branches and root: shoot ratio and reduced height in *Cosmos* liners and increased the numbers of branches and leaders and reduced width and shoot dry weight in finished plants. Plants appeared more compact and upright (Figure 4.1). Treatment with lower concentrations of dikegulac sodium or ethephon did not affect the number of branches or leaders in *Cosmos* liners and finished plants.

Verbena bonariensis 'Lollipop': plant height was reduced with all growth regulator treatments at 3 WAT, especially with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium although width was unaffected (Table 4.7). Number of branches was significantly increased with all treatments compared to controls, especially with dikegulac sodium treatments; number of leaders was unaffected. Shoot dry weight was reduced in liners treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium or 500 $mg \cdot L^{-1}$ ethephon while root dry weight was unchanged. Root: shoot ratio was increased with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium. Plants did not flower as liners (Figure 4.2).

Height and width were not significantly different in finished *Verbena* plants treated with growth regulators (Table 4.8). Treatment with 800 $mg \cdot L^{-1}$ dikegulac sodium increased number of branches while treatment with ethephon decreased the number of branches. Treatment with 1600 $mg \cdot L^{-1}$ dikegulac sodium increased the number of leaders and decreased shoot dry weight. Root dry weight and root: shoot ratio in finished plants was unaffected by growth regulator treatments. Fewer finished plants treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium flowered compared to untreated controls.

Both dikegulac sodium and ethephon increased the number of branches and decreased height and shoot weight in *Verbena* liners. Finished plants treated with the higher concentrations of dikegulac sodium had persistent increases in branches or leaders as well as delayed flowering (Figure 4.3).

Rosmarinus 'Hill Hardy': at 4 WAT height was not different in liners treated with dikegulac sodium or a foliar spray of ethephon while liners treated with a drench of 500 $mg \cdot L^{-1}$ ethephon had reduced height (Table 4.9). All PGR treatments reduced width. Number of branches in growth regulator treated plants did not differ from controls while number of leaders was increased in plants treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium. Shoot and root dry weights in treated plants were not significantly different from controls although root: shoot ratio was increased in plants treated with 400 or 1600 $mg \cdot L^{-1}$ dikegulac sodium or 500 $mg \cdot L^{-1}$ ethephon applied as a drench.

Height was reduced in finished plants treated with 800 $mg \cdot L^{-1}$ dikegulac sodium; width was reduced in finished plants treated with 500 $mg \cdot L^{-1}$ ethephon applied as a drench (Table 4.10). Number of branches were increased in finished plants treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium; leaders were increased with 1600 $mg \cdot L^{-1}$ dikegulac sodium. Again, while shoot and root dry weights were unaffected by growth regulator treatments, root: shoot ratio was increased with 400 or 800 $mg \cdot L^{-1}$ dikegulac sodium or 500 $mg \cdot L^{-1}$ ethephon applied as a drench. *Rosmarinus* treated with dikegulac sodium had increased branches and leaders as liners and finished plants with no effects on shoot or root dry weight.

Veronica spicata 'Goodness Grows': height was significantly reduced in liners treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium at 4 WAT (Table 4.11, Figure 4.4) while width was reduced in liners treated with any concentration of dikegulac sodium. Dikegulac sodium or ethephon drench increased the number of branches whereas number of leaders was unaffected by treatment with growth regulators. Shoot weight was reduced in liners treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium and root: shoot ratio was increased in liners treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium although root weight was not significantly different in treated plants compared to controls. *Veronica* liners were not flowering at 4 WAT.

Growth was stunted in finished *Veronica* plants treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium; both height and width were significantly reduced compared to untreated controls (Table

4.12, Figure 4.5). Treatment with 1600 mg·L^{-1} dikegulac sodium decreased the number of branches in finished plants. Number of leaders was not affected by PGR treatment. Shoot and root dry weights were reduced in plants treated with dikegulac sodium or 500 mg·L^{-1} ethephon applied as a drench and root: shoot ratio was increased in plants treated with 1600 mg·L^{-1} dikegulac sodium.

Dikegulac sodium increased branches and leaders of *Veronica* liners although treatment caused stunting in liners and finished plants treated with the two higher concentrations. Ethephon as a drench or 400 mg·L^{-1} dikegulac sodium increased branches without negative growth effects in *Veronica*.

Discussion

Treating herbaceous perennial liners with dikegulac sodium or ethephon prior to transplant changed the growth of the plants although the results varied by species, as seen with other growth regulators (Gent and McAvoy, 2000). Treatment effects were most apparent in finished liners at 3 to 4 WAT. At this time, 800 or 1600 mg·L^{-1} dikegulac sodium increased branches and/or leaders in all taxa except *Campanula* and reduced height of all taxa except *Campanula* and *Rosmarinus*. Width was reduced in liners of four species with dikegulac sodium treatment. Shoot dry weight was reduced with higher rates of dikegulac sodium in three crops and with ethephon spray in *Verbena* whereas root dry weight was not affected in any of the crops by any of the PGR treatments. Higher rates of dikegulac sodium increased root:shoot ratio in four crops, while ethephon increased root:shoot ratio in two crops.

Increases in number of branches were persistent in the finished plants of three taxa at 8 WAT: *Cosmos, Rosmarinus* and *Verbena*. Ethephon increased branches and reduced height in *Veronica* and *Verbena* liners, however finished plants treated with ethephon were not different from controls. Finished plants of three crops had reduced height and/or width following treatment with the higher rates of dikegulac sodium or with ethephon. Root and shoot dry weights were unaffected in most crops. Only *Aster*, *Cosmos,* and *Verbena* flowered during the study. While flowering of *Aster* and *Cosmos* was not affected by PGR treatment, fewer *Verbena* finished plants treated with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium were flowering than untreated controls.

Comparable results were seen in seedlings of *Zinnia* 'Scarlet Flame,' *Helianthus annuus* 'Peredovic,' and rooted cuttings of *Chrysanthemum morifolium* 'Escapade' treated with 100 to 750 $mg \cdot L^{-1}$ foliar sprays of dikegulac sodium after transplant: dikegulac inhibited the elongation of internodes and stimulated the elongation of axillary branches in all three species (Arzee et al., 1977). Chlorosis and distorted leaves were noted on these seedlings but was found to be a transient effect of treatment. Similarly, branching of *Gaillardia aristata* Pursh. 'Gallo Yellow' was increased by foliar sprays of 400 or 800 $mg \cdot L^{-1}$ dikegulac sodium in plants treated after transplant whereas higher spray rates of 1600 or 3200 $mg \cdot L^{-1}$ dikegulac sodium caused stunting and phytotoxicity (Latimer and Freeborn, 2010).

Hayashi et al. (2001) had mixed results in controlling plant growth with ethephon: three foliar sprays of 1000 $mg \cdot L^{-1}$ ethephon reduced height in five of eight herbaceous perennials tested (*Achillea millefolium* L. 'West River Sandstone,' *Echinacea purpurea* Moench 'Bravado', *Leucanthemum x superbum* Bergmans ex. J. Ingram 'Thomas Killen', *Monarda didyma* L. 'Blue Stocking,' and *Physostegia virginiana* Bentham 'Summer Snow'); ethephon did not affect the number of shoots per pot in seven species and reduced the number of shoots in *Leucanthemum*. Similarly, two applications of 500 $mg \cdot L^{-1}$ ethephon reduced height of *Salvia* x *sylvestris* L. 'May Night' ('Mainacht') and *Scabiosa columbaria* L. 'Butterfly Blue'; numbers of inflorescences were increased in *Salvia* but not *Scabiosa* (Banko et al., 2001). In our study, ethephon increased branching in *Verbena* liners and finished plants and in *Veronica* liners. Ethephon caused height and width reductions in three crops.

The higher rates of dikegulac sodium delayed flowering in *Verbena*; flowering in *Aster* was not affected by PGR treatment and the other crops did not flower during the study. Nightengale et al. (1985) found that foliar applications of 750 to 2250 $mg \cdot L^{-1}$ dikegulac sodium increased the number of inflorescences in *Kalnchoe* x spp., however all plants were in flower when data were collected thus time to flower was not examined.

Treating plants with dikegulac sodium or ethephon as liners prior to transplant resulted in more branching which produced a liner that appeared fuller at an earlier stage of growth; although plant response varied by species and fewer plants responded to ethephon. In most of the crops tested, branching of the untreated liners eventually matched that of plants treated with dikegulac sodium or ethephon, suggesting that multiple applications of growth regulators would be beneficial. In summary, producers of herbaceous perennial liners may use dikegulac sodium or ethephon to increase liner size and branching; testing for plant responsiveness is recommended. Finished plant producers should consider applying dikegulac sodium or ethephon again on responsive plants either in the flat prior to transplanting or in the finishing container shortly after transplanting.

Literature Cited

Albrecht, M.L. and H.K. Tayama. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assoc., Columbus, Ohio.

Arzee, T., H. Langenauer and J. Gressel. 1977. Effect of dikegulac, a new growth regulator, on apical growth and development of three Compositae. Bot. Gaz. 138(1):18–28.

Banko, T.J. and M.A. Stefani. 1995. Cutless and Atrimmec for controlling growth of woody landscape plants in containers. J. Environ. Hort. 13(1):22-26.

Banko, T.J., M.A. Stefani, and M.S. Dills. 2001. Growth and flowering response of 'May Night' *Salvia* and 'Butterfly Blue' *Scabiosa* to growth retardants. J. Environ. Hort. 19(3):145-149.

Cline, M.G. 1991. Apical dominance. Bot. Rev. 57:318-358.

Foley, J.T. and G.J. Keever. 1992. Chemical promotion of axillary shoot development of geranium stock plants. J. Environ. Hort. 10(2):90-94.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture: a critical appraisal, p. 89-130. In Basra, A.S. (ed.) Plant growth regulators in agriculture and horticulture: their role and commercial uses. Food Products Press, Binghamton.

Latimer, J.G. and J. Freeborn. 2010. Branching enhancers, Configure (6-BA) and Augeo (dikegulac sodium), affect branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 37:148-152.

Nightingale, A.E., S.E. Cross and M.T. Longnecker. 1985. Dikegulac alters growth and flowering of Kalanchoe. HortScience 20:722-724.

Sachs, R.M., H. Hield, and J. DeBie. 1975. Dikegulac: A promising new foliar-applied growth regulator for woody species. HortScience 10(4):367-369.

Whipker, B.E., J.L. Gibson, and C.B. Cerveny. 2006. Rooting hormones and plant growth regulators, p. 89-100. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Table 4.1. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Aster* 'Professor Anton Kippenberg' liners at 3 weeks after treatment (WAT) with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (mg)	Root dry weight (mg)	Root: shoot ratio
0	11.1a	7.6a	17.6	3.4b	290a	54.1	0.19
400 DS	11.5a	7.0a	19.8	3.1b	313a	62.5	0.20
800 DS	10.1a	6.9a	18.5	3.6b	268a	61.7	0.24
1600 DS	4.8b	5.4b	23.3	4.8a	192b	44.6	0.24
500 ES	12.0a	7.4a	20.8	3.5b	315a	73.3	0.23
p value	0.0001	0.0005	0.2382	0.0317	0.0008	0.2677	0.6873
LSD	2.2	0.8	5.4	1.1	51.8	26.8	0.10

Table 4. 2. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Aster* 'Professor Anton Kippenberg' finished plants at 8 weeks after treatment with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (g)	Root dry weight (mg)	Root: shoot ratio	Percent plants flowering
0	11.8	11.8	82.4	16.3	1.79	245	0.17	100
400 DS	10.9	11.7	95.5	17.3	1.86	292	0.20	100
800 DS	10.3	11.7	84.8	20.0	1.65	216	0.17	100
1600 DS	9.5	12.9	80.5	19.8	1.85	254	0.17	88
500 ES	110	10.9	86.3	19.1	1.68	240	0.17	100
p value	0.2757	0.1781	0.5165	0.8117	0.7498	0.8206	0.87	0.5051
LSD	2.1	1.6	5.2	26.6	na[z]	na	na	na[y]

[z] LSD not calculated due to uneven data set

[y]LSD not calculated in nominal logistical regression

Table 4.3. Plant height, average plant width, number of basal branches, shoot dry weight, root dry weight, and root: shoot ratio of *Campanula punctata* 'Cherry Bells' liners at 3 weeks after treatment (WAT) with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Width (cm)	Number of branches	Shoot weight (mg)	Root weight (mg)	Root: shoot ratio
0	9.8	18.0a	3.6	411	102	0.24
400 DS	8.6	15.2ab	3.0	324	77.5	0.24
800 DS	8.8	14.5b	5.0	378	105	0.30
1600 DS	7.0	14.7b	3.8	334	79.2	0.23
500 ES	9.7	17.9a	2.9	334	93.3	0.29
p value	0.224	0.0366	0.0841	0.4825	0.3175	0.0758
LSD	2.6	2.8	1.5	111	33.4	0.06

Table 4.4. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Campanula punctata* 'Cherry Bells' finished plants at 8 weeks after treatment with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Shoot dry weight (g)	Root dry weight (mg)	Root: shoot ratio
0	4.8	28.6	6.8	2.17	102	0.18
400 DS	6.0	26.8	7.8	2.28	77.5	0.23
800 DS	4.6	26.6	10.1	2.37	105	0.25
1600 DS	5.0	27.3	12.3	2.42	79.2	0.24
500 ES	6.4	28.4	12.4	2.67	93.3	0.23
p value	0.0653	0.1077	6.67	0.6448	0.3175	0.2225
LSD	1.4	1.8	0.3	na[z]	33.4	na

[z] na, not available, LSD not calculated due to uneven data set

Table 4.5. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Cosmos atrosanguineus* liners at 3 weeks after treatment (WAT) with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (mg)	Root dry weight (mg)	Root: shoot ratio
0	22.3a	8.9	4.4bc	1.0	387	115	0.28c
400 DS	23.8a	10.0	3.9bc	1.0	349	126	0.37bc
800 DS	20.4a	10.7	5.6b	1.5	349	118	0.35bc
1600 DS	11.4b	10.4	8.1a	1.5	286	168	0.57a
500 ES	23.8a	10.9	2.5c	1.1	358	154	0.44ab
p value	0.002	0.422	0.002	0.2969	0.1063	0.1619	0.0035
LSD	5.8	2.3	2.3	0.7	73.0	51.3	0.13

[z] na, not available, LSD not calculated in nominal logistical regression

Table 4.6. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Cosmos atrosanguineus* finished plants at 8 WAT with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (g)	Root dry weight (mg)	Root: shoot ratio	Percent flowering
0	7.9ab	24.3a	9.6bc	2bc	1.34ab	201	0.15	12.5
400 DS	7.3b	26.1a	12.1bc	2.6bc	1.48a	329	0.21	12.5
800 DS	13.3a	19.9b	14.9b	2.9b	1.09bc	215	0.20	12.5
1600 DS	13.5a	15.1c	28.3a	7.3a	0.93c	247	0.30	0.0
500 ES	4.5b	20.4b	7.9c	1.3c	1.05bc	245	0.21	25.0
p value	0.011	<.0001	<.0001	<.0001	0.003	0.1133	0.056	0.548
LSD	5.8	3.9	1.6	6.8	na[z]	na[z]	na[z]	na[y]

[z] na, not available, LSD not calculated due to uneven data set
[y] na, not available, LSD not calculated in nominal logistical regression

Table 4.7. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Verbena bonariensis* 'Lollipop' liners at 3 weeks after treatment (WAT) with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (mg)	Root dry weight (mg)	Root: shoot ratio
0	21.1a	6.9	1.3d	1.0	373a	170	0.47b
400 DS	13.9bc	7.4	9.2b	1.1	356ab	202	0.57b
800 DS	10.7c	7.2	10.1b	1.4	255c	182	0.71a
1600 DS	7.1d	7.0	12.2a	1.2	284bc	205	0.72a
500 ES	15.8b	6.9	4.7c	1.0	287bc	143	0.50b
p value	<0.0001	0.6058	<0.0001	0.1292	0.0190	0.1009	0.0012
LSD	3.2	0.8	1.9	0.3	75.4	50.0	0.13

Table 4.8. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Verbena bonariensis* 'Lollipop' finished plants at 8 weeks after treatment with dikegulac sodium (DS) and ethephon foliar spray (ES). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (g)	Root dry weight (mg)	Root: shoot ratio	Percent flowering
	36.3	33.2	27.5b	4.0bc	3.07ab	449	0.14	100
400 DS	39.9	30.1	29.5b	3.5c	3.14a	607	0.19	88
800 DS	40.6	32.0	37.9a	3.4c	3.09ab	669	0.22	38
1600 DS	34.8	32.2	31.9b	5.4a	2.47c	477	0.19	25
500 ES	33.0	34.5	17.8c	4.6ab	2.79bc	496	0.16	100
p value	0.1433	0.6648	<0.0001	0.004	0.0034	0.0736	0.266	0.0001
LSD	6.9	6.1	5.3	1.1	na[z]	na	na	na

[z] LSD not calculated due to uneven data set

Table 4.9. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Rosmarinus* 'Hill Hardy' liners at 4 weeks after treatment (WAT) with dikegulac sodium (DS), ethephon foliar spray (ES) and ethephon drench (ED). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (mg)	Root dry weight (mg)	Root: shoot ratio
0	11.3ab	5.9a	19.7	1.7c	328	65.8	0.21c
400 DS	11.4ab	5.1b	22.8	4.0bc	304	96.7	0.32a
800 DS	12.1a	5.0bc	24.7	6.2ab	325	63.8	0.20c
1600 DS	9.1bc	5.2b	22.6	7.3a	245	76.3	0.34a
500 ES	11.3ab	4.8bc	21.5	1.8c	296	69.2	0.24bc
500 ED	8.4c	4.4c	20.6	2.5c	240	70.4	0.30ab
p value	0.0298	0.0025	0.0953	0.001	0.0887	0.1674	0.0051
LSD	2.5	0.6	3.5	2.7	75.4	26.8	0.08

Table 4.10. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Rosmarinus* 'Hill Hardy' finished plants at 8 weeks after treatment with dikegulac sodium (DS), ethephon foliar spray (ES) and ethephon drench (ED). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (mg)	Root dry weight (mg)	Root: shoot ratio
0	17.6a	9.1ab	45.5c	11.3bc	911	176	0.20de
400 DS	16.0a	8.7ab	48.5bc	10.6bc	795	191	0.24b
800 DS	13.1b	9.8a	63.6a	13.8ab	871	200	0.23bc
1600 DS	15.6ab	9.6a	55.6ab	15.1a	975	178	0.18e
500 ES	17.3a	7.9bc	39.1c	11.0bc	800	164	0.21cd
500 ED	15.5ab	7.1c	41.1c	8.4c	769	220	0.29a
p value	0.0296	0.0033	<0.0001	0.0157	0.2180	0.1616	<0.0001
LSD	2.7	1.5	9.4	3.8	187	44.2	0.02

Table 4.11. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Veronica spicata* 'Goodness Grows' liners at 4 weeks after treatment (WAT) with dikegulac sodium (DS), ethephon foliar spray (ES) and ethephon drench (ED). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (mg)	Root dry weight (mg)	Root: shoot ratio
0	8.4ab	10.0ab	0.6d	1.0	433a	173	0.40c
400 DS	7.5b	7.9c	8.0b	1.1	400a	165	.42bc
800 DS	4.0c	7.7cd	13.5a	1.1	374a	186	0.53b
1600 DS	1.1d	6.6d	7.7bc	1.2	227b	150	0.73a
500 ES	9.6a	11.1a	4.1cd	1.1	446a	166	0.40c
500 ED	9.4a	9.6b	4.8bc	1.0	388a	149	0.38c
p value	<0.0001	<0.0001	<0.0001	0.7703	0.00160	0.2825	<0.0001
LSD	1.7	1.2	3.7	0.3	93.9	35.1	0.10

Table 4.12. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Veronica spicata* 'Goodness Grows' finished plants at 8 weeks after treatment with dikegulac sodium (DS), ethephon foliar spray (ES) and ethephon drench (ED). Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Average width (cm)	Number of Branches	Number of Leaders	Shoot Dry weight (g)	Root Dry Weight (mg)	Root: shoot ratio
0	10.0a	15.5a	19.6ab	1.0	1.50a	809a	0.54b
400 DS	6.0abc	15.4a	13.3bc	1.8	1.10b	518c	0.46b
800 DS	3.2c	10.5b	24.3a	2.3	0.77c	330d	0.45b
1600 DS	4.5bc	6.8c	11.0c	1.0	0.37d	268d	0.78a
500 ES	8.0ab	14.8a	21.3a	1.0	1.37ab	759ab	0.55b
500 ED	9.8a	15.3a	18.8ab	1.1	1.13b	606bc	0.53b
p value	0.0226	<0.0001	0.0072	0.1065	<0.0001	<0.0001	<0.0001
LSD	4.7	2.5	7.4	1.1	0.27	167	0.12

Appendix

Table 4.A.1. Plant height, average plant width, number of branches, number of leaders, shoot dry weight, root dry weight, and root: shoot ratio of *Aster* 'Professor Anton Kippenberg,' *Campanula punctata* 'Cherry Bells,' *Cosmos atrosanguineus, Verbena bonariensis 'Lollipop,' Rosmarinus 'Hill Hardy,' Veronica spicata 'Goodness Grows'* at 0 weeks after treatment (WAT) dikegulac sodium (DS), ethephon foliar spray (ES) and ethephon drench (ED). Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=4 based on 6 subsamples).

Taxon	Growth regulator concn ($mg \cdot L^{-1}$)	Height (cm)	Avg. width (cm)	Number of branches	Number of leaders	Shoot dry weight (g)	Root dry weight (g)	Root: shoot ratio
Aster	0	4.8	6.0	5.5	1.1	0.10	0.04	0.44
	400 DS	4.1	5.6	5.8	1.0	0.08	0.03	0.67
	800 DS	3.9	5.7	6.5	1.0	0.09	0.04	0.44
	1600 DS	4.6	5.9	4.8	1.0	0.09	0.05	0.53
	500 ES	4.1	5.5	5.0	1.0	0.09	0.04	0.42
	p value	0.8323	0.3847	0.7354	0.7213	0.1923	0.2195	0.7959
	LSD	1.8	0.6	2.7	0.2	0.02	0.01	0.48
Campanula	0	5.2	9.8	1.0	na	0.16	0.03	0.19
	400 DS	6.0	10.8	1.0	na	0.21	0.04	0.20
	800 DS	5.6	10.6	1.0	na	0.74	0.03	0.20
	1600 DS	5.9	10.6	1.0	na	0.16	0.04	0.27
	500 ES	6.0	10.3	1.0	na	0.15	0.04	0.24
	p value	0.5717	0.8998			0.4225	0.2196	0.1377
	LSD	1.3	2.3			0.76	0.01	0.08
Cosmos	0	6.0	8.0	1.2	1.0	0.15	0.06	0.43
	400 DS	7.1	7.7	1.0	1.0	0.15	0.10	0.72
	800 DS	7.2	7.8	1.2	1.0	0.16	0.10	0.64
	1600 DS	6.0	8.0	1.6	1.0	0.16	0.10	0.62
	500 ES	6.4	8.1	1.9	1.0	0.17	0.07	0.44
	p value	0.6377	0.9632	0.4526	0.438	0.4835	0.0926	0.2016
	LSD	2.2	1.4	1.1	0.1	0.04	0.04	0.29

Rosmarinus	0	2.8	4.4	8.1	1	0.11	0.03	0.30
	400 DS	3.5	4.4	9.0	1	0.12	0.04	0.31
	800 DS	3.0	4.0	7.9	1	0.11	0.03	0.24
	1600 DS	2.8	4.1	7.6	1	0.11	0.03	0.24
	500 ES	3.4	4.3	7.5	1	0.1	0.03	0.30
	500 ED	3.2	4.4	8.9	1	0.11	0.03	0.27
	p value	0.7829	0.5524	0.5983	0.8424	0.944	0.4968	0.2205
	LSD	1.2	0.5	2.1	0.2	0.03	0.01	0.68
Verbena	0	4.2	6.5	1.2	1	0.13	0.09	0.67
	400 DS	3.7	6.4	1.2	1	0.11	0.08	0.74
	800 DS	3.9	6.1	0.4	1	0.12	0.08	0.69
	1600 DS	4.1	6.8	0.8	1	0.15	0.09	0.62
	500 ES	3.8	6.7	0.8	1	0.12	0.09	0.72
	p value	0.9136	0.3212	0.438		0.3899	0.6838	0.3255
	LSD	1.3	0.7	1.0		0.05	0.02	0.12
Veronica	0	1.8	8.4	0.3	1.2	0.26	0.08	0.34
	400 DS	1.4	7.2	0.2	1.1	0.23	0.10	0.45
	800 DS	1.6	9.5	0.0	1.0	0.28	0.09	0.36
	1600 DS	1.6	7.3	0.0	1.0	0.24	0.08	0.35
	500 ES	1.3	7.4	0.1	1.0	0.21	0.08	0.38
	500 ED	1.3	7.4	0.0	1.0	0.26	0.1	0.37
	p value	0.6046	0.3152	0.4119	0.4625	0.33250	0.3569	0.607
	LSD	0.7	2.4	0.3	0.2	0.06	0.03	0.14

Figure 4.1. The effects of 1600 mg·L^{-1} dikegulac sodium on *Cosmos astrosanguineus* at 8 weeks after treatment (8 WAT). On the left, plant treated with 0 mg·L^{-1} dikegulac sodium (untreated control). On the right plant treated with 1600 mg·L^{-1} dikegulac sodium.

Figure 4.2. The effects of dikegulac sodium and ethephon on *Verbena bonariensis 'Lollipop'* at 3 weeks after treatment (WAT). From left, plants treated with 0 $mg \cdot L^{-1}$ dikegulac sodium (untreated control), 400 $mg \cdot L^{-1}$ dikegulac sodium, 800 $mg \cdot L^{-1}$ dikegulac sodium, 1600 $mg \cdot L^{-1}$ dikegulac sodium, 500 $mg \cdot L^{-1}$ ethephon applied as a foliar spray.

Figure 4.3. The effects of dikegulac sodium and ethephon on *Verbena bonariensis 'Lollipop'* finished plants at 8 weeks after treatment (WAT). From left, plants treated with 0 $mg \cdot L^{-1}$ dikegulac sodium (untreated control), 400 $mg \cdot L^{-1}$ dikegulac sodium, 800 $mg \cdot L^{-1}$ dikegulac sodium, 1600 $mg \cdot L^{-1}$ dikegulac sodium, 500 $mg \cdot L^{-1}$ ethephon applied as a foliar spray.

Figure 4.4. The effects of dikegulac sodium and ethephon on *Veronica spicata* ‘Goodness Grows’at 4 weeks after treatment (WAT). From left, plants treated with 0 mg·L^{-1} dikegulac sodium (untreated control), 400 mg·L^{-1} dikegulac sodium, 800 mg·L^{-1} dikegulac sodium, 1600 mg·L^{-1} dikegulac sodium, 500 mg·L^{-1} ethephon applied as a foliar spray, 500 mg·L^{-1} ethephon applied as a drench.

Figure 4.5. The effects of dikegulac sodium and ethephon on *Veronica spicata* ‘Goodness Grows’ finished plants at 8 weeks after treatment (WAT). From left, plants treated with 0 mg·L^{-1} dikegulac sodium (untreated control), 400 mg·L^{-1} dikegulac sodium, 800 mg·L^{-1} dikegulac sodium, 1600 mg·L^{-1} dikegulac sodium, 500 mg·L^{-1} ethephon applied as a foliar spray, 500 mg·L^{-1} ethephon applied as a drench.

Chapter 5. The Effects of Application Time of Benzyladenine on the Branching and Growth of Herbaceous Perennial Liners

Growers of herbaceous perennials control plant growth by using both physical controls, including plant nutrition, light and temperature, as well as chemical controls, i.e. plant growth regulators (PGRs) (Albrecht and Tayama, 1992; Whipker et al., 2006). However, using PGRs can be challenging, because plants respond in different ways to PGRs depending on species, cultivar, growing conditions, and the PGR utilized (Gent and McAvoy, 2000).

PGRs can increase branching and improve plant architecture in plants by releasing apical dominance and allowing dormant later buds to expand which results in fuller, more well-branched plants (Cline, 1991). Benzyladenine (BA), a synthetic cytokinin, is a PGR which has been show to increase branching when sprayed on ornamental plants (Latimer and Freeborn, 2008; Martin and Singletary, 1999) The number of branches doubled in *Echinacea purpurea* (L.) Moench ‘White Swan’ and ‘Double Decker’ treated with foliar sprays of 300 to 600 $mg \cdot L^{-1}$ BA after transplant to quart size (1.1 L) pots (Latimer and Freeborn, 2008). Of 18 juvenile perennials treated with BA as a foliar spray at rates of 1000, 2000, or 4000 $mg \cdot L^{-1}$, 89% had an increase in the number of lateral branches although no additional branching was seen in the higher two rates as compared to 1000 $mg \cdot L^{-1}$ (Martin and Singletary, 1999).

Treating liners (rooted cuttings) before transplant can have significant benefits for growers including reduced time of application and reduced chemical cost. The question of when to apply BA during liner production of herbaceous perennials has not been widely studied. Benzyladenine was applied to *Verbena* cuttings (*Verbena* x *hybrids* Voss) in order to determine the effects of BA on adventitious root formation and lateral bud elongation (Svenson, 1991). Low concentrations of BA, either 30 or 100 mg·L^{-1}, applied as foliar sprays immediately or 12 hours after sticking increased root dry weight of *Verbena* cuttings whereas 300 mg·L^{-1} BA reduced root dry weight when compared to untreated controls. Lateral bud elongation was increased by 20% and 49% in subsequently rooted shoots treated with 10 or 30 mg·L^{-1} BA, respectively (Svenson, 1991). The objective of this study is to evaluate the effects of timing of BA application on branching and shoot and root growth of herbaceous perennials during liner production.

Materials and Methods

Experiment One: Two herbaceous perennials were studied: *Agastache* Clayton ex Gronov. 'Tutti Frutti' and *Verbena bonariensis* L. 'Lollipop'. Plants arrived as unrooted cuttings, which were dipped for ten seconds in 1500 mg·L-^{1} IBA rooting hormone (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp, New York, NY) as a basal treatment and stuck into 72 size (cells: height 5.71 cm, volume 35.4 ml) trays filled with a peat and perlite based growing media (Canadian sphagnum peat moss, 70-75%/volume, Promix BX, Premier Tech Horticulture, Quakertown, PA), with 10% extra coarse perlite added (volume to volume). Cuttings were allowed to root under mist with bottom heat at 22°C for 2 weeks. Cuttings received clear water under mist, but after removal from mist received 100 mg·L^{-1} N with each irrigation using 20N-4.4P-16.6K Peters Professional General Purpose fertilizer (The Scotts Co. LLC, Marysville OH).

Benzyladenine (BA, Configure, Fine Americas, Inc., Walnut Creek, CA) was applied to liners at four different treatment times, using two rates: control (0 mg·L^{-1}), or 600 mg·L^{-1} BA. Treatment times included at the time of sticking or 0 days after sticking (DAS), 7 DAS, 14 DAS, or 21 DAS. For the first three application times, plants were treated in the evening two or more hours after the mist was turned off for the day. *Verbena* was removed from mist at 14 days after sticking; *Agastache* was removed from mist 16 days after sticking. Thus, for the application time of 21 DAS, plants were already off the mist bench and were treated in the morning. Treatments were applied as foliar sprays of BA with a CO_2 backpack sprayer (R&D Sprayers, Inc., Opelousas, LA) applying 210 ml·m $^{-2}$. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W) from April through June, 2011. Greenhouse light levels averaged 22.2 mol·m^{-2}·d^{-1} and temperatures averaged 22.2°C. The experimental setup was a completely randomized design with each plant species conducted as a separate experiment. Experimental units consisted of six plants in a single six-cell pack with six replications of the experimental unit per treatment. An additional set of replications was included for evaluation of liner grow out as described below.

Data were collected at 35 DAS on individual plants in each experimental unit. At this time liners were finished and ready to be transplanted. Measurements included percentage of plants rooted, plant height measured from the top of the container, average width which was the average of the width measured at the widest point of the plant and perpendicular to this point, number of branches, days to first flower counted from the day of sticking, number of plants in flower, and phytotoxicity. Branches were counted if they were 2 mm long or longer as leaders (primary branches with secondary lateral branches) and secondary lateral branches. Root, shoot, and flower and bud dry weights were determined after drying plant material at 66°C (150°F) for 48 hours. Root:shoot dry weight ratio was calculated using total shoot dry weight (shoot plus flowers and buds, when present).

After data were collected at 35 DAS, eight plants of each treatment were randomly selected from the remaining replications, potted into quart sized plastic pots (1.1 liter) filled with Promix BX medium with 10% extra coarse perlite added (volume to volume) and grown out for a period of three additional weeks to assess liner treatment effects on the finished plant. These plants were arranged as single plant replications in a completely randomized design for each crop.

Experiment Two: As in experiment one, *Agastache* 'Tutti Frutti' and *Verbena bonariensis* 'Lollipop' arrived as unrooted cuttings which were dipped in IBA, stuck into 72 size flats filled with Pro-Mix BX with 10% extra coarse perlite added, and allowed to root under mist for 2 weeks. BA was applied at three different treatment times at two rates: 0 $mg \cdot L^{-1}$ BA (control) or 600 $mg \cdot L^{-1}$ BA. Based on negative results in experiment one in plants that were treated before rooting occurred, treatment times were the day after removal from mist which was 14 days after sticking (DAS), 3 days later at 17 DAS or 6 days later at 20 DAS. Treatments were applied as foliar sprays of BA with a CO_2 backpack sprayer applying 210 $ml \cdot m^{-2}$. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W) from November through December, 2011. Greenhouse light levels averaged 14.2 $mol \cdot m^{-2} \cdot d^{-1}$ and temperatures averaged 21.1°C. The experimental setup was a completely randomized design with each plant species conducted as a separate experiment. Experimental units consisted of six plants in a six-cell pack with six replications of the experimental unit per treatment. An additional set of replications was included for evaluation of liner grow out. Data were collected as above at 28 DAS when liners were finished and ready for transplant. Eight plants of each treatment were then transplanted into quart size pots and grown out for an additional two weeks before a final data collection at 56 DAS.

In both experiments data were analyzed by ANOVA and subjected to LSD means separation ($P \leq 0.05$) using JMP®9.0 ©2010 SAS Institute Inc. (Cary, NC).

Results

Experiment one *Agastache* 'Tutti Frutti': At 35 DAS, BA caused a reduction in rooting percentage in treated liners (Figure 5.1, Table 5.1), especially those treated at 0 DAS and 21 DAS which were treated after removal from mist. All BA-treated plants had reduced height, especially plants treated at 0 DAS; reduced width was only seen in plants treated at 0 DAS. While number of leaders was unaffected at this time, number of branches was reduced in plants treated at 0 or 7 DAS. Root dry weight and shoot dry weights were reduced in plants treated at 0 or 7 DAS although root: shoot ratio was not affected by BA treatment. Liners were not flowering at 35 DAS.

Finished plants treated with BA at all treatment times had reduced height compared to untreated controls, particularly in plants treated at 0 DAS (Figure 5.2, Table 5.2). While plants treated at 0 DAS had reduced width, plants treated at 21 DAS had increased width. Plants treated at 0 DAS or 14 DAS had fewer leaders than untreated plants, while plants treated at 0 DAS had fewer branches. Root dry weight was only reduced in plants treated at 0 DAS; however, shoot dry weight was reduced in plants treated at 0 or 7 DAS and flower and bud dry weight was reduced with all treatment times except 21 DAS. Root: shoot ratio was unaffected by treatment with BA. The percent of plants flowering was reduced with BA treatment especially in plants treated at 0, 7, or 14 DAS. Treatment with 600 $mg \cdot L^{-1}$ BA at 0 or 7 DAS had the effect of reducing growth in *Agastache* 'Tutti Frutti' liners and finished plants.

Experiment 1 *Verbena bonariensis* 'Lollipop': All verbena liners rooted (Table 5.3). Liners treated with BA at all treatment times had reduced height at 35 DAS; plants treated at 0, 7, or 21 DAS had reduced width (Table 5.3, Figure 5.3). Number of leaders was increased in plants treated at 0 or 14 DAS while the number of branches was decreased in plants treated at 0, 14, or 21 DAS. Root dry weight was reduced only in liners treated at 0 DAS although shoot dry weight was reduced with all BA treatments at 35 DAS. Root:shoot ratio was increased in liners treated at 14 DAS. Plants treated at 21 DAS had phytotoxic response to BA treatment in the form of twisted and distorted leaves (Figure 5.4) which were still persistent on finished plants (Figure 5.5).

Finished plants treated with BA were no longer different from untreated controls in the measurements of height and width (Figure 5.6, Table 5.4). Only plants treated at 7 DAS had fewer leaders while number of branches was unaffected by BA treatment at 56 DAS. Root and shoot dry weights and root: shoot ratio were unaffected by BA treatment in finished plants. While number of days to flower and percent of plants flowering were not significantly from controls at 56 DAS, flower and bud dry weight was reduced in plants treated at 7, 14 or 21 DAS. Damaged leaves persisted in finished plants treated at 21 DAS continued due to phytotoxicity (Figure 5.6). Treatment of *Verbena* with BA had the effect of reducing growth in liners although this effect was not evident in finished plants.

Experiment two: *Agastache* 'Tutti Frutti': Liners treated with BA at all treatment times had reduced height at 28 DAS, especially in plants treated at 14 DAS (Figure 5.7, Table 5.5). At this time width and numbers of leaders and branches were not different in treated plants compared to untreated controls. Root dry weight, shoot dry weight and root: shoot ratio of liners were not affected by BA treatment. In finished plants at 42 DAS, height was no longer affected by BA treatment; plants treated at 14 DAS had increased width, number of leaders and numbers of branches (Figure 5.8, Table 5.6). As in liners, the root dry weight, shoot dry weight and root: shoot ratio of BA-treated finished plants were not different from controls (Table 5.6). Treatment with BA had the effect of reducing height in *Agastache* liners, while finished plants had increased branching as a result of treatment at 14 DAS, the day after plants were removed from mist. Later treatment had no benefit.

Experiment two *Verbena bonariensis* 'Lollipop': at 28 DAS liners treated with BA had reduced height although width was unaffected (Figure 5.9, Table 5.7). At this time numbers of leaders and branches were not different in BA-treated plants compared to controls. Root dry weight was increased in plants treated at 17 DAS while shoot dry weight was reduced in plants treated at 14 DAS. Root: shoot ratio was increased in plants treated at 14 or 17 DAS.

In finished plants at 42 DAS, height, width, and number of leaders of BA-treated plants were not significantly different than control plants (Figure 5.10, Table 5.8). At this time there were fewer branches in plants treated at 14 or 20 DAS. Root dry weight was unaffected by BA treatment although shoot dry weight was reduced with BA treatment at 14 or 20 DAS. Root: shoot ratio was not different in BA-treated finished plants compared to controls. BA reduced height in *Verbena* liners and decreased the number of branches and shoot dry weight in *Verbena* finished plants treated at 14 or 20 DAS.

Discussion

In experiment one, in order to determine the optimal time for application of BA to perennials during liner production, BA was applied to *Agastache* and *Verbena* at four times: the day of sticking or 1, 2, or 3 weeks later. In *Agastache*, the application of BA on the day of sticking reduced rooting (both the percentage of plants rooted and root dry weight), while rooting was not affected in *Verbena*. Svenson (1991) also found that the rooting of *Verbena* x *hybrids* Voss cuttings was not affected by application of 30 to 300 $mg \cdot L^{-1}$ BA immediately or 12 hours after sticking. In rooting trials the application of exogenous cytokinins to unrooted cuttings has an insignificant or an inhibitory effect on adventitious rooting (Van Staden and Harty, 1988).

Percentage of plants rooted was also reduced in *Agastache* following application of BA at 21 DAS. At this time liners were well grown and may have been ready for transplant with little room left in the cell of the liner tray for root growth. While application of BA did not affect rooting in *Verbena*, *Verbena* liners treated with BA at 21 DAS had significant phytotoxicity. Similar to *Agastache*, *Verbena* was already well grown in the plug tray by this time.

Agastache liners treated at 0 or 7 DAS had significant reductions in height, numbers of branches and root and shoot dry weight at 35 DAS when finished liners were measured. Application of BA to *Agastache* cuttings before rooting has occurred reduced growth in liners; this reduction in growth persisted in finished plants. While BA application reduced height and shoot dry weight in all treated *Verbena* liners at 35 DAS, these differences were no longer significant in finished plants. Similarly, foliar sprays of 250 to 1000 $mg \cdot L^{-1}$ BA applied at the one leaf stage to *Synogonium prodophyllum* Schott. ‘White Butterfly’ liners had no effect on lateral shoots whereas BA applied at the three or five leaf stage resulted in significant increases; however, there were no differences in controls and BA-treated finished plants at 10 weeks after treatment (Wang and Boogher, 1987). Whipker et al. (2006) recommend that PGRs for height control may be applied to liners during late stage 3 (root development) or stage 4 (toning the rooted cutting) of propagation.

In *Agastache* liners, the number of leaders was not affected by BA treatment, while the number of branches was reduced with the early treatments, 0 or 7 DAS. In finished *Agastache* plants the numbers of leaders and branches were reduced with BA treatment at 0 DAS; other application times did not affect leaders and branches. *Agastache* 'Purple Haze' liners had increased branching following treatment after rooting but before transplant with one or two applications of 300 mg·L^{-1} BA or one application of 600 mg·L^{-1} BA; finished plants treated with two applications of 300 mg·L^{-1} BA or one application of 600 mg·L^{-1} BA had increased numbers of leaders and branches (Grossman et al., 2012). *Verbena* liners had an increased number of leaders with treatment at either 0 or 14 DAS; number of branches in liners and numbers of leaders or branches finished plants were not increased with any BA treatment. In a previous study (Grossman thesis, chapter 3, unpublished) the number of branches was increased in *Verbena* liners at 2 weeks after treatment although increases were no longer seen in finished plants. Svenson (1991) found no difference in *Verbena* x *hybrids* treated with 30, 100, or 300 mg·L^{-1} BA applied immediately, 48 hours, or 96 hours after sticking. Hosta divisions which received a sinlge foliar spray of 3000 mg·L^{-1} BA either at the time of potting or 4, 5 or 6 weeks later did not produce more offsets than untreated controls, while plants treated 1, 2 or 3 weeks after potting had significantly more offsets (Schultz et al., 2000).

Since application of BA at 0 or 7 DAS had negative effects on *Agastache* and no positive effects on *Verbena*, experiment two examined three application times beginning with the time the plants were removed from mist. At this time, liners were rooted but were not yet ready for transplant. BA-treated *Agastache* finished plants had increased leaders and branches at 42 DAS in plants treated 14 DAS; however, *Verbena* plants did not have increases in leaders or branches with any time of BA application as finished liners (28 DAS) or finished plants (42 DAS). Variation in response to PGRs could be attributed to species and cultivar variation (Gent and McAvoy, 2000) as well as season of application. For example, Nauer and Boswell (1981) found the response of *Citrus reticulata* to 1000 mg·L^{-1} BA varied with more buds stimulated into growth following application in April and May than in February. Similarly, Thomas et al. (1992) found spray application of 250 to 1500 $mg \cdot L^{-1}$ Promalin ($BA + GA_4 + GA_7$) to be more effective at increasing number of branches of *Hypericum calycinum* when applied in the spring than when applied in January when plants were dormant.

Optimal application time of BA to herbaceous perennials during liner production varies with cultivar, species and time of year. However, it seems clear that applications are best made after cuttings have developed roots but before the roots have filled the cells in the liner tray.

Literature Cited

Albrecht, M.L. and H.K. Tayama. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assoc., Columbus, Ohio.

Cline, M.G. 1991. Apical dominance. Bot. Rev. 57:318-358.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture: a critical appraisal, p. 89-130. In Basra, A.S. (ed.) Plant growth regulators in agriculture and horticulture: their role and commercial uses. Food Products Press, Binghamton.

Grossman,M., J. Freeborn, H. Scoggins, and J. Latimer. 2012. Benzyladenine increases branching but reduces root growth of herbaceous perennial liners. HortScience (In press).

Latimer, J. and J. Freeborn. 2008. Enhance branching of *Echinacea* with PGRs. Greenhouse Product News 18(4):24–28.

Nauer, E.M., and S.B. Boswell. 1981. Stimulating growth of quiescent citrus buds with 6-benzylamino purine. HortScience 16 (2):162-163.

Martin, S. and S. Singletary. 1999. N-6 Benzyladenine increases lateral offshoots in a number of perennial species. Proc. Intl. Plant Prop. Soc. 49:329-334.

Schultz, H.C., G.J. Keever, J.R.J. Kessler, and R.R. Dute. 2000. BA Application timing affects offset formation in *Hosta*. J. Environ. Hort. 18 (2):63-65.

Svenson, S.E. 1991. Rooting and lateral shoot elongation of verbena following benzylaminopurine application. HortScience 26(4):391-392.

Thomas, P.A., J.G. Latimer, D. Zhang, and S. Hartzler. 1992. Effects of plant growth regulators on lateral branching and shoot growth of *Hypericum*. Proc. of Southern Nursery Assn. 37:261-262.

Wang, Y.T., and C.A. Boogher. 1987. Effect of stock plant shading, developmental stage and cytokinin on growth and lateral branching of *Syngonium podophyllum* 'White Butterfly'. Scientia Hort. 33:137-145.

Van Staden, J. and A.R. Harty. 1988. Cytokinins and adventitious root formation, p. 185-201. In T.D. Davis, B.E. Haissig, and N. Sankhla (eds.). Adventitious root formation in cuttings. Dioscorides, Portland, OR.

Whipker, B.E., J.L. Gibson, and C.B. Cerveny. 2006. Rooting hormones and plant growth regulators, p. 89-100. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Whitman, C. and E. Runkle. 2003. PGR rates and timing for plug production. Greenhouse Product News 13(12):38-43.

Table 5.1. Percent rooted, plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, and root: shoot ratio of *Agastache* 'Tutti Frutti' at 35 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} benzyladenine (BA) at 0, 7, 14 and 21 DAS. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=6 based on 6 subsamples).

Treatment time/ BA concn (mg·L^{-1})	Percent rooted	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (mg)	Root: shoot ratio
0 DAS/0	100	21.8a	7.3ab	1.0	11.9ab	100a	517a	0.19
0 DAS/600	81	8.6c	5.5c	1.3	5.8d	27.0c	213c	0.13
7 DAS/600	97	12.9b	6.5bc	1.4	8.5c	55.5bc	368b	0.14
14 DAS/600	94	15.9b	6.6bc	1.5	11.5b	78.4ab	450ab	0.19
21 DAS/600	75	14.1b	8.5a	1.6	13.2a	73.0ab	495a	0.17
p value	0.0003	<0.0001	0.0003	0.599	<0.0001	0.0043	<0.0001	0.344
LSD	na^{z}	3.8	1.2	0.8	1.7	34.9	101	0.08

^{z}LSD not calculated in nominal logistical regression

Table 5.2. Plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, root: shoot ratio, percent flowering, and flower and bud weight of *Agastache* 'Tutti Frutti' at 56 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} BA at 0, 7, 14 and 21 DAS. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=8).

Treatment time/ BA concn (mg·L^{-1})	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (g)	Root: shoot ratio^{x}	Percent flow- ering	Flower and bud weight (mg)
0 DAS/0	69.9a	27.9b	9.6a	28.1ab	323a	3.27a	0.10	100	138a
0 DAS/600	26.5d	20.7c	5.1c	20.1c	134b	1.07c	0.24	50	37.2b
7 DAS/600	35.9cd	26.4b	7.9ab	29.1ab	264a	2.11b	0.13	38	29.4b
14 DAS/600	44.5bc	26.1b	6.5bc	26.0bc	261a	2.83ab	0.09	13	16.7b
21 DAS/600	50.9b	33.1a	7.3abc	33.4a	333a	3.28a	0.1	88	96.9a
p value	<0.0001	0.0005	0.0105	0.0026	0.0005	<0.0001	0.4467	0.0003	<0.0001
LSD	13.4	5.0	2.4	6.2	89.2	0.72	0.18	na^{z}	na^{y}

^{z}LSD not calculated in nominal logistical regression
^{y}LSD not calculated due to uneven data set
^{x}Root: shoot ratio calculated based on the total of shoot dry weight and flower and bud dry weight

Table 5.3. Percent rooted, plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, and root: shoot ratio of *Verbena bonariensis* 'Lollipop' at 35 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} benzyladenine (BA) at 0, 7, 14 and 21 DAS. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=6 based on 6 subsamples).

Treatment time/ BA concn (mg·L^{-1})	Percent rooted	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (mg)	Root: shoot ratio
0 DAS/0	100	20.4a	12.2a	1.1bc	12.8a	153ab	487a	0.32b
0 DAS/600	100	15.3b	10.0b	1.4a	9.9b	100c	374b	0.27b
7 DAS/600	100	13.6b	10.0b	1.3ab	11.6a	130abc	357b	0.37b
14 DAS/600	100	15.0b	11.0ab	1.5a	9.5b	164a	380b	0.49a
21 DAS/600	100	11.1c	7.5c	1.0c	7.0c	124bc	355b	0.35b
p value		<0.0001	<0.0001	0.0091	<0.0001	0.0138	0.0001	0.005
LSD		2.3	1.4	0.3	1.6	36.0	54.9	0.11

Table 5.4. Plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, root: shoot ratio, percent flowering, days to flower, and flower and bud weight of *Verbena bonariensis* 'Lollipop' at 56 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} BA at 0, 7, 14 and 21 DAS. Data analysis performed by ANOVA and logistical regression using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=8).

Treatment time/ BA concn (mg·L^{-1})	Plant height (cm)	Plant width (cm)	No. of leaders	No. of lateral branches	Root dry weight (mg)	Shoot dry weight (g)	Root: shoot ratio^{x}	Percent flow-ering	Days to flower	Flower and bud weight (mg)
0 DAS/0	32.8	30.6	4.8a	30.3	438	2.08	0.19	100	41.4	271a
0 DAS/600	27.8	30.2	4.1a	29.9	458	2.00	0.27	100	42.2	231a
7 DAS/600	34.0	26.8	2.8b	24.6	429	2.47	0.16	75	45.0	126b
14 DAS/600	30.9	27.7	3.7ab	26.9	375	2.22	0.16	75	44.1	121b
21 DAS/600	28.8	26.3	3.7ab	27.6	304	1.89	0.15	100	43.1	111b
p value	0.1357	0.1434	0.0505	0.5362	0.0716	0.1811	0.1851	0.1039	0.2139	0.0012
LSD	5.5	4.2	1.3	7.4	117	na^{y}	na	na^{z}	3.6	89.2

^{z}LSD not calculated in nominal logistical regression
^{y}LSD not calculated due to uneven data set
^{x}Root: shoot ratio calculated based on the total of shoot dry weight and flower and bud dry weight

Table 5.5. Plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, and root: shoot ratio of *Agastache* 'Tutti Frutti' at 28 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} benzyladenine (BA) at 14, 17 and 20 DAS. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=6 based on 6 subsamples).

Treatment time/ BA concn (mg·L^{-1})	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (mg)	Root: shoot ratio
14 DAS/0	16.3a	6.9	1.0	7.9	55.3	218	0.27
14 DAS/600	5.7c	6.7	1.1	8.1	46.8	183	0.27
17 DAS/600	11.8b	7.7	1.0	7.4	60.2	244	0.25
20 DAS/600	9.0bc	7.6	1.1	6.0	73.2	218	0.35
p value	<0.0001	0.1022	0.3031	0.0933	0.1410	0.3106	0.2241
LSD	3.3	1.0	0.1	1.8	22.7	66.1	0.11

Table 5.6. Plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, and root: shoot ratio of *Agastache* 'Tutti Frutti' at 42 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} benzyladenine (BA) at 14, 17 and 20 DAS. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=8).

Treatment time/ BA concn (mg·L^{-1})	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (g)	Root: shoot ratio
14 DAS/0	23.8	14.1b	1.8b	16.9b	248	1.7	0.14
14 DAS/600	20.1	18.6a	4.0a	25.5a	223	1.7	0.13
17 DAS/600	25.5	14.2b	2.3b	18.6b	286	1.8	0.16
20 DAS/600	23.3	15.3b	2.4b	19.0b	296	1.9	0.16
p value	0.3608	0.0055	0.0068	0.0018	0.1409	0.8518	0.1416
LSD	6.2	2.7	1.3	4.3	69.9	0.38	0.03

Table 5.7. Plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, and root: shoot ratio of *Verbena bonariensis* 'Lollipop' at 28 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} benzyladenine (BA) at 14, 17 and 20 DAS. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=6 based on 6 subsamples).

Treatment time/ BA concn (mg·L^{-1})	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (mg)	Root: shoot ratio
14 DAS/0	9.7a	6.9	1.0	1.6	97.4b	220ab	0.44b
14 DAS/600	5.3c	6.4	1.0	1.5	89.6b	169c	0.55a
17 DAS/600	6.4bc	7.1	1.0	2.1	140a	246a	0.58a
20 DAS/600	7.1b	6.8	1.0	1.2	87.6b	196bc	0.46b
p value	0.0003	0.2821	0.4133	0.4374	0.0002	0.0198	0.0034
LSD	0.2	0.8	0.0	1.1	22.6	47.7	0.08

Table 5.8. Plant height, average plant width, number of leaders, number of branches, root dry weight, shoot dry weight, and root: shoot ratio of *Verbena bonariensis* 'Lollipop' at 42 days after sticking (DAS). Treatments include untreated control and treatment with 600 mg·L^{-1} benzyladenine (BA) at 14, 17 and 20 DAS. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test. P<0.05, n=8).

Treatment time/ BA concn (mg·L^{-1})	Plant height (cm)	Plant width (cm)	Number of leaders	Number of lateral branches	Root dry weight (mg)	Shoot dry weight (g)	Root: shoot ratio
14 DAS/0	18.6	14.9	1	15.6a	321	1.5a	0.21
14 DAS/600	16.2	14.3	1	11.9c	309	1.2b	0.26
17 DAS/600	14	14.4	1.3	14.8ab	320	1.3ab	0.25
20 DAS/600	15.6	13.5	1.1	12.9bc	255	1.2b	0.22
p value	0.0917	0.4172	0.278	0.0131	0.0604	0.0186	0.0962
LSD	3.6	1.7	0.3	2.4	54.3	0.23	0.04

Figure 5.1. Effect of benzyladenine (BA) treatment on *Agastache* 'Tutti Frutti' at 35 days after sticking (DAS). From left to right: untreated control, plant treated with 600 mg·L^{-1} BA at 0, 7 14, and 21 DAS.

Figure 5.2. Effect of benzyladenine (BA) treatment on *Agastache* 'Tutti Frutti' at 56 days after sticking (DAS). From left to right: untreated control, plant treated with 600 mg·L^{-1} BA at 0, 7 14, and 21 DAS.

Figure 5.3. Effect of benzyladenine (BA) treatment on *Verbena bonariensis* 'Lollipop' at 35 days after sticking (DAS). From left to right: untreated control, plant treated with 600 mg·L^{-1} BA at 0, 7 14, and 21 DAS.

Figure 5.4. Phytotoxic effect of benzyladenine (BA) treatment on *Verbena bonariensis* 'Lollipop' at 35 days after sticking (DAS). Untreated control on the left, plant treated with 600 mg·L^{-1} BA at 21 DAS on the right. Note twisted and distorted leaves in treated plant.

Figure 5.5. Phytotoxic effect of benzyladenine (BA) treatment on *Verbena bonariensis* 'Lollipop' at 56 days after sticking (DAS), plant treated with 600 mg·L^{-1} BA at 21 DAS.

Figure 5.6. Effect of benzyladenine (BA) treatment on *Verbena bonariensis* 'Lollipop' at 56 days after sticking (DAS). From left to right: untreated control, plant treated with 600 mg·L^{-1} BA at 0, 7, 14, and 21 DAS.

Figure 5.7. Effect of benzyladenine (BA) treatment on *Agastache* 'Tutti Frutti' at 28 days after sticking (DAS). From left to right: untreated control, plant treated with 600 mg·L^{-1} BA at 14 DAS, 17 DAS, and 20 DAS.

Figure 5.8. Effect of benzyladenine (BA) treatment on *Agastache* 'Tutti Frutti' at 42 days after sticking (DAS). From left to right: untreated control, plant treated with 600 mg·L^{-1} BA at 14 DAS, 17 DAS, and 20 DAS.

Figure 5.9. Effect of benzyladenine (BA) treatment on *Verbena bonariensis* ‘Lollipop’ at 28 days after sticking (DAS). From left to right: untreated control, plant treated with 600 $mg \cdot L^{-1}$ BA at 14 DAS, 17 DAS, and 20 DAS.

Figure 5.10. Effect of benzyladenine (BA) treatment on *Verbena bonariensis* ‘Lollipop’ at 42 days after sticking (DAS). From left to right: untreated control, plant treated with 600 $mg \cdot L^{-1}$ BA at 14 DAS, 17 DAS, and 20 DAS.

Chapter 6. The Effects of Application Time of Dikegulac Sodium and Benzyladenine on Branching of Herbaceous Perennial Plants

In order to meet production challenges, growers of herbaceous perennials control plant growth by using both cultural controls, including plant nutrition, light and temperature, as well as chemical controls, i.e. plant growth regulators (PGRs) (Albrecht and Tayama, 1992; Whipker et al., 2006). However, using PGRs can be challenging, because plants respond in different ways to PGRs depending on species, cultivar, growing conditions, and the PGR utilized (Gent and McAvoy, 2000). PGRs can increase branching and improve plant architecture in plants by releasing apical dominance and allowing dormant lateral buds to expand which results in fuller, more well-branched plants (Cline, 1991).

Benzyladenine (BA), a synthetic cytokinin, is a PGR which has been show to increase branching when sprayed on ornamental plants (Latimer and Freeborn, 2008; Martin and Singletary, 1999). The number of branches doubled in *Echinacea* (L.) Moench 'White Swan' and 'Double Decker' treated with foliar sprays of 300 to 600 $mg \cdot L^{-1}$ BA after transplant to quart size pots (Latimer and Freeborn, 2008).

Dikegulac sodium has been used as a chemical pinch to prevent elongation in woody plants as well as increase branching in herbaceous plants. Banko and Stefani (1995) assessed the use of dikegulac on container grown woody ornamentals. Of the nine species they studied, dikegulac effectively controlled growth in five, producing plants that were more compact and appeared to have more dense shoot growth. When three year old field-grown *Lavandula* × *intermedia* Emeric ex Loisel.'Twickle Purple' plants were treated with 0.5%, 1.0%, or 2.0% Atrinal (containing 20% dikegulac sodium), the numbers of vegetative shoots and inflorescences and oil yield increased significantly compared to untreated plants (Porter and Shaw, 1983). Branching of *Gaillardia aristata* Pursh. 'Gallo Yellow' was increased by foliar sprays of 400 or 800 $mg \cdot L^{-1}$ dikegulac sodium (Latimer and Freeborn, 2010).

PGRs are often applied after transplant, when plants are in active growth and have started to expand. Treating liners (rooted cuttings) before transplant can have significant benefits for growers including reduced time of application and reduced chemical cost. Grossman et al. (2012) showed increases in branching in four of five herbaceous perennials treated with BA before transplant; of these only two had persistent increases in branching after plants grew to finished size. The question of when to apply growth regulators to achieve increased branching in finished plants is an important one to growers who want to grow out liners to finished, marketable plants. The objective of this study is to examine the effects of application time of dikegulac sodium, benzyladenine and a combination of the two on the growth and branching of herbaceous perennial plants during liner production and grow out of finished plants.

Materials and Methods

Six herbaceous perennials were studied: *Sedum spectabile* Boreau 'Autumn Joy,' *Gaillardia aristata* Pursh 'Gallo Red,' *Phlox paniculata* L. 'Bright Eyes,' *Nepeta racemosa* Lam. 'Walker's Low,' *Delosperma* NE Br. 'Table Mountain,' and *Achillea* L. 'Moonshine.' Plants arrived as unrooted cuttings, which were dipped for ten seconds in 1500 $mg \cdot L^{-1}$ IBA rooting hormone (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp., New York, NY) as a basal treatment and stuck into 72 size cell (height 5.71 cm, volume 35.4 ml) trays filled with a peat moss media with pine bark, perlite and vermiculite (45%, 25%, 15%, and 15%, respectively; Fafard 3B, Conrad Fafard, Inc. Agawam, MA). Cuttings were allowed to root under mist with bottom heat at 22°C (72°F) for 2 to 3 weeks depending on the crop. Cuttings received clear water under mist, but after removal from mist received 100 $mg{\cdot}L^{-1}$ N with each irrigation using 20N-4.4P-16.6K Peters Professional General Purpose fertilizer (The Scotts Co. LLC, Marysville OH).

Growth regulators were applied to plants at three treatment times: liner (plants received a single application of PGR when roots from cuttings were evident on all four sides of the root ball, but liners were not fully rooted and ready for transplant), post-transplant (plants received a single application of PGR 5 to 7 days after liners were transplanted to quart size pots) or both (plants received two applications of PGR, the first at the liner treatment time and the second at the post-transplant treatment time). Growth regulators were applied as foliar sprays to liners for the liner and both treatments at least 8 hours after removal from mist, between 7 and 27 days after sticking (DAS) depending on the crop (*Nepeta* at 7 DAS, *Delosperma* at 14 DAS, *Sedum* at 18 DAS, *Achillea* and *Gaillardia* at 21 DAS, and *Phlox* at 26 DAS).The following PGR treatments were applied: control (0 $mg{\cdot}L^{-1}$), dikegulac sodium (Augeo, 18% dikegulac sodium, OHP, Inc, Mainland PA) at 400 $mg{\cdot}L^{-1}$, 800 $mg{\cdot}L^{-1}$, or 1600 $mg{\cdot}L^{-1}$, benzyladenine (BA, Configure, 2% benzyladenine, Fine Americas, Inc., Walnut Creek, CA) at 600 $mg{\cdot}L^{-1}$ or a tank mix combination of 400 $mg{\cdot}L^{-1}$ dikegulac sodium and 600 $mg{\cdot}L^{-1}$ BA. Foliar sprays were applied with a CO_2 backpack sprayer (R&D Sprayers, Inc., Opelousas, LA) applying 210 $ml{\cdot}m^{-2}$. Plants were grown in a double polyethylene greenhouse located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W) from May through September, 2011. Greenhouse light levels averaged 17.1 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ and temperatures averaged 23.7°C. The experimental setup was a split plot design with time of application as the main plot factor and growth regulator treatment as the subplot factor. Each plant species was conducted as a separate experiment. Experimental units consisted of two plants in a two-cell pack with six replications of the experimental unit per treatment for each of two destructive harvests for each crop. An additional set of replications was included for evaluation of liner grow out as described below.

Data were collected at 0 and at 2 or 3 weeks after initial treatment (WAIT) on individual plants in each experimental unit; at this time liners were finished and ready to be transplanted. Measurements included plant height measured from the top of the container to the top of the plant, average width which was the average of the width measured at the widest point of the plant and again perpendicular to this point, number of branches, number of days to flower from date of sticking, shoot dry weight and phytotoxicity. Branches were counted if they were 2 mm long or longer. Based on growth habit, branches counted in *Achillea* were basal branches which had no secondary laterals and in *Sedum*, *Gaillardia*, *Phlox, Nepeta*, and *Delosperma*, leaders (primary branches with secondary lateral branches) and secondary lateral branches were counted. Shoot dry weights were determined after drying shoots at 66°C (150°F) for 48 hours. Data on flower and bud dry weight and flower stalk height were also collected as applicable.

After data were collected at 2 or 3 WAIT, eight plants of each treatment were randomly selected from the remaining replications, potted into quart sized plastic pots (1.1 liter) filled with Fafard 3B medium. Approximately one week after transplant, growth regulators were applied to liners for post-transplant and both treatments and plants were grown out for a period of three to five additional weeks to assess treatment time and growth regulator treatment effects on the finished plants.

Data were analyzed by ANOVA ($P \leq 0.05$, Student's t-test) using JMP®9.0 ©2010 SAS Institute Inc.

Results

In all plants, measurements taken at 0 weeks after initial treatment (WAIT) indicated no significant differences between control plants and plants treated with PGRs in plant height, width, numbers of leaders and lateral or basal branches, or shoot dry weights (data not presented). None of the plants were flowering. In finished liners at 2 or 3 WAIT, only one application of growth regulators had been applied; therefore only the effects of growth regulator treatments will be discussed in liners, whereas in finished plants the main plot effects of time of application as well as the subplot effects of growth regulator treatments will be examined.

Sedum: at 3WAIT the number of leaders of *Sedum* liners was not affected by any of the growth regulator treatments, however the number of branches was increased with all treatments, especially BA or the dikegulac sodium and BA combination (Table 6.1). Height was reduced with 1600 $mg{\cdot}L^{-1}$ dikegulac sodium, 600 $mg{\cdot}L^{-1}$ benzyladenine, or the dikegulac sodium and BA combination while width was increased in plants treated with 400 $mg{\cdot}L^{-1}$ dikegulac sodium or the dikegulac sodium and BA combination compared to untreated controls. Shoot dry weight was decreased with 1600 $mg{\cdot}L^{-1}$ dikegulac sodium although it was increased in plants treated with BA. Phytotoxicity was noted in all dikegulac sodium or BA treated plants at 3 WAIT in the form of puckered leaves; however the phytotoxicity was moderate in nature and would not reduce the marketability of the liners.

In finished *Sedum* plants, application at both times increased the numbers of leaders and branches compared to application once at either liner or post-transplant stage (Table 6.2). Number of leaders was affected by an interaction between application time and growth regulator treatment. Plants treated only as liners were not significantly different from controls whereas plants treated at post-transplant with 600 mg·L^{-1} benzyladenine or the dikegulac sodium and BA combination and plants treated both times with any of the PGRs tested had increased numbers of leaders. Number of branches was also affected by an interaction between application time and PGR treatment. Plants treated only as liners were not different from controls while plants treated at post-transplant with 800 mg·L^{-1} dikegulac sodium, 600 mg·L^{-1} benzyladenine, or the dikegulac sodium and BA combination and plants treated both times with any of the PGRs tested had increased numbers of branches.

Sedum plants treated at post-transplant or both times had decreased height, width, and shoot dry weight compared to plants treated only as liners (6.3). There were significant interactions of application time and PGR treatment in all three measurements. Plants treated with 1600 mg·L^{-1} dikegulac sodium had reduced height at all treatment times. While width was not different in plants treated once as liners or post-transplant compared to control plants, width was reduced in plants treated both times with 400, 800 or 1600 mg·L^{-1} dikegulac sodium or the dikegulac sodium and BA combination. Shoot dry weight was not different in plants treated once as liners compared to untreated controls. Plants treated with 400, 800 or 1600 mg·L^{-1} dikegulac sodium post-transplant had reduced shoot dry weight while plants treated with BA post-transplant had increased shoot dry weight. Shoot dry weight was reduced in plants treated both times with 800 or 1600 mg·L^{-1} dikegulac sodium. Phytotoxicity in the form of yellow leaves was noted in plants treated at post-transplant with 800 or 1600 mg·L^{-1} dikegulac sodium or the dikegulac sodium and BA combination and in plants treated both times with 1600 mg·L^{-1} dikegulac sodium (Figure 6.1). No plants flowered during the study although all plants were in bud at 6 WAIT. Applying growth regulators at both times resulted in the greatest numbers of branches and leaders and the branches were more well developed (Figure 6.1). Both dikegulac sodium and BA were effective in increasing branches in liners and finished plants, however higher rates of dikegulac sodium reduced growth and resulted in greater phytotoxicity.

Gaillardia aristata ‘Gallo Red’: A few liners were budding and flowering when removed from mist; to prevent premature flowering all plants were cut back to about 5 cm before treatment. At 2 WAIT treatment BA or the dikegulac sodium and BA combination increased the numbers of leaders and branches, while treatment with 1600 $mg \cdot L^{-1}$ dikegulac sodium reduced the numbers of leaders and branches (Table 6.4). Height was reduced with 1600 $mg \cdot L^{-1}$ dikegulac sodium, 600 $mg \cdot L^{-1}$ benzyladenine, or the dikegulac sodium and BA combination. Width was not significantly different in BA or dikegulac sodium treated plants compared to controls. Shoot dry weight was reduced with 1600 $mg \cdot L^{-1}$ dikegulac sodium although shoot dry weight was increased with BA or the dikegulac sodium and BA combination. A few liners were budding and flowering when removed from mist; to prevent premature flowering all plants were cut back to about 5 cm before treatment.

Finished *Gaillardia* plants treated both times had more leaders and branches than plants treated once either at liner or post transplant (Table 6.5). There were significant interactions of application time and PGR treatment in both measurements. Plants treated once with BA as liners had more leaders than untreated controls. Plants treated once post transplant with 1600 $mg \cdot L^{-1}$ dikegulac sodium or BA had fewer leaders. Plants treated twice with either BA or the dikegulac sodium and BA combination had more leaders than untreated controls while plants treated twice with 1600 $mg \cdot L^{-1}$ dikegulac sodium had fewer leaders. Number of branches was increased with 400 $mg \cdot L^{-1}$ dikegulac sodium applied at the liner treatment time whereas the number of branches decreased in plants treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium as liners. Although dikegulac sodium had no effect, treatment with the dikegulac sodium and BA combination post-transplant increased the number of branches compared to untreated controls. In plants treated both times, the number of branches was decreased with 1600 $mg \cdot L^{-1}$ dikegulac sodium and increased with BA or the BA dikegulac sodium combination.

Plants treated at post transplant or both times had reduced height, width, and shoot dry weight compared to plants treated as liners at 8 WAIT (Table 6.6). Height of plants treated only as liners was reduced only by 1600 $mg \cdot L^{-1}$ dikegulac sodium, whereas height was reduced in plants treated post-transplant or both times with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium or with the dikegulac sodium and BA combination. Width was reduced with 1600 $mg \cdot L^{-1}$ dikegulac sodium applied at the liner treatment time, with all treatments post-transplant, and with all treatments except BA at both treatment times, however the greatest reductions were with the application of 1600 $mg \cdot L^{-1}$ dikegulac sodium. Shoot dry weight was reduced with 1600 $mg \cdot L^{-1}$ dikegulac sodium at liner treatment time, with all treatments except 400 $mg \cdot L^{-1}$ dikegulac sodium at post transplant, and with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium both times; shoot dry weight was increased with two application of 600 $mg \cdot L^{-1}$ BA.

Days to first flower was delayed in plants treated as liners compared to those treated post transplant; not all plants treated both times flowered (Table 6.7). Plants treated as liners only had delayed flowering with all treatments except 400 $mg \cdot L^{-1}$ dikegulac sodium. Plants treated both times with 800 $mg \cdot L^{-1}$ dikegulac sodium had delayed flowering and plants treated both times with 1600 $mg \cdot L^{-1}$ dikegulac sodium or BA or the BA and dikegulac sodium combination did not flower during the study (Figure 6.2). Flower and bud dry weight of *Gaillardia* was reduced in plants treated post transplant compared to plants treated at the liner treatment time; not all plants treated at both times were budding or flowering. Among finished plants treated only at the liner stage, flower and bud weight was reduced with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium and increased with BA treatment. All finished plants treated with growth regulators post transplant or both times had reduced flower and bud weight compared to untreated controls.

Gaillardia liners treated with 1600 $mg{\cdot}L^{-1}$ dikegulac sodium had reductions in growth, while those liners treated with BA or the dikegulac sodium and BA combination had increased leaders, branches and shoot dry weight. Finished plants treated twice with BA or the dikegulac sodium and BA combination had increased branches and leaders, although plants treated both times with the dikegulac sodium and BA combination had reduced height and width. Plants treated with 400 $mg{\cdot}L^{-1}$ dikegulac sodium as liners only had increased branches while plants treated with BA as liners only had increased leaders; neither of these treatments reduced height, width, or shoot weight. Flowering delays were considerable in plants treated as liners (14 to 33 day delay) or both times (more than 33 day delay) with all treatments except 400 $mg{\cdot}L^{-1}$ dikegulac sodium. The goal of treating plants with BA and dikegulac sodium is to increase branching and improve plant quality. In *Gaillardia* higher rates of dikegulac sodium had negative effects on plant growth, while BA and the low rate of dikegulac sodium increased branching without reducing growth; however delays in flowering may negate the positive effects of PGR treatment.

Phlox paniculata 'Bright Eyes': at 2 WAIT the number of leaders of *Phlox* liners was not affected by dikegulac sodium or BA treatment, although the number of branches was increased with 1600 $mg{\cdot}L^{-1}$ dikegulac sodium, BA, or the dikegulac sodium and BA combination (Table 6.8). Height was reduced with 800 or 1600 $mg{\cdot}L^{-1}$ dikegulac sodium, whereas width was not affected by treatment. Shoot dry weight decreased with 1600 $mg{\cdot}L^{-1}$ dikegulac sodium and increased with BA or the dikegulac sodium and BA combination. Plants were not flowering at 2 WAIT.

In finished *Phlox* plants, number of leaders was not affected by application time or by growth regulator treatment (Table 6.9). Number of branches was not affected by application time; however there was an interaction between application time and PGR treatment. The number of branches was not affected by PGR treatment in plants treated once as liners or post-transplant, whereas plants treated both times with 1600 $mg \cdot L^{-1}$ dikegulac sodium or 600 $mg \cdot L^{-1}$ BA had more branches than controls. Plants treated both times had reduced height compared to plants treated post transplant; height was not affected by PGR treatment (Table 6.10). Width and shoot dry weight (Table 6.10), days to first flower and flower and bud weight (Table 6.11) were not affected by either application time or PGR treatment. Flower stalk height was not affected by application time, however all treatments except BA reduced flower stalk height compared to untreated controls.

Phlox liners had increased branches with 1600 $mg \cdot L^{-1}$ dikegulac sodium, although this treatment reduced height and shoot dry weight. BA or the BA and dikegulac sodium combination increased branches without reducing growth in liners. In finished plants, both 1600 $mg \cdot L^{-1}$ dikegulac sodium and BA treatment increased branches in plants treated twice, although 1600 $mg \cdot L^{-1}$ dikegulac sodium significantly reduced flower stalk height (Figure 6.3).

Nepeta x faassenii 'Walker's Low': at 2 WAIT *Nepeta* liners treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium had increased leaders while plants treated with either 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium had increased branches (Table 6.12). Height was reduced only in plants treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium while width and shoot dry weight were not affected by treatment. Plants treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium had phytotoxicity in the form of yellow leaves.

Finished *Nepeta* plants treated post transplant or both times had more leaders than plants treated once as liners (Table 6.13). There was an interaction between application time and PGR treatment. The number of leaders in plants treated only as liners was not affected by PGR treatment. Plants treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium or BA post-transplant or 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium or the dikegulac sodium and BA combination both times had increased leaders compared to untreated controls. Plants treated post transplant or both times also had more branches than plants treated as liners. Treatment with 1600 $mg \cdot L^{-1}$ dikegulac sodium at the liner stage only resulted in a reduction in number of branches. Plants treated with 800 $mg \cdot L^{-1}$ dikegulac sodium or BA post transplant or treated both times with 1600 $mg \cdot L^{-1}$ dikegulac sodium, BA, or the dikegulac sodium and BA combination had more branches than control plants. In addition to increased branches and leaders, plants treated post transplant or both times had reduced height and width (Table 6.14). Plants treated as liners only had reduced height with 400 or 1600 $mg \cdot L^{-1}$ dikegulac sodium. Post transplant treatment with 400 or 1600 $mg \cdot L^{-1}$ dikegulac sodium or the BA dikegulac sodium combination reduced height. In plants treated both times only treatment with 1600 $mg \cdot L^{-1}$ dikegulac sodium reduced height. Reduced width was seen with 1600 $mg \cdot L^{-1}$ dikegulac sodium or BA at the liner application time. Width was also reduced in plants treated post transplant with 1600 $mg \cdot L^{-1}$ dikegulac sodium or the dikegulac sodium and BA combination. All treatments except the dikegulac sodium and BA combination reduced width in plants treated both times. Treatment with 1600 $mg \cdot L^{-1}$ dikegulac sodium caused reduced height and width in *Nepeta* at all treatment times.

Shoot dry weight was reduced with treatment application post-transplant or both compared to liner treatment (Table 6.15). There was a significant interaction between application time and PGR treatment. Shoot dry weight of plants treated only as liners was not different from controls.

Plants treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium post transplant or 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium both times had reduced shoot dry weight, while treatment both times with BA increased shoot dry weight. Days to first flower was not significantly affected by treatment however none of the plants which received 1600 $mg \cdot L^{-1}$ dikegulac sodium treatment both times flowered during the study. At 6 WAT phytotoxity (yellow leaves) was noted in plants treated both times with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium.

Nepeta liners treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium had increased branches and leaders as well as reduced height. In finished plants, application at post transplant or both times increased numbers of branches and leaders and reduced height, width and shoot dry weight. Plants treated both times with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium were especially reduced in growth which would reduce the plants marketability, while two applications of 600 $mg \cdot L^{-1}$ BA increased branches without reducing growth. Flowering was delayed in *Nepeta* only with two treatments of 1600 $mg \cdot L^{-1}$ dikegulac sodium; these plants did not flower during the study.

Delosperma 'Table Mountain': at 3 WAIT, *Delosperma* liners treated with BA or the dikegulac sodium and BA combination had an increased number of leaders (Table 6.16). Number of branches was reduced in plants treated with 400 $mg \cdot L^{-1}$ dikegulac sodium. Height and width were not affected by treatment, however shoot dry weight was reduced in plants treated with 800 $mg \cdot L^{-1}$ dikegulac sodium, BA or the dikegulac sodium and BA combination.

In finished *Delosperma* plants, the numbers of leaders and branches were increased in plants treated only as liners or both times compared to plants treated post-transplant (Table 6.17). Plants treated post-transplant flowered about 4 days sooner than plants treated as liners only or both times. Time of application or PGR applied did not affect height (Table 6.18). Plants treated post-transplant had reduced width compared to plants treated as liners only. Shoot dry weight also was decreased in plants treated post-transplant. There was not an interaction between application time and treatment in shoot dry weight; all treatments except 400 $mg \cdot L^{-1}$ dikegulac sodium reduced shoot dry weight compared to controls.

Achillea 'Moonshine': Number of basal branches was not affected by treatment at 2 WAIT in *Achillea* liners (Table 6.19). Height was greater with treatment with BA and decreased with 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium. Average width and shoot dry weight were not affected in liners.

In finished *Achillea* plants, number of branches was not affected by application time (Table 6.20). Number of branches in plants treated once as liners or post transplant was not different from controls; however plants treated both times with 800 $mg \cdot L^{-1}$ dikegulac sodium, BA or the dikegulac sodium and BA combination had increased branches. Height, width and shoot dry weight were reduced in plants treated both times (Table 6.21). Height was reduced in plants treated once with 1600 $mg \cdot L^{-1}$ dikegulac sodium as liners only or post-transplant. Treatment both times with 400, 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium reduced plant height compared to controls. Plant width was reduced with one application of 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium at liner or post-transplant. Treatment both times with 400, 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium reduced width. Shoot dry weight was reduced with one application of 800 or 1600 $mg \cdot L^{-1}$ dikegulac sodium at either liner or post-transplant; whereas one treatment of the dikegulac sodium and BA combination in plants treated as liners only increased shoot dry weight. Two treatments of 400, 800, or 1600 $mg \cdot L^{-1}$ dikegulac sodium reduced shoot dry weight while two treatments of BA increased shoot dry weight.

Achillea did not flower during the study. Phytotoxocity, yellowing and narrow leaves, was noted in plants treated as liners or post transplant with 1600 mg·L^{-1} dikegulac sodium, and with plants treated both times with 800 or 1600 mg·L^{-1} dikegulac sodium. Neither BA, dikegulac sodium nor the combination affected branches in *Achillea* liners, while BA increased height in liners and the higher rates of dikegulac sodium decreased height in liners. Two application of the higher rates of dikegulac sodium caused stunting in *Achillea* finished plants, whereas two applications of BA increased branches without reducing plant growth.

Discussion

Time of PGR application had a significant effect on the branching of four of the six crops tested; in all crops except *Phlox* and *Achillea*, applying PGRs both as liners and after transplant resulted in an increase in branching compared to one treatment as liners only. However in both *Phlox* and *Achillea* two applications of BA resulted in an increase in branching without the negative growth effects caused by dikegulac sodium. Likewise, multiple applications of BA increased shoot counts in *Nandina domestica* Thunb. (Keever and Morrison, 2003) and basal shoots in *Diffenbachia* hybrid AREC-A #7901 (Henny, 1986). *Photinia* x *fraseri* treated with a single application of 6000 mg·L^{-1} dikegulac sodium (Atrinal) or two or three applications of 3000 mg·L^{-1} dikegulac sodium had three to four times as many branches as untreated controls (Ryan, 1985). However two applications of dikegulac sodium (Atrimmec) at concentrations of 1500 to 4500 mg·L^{-1} applied 2 weeks after transplant and 6 weeks later had the effect of stunting growth of *Vinca minor* L. (Keever et al., 2005). In our experiment, two applications of BA increased branching in all crops except *Delosperma* without reducing plant growth or causing phytotoxicity.

Dikegulac sodium caused varying levels of phytotoxicity in *Zinnia* 'Scarlet Flame' with yellow leaves at concentrations of up to 500 $mg \cdot L^{-1}$; concentrations over 750 $mg \cdot L^{-1}$ caused more pronounced chlorosis and twisted leaves that lasted more than 2 weeks (Arzee et al., 1977). Concentrations of 800 to 3200 $mg \cdot L^{-1}$ caused stunting and phytotoxicty in *Gaillardia* 'Gallo Yellow' finished plants 6 weeks after treatment whereas 400 $mg \cdot L^{-1}$ increased branches without negative growth effects (Latimer and Freeborn, 2010). In our experiment, two applications of 1600 $mg \cdot L^{-1}$ had the effect of stunting growth and causing yellow foliage in all crops except *Delosperma* treated with growth regulators.

The combination of BA and dikegulac sodium was effective at increasing the number of branches in four of six plants studied. In *Sedum*, two applications of the combination increased branches more than two applications of either BA or dikegulac sodium alone. In *Gaillardia, Nepeta* and *Achillea* the combination increased the number of branches as much as BA alone and more than dikegulac sodium alone. With the growth retardants daminozide, chlormequat chloride, ethephon and unicaonazole studied in combination or alone on *Salvia x sylvestris* L. May night' (Mainacht) and *Scabiosa columbaria* L. 'Butterfly Blue,' the combination treatments were not found to be more effective than the PGR alone (Banko et al., 2001). More work will need to be done to examine if synergistic effects exist between BA and dikegulac sodium.

Both BA and dikegulac sodium caused flower delay in *Gaillardia* in plants treated as liners and both times; control plants flowered 54 days after sticking (DAS) while plants treated with 800 $mg \cdot L^{-1}$ dikegulac sodium flowered 82 DAS and plants treated with 1600 $mg \cdot L^{-1}$ dikegulac sodium, BA or the BA and dikegulac sodium combination did not flower during the study. *Nepeta* treated at both times with 1600 $mg \cdot L^{-1}$ dikegulac sodium did not flower during the study while controls flowered at 41 DAS. Foliars sprays of 750 to 2250 $mg \cdot L^{-1}$ dikegulac sodium increased the number of inflorescences in *Kalanchoe* x spp. although data were collected when all plants were flowering and days to flowering was not noted (Nighingale et al., 1985). Flowering was delayed 7 days in *Coreopsis verticillata* L. 'Moonbeam' treated with 250 to 500 $mg \cdot L^{-1}$ BA, while delays of up to 19 days and persistent chlorosis was seen in plants treated with 1000 to 2000 $mg \cdot L^{-1}$ BA (Farris et al., 2009). Growers will need to consider the effects on flowering in regards to timing PGR applications in plants such as *Gaillardia* which have had delays following PGR applications.

Applying dikegulac sodium and BA to herbaceous perennial liners prior to transplant increased branches in all species studied, with higher rates of dikegulac sodium and BA being most effective in liners. However after transplant and grow out to finished plants, high rates of dikegulac sodium caused reduced plant growth in most plants studied; while a level of growth reduction is acceptable, the stunting seen with two applications of the highest rate of dikegulac sodium would reduce the marketability of plants. Two applications of PGRs was most effective in promoting long term effects in finished plants.

Literature Cited

Albrecht, M.L. and H.K. Tayama. 1992. Tips on the use of chemical growth regulators on floriculture crops. Ohio Florists' Assoc., Columbus, Ohio.

Arzee, T., H. Langenauer and J. Gressel. 1977. Effect of dikegulac, a new growth regulator, on apical growth and development of three Compositae. Bot. Gaz. 138(1):18–28.

Banko, T.J. and M.A. Stefani. 1995. Cutless and Atrimmec for controlling growth of woody landscape plants in containers. J. Environ. Hort. 13(1):22-26.

Banko, T.J., M.A. Stefani, and M.S. Dills. 2001. Growth and flowering response of ‘May Night’ *Salvia* and ‘Butterfly Blue’ *Scabiosa* to growth retardants. J. Environ. Hort. 19(3):145-149.

Cline, M.G. 1991. Apical dominance. Bot. Rev. 57:318-358.

Farris, M.E., G.J. Keever, J.R. Kessler, and J.W. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of ‘Moonbeam’ *Coreopsis*. J. Environ. Hort. 27(3):176–182.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture: a critical appraisal, p. 89-130. In Basra, A.S. (ed.) Plant growth regulators in agriculture and horticulture: their role and commercial uses. Food Products Press, Binghamton.

Henny, R.J. 1986. Increasing basal shoot production in a non-branching *Dieffenbachia* hybrid with BA. HortScience 21(6):1386-1388.

Keever, G.J., J.B. Clark, and T.A. Morrison. 2005. Growth regulation of *Vinca minor*. J. Environ. Hort. 23(1):14-16.

Keever, G. J., and T. J. Morrison. 2003. Multiple benzyladenine applications increase shoot formation in *Nandina*. J. Environ. Hort. 21(3):144-147.

Latimer, J. and J. Freeborn. 2008. Enhance branching of *Echinacea* with PGRs. Greenhouse Product News 18(4):24–28.

Latimer, J.G. and J. Freeborn. 2010. Branching enhancers, Configure (6-BA) and Augeo (dikegulac sodium), affect branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 37:148-152.

Martin, S. and S. Singletary. 1999. N-6 Benzyladenine increases lateral offshoots in a number of perennial species. Proc. Intl. Plant Prop. Soc. 49:329-334.

Nightingale, A.E., S.E. Cross and M.T. Longnecker. 1985. Dikegulac alters growth and flowering of Kalanchoe. HortScience 20:722-724.

Porter, N.G. and M.L. Shaw. 1983. Increasing growing points and oil yield in lavender by growth regulator sprays. J. Plant Growth Regul. 2:151-158.

Ryan, G.F. 1985. Branching of *Photinia* x *fraseri* in response to growth regulators and fertilizer. J. Environ. Hort. 3 (1):15-18.

Whipker, B.E., J.L. Gibson, and C.B. Cerveny. Rooting hormones and plant growth regulators, p. 89-100. In J.M. Dole and J.L. Gibson (eds.). Cutting propagation: A guide to propagating and producing floriculture crops. Ball Publishing, Batavia, IL.

Table 6.1. Number of leaders, number of lateral branches, height, average width and shoot dry weight of *Sedum spectabile* 'Autumn Joy' liners at 3 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on two subsamples).

Treatment	Number of leaders	Number of branches	Height (cm)	Average Width (cm)	Shoot dry weight (mg)
0 $mg \cdot L^{-1}$ DS	2.0	2.8e	13.6a	9.5bc	692bc
400 $mg \cdot L^{-1}$ DS	1.8	5.7d	13.0abc	10.6a	752ab
800 $mg \cdot L^{-1}$ DS	1.8	7.0c	13.3ab	8.9c	627cd
1600 $mg \cdot L^{-1}$ DS	1.5	9.5b	10.1d	9.3c	583d
600 $mg \cdot L^{-1}$ BA	2.1	12.8a	12.4bc	10.1ab	780a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	1.8	13.4a	12.3c	10.7a	0.72ab
Treatment effect	0.3124	<0.0001	<0.0001	0.0002	<0.0001
LSD	0.5	1.2	1.0	0.9	81.1

Table 6.2. Number of leaders and number of lateral branches of *Sedum spectabile* 'Autumn Joy' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Number of leaders			Number of branches		
Application Time						
Liner		4.5b			28.3c	
Post-transplant		4.3b			34.7b	
Both		8.8a			57.7a	
Application time effect		<0.0001			<0.0001	
LSD		0.6			2.4	
PGR Treatment	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 mg·L^{-1} DS	2.7	1.5b	3.6d	22.6	25.0d	21.4c
400 mg·L^{-1} DS	5.1	2.0b	7.8bc	33.8	26.9cd	60.5b
800 mg·L^{-1} DS	3.8	3.8b	7.0c	28.0	36.0bc	57.4b
1600 mg·L^{-1} DS	4.9	2.9b	10.4b	27.6	26.9cd	60.9b
600 mg·L^{-1} BA	5.0	7.8a	8.0bc	32.3	49.3a	53.6b
400 mg·L^{-1} DS + 600 mg·L^{-1}BA	5.5	8.0a	16.1a	25.8	44.3ab	92.6a
Treatment effect	0.3755	<0.0001	<0.0001	0.0695	<0.0001	<0.0001
LSD	2.8	2.8	2.9	7.6	9.3	16.5
Application Time * PGR Treatment		<0.0001			<0.0001	

Table 6.3. Height, average width and shoot dry weight of *Sedum spectabile* ‘Autumn Joy’ finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=8).

Treatment	Height (cm)			Width (cm)			Shoot dry weight (g)		
Application time									
Liner		26.2a			25.4a			10.0a	
Post-ransplant		23.8b			23.4b			7.00c	
Both		24.7b			23.7b			8.32b	
Application time effect		<0.001			<0.0001			<0.0001	
LSD		0.5			0.5			0.27	
PGR applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 $mg \cdot L^{-1}$ DS	26.1a	25.1ab	25.4cd	25.7abc	24.4	27.2a	10.3	7.91b	10.0ab
400 $mg \cdot L^{-1}$ DS	27.3a	25.1ab	29.6a	25.1abc	23.1	24.6b	10.6	6.78cd	10.1ab
800 $mg \cdot L^{-1}$ DS	26.1a	23.5ab	23.4d	27.2a	24.6	22.1c	10.5	6.14d	6.24c
1600 $mg \cdot L^{-1}$ DS	22.5b	20.4c	16.0e	23.4c	21.4	18.3d	8.0	4.80e	3.23d
600 $mg \cdot L^{-1}$ BA	27.7a	25.9a	28.0ab	24.6bc	23.7	25.5ab	10.1	9.02a	10.8a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	27.6a	23.0b	26.0bc	26.2ab	23.3	24.3b	10.7	7.13bc	9.47b
PGR effect	0.0021	0.0007	<0.0001	0.033	0.1538	<0.0001	0.0532	<0.0001	<0.0001
LSD	2.6	2.5	2.1	2.3	2.5	1.9	1.88	0.87	1.02
Application Time * PGR		<0.0001			<0.0001			<0.0001	

Table 6.4. Number of leaders, number of lateral branches, height, average width and shoot dry weight of *Gaillardia aristata* 'Gallo Red' liners at 2 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on two subsamples).

Treatment	Number of leaders	Number of branches	Height (cm)	Average width (cm)	Shoot dry weight (mg)
0 $mg \cdot L^{-1}$ DS	1.8b	4.8b	7.7a	9.3	326bc
400 $mg \cdot L^{-1}$ DS	1.8b	5.7b	7.4ab	10.3	341ab
800 $mg \cdot L^{-1}$ DS	1.6bc	5.1b	7.6ab	9.9	297cd
1600 $mg \cdot L^{-1}$ DS	1.1c	2.5c	6.4c	9.8	274d
600 $mg \cdot L^{-1}$ BA	3.3a	8.7a	6.8bc	9.9	374a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	3.2a	9.1a	6.3c	9.5	374a
Treatment effect	<0.0001	<0.0001	0.0022	0.5929	<0.0001
LSD	0.5	1.1	0.9	1.2	38.3

Table 6.5. Number of leaders and number of lateral branches of *Gaillardia aristata* 'Gallo Red' finished plants at 8 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Number of leaders			Number of branches		
Application time						
Liner		10.4b			30.8b	
Post-transplant		10.9b			29.0b	
Both		13.7a			53.0a	
Application time effect		0.0001			<0.0001	
LSD		0.8			2.2	
PGR applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 $mg \cdot L^{-1}$ DS	9.2b	12.8ab	10.2c	28.5b	22.7bc	37.7b
400 $mg \cdot L^{-1}$ DS	9.0b	12.7ab	11.5c	35.7a	31.2b	40.5b
800 $mg \cdot L^{-1}$ DS	10.2b	10.8bc	10.3c	32.8ab	31.0b	39.7b
1600 $mg \cdot L^{-1}$ DS	9.2b	6.2d	3.2d	19.7c	13.2c	11.8c
600 $mg \cdot L^{-1}$ BA	13.4a	8.2cd	28.3a	33.4ab	26.8b	100.0a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	11.3ab	15.0a	18.8b	34.7ab	49.2a	88.0a
PGR effect	0.0026	0.0004	<0.0001	0.0006	<0.0001	<0.0001
LSD	2.4	3.8	5.2	7.1	9.5	15.4
Application Time * PGR		<0.0001			<0.0001	

Table 6.6. Height, average width and shoot dry weight of *Gaillardia aristata* 'Gallo Red' finished plants at 8 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Height (cm)			Width (cm)			Shoot dry weight (g)		
Application time									
Liner		14.0a			21.5a			4.27a	
Post-transplant		12.7b			17.7b			3.59b	
Both		11.9c			17.0b			3.57b	
Application time effect		<0.0001			<0.0001			<0.0001	
LSD		0.4			0.4			0.16	
PGR applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 $mg \cdot L^{-1}$ DS	14.4a	15.4a	15.0a	21.9a	21.7a	21.6a	4.28a	4.79a	4.64b
400 $mg \cdot L^{-1}$ DS	14.1a	13.9ab	14.8a	21.7a	19.3b	19.0b	4.81a	4.38ab	4.05b
800 $mg \cdot L^{-1}$ DS	14.4a	12.4bc	9.6c	22.5a	18.4b	15.6c	4.54a	3.03d	2.02c
1600 $mg \cdot L^{-1}$ DS	11.4b	8.9d	4.6d	18.7b	12.7d	6.8d	2.49b	1.58e	0.69d
600 $mg \cdot L^{-1}$ BA	15.1a	14.1a	15.3a	22.1a	18.3b	21.4a	4.73a	4.10bc	6.12a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	14.9a	11.8c	12.3b	22.2a	15.9c	17.3bc	4.73a	3.67c	3.90b
PGR effect	0.0002	<0.0001	<0.0001	0.0015	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	1.6	1.6	2.1	1.8	1.9	2.3	0.94	0.61	0.78
Application Time * PGR		<0.0001			<0.0001			<0.0001	

Table 6.7. Days to first flower and flower and bud dry weight of *Gaillardia aristata* 'Gallo Red' finished plants at 8 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Days to first flower			Flower and bud dry weight (g)		
Application time						
Liner	64.7a			1.32a		
Post-transplant	49.6b			0.73b		
Both	na[z]			na		
Application time effect	<0.0001			<0.0001		
LSD	na			na		
PGR Applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 mg·L^{-1} DS	48.5d	52.4	53.5b	1.52bc	1.66a	1.72a
400 mg·L^{-1} DS	52.4d	48.3	47.9b	1.44c	1.13b	1.04b
800 mg·L^{-1} DS	64.8c	47.8	82.0a	0.937d	0.387cd	0.087b
1600 mg·L^{-1} DS	82.0a	49	na	0.284e	0.220d	na
600 mg·L^{-1} BA	70.5b	50.5	na	1.98a	0.563c	0.135c
400 mg·L^{-1} DS + 600 mg·L^{-1}BA	70.3b	50	na	1.77ab	0.427cd	0.098c
PGR effect	<0.0001	0.6533	0.0003	<0.0001	<0.0001	<0.0001
LSD	5.4	5.9	na	0.27	0.21	na
Application Time * PGR	<0.0001			<0.0001		

[z] na, not available. Plants treated with both 1600 mg·L^{-1} DS, 600 mg·L^{-1} BA, or 400 mg·L^{-1} DS + 600 mg·L^{-1}BA did not flower during the study.

Table 6.8. Number of leaders, number of branches, height, average width and shoot dry weight of *Phlox paniculata* 'Bright Eyes' liners at 2 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on two subsamples).

Treatment	Number of leaders	Number of branches	Height (cm)	Average Width (cm)	Shoot dry weight (mg)
0 $mg \cdot L^{-1}$ DS	1	2.1c	8.8a	9.3	300b
400 $mg \cdot L^{-1}$ DS	1	2.0c	7.9ab	9.0	298b
800 $mg \cdot L^{-1}$ DS	1	2.7bc	7.3bc	9.1	274bc
1600 $mg \cdot L^{-1}$ DS	1	4.5a	6.2c	9.3	262c
600 $mg \cdot L^{-1}$ BA	1	3.8ab	8.8a	10.3	334a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	1	5.2a	8.5ab	10.2	340a
Treatment effect	0.4256	0.0003	0.0026	0.0582	<0.0001
LSD	0.1	1.6	1.4	1.1	35.7

Table 6.9. Number of leaders and number of lateral branches of *Phlox paniculata* 'Bright Eyes' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Number of leaders	Number of branches		
Application Time				
Liner	1.7		10.4	
Post-transplant	1.5		11.4	
Both	1.8		11.4	
Application time effect	0.4974		0.3554	
LSD	0.2		0.8	
PGR applied		Liner	Post-transplant	Both
0 mg·L^{-1} DS	1.3	9.6	10.1	8.8c
400 mg·L^{-1} DS	1.5	9.4	11.8	7.6c
800 mg·L^{-1} DS	1.7	9.5	11.5	10.3bc
1600 mg·L^{-1} DS	1.9	10.4	11.3	16.8a
600 mg·L^{-1} BA	1.7	13.0	11.6	13.8ab
400 mg·L^{-1} DS + 600 mg·L^{-1}BA	2.1	10.8	11.9	11.3bc
PGR effect	0.0609	0.2473	0.9329	0.0007
LSD	0.3	3.3	3.6	4.2
Application Time * PGR	0.1689		0.0317	

Table 6.10. Height, average width and shoot dry weight of *Phlox paniculata* 'Bright Eyes' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Height (cm)	Width (cm)	Shoot dry weight (g)
Application time			
Liner	11.6ab	13.3	0.99
Post-transplant	13.5a	13.2	1.18
Both	10.3b	12.7	0.99
Application time effect	0.0136	0.6033	0.1235
LSD	1.1	0.7	0.12
PGR applied			
0 $mg{\cdot}L^{-1}$ DS	12.9	13.0	1.13
400 $mg{\cdot}L^{-1}$ DS	10.7	11.5	0.78
800 $mg{\cdot}L^{-1}$ DS	10.9	12.5	0.94
1600 $mg{\cdot}L^{-1}$ DS	11.8	13.8	1.16
600 $mg{\cdot}L^{-1}$ BA	14.0	14.3	1.26
400 $mg{\cdot}L^{-1}$ DS + 600 $mg{\cdot}L^{-1}$BA	10.5	13.1	0.98
PGR effect	0.1378	0.0539	0.0686
LSD	1.5	0.9	0.17
Application Time * PGR	0.4675	0.1346	0.9186

Table 6.11. Flower and bud dry weight, days to first flower, and flower stalk height of *Phlox paniculata* 'Bright Eyes' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, $n=8$).

Treatment	Days to first flower	Flower and bud dry weight (mg)	Flower stalk height (cm)
Application Time			
Liner	56.5	682	17.1
Post-transplant	60.4	653	18.0
Both	58.3	623	16.1
Application time effect	0.3593	0.6009	0.1629
LSD	2.1	56.5	1.0
PGR applied			
0 $mg \cdot L^{-1}$ DS	59.6ab	721	19.5a
400 $mg \cdot L^{-1}$ DS	55.8b	677	16.4bc
800 $mg \cdot L^{-1}$ DS	57.9ab	671	15.6c
1600 $mg \cdot L^{-1}$ DS	63.1a	599	16.2bc
600 $mg \cdot L^{-1}$ BA	62.3a	623	18.9ab
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	53.9b	607	15.5c
PGR effect	0.0206	0.6364	0.015
LSD	na[z]	na	na
Application Time * PGR	0.6724	0.1533	0.1891

[z] na, LSD not available due to uneven data set

Table 6.12. Number of leaders, number of lateral branches, height, average width and shoot dry weight of *Nepeta racemosa* 'Walker's Low' liners at 2 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on two subsamples).

Treatment	Number of leaders	Number of branches	Height (cm)	Average width (cm)	Shoot dry weight (mg)
0 $mg \cdot L^{-1}$ DS	1.0b	15.4c	22.4a	8.5	346
400 $mg \cdot L^{-1}$ DS	1.0b	15.8c	22.0a	8.3	321
800 $mg \cdot L^{-1}$ DS	1.3b	17.9ab	21.8a	8.8	350
1600 $mg \cdot L^{-1}$ DS	3.3a	18.7a	18.9b	8.6	325
600 $mg \cdot L^{-1}$ BA	1.0b	16.7bc	22.8a	8.8	387
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	1.1b	17.3abc	22.9a	8.4	376
Treatment effect	<0.0001	0.0067	<0.0001	0.633	0.117
LSD	0.7	2.0	1.5	0.7	56.6

Table 6.13. Number of leaders and number of lateral branches of *Nepeta racemosa* 'Walker's Low' finished plants at 5 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Number of leaders			Number of branches		
Application time						
Liner		20.9b			171b	
Post-transplant		39.7a			200a	
Both		38.9a			213a	
Application time effect		<0.0001			0.0001	
LSD		2.5			9.6	
PGR applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 $mg \cdot L^{-1}$ DS	21.0	19.8b	18.0c	179a	159cd	151b
400 $mg \cdot L^{-1}$ DS	23.4	29.2b	22.8bc	169a	192bc	171b
800 $mg \cdot L^{-1}$ DS	22.0	34.0b	33.6b	179a	213b	169b
1600 $mg \cdot L^{-1}$ DS	17.0	61.2a	63.4a	127b	144d	242a
600 $mg \cdot L^{-1}$ BA	21.0	62.0a	29.2bc	181a	294a	261a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	21.2	32.0b	66.6a	191a	196bc	285a
PGR effect	0.0979	<0.0001	<0.0001	0.0188	<0.0001	0.0001
LSD	4.3	15.2	15.3	36	48	59
Application Time * PGR		<0.0001			<0.0001	

Table 6.14. Height and average width of *Nepeta racemosa* 'Walker's Low' finished plants at 5 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment		Height (cm)			Width (cm)	
Application time						
Liner		15.7a			45.3a	
Post-transplant		13.2b			40.1b	
Both		13.2b			40.7b	
Application time effect		0.0015			<0.0001	
LSD		0.8			1.2	
PGR applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 $mg \cdot L^{-1}$ DS	17.4a	19.0a	13.8ab	49.3a	47.4ab	50.0a
400 $mg \cdot L^{-1}$ DS	14.6b	10.8b	15.4ab	48.6ab	48.1a	42.9b
800 $mg \cdot L^{-1}$ DS	17.2ab	15.2a	11.0bc	45.9ab	41.9bc	39.4b
1600 $mg \cdot L^{-1}$ DS	11.2c	9.6b	7.0c	38.2c	21.7d	25.4c
600 $mg \cdot L^{-1}$ BA	15.8ab	16.2a	18.2a	44.4b	42.7abc	42.9b
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	18.2a	8.6b	14.0ab	45.5ab	38.9c	43.8ab
PGR effect	0.0002	<0.0001	0.001	0.0005	<0.0001	<0.0001
LSD	2.7	4.0	4.6	4.5	6.1	6.2
Application Time * PGR		<0.0001			0.0028	

Table 6.15. Shoot dry weight and days to first flower of *Nepeta racemosa* 'Walker's Low' finished plants at 5 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, n=8).

Treatment	Shoot dry weight (g)			Days to first flower
Application time				
Liner		8.03a		43.2
Post-transplant		7.41b		42.4
Both		6.97c		na[z]
Application time effect		<0.0001		0.3717
LSD		0.19		1.0
PGR applied	Liner	Post-transplant	Both	
0 $mg \cdot L^{-1}$ DS	7.55ab	8.11a	7.77bc	40.7
400 $mg \cdot L^{-1}$ DS	8.38a	8.59a	7.19c	43.0
800 $mg \cdot L^{-1}$ DS	8.09ab	7.71a	5.85d	42.9
1600 $mg \cdot L^{-1}$ DS	7.25b	3.24b	3.21e	42.8
600 $mg \cdot L^{-1}$ BA	8.46a	8.20a	9.31a	43.6
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	8.46a	8.61a	8.49ab	44.7
PGR effect	0.0431	<0.0001	<0.0001	0.0919
LSD	0.91	1.03	1.02	1.3
Application Time * Treatment		<0.0001		0.1237

[z] na, not available. None of the Both 1600 Augeo plants flowered during the study

Table 6.16. Number of leaders, number of lateral branches, height, average width and shoot dry weight of *Delosperma* 'Table Mountain' liners at 3 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on two subsamples).

Treatment	Number of leaders	Number of branches	Height (cm)	Average Width (cm)	Shoot dry weight (mg)
0 mg·L^{-1} DS	1.8c	15.2ab	2.4	8.7	358a
400 mg·L^{-1} DS	2.1abc	13.3c	2.5	8.0	336abc
800 mg·L^{-1} DS	1.7c	14.0bc	2.5	7.9	318bc
1600 mg·L^{-1} DS	1.9bc	14.4abc	2.9	8.1	348ab
600 mg·L^{-1} BA	2.5a	14.8ab	2.5	7.4	312c
400 mg·L^{-1} DS + 600 mg·L^{-1}BA	2.4ab	15.6a	2.8	8.1	314bc
Treatment effect	0.0209	0.017	0.1096	0.0563	0.0493
LSD	0.6	1.4	0.5	0.8	34.7

Table 6.17. Number of leaders, number of lateral branches, and days to first flower of *Delosperma* 'Table Mountain' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=5). Data based on a single set of pooled control plants.

Treatment	Number of leaders	Number of branches			Days to first flower
Application time					
Liner	39.3a		250b		60.7a
Post-transplant	34.1b		209c		56.8b
Both	39.7a		276a		60.6a
Application time effect	0.0149		<0.0001		0.0451
LSD	2.1		10.6		1.8
PGR applied		Liner	Post-transplant	Both	
0 $mg \cdot L^{-1}$ DS	40.9	263	263a	263	59.4
400 $mg \cdot L^{-1}$ DS	39.1	239	206b	319	58
800 $mg \cdot L^{-1}$ DS	37.2	278	189b	283	61.1
1600 $mg \cdot L^{-1}$ DS	34.5	224	191b	272	58.5
600 $mg \cdot L^{-1}$ BA	37.9	262	215ab	253	60.3
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	36.8	233	190b	266	58.8
PGR effect	0.3116	0.3150	0.0180	0.2462	0.8315
LSD	2.7	55	53	58	2.5
Application Time * PGR	0.1192		0.0422		0.2393

Table 6.18. Height, average width, shoot dry weight and days to first flower of *Delosperma* 'Table Mountain' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Height (cm)	Average width (cm)	Shoot dry weight (g)
Application Time			
Liner	6.0	28.6a	7.14a
Post-transplant	5.9	27.3b	5.61b
Both	6.4	28.0ab	7.15a
Application time effect	0.1626	0.0216	<0.0001
LSD	0.3	0.5	0.13
PGR applied			
0 $mg \cdot L^{-1}$ DS	6.1	29.4	7.09a
400 $mg \cdot L^{-1}$ DS	5.8	27.8	6.75ab
800 $mg \cdot L^{-1}$ DS	6.7	28.0	6.57bc
1600 $mg \cdot L^{-1}$ DS	5.8	27.3	6.21c
600 $mg \cdot L^{-1}$ BA	5.9	28.1	6.65b
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	6.4	28.1	6.54bc
PGR effect	0.1084	0.6946	0.0004
LSD	0.4	0.7	0.18
Application Time * PGR	0.4979	0.0738	0.2916

Table 6.19. Number of basal branches, height, average width and shoot dry weight of *Achillea* 'Moonshine' liners at 2 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=6 based on two subsamples).

Treatment	Number of basal branches	Height (cm)	Average Width (cm)	Shoot dry weight (mg)
0 $mg \cdot L^{-1}$ DS	1	7.2b	11.6	412
400 $mg \cdot L^{-1}$ DS	1	6.6bc	13.1	395
800 $mg \cdot L^{-1}$ DS	1	6.3c	11.8	344
1600 $mg \cdot L^{-1}$ DS	1	5.9c	11.6	371
600 $mg \cdot L^{-1}$ BA	1	8.0a	11.6	430
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	1	6.7bc	12.3	418
Treatment effect	na	0.0001	0.2888	0.1775
LSD		0.9	1.5	73.1

Table 6.20. Number of basal branches of *Achillea* ‘Moonshine’ finished plants at 7 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=8).

Treatment	Number of branches		
Application time			
Liner	5.9		
Post-transplant	6.1		
Both	6.4		
Application time effect	0.6852		
LSD	0.5		
PGR applied	Liner	Post-transplant	Both
0 $mg \cdot L^{-1}$ DS	4.8	6.6	5.3b
400 $mg \cdot L^{-1}$ DS	6.8	6.1	4.6b
800 $mg \cdot L^{-1}$ DS	4.4	6.1	9.1a
1600 $mg \cdot L^{-1}$ DS	6.3	5.9	3.3b
600 $mg \cdot L^{-1}$ BA	6.6	6.1	8.5a
400 $mg \cdot L^{-1}$ DS + 600 $mg \cdot L^{-1}$BA	6.9	5.8	7.3a
PGR effect	0.1144	0.9908	<0.0001
LSD	2.2	2.7	2.0
Application Time * PGR		0.0002	

Table 6.21. Height, average width and shoot dry weight of *Achillea* 'Moonshine' finished plants at 7 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA) or a combination of the two. Data analysis performed by ANOVA using JMP 9.0 by SAS Institute, Inc. (Cary, NC). Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Treatment	Height (cm)			Width (cm)			Shoot dry weight (g)		
Application time									
Liner		8.5a			22.8a			2.27a	
Transplant		8.7a			22.5a			2.25a	
Both		7.1b			18.8b			1.91b	
Application time effect		<0.0001			<0.0001			0.002	
LSD		0.4			0.8			0.11	
PGR applied	Liner	Post-transplant	Both	Liner	Post-transplant	Both	Liner	Post-transplant	Both
0 mg·L^{-1} DS	8.9ab	10.3a	10.4a	25.2a	26.6a	26.1a	2.78b	2.84a	2.70b
00 mg·L^{-1} DS	9.6ab	10.9a	7.8b	27.2a	27.2a	20.4b	3.01ab	2.70a	1.56c
800 mg·L^{-1} DS	8.1b	10.0a	3.9c	17.3b	19.4b	11.0c	1.09c	1.56b	0.76d
1600 mg·L^{-1} DS	3.4c	2.0b	1.0d	12.8b	13.3c	4.9d	0.75c	0.68c	0.420d
600 mg·L^{-1} BA	10.6a	9.5a	9.9a	25.4a	23.9a	25.8a	2.72b	2.72a	3.36a
400 mg·L^{-1} DS + 600 mg·L^{-1}BA	10.6a	9.6a	9.6ab	28.8a	24.9a	24.7a	3.30a	3.02a	2.69b
PGR effect	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	2.1	1.8	2.0	4.4	3.7	3.4	0.49	0.59	0.56
Application Time * PGR		<0.0001			0.0004			<0.0001	

Figure 6.1. *Sedum spectabile* 'Autumn Joy' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA), or a combination of the two at treatment times liner (top row), post-transplant (middle row) or both (bottom row).

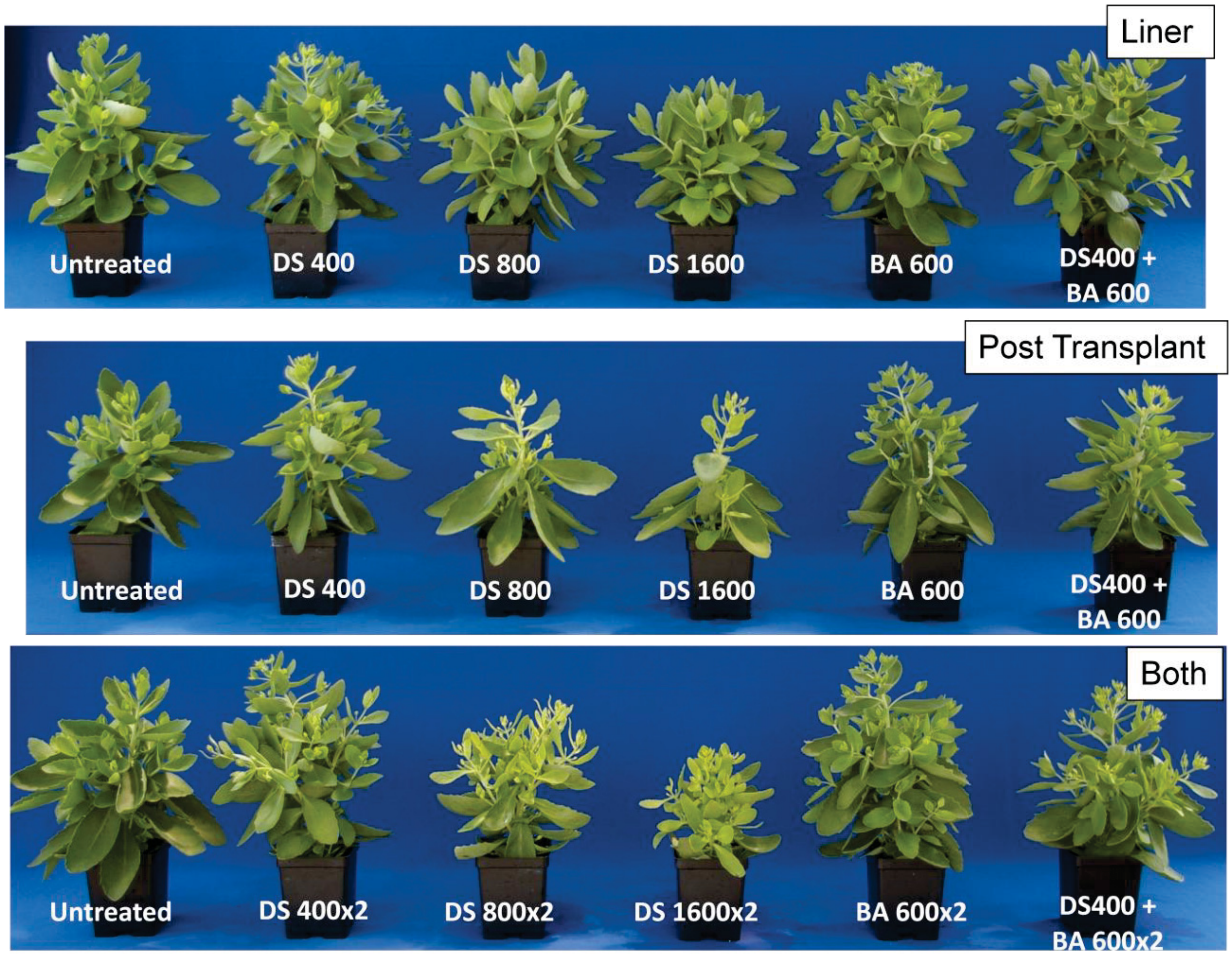


Figure 6.2. *Gaillardia aristata* 'Gallo Red' finished plants at 8 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA), or a combination of the two at treatment times liner (top row), post-transplant (middle row) or both (bottom row).

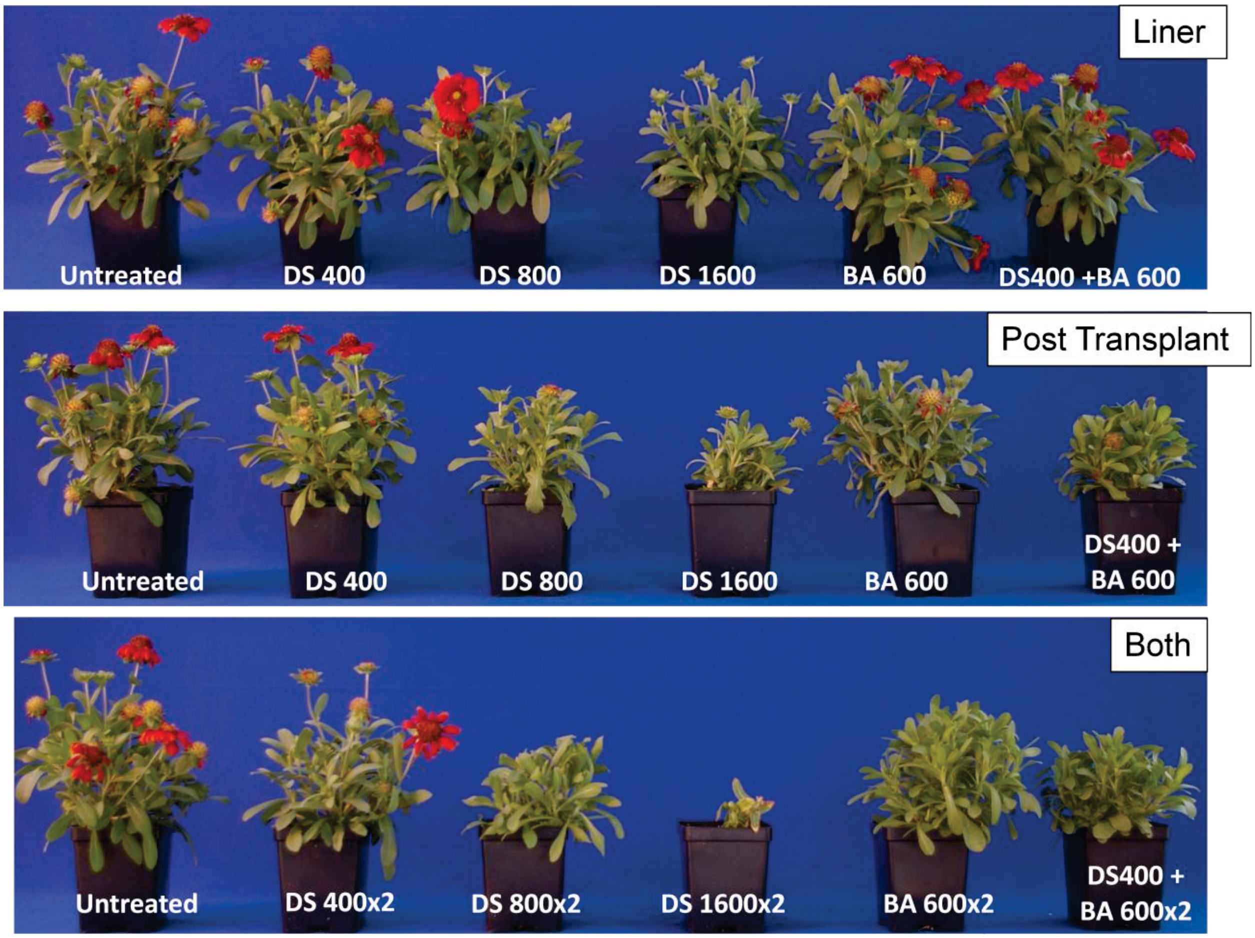


Figure 6.3. *Phlox paniculata* 'Bright Eyes' finished plants at 6 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA), or a combination of the two at treatment times liner (top row), post-transplant (middle row) or both (bottom row).

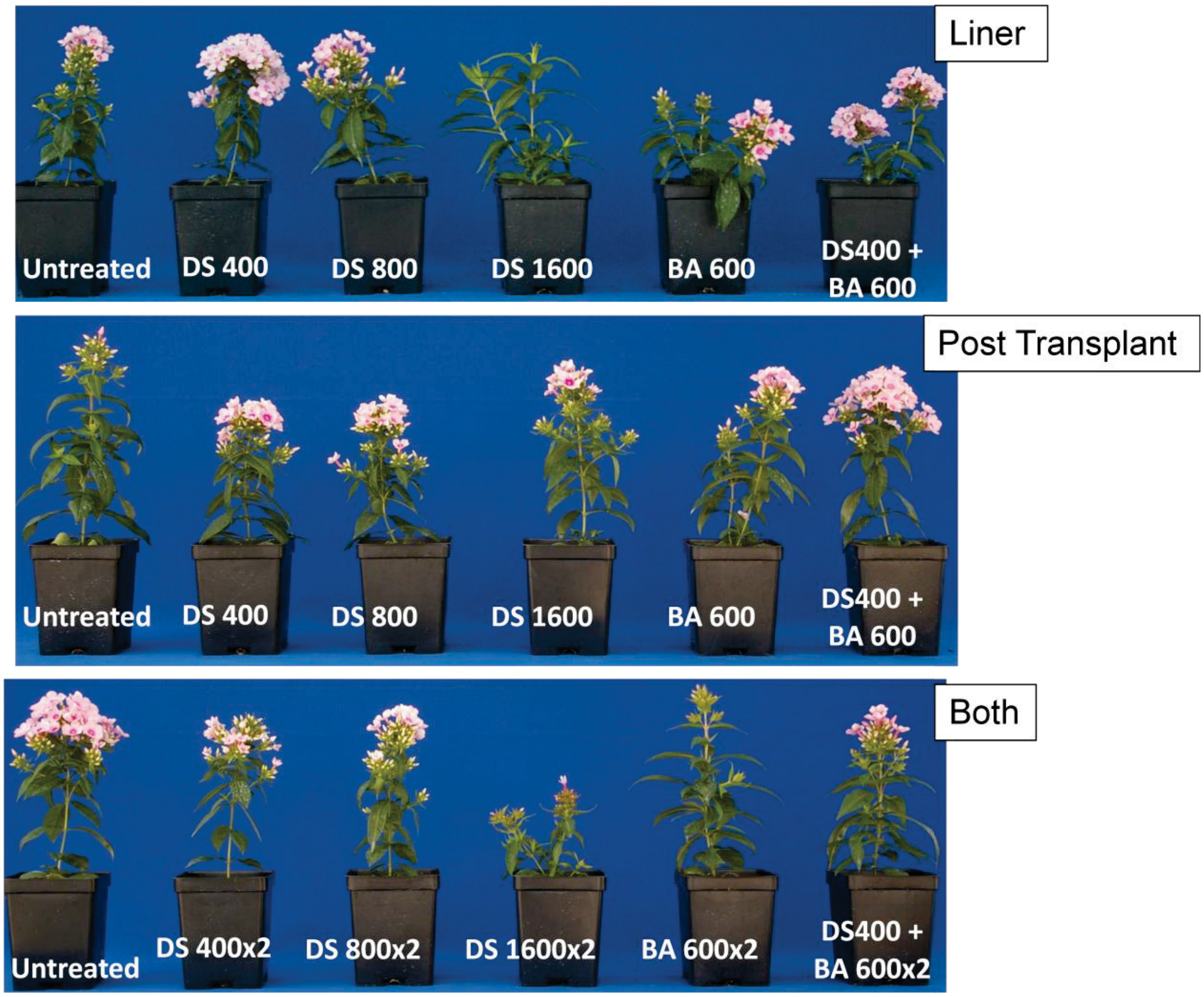
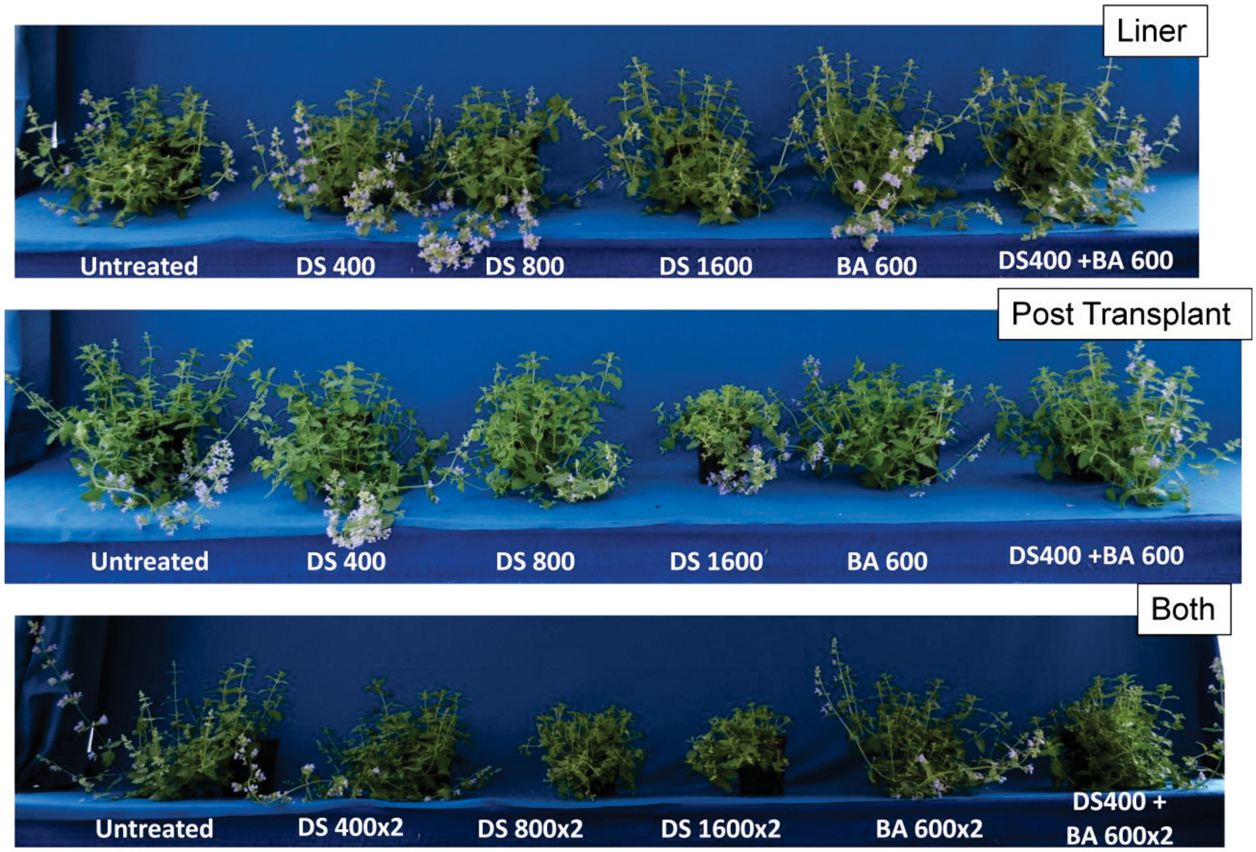


Figure 6.4. *Nepeta x faassenii* ‘Walker’s Low’ at 5 weeks after initial treatment (WAIT) with dikegulac sodium (DS), benzyladenine (BA), or a combination of the two at treatment times liner (top row), post-post-transplant (middle row) or both (bottom row).



Chapter 7 Summary: Enhancing Branching in Herbaceous Perennial Liners and Finished Plants Using PGRs

Introduction

Plant growth regulators (PGRs) are widely used by growers as a tool to control plant height, form and flowering in ornamental plant production. However, using PGRs can be challenging, because plants respond in different ways to PGRs depending on species, cultivar, growing conditions, and the PGR utilized (Gent and McAvoy, 2000). PGRs can be used to improve the marketability and appearance of plants by producing plants that are fuller and well-branched and may be able to substitute for pinching and shearing plants.

There are several new PGRs which control branching available in the marketplace. These branching agents give growers new tools to control and enhance plant growth. Over the last two years, we have been studying the effects of timing and application rates of PGRs on the branching of herbaceous perennial plants during liner production and on the growth of finished plants.

Currently many growers treat with PGRs after transplant, however treating before transplant can have significant benefits for growers. Reduced time of application and reduced chemical cost in treating plug flats results in a more cost effective method of controlling plant growth (Whitman and Runkle, 2003).

We evaluated the following branching agents: Configure (Fine Americas, Inc.), Augeo (OHP, Inc.) and Florel (Monterey Chemical). Configure is a PGR which contains benzyladenine (BA), a synthetic cytokinin. The application of additional cytokinin disrupts apical dominance and stimulates the growth of lateral buds (Cline, 1991), resulting in more basal or lateral branching, depending on the plant's growth habit, and fuller plants. In a study of 18 juvenile perennials tested after transplanting to 3.5" pots, BA increased lateral offshoots in 89% of the perennials tested (Martin and Singletary, 1999). When applied to several petunia cultivars, BA increased branching and flowering (Carey et al., 2008).

Augeo, is another PGR available for use by growers. Based on the active ingredient dikegulac sodium, Augeo acts as a chemical pinch to decrease apical dominance and stimulate bud formation, primarily in woody plants. In herbaceous plants dikegulac sodium improves branching in *Zinnia* 'Scarlet Flame,' *Helianthus annuus* 'Peredovic,' and rooted cuttings of *Chrysanthemum morifolium* 'Escapade', and *Chrysanthemum* (Arzee et al., 1977). Branching of *Gaillardia aristata* 'Gallo Yellow' was increased by foliar sprays of 400 or 800 $mg{\cdot}L^{-1}$ dikegulac sodium whereas higher spray rates of 1600 or 3200 $mg{\cdot}L^{-1}$ dikegulac sodium caused stunting and phytotoxicity (Latimer and Freeborn, 2010).

Florel is a plant growth regulator which is labeled for increasing lateral branching, delaying flowering, and inhibiting internode elongation of floricultural crops. In plant tissue, ethephon transforms into the plant hormone ethylene (Gent and McAvoy, 2000). Although the role of ethylene in regards to apical dominance is not well understood, ethephon is used as a pinching agent which inhibits terminal buds and releases outgrowth of axillary buds (Cline, 1991).

Methods and materials

In our studies, plants arrived as unrooted cuttings, which were then dipped in rooting hormone and stuck into 72-cell flats filled with media. Cuttings were allowed to root under mist with bottom heat for 2 to 3 weeks. As soon as plants were showing roots on four sides of the root ball but before the root ball was tightly held together (Figure 7.1), plants were treated with PGRs and compared to an untreated control. PGR treatments included:

- Configure: one application of 300 ppm, two applications of 300 ppm with the second application two weeks after the first, or one application of 600 ppm, applied as foliar spray(s).
- Augeo: 400, 800, or 1600 ppm applied as a foliar spray.
- Florel: 500 ppm applied as either a foliar spray or a drench

After treatment, plants were grown in the 72-cell flats under greenhouse conditions for 3 to 4 weeks until they were ready for transplant, and then were potted up into quart pots and grown for four more weeks. Data measurements were taken at the time the liners were finished and ready for transplant (2 to 4 weeks after treatment) and on finished plants 3 to 4 weeks after transplant. Measurements included: plant height, width, number of branches, phytotoxicity, flowering status, and root and shoot dry weights.

In another study we examined the effects of multiple versus single applications of PGRs. We applied foliar sprays of 0, 400, 800, or 1600 ppm dikegulac sodium, or 600 ppm BA to plants at the following times: as liners after rooting; to plants one week after transplant; or twice, once as liners and once post-transplant.

Results and Discussion

Of the 18 crops tested with Configure, 10 showed increased branching as liners (Table 7.1, Figure 7.2). Two crops, *Aster* and *Cosmos* had significant phytotoxicity following application of Configure. Of the 12 crops tested with Augeo, 8 showed increased branching in liners. Of the six crops we tested with Florel, the number of branches was increased only in *Verbena* and *Veronica* (Figure 7.4).

In finished plants treated with Configure in the liner stage, only *Gaura* and *Lavandula* had increased numbers of branches as finished plants 4 weeks after transplant. Increased branching was evident in finished plants of *Cosmos, Gaillardia, Rosmarinus* and *Verbena* treated with Augeo at the liner stage.

Overall, we found that plants treated twice with either Augeo or Configure (once as liners and once post transplant) had more branches than those treated once at either time (Figure 7.3). In general, two applications of 600 ppm Configure increased branches without reducing shoot growth or causing phytotoxity while two application of 1600 ppm Augeo caused stunting and yellowing in most plants.

Generally, we have seen the best results when PGRs are applied to liners after removal from mist after rooting has occurred. This time varied by crop; in our studies *Verbena* was ready for treatment at 14 days after sticking while other crops such as *Veronica* and *Rosmarinus* were ready at 28 days after sticking.

Guidelines for Using Branching Agents on Herbaceous Perennial Liners

To conduct your own trials for use on liners in your growing environment, use the following guidelines:

Treat liners when roots are evident on all sides of the root ball but before the liners are fully rooted and ready for transplant.

Spray liners early in the day. Plants should be well-irrigated with dry foliage at the time of PGR application.

For Configure, we have found that one application of 600 ppm is effective in increasing branches in liners. In responsive plants, a second application about a week after transplant is effective in increasing branches in finished plants.

For Augeo, rates of 400 or 800 ppm are effective in increasing branching without the height reductions seen with 1600 ppm. A typical reaction to Augeo is a temporary yellowing of foliage, so be sure to apply Augeo early in production, depending on the crop, 3 to 4 weeks before plants are market ready.

Be sure to hold back a few untreated plants so you can determine the effectiveness of the PGR application.

Monitor results and consider reapplying PGRs after 2 to 3 weeks to further encourage branching.

Resources for Growers

Virginia Cooperative Extension publication Selecting and Using Plant Growth Regulators on Floricultural Crops

http://pubs.ext.vt.edu/HORT/HORT-3P/HORT-3P.html

Configure Product Information and University Trial Results

http://www.fine-americas.com/_Attachments/Resources/750_S4.pdf

OHP PGR Solutions

http://www.ohp.com/Literature/pdf/PGR_Solutions.pdf

Plant growth regulator calculator (PGRCALC) developed by floriculture specialists from North Carolina State University and the University of New Hampshire Cooperative Extension http://extension.unh. edu/agric/AGGHFL/Plantgrowthregulatorcalculator.cfm

PGR Mix Master, a mobile app for Android, iPhone and Blackberry developed by The University of New Hampshire Cooperative Extension.

http://extension.unh.edu/Agric/AGGHFL/PGRMixMasterHome.htm

Literature Cited

Arzee, T., H. Langenauer and J. Gressel. 1977. Effect of dikegulac, a new growth regulator, on apical growth and development of three Compositae. Bot. Gaz. 138(1):18–28.

Carey, D., B. Whipker, I. McCall, and W. Buhler. 2008. Cytokinin based PGR affects growth of vegetative petunia. Proc. Plant Growth Regulat. Soc. Amer. 35:85-89.

Cline, M.G. 1991. Apical dominance. Bot. Rev. 57:318-358.

Gent, M.P.N. and R.J. McAvoy. 2000. Plant growth retardants in ornamental horticulture: a critical appraisal, p. 89-130. In Basra, A.S. (ed.) Plant growth regulators in agriculture and horticulture: Their role and commercial uses. Food Products Press, Binghamton.

Latimer, J.G. and J. Freeborn. 2010. Branching enhancers, Configure (6-BA) and Augeo (dikegulac sodium), affect branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 37:148-152.

Table 7.1 Effects of branching agents applied to moderately rooted herbaceous perennial liners as assessed 2 to 4 weeks after initial treatment.

Taxa	Branching agents tested	Effects on branching or growth
Achillea ‘Moonshine’	Configure	No increased branching, increased height
	Augeo	No increased branching, decreased height with 800 or 1600 ppm
Agastache 'Purple Haze’	Configure	Increased branching 1 or 2 applications of 300 ppm or 1 application of 600 ppm
Aster 'Professor Anton Kippenburg'	Configure	Tip burn caused damage to plants
	Augeo	Increased branching and height and shoot weight with 400 or 800 ppm but growth? reduced with 1600 ppm
	Florel	No effect
Campanula punctata ‘Cherry Bells’	Configure	No effect
	Augeo	No effect
	Florel	No effect
Cosmos atrosanguineus	Configure	Increased branching but distorted leaves
	Augeo	Increased branching with 800 or 1600 ppm. Reduced height with 1600 ppm
	Florel	Reduced branching with 500 ppm spray
Delosperma ‘Table Mountain’	Configure	Reduced shoot weight
	Augeo	Reduced branching with 400 ppm, reduced shoot weight with 800 ppm
Gaillardia aristata ‘Gallo Red’	Configure	Increased branching with 600 ppm
	Augeo	Decreased branching, height and shoot weight with 1600 ppm
Gaura lindheimeri 'Siskiyou Pink'	Configure	Increased branching with 1 or 2 applications of 300 ppm or 1 application of 600 ppm
Lavandula ×intermedia 'Provence'	Configure	Increased branching with 600 ppm
Leucanthemum ×superbum 'Snowcap'	Configure	Increased branching with 1 or 2 applications of 300 ppm or 1 application of 600 ppm
Nepeta racemosa ‘Walker’s Low’	Configure	No effect
	Augeo	Increased branching with 800 or 1600 ppm, reduced height with 1600 ppm
Phlox paniculata ‘Bright Eyes’	Configure	Increased branching and shoot weight with 600 ppm
	Augeo	Increased branching and reduced height and shoot weight with 1600 ppm
Rosmarinus officinalis 'Hill Hardy'	Configure	Increased branching with 2 applications of 300 ppm or 1 application of 600 ppm
	Augeo	Increased branching with 400, 800 or 1600 ppm

	Florel	No effect with 500 ppm spray or drench
Salvia ×sylvestris 'May Night'	Configure	No effect
Sedum spectabile 'Autumn Joy'	Configure	400% increase in number of branches with 600 ppm
	Augeo	200% to 300% increase in branching with all rates, reduced height and shoot dry weight with 1600 ppm
Verbena bonariensis 'Lollipop'	Configure	No effect
	Augeo	Significant increase in number of branches with 400, 800, or 1600 ppm, reduced height with all rates especially 1600 ppm
	Florel	Increased branching with 500 ppm spray
Veronica 'Goodness Grows'	Configure	Increased branching with 1 or 2 applications of 300 ppm or with 1 application of 600 ppm
	Augeo	Increased branching with 400 or 800 ppm, stunting with 1600 ppm
	Florel	Increased branching with 500 ppm spray

Table 7.2 The effects of branching agents applied to moderately rooted herbaceous perennial liners on the finished plants at 4 weeks after transplant.

Taxa	Branching agents tested	Effects on branching or growth
Achillea 'Moonshine'	Configure	No effect
	Augeo	No effect
Agastache 'Purple Haze'	Configure	Reduced branching in plants treated with 2 applications of 300 ppm or 1 application of 600 ppm
Aster 'Professor Anton Kippenburg'	Configure	Stunting in plants treated with 2 applications of 300 ppm
	Augeo	No effect
	Florel	No effect
Campanula punctata 'Cherry Bells'	Configure	No effect
	Augeo	No effect
	Florel	No effect
Cosmos atrosanguineus	Configure	Distorted leaves still evident in finished plants
	Augeo	Increased branching and reduced shoot weight with 1600 ppm
	Florel	No increased branching, reduced height with 500 ppm spray
Delosperma 'Table Mountain'	Configure	No effect
	Augeo	No effect
Gaillardia aristata 'Gallo Red'	Configure	Delayed flowering
	Augeo	Increased branching with 400 ppm, reduced height and shoot weight with 1600 ppm, delayed flowering with 800 or 1600 ppm
Gaura lindheimeri 'Siskiyou Pink'	Configure	Increased branching with all treatments
Lavandula ×intermedia 'Provence'	Configure	Increased branching with 2 applications of 300 ppm
Leucanthemum ×superbum 'Snowcap'	Configure	No effect
Nepeta racemosa 'Walker's Low'	Configure	No effect
	Augeo	No effect
Phlox paniculata 'Bright Eyes'	Configure	No effect
	Augeo	No effect
Rosmarinus officinalis 'Hill Hardy'	Configure	No effect
	Augeo	Increased branching with 800 or 1600 ppm
	Florel	No effect
Salvia ×sylvestris 'May Night'	Configure	No effect

Sedum spectabile 'Autumn Joy'	Configure	No effect
	Augeo	No effect
Verbena bonariensis 'Lollipop'	Configure	No effect
	Augeo	Increased branching with 800 or 1600 ppm
	Florel	No effect
Veronica 'Goodness Grows'	Configure	No effect
	Augeo	Stunting with 800 or 1600 ppm
	Florel	No effect

Table 7.3 Effects of single vs. multiple applications of branching agents on finished herbaceous perennial plants. PGRs were applied as liners, post-transplant, or both times.

Taxa	Branching agents tested	Effects
Achillea 'Moonshine' yarrow	Configure	Increased branching in plants treated both times
	Augeo	Stunting in plants treated both times with 800 or 1600 ppm
Delosperma 'Table Mountain' iceplant	Configure	No effect
	Augeo	No effect
Gaillardia aristata 'Gallo Red' blanketflower	Configure	Increased number of branches in plants treated both times; delayed flowering in plants treated as liners or both times
	Augeo	Increased branching in plants treated as liners with 400 ppm. Reduced height and shoot weight in plants treated with 800 or 1600 ppm at all treatment times. Delayed flowering in plants treated with 800 or 1600 ppm as liners or both times.
Nepeta racemosa 'Walker's Low' catmint	Configure	Increased branching in plants treated post-transplant or both times
	Augeo	Increased branches in plants treated with 800 ppm post –transplant or both times with 1600 ppm. Stunting in plants treated both times with 800 or 1600 ppm.
Phlox paniculata 'Bright Eyes' garden phlox	Configure	Increased branching in plants treated both times.
	Augeo	Increased branching in plants treated both times with 1600 ppm, significant reduction in flower stalk height
Sedum spectabile 'Autumn Joy' stonecrop	Configure	Plants treated post transplant or both times had increased branching
	Augeo	Plants treated both times had increased branching, reduced shoot weight and yellowing with 800 or 1600 ppm.

Figure 7.1 *Achillea* ‘Moonshine liner at the time of treatment

Figure 7.2 *Gaura* ‘Siskyou Pink’ liners at 4 weeks after treatment with Configure. From left: untreated control, liner treated with one application of 300 ppm, liner treated with two applications of 300 ppm, liner treated with one application of 600 ppm.

Figure 7.3 *Sedum spectabile* 'Autumn Joy' finished plants treated twice with PGRs, once as liners and once post-transplant. From the left untreated, plant treated twice with 400 ppm Augeo, plant treated twice with 800 ppm Augeo, plant treated twice with 1600 ppm Augeo, plant treated twice with 600 ppm Configure.

Figure 7.4 *Veronica* 'Goodness Grows' finished liners at 3 weeks after treatment with Augeo or Florel. From left: untreated, liner treated with 400 ppm Augeo, 800 ppm Augeo, 1600 ppm Augeo, 500 ppm Florel spray.