Controlling Growth in *Echinacea* Hybrids

Mara Celeste Grossman

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

Doctor of Philosophy

In

Horticulture

Holly L. Scoggins, Chair

Joyce G. Latimer

Erik H. Ervin

J. Roger Harris

Richard E. Veilleux

February 10, 2017

Blacksburg, Virginia

Keywords: Ornamental horticulture, plant growth regulators, herbaceous perennial

Controlling Growth in *Echinacea* Hybrids

Mara Celeste Grossman

ABSTRACT

New hybrid *Echinacea* cultivars, based on crosses of *Echinacea purpurea* (L.) Moench with several other *Echinacea* species, have generated interest and excitement in the marketplace due to novel flower colors and forms. However, these cultivars vary significantly in their growth habits and requirements from the species. We examined factors in the production of *Echinacea* hybrid cultivars to provide guidance to growers. Foliar sprays 600 $mg \cdot L^{-1}$ benzyladenine (BA) increased numbers of branches between 19% and 83% in *Echinacea* cultivars while 400 $mg \cdot L^{-1}$ dikegulac sodium or 500 $mg \cdot L^{-1}$ ethephon did not improve branching. Of several height control PGRs applied to *E.* 'Marmalade,' only plants treated with two applications of 5000 $mg \cdot L^{-1}$ daminozide were shorter (24%) compared to untreated controls although flowering was also reduced by 70%. *Echinacea* 'Harvest Moon' plants were shorter in response to all of the PGRs applied, with the best results seen in plants treated with foliar sprays of uniconazole (one application of 30 $mg \cdot L^{-1}$ or two applications of 15 $mg \cdot L^{-1}$), two applications of 5000 $mg \cdot L^{-1}$ daminozide, or 4 $mg \cdot L^{-1}$ paclobutrazol applied once as a drench. Supplying N at 150 $mg \cdot L^{-1}$ during the growing season provided *Echinacea* cultivars adequate nutrition and maximized numbers of branches and flowers and shoot dry weight. In overwintering, fertilization treatments that resulted in low substrate electrical conductivity going into dormancy, 5.0 kg·m controlled release fertilizer 15N-3.9P-10K or 150 $mg \cdot l^{-1}$ N using 15N-2.2P-12.5K applied using constant liquid feed, resulted in the highest survival rates of *Echinacea* cultivars. As a monitoring tool, SPAD measurements were not successful in predicting tissue N levels in *Echinacea* hybrids. Twenty-one hybrid cultivars acquired as stage 3 tissue culture plantlets were grown under one of three photoperiods (10-hour, 16-hour, or 24-hour) for 10 weeks before being transplanted to larger containers and grown under natural daylength until flowering. Providing *Echinacea* hybrid cultivars with a 16-hour photoperiod during liner production resulted in plants which flowered soonest without negative effects on growth. The need for height control PGRs varied by cultivar; however, overall height control PGRs controlled flower stalk height and increased market rating.

Controlling Growth in *Echinacea* Hybrids

Mara Celeste Grossman

GENERAL AUDIENCE ABSTRACT

New hybrid *Echinacea* cultivars, based on crosses of *Echinacea purpurea*, purple coneflower, with several other *Echinacea* species, have generated interest and excitement in the marketplace for perennial plants due to novel flower colors and forms. However, these cultivars vary significantly in their growth habits and requirements from the species. Little information exists on nursery and greenhouse containerized cultutral protocols for many of these relatively expensive hybrids. Our objective in this study was to examine production factors in the production of *Echinacea* hybrid cultivars, including the use of plant growth regulators (PGRs), fertilization and photoperiod (or daylength) to provide guidance to nursery and greenhouse growers. We examined the effect of several PGRs to increase branching, thus creating a fuller, more marketable plant, in two widely-grown cultivars (*Echinacea* 'Marmalade' and 'Harvest Moon'); foliar sprays of benzyladenine (BA) increased the number of branches in *Echinacea* cultivars while dikegulac sodium or ethephon did not improve branching. Of several PGRs used to control plant height for more compact plants only two applications of daminozide were effective on *Echinacea* ‘Marmalade,’ although flowering was also reduced. *Echinacea* ‘Harvest Moon’ plants were shorter in response to all of the PGRs applied, with the best results seen in plants treated with foliar sprays of uniconazole or daminozide, or paclobutrazol applied as a drench. Several studies were conducted to determine optimum fertilization strategies for *Echinacea* hybrid cultivars. Supplying nitrogen (N) at 150 $mg \cdot L^{-1}$ during the growing season provided *Echinacea* cultivars adequate nutrition and maximized numbers of branches and flowers and shoot dry weight. In overwintering, fertilization treatments that resulted in low substrate electrical conductivity, a measure which indicates level of plant available nutrients, going into dormancy resulted in the highest survival rates of *Echinacea* cultivars. Providing *Echinacea* hybrid cultivars with a 16-hour photoperiod after transplant of tissue culture plantlets resulted in plants which flowered soonest without negative effects on growth. The need for height control PGRs varied by cultivar; however, overall, height control PGRs reduced flower stalk elongation and increased market rating.

Acknowledgments

I would like to take this opportunity to express my sincere gratitude to the many people who have assisted and contributed along the way on my journey to completing this Ph.D.

First of all, I would like to thank the members of my graduate committee. To my advisor, Holly Scoggins, thank you for helping me see this dissertation to completion while maintaining a sense of humor and humility. Thanks to Joyce Latimer, whose guidance and support I have relied on over the years. Thanks to Roger Harris for being a mentor and champion, in teaching and in research. To my committee members Erik Ervin and Richard Veilleux, I am very grateful to you for your assistance and suggestions, as well as for providing me with a fresh perspective.

I would like to acknowledge Margaret Aiken for all of her research assistance and hard work. I would also like to thank the many other people who were critical in this research including Jeff Burr, Sarah Holt, and John James; along with student researchers Leslie Peck, Erika Lyons, Lauren Maletto, Chris Artigue, Becca Good, Travis Higginbotham, Parker Laimbeer, James Rockwell, and Elizabeth Harper. I am grateful to my fellow Horticulture Department graduate students, for their companionship and friendship.

I am grateful to Battlefield Farms Inc., Fine Americas, Inc., Sungro Horticulture, AB Cultivars Inc., and the Virginia Nursery and Landscape Association for their generous donations of funding and materials.

Lastly, I would like to thank my family for their love and support. I am so grateful to my children, for believing in me and putting up with me through it all. Thanks to my husband for whose encouragement and patience made completion of this Ph.D. possible.

Table of Contents

List of Tables

List of Figures

Chapter 1. Literature Review

Objective of Study

This study intends to look into factors which affect the production of *Echinacea* liners (rooted cuttings) and finished plants. The aim is to develop protocols for liners and finished plant production for newer *Echinacea* cultivars available today which have not yet been studied extensively and which present challenges to growers. Factors to be examined include fertility, plant growth regulators (PGRs), and photoperiod. In combining best practices, we hope to develop enhanced, value-added liners, which are of increased quality and may reduce time to finish for growers.

Introduction

Nursery and greenhouse production contributes significantly to the U.S. economy, with sales of $20.4 billion annually, and provides over 240,000 jobs (Hodges et al., 2015). As economic indicators, including private investment, employment, consumer spending, and a growing housing market, point to growth in 2016, the outlook for the green industry is strong and demand for green industry products is projected to increase over the next several years (Hall, 2016).

Overall, floriculture crops are increasing in sales in the United States. In 2014, sales of floriculture crops from all states were $5.9 billion, according to the 2012 Census of Agriculture Census of Horticultural Specialties (2014), up from $5.0 billion in the most recent previous census in 2009 (USDA, 2015). The market for perennial plants, a subset of the overall floriculture market, is also robust in the United States; sales of herbaceous perennial plants in 2014 rose to $945 million, up from $844 million in 2009 (USDA, 2015). There are thousands of species of perennials in cultivation today; this tremendous variation in species, flower time and cultural requirements presents challenges to growers (Kessler, 2014).

Echinacea

Echinacea L. is a genus of nine species in the Asteraceae family which is native to most of North America (Ault, 2007). *Echinacea purpurea* (L.) Moench, eastern purple coneflower, is a popular, long-blooming garden plant which is also used as a cut flower (Armitage, 2008).

Other taxa include: *E. pallida*, *E. paradoxa*, *E. angustifolia*, *E. atrorubens, E. laevigata*, *E. sanguinea*, *E. simulata*, and *E. tennesseensis* (Table 1.1).

Echinacea was used by Native Americans as a medicinal plant and continues to be used today as an herbal medical supplement commonly used to treat cold and flu symptoms (USDA, 2014). *Echinacea* is one of the top selling perennials in the United States; with $15.7 million in sales in 2014, it is the 5th highest selling perennial in the United States (USDA, 2015).

The discovery that different *Echinacea* species readily cross with one another (Ault, 2007; Frett, 2009) has led to the introduction of many hybrid cultivars (Table 1.2, vegetative cultivars, and Table 1.3, seed cultivars) with new flower colors and forms (Armitage, 2008; Schoellhorn and Richardson, 2006). By crossing plants of different species, resulting hybrids have different growth habits, hardiness, and heat and drought tolerance than parent plants (Ault and Thomas, 2014). Many hybrids are infertile and must be vegetatively propagated (Ault and Thomas, 2014). As *E. purpurea* is more shade and moisture tolerant than other *Echinacea* species, hybrids based on *E. purpurea* crossed with other species are less tolerant of shade and wet conditions than the species (Frett, 2009). New hybrid cultivars may be less hardy and vigorous than the species (Kaiser et al., 2015). Armitage (2008) states that the more hardy hybrids contain more *E. purpurea* genetic content; however, as breeders do not disclose genetic information, it is difficult to know which hybrids have more *E. purpurea* germplasm. Field trials in Vermont have shown some *Echinacea* hybrids are less hardy than others (Perry, 2015). Of 124 cultivars trialed in USDA zone 4a, the following cultivars died after planting in at least three growing seasons between 2009 and 2015: Burgundy Fireworks, Crazy Pink, Flame Thrower, Harvest Moon, Red Knee High, Secret Desire, Solar Flare, Tangerine Dream, and Tiki Torch.

The rise in the number of hybrids began in the early 2000s. A double flowering coneflower was discovered in the Netherlands which was released in the marketplace in 2003 as 'Razzmatazz' (Carey and Avent, 2014). By breeding *E. purpurea* with *E. paradoxa*, Dr. Jim Ault of the Chicago Botanical Gardens created yellow and orange flowering hybrids, released as the Meadowbrite Series in 2004 (Schoellhorn and Richardson, 2006). The breeding program at Chicago Botanical Gardens has released two- and three-species hybrids from five species of *Echinacea* (Ault and Thomas, 2014). Richard Saul of ItSaul Nursery (Alpharetta, GA) created hybrids based on *E. purpurea* and *E. paradoxa* (Schoellhorn and Richardson, 2006). Terra Nova Nurseries (Oregon) introduced hybrids with novel, intense colors, while Arie Bloom (Holland) produced many double flowered forms (Carey and Avent, 2014). New cultivars continue to be bred and evaluated in trials (Armitage, 2011; Ault and Thomas, 2014).

While the introduction of novel colors, forms, and even fragrance has resulted in a revolution in the genus (Armitage, 2011; Baggett, 2008), new cultivars have proved challenging for growers to produce. Among the difficulties: achieving uniform and consistent flowering (Grossman et al., 2015; Warner et al., 2013), determining greenhouse crop times for new introductions (Whitman et al., 2007), achieving a well-branched plant (Latimer and Freeborn, 2009), rooting poorly and experiencing slow establishment of starter material along with significant plant losses after transplant (Padhye and Whitman, 2008; Westervelt, 2016), and developing protocols for use of plant growth regulators (PGRs) to control height of taller cultivars (Whitman et al., 2007).

Light and *Echinacea*

Photoperiod

Photoperiod, or daylength, affects flowering in some plants. Plants can be divided into groups based on their response to photoperiod: short-day (SD) plants require less than a critical period of light per day to trigger flowering, long-day (LD) plants require more than a critical period of light, day-neutral (DN) plants flower regardless of photoperiod, and intermediate day-length (ID) plants flower under a specific range of light period from 12.5 to 16 hours (Thomas and Vince-Prue, 1996). In natural SD, breaking up the night by providing a brief period of light, called night-interruption (NI) lighting, can induce flowering in LD plants, as plants perceive and respond to the length of the night (Thomas and Vince-Prue, 1996).

Investigations into what photoperiod induces flowering in *Echinacea* have shed some light on flowering in the species. Night interruption treatments, with intervals from 30 minutes to 4 hours, induced flowering in *E. purpurea* ‘Bravado’ while plants under continuous SD did not flower (Runkle et al., 1998). In a subsequent study, Runkle et al. (2001) found that *E. purpurea* ‘Bravado’ and ‘Magnus’ flowered fastest under ID photoperiods (13-15 hours) or when provided with a night interruption (NI); flowering was inhibited by SD less than 12 h or under a 24 h photoperiod. Seedlings in this study were kept under ID photoperiod until 8 weeks after germination when they were transplanted and placed under one of eight photoperiods: 10, 12, 13, 14, 15, 16, or 24 h of light, or 9 h with NI. A low percentage (10-15%) of plants in 10 or 24 h photoperiods flowered, which the authors ascribe to exposure to inductive photoperiod during seedling growth.

Heide (2004) found that *E. purpurea* 'Bravado' flowers best in SD followed by LD whereas no plants flowered in continuous SD or LD. In addition, ID photoperiods between 13 h and 16 h can meet both the SD and LD requirements. Treatments in this study began 9 weeks after germination, when plants had four to five leaves, and were ready for transplant to larger (0.9 L) pots; prior to this, germinated seedlings were all kept under a 24 h photoperiod. Kim et al. (2005) had similar results, finding that *Echinacea* flowers completely (100% flowering) and earliest under a continuous 14 h photoperiod (ID), although complete flowering was also achieved with 4 weeks of SD followed by 16 h photoperiod (LD) or 6 weeks of SD followed by 24 h photoperiod. In some plants, flower initiation depends on not one but two photoperiod treatments, this is known as having a dual daylength or dual induction requirement (Thomas and Vince-Prue, 1996). Thus, *Echinacea* can be considered to be both an ID flowering plant and a dual induction SD/LD plant.

Warner et al. (2013) investigated the length of the intermediate photoperiod that best induces flowering in seed grown *Echinacea* hybrid cultivars; flowering was most rapid and uniform for plants grown under a constant 14 h photoperiod, compared with those grown under a 9 h or 12 h photoperiod. In clonally propagated *Echinacea* hybrid cultivars, SD treatment inhibited flowering (Warner et al., 2013). *Echinacea* 'Sunrise,' a yellow flowered hybrid, flowered only at photoperiods above 13 h (Padhye and Whitman, 2008).

Articles in trade publications have mentioned the effect of photoperiod in liner production of tissue culture *Echinacea*. In an article in Grower Talks magazine, Chris Fifo (2010) of Swift Greenhouses (Gilman, IA) recommends 24 h lighting immediately after transplanting tissue culture plantlets of *Echinacea* in order to prevent premature flowering and long day photoperiod after transplant to encourage flowering. Paul Pilon (2013) of Perennial Solutions advises 24 h lighting immediately after transplanting tissue culture plantlets continuing after transplant until plants are sufficiently bulked with long days of 14 h after bulking to encourage flowering.

Daily light integral (DLI)

While photoperiod is a measure of how long plants receive light in a 24 h period, DLI is a measure of how much light plants receive in a day and is also an important factor in plant growth and development (Torres and Lopez, 2010). DLI measures the amount of photosynthetically active radiation (PAR) received in a day, expressed as mol·m^{-2}·d^{-1} (moles per m^2 per day). Increasing DLI improves plant size and quality (Runkle, 2005) while plants grown under low light conditions have delayed development (Torres and Lopez, 2010). Plants can be divided into two groups regarding DLI, irradiance indifferent plants, which do not develop flowers at an earlier developmental stage when provided with additional light, or facultative irradiance plants, which develop flowers earlier when provided with extra lighting (Pilon, 2006). DLI is a factor in flowering in *Echinacea*; while either of two LD treatments (16 h LD or 9 h plus NI) induced flowering of *E.* hybrid cultivars, the 16 h treatment induced flowering earlier than NI (Warner et al., 2013). Finished *Echinacea* need at least 6 mol·m^{-2}·d^{-1} for good quality growth, with highest quality achieved at over 16 mol·m^{-2}·d^{-1} (Torres and Lopez, 2010).

Photosynthesis and light

A portable photosynthesis system (such as LI-COR LI-6400XT, LI-COR Inc., Lincoln, NE) has often been used to measure photosynthesis and gas exchange to estimate the effect of light and light treatments on the growth and morphology of plants. Lighting used in plant production, such as high pressure sodium (HPS) lamps or light emitting diode (LED) lights, may affect photosynthesis and plant growth. In manipulating light to provide adequate light intensity and the appropriate photoperiod, it is important to understand these effects. Photosynthesis of *Euphorbia pulcherrima* was not affected by supplemental light source, HPS lights or white or red/blue LED lights, nor was there a correlation between photosynthesis and biomass (Bergstrand and Schüssler, 2012). In this study, plants grown under HPS lights had greater shoot elongation than those grown under LED lights. Similarly, photosynthesis and growth of *Impatiens*, *Pelargonium*, or *Petunia* cuttings were not affected by growth under supplemental HPS or LED lights; stem length of *Petunia* cuttings was less under LED lights compared to HPS lights (Currey and Lopez, 2013). While DLI affected growth and morphology of *Heuchera americana* grown under DLI's ranging from 7.5 to 21.8 mol·m^{-2}·d^{-1}, photosynthesis and respiration were not affected by DLI treatments (Garland et al., 2012). In a study comparing the effects of sole-source lighting on the growth of *Echinacea* seedlings, fresh weight and shoot dry weight were reduced in plants grown under LED or fluorescent lights compared to those grown under natural sunlight in a 16 h photoperiod; however, photosynthesis and respiration were not affected by light treatments when measured 50 days after treatment (Castronuovo et al., 2016).

Regardless of type of lighting used, photoperiod can affect photosynthesis in plants. In two *Peonia lactiflora* cultivars grown under 9, 14, or 18 h photoperiods, photosynthesis was reduced in one cultivar grown under the 18 h photoperiod compared to those grown under shorter photoperiods (Han et al., 2015) while photosynthesis was not affected by photoperiod in the other cultivar. Likewise, in three *Rosa* L. cultivars, photosynthesis was reduced in plants grown under a 14 h photoperiod compared to a 10 h photoperiod with no differences among cultivars (Grossi et al., 2003). However, in *Chrysanthemum morifolium*, a short day plant, chlorophyll concentration, which is highly correlated with photosynthesis (Netto et al., 2005), was increased by LD conditions as compared to SD conditions (Kazaz et al., 2005). Measuring photosynthesis can provide data on the effectiveness and desirability of light and other growth treatments.

Vernalization

A cold temperature treatment, or vernalization, affects flowering in some plants. Plants can have an obligate (cold treatment is required for flowering) or facultative (cold treatment increases the rate at which plants flower) response or no vernalization requirement at all (Ha, 2014). There is some disagreement in the literature on whether or not *Echinacea* requires or benefits from vernalization. Schoellhorn and Richardson (2006) state that *Echinacea* cultivars do not require vernalization but will flower 4 to 8 weeks sooner when vernalized, which suggests a facultative response to vernalization. Kessler (2014) lists *Echinacea pupurea* as a plant which benefits from vernalization. Pilon (2016) agrees that *Echinacea* benefits from vernalization in that non-vernalized liners frequently have fewer basal branches than vernalized liners and take more time to bulk up.

However, other recent studies which have examined the effect of vernalization on flowering in *Echinacea* have found that *Echinacea* has no response to vernalization. Runkle et al. (2001) grew both cooled and non-cooled *Echinacea* ‘Magnus’ and ‘Bravado’ under various photoperiods; although photoperiod affected days to flower, cold treatment did not affect days to flower in either cultivar. Similarly, in examining the response of newly introduced herbaceous perennials to photoperiod and cold treatments, Whitman and Runkle (2013) found that flowering of *Echinacea* ‘Secret Passion’ was not affected by a low temperature treatment.

Branching in *Echinacea*

Basal branches are produced in *Echinacea* while the plant is in a vegetative (non-flowering) state, however premature flowering limits branching and is an issue with many of the newer varieties typically produced through tissue culture (Fifo, 2010; Pilon, 2011; Whitman et al., 2007). *Echinacea* is a SD/LD plant; SD are needed for bulking followed by LD to initiate flowering (Heide, 2004; Warner et al., 2013). When grown at times of the year when these conditions do not happen naturally, *Echinacea* may branch poorly (Padhye and Whitman, 2008). Pinching has not been shown to increase branching in *Echinacea* (Padhye and Whitman, 2008; Whitman et al., 2007).

Spray applications of benzyladenine (BA) have been successful in increasing branching of *Echinacea*. Six *Echinacea* cultivars sprayed with 600 $mg \cdot L^{-1}$ BA (Configure, Fine Americas, Inc., Walnut Creek, CA) two weeks after transplant had significantly more branches than untreated controls at 4 weeks after treatment (Latimer and Freeborn, 2009). Branches in *Echinacea* 'Double Decker,' 'White Swan,' 'Ruby Star,' and 'Magnus' more than doubled at 4 to 8 weeks after treatment when treated with a single application of 300 $mg \cdot L^{-1}$ BA 2 weeks after transplant (Latimer et al., 2008).

Plant species as well as cultivars within the same species can have differing responses to plant growth regulators (Pilon, 2011). Although *Echinacea* 'Double Decker' and 'White Swan,' both had greater numbers of branches with increasing rates of BA from 600 to 1200 $mg \cdot L^{-1}$ BA, flowering was delayed 4 to 7 days in 'Doubledecker' while there was no delay in flowering seen in 'White Swan' (Latimer et al., 2008). In this study, there was little increase in number of branches in 'Magnus' with increasing rates of BA application over 300 $mg \cdot L^{-1}$ BA. Latimer et al. (2009) found that while numbers of branches increased in all six *Echinacea* cultivars treated with 600 $mg \cdot L^{-1}$ BA, older seed-grown cultivars White Swan, Magnus, Doubledecker and Ruby Star had more of an increase in branching than newer cultivars Fragrant Angel, Merlot, and Tiki Torch tested. In *Echinacea* 'After Midnight,' 600 $mg \cdot L^{-1}$ BA was most effective for increasing the number of basal branches in treated plants, while applications of 300, 600 or 900 $mg \cdot L^{-1}$ BA increased numbers of branches in 'Harvest Moon,' 'Sunrise,' and 'Magnus' with equal effectiveness (Padhye et al., 2010).

As BA acts to release dormant lateral buds (not to create new buds), the application of BA is effective as long as the plant is actively growing (Carey et al., 2010). *Echinacea purpurea*

‘White Swan’ treated with 600 $mg \cdot L^{1}$ BA at 0, 1, 2, 3 or 4 weeks after transplant had increased basal branching compared to untreated plants (Tackett et al., 2010); the timing of application did not affect final basal branching, however earlier treatment resulted in earlier pot fill. Similarly, *Echinacea* ‘Harvest Moon,’ ‘Sunrise,’ and ‘Magnus’ treated with foliar sprays of 300, 600, or 900 $mg \cdot L^{-1}$ BA had increased numbers of branches compared to controls regardless of whether plants were treated at transplant or 3 weeks later (Padhye and Groninger, 2010b).

Benzyladenine increased branches in well-rooted liners treated with a single application of 300 $mg \cdot L^{-1}$ on the day of receipt; after 3 weeks, treated liners had three times as many branches as untreated liners or liners treated with 300 $mg \cdot L^{-1}$ ethephon (Florel, Monterey Chemical, Fresno, CA) (Padhye and Groninger, 2010a).

Multiple applications of BA at lower rates may be more effective in increasing branching during plant production than a single application at higher rates (Carey et al., 2010).To increase branching on the *Echinacea* Pow Wow series, cultural guidelines recommend two applications of 300 $mg \cdot L^{-1}$ BA spaced 2 weeks apart, with the first application 2 weeks after transplant and the second application 2 weeks later (Lacy, 2010; PanAmerican Seed, 2013).

Controlling Height in *Echinacea*

As many of the newer *Echinacea* cultivars are relatively tall, growers will likely need plant growth retardants in order to produce compact plants (Whitman et al., 2007). Previous work has shown *E. purpurea* is responsive to a number of different commercially available growth retardants including ancymidol, chlormequat chloride, daminozide, paclobutrazol, uniconazole, and flurprimidol (Latimer, 2016). *Echinacea purpurea* treated with two applications of 5000 $mg \cdot L^{-1}$ daminozide was 20% shorter than controls; spray applications of 240 $mg \cdot L^{-1}$ paclobutrazol or 40 $mg \cdot L^{-1}$ uniconazole resulted in plants 50% or 70% shorter respectively than untreated plants (Latimer et al., 1997). While foliar sprays of 40 to 160 $mg \cdot L^{-1}$ uniconazole reduced height in *E. purpurea* at 8 weeks after potting (6 weeks after treatment), at 12 weeks after potting only plants treated with 120 or 160 $mg \cdot L^{-1}$ were significantly shorter than controls (Latimer and Thomas, 1997). Research at Michigan State University has shown spray applications of ancymidol, daminozide, chlormequat chloride, or uniconazole to be effective at reducing height of *Echinacea*; multiple applications are recommended as well as applying PGRs before significant flower stem elongation occurs (Runkle, 2010). A spray application tank mix of daminozide and chlormequat chloride (Fifo, 2010) or daminozide and uniconazole (Pilon, 2014) is recommended to control height of *Echinacea*.

PGRs used to increase branching can have an effect on height as well. Ethephon delayed flowering, controlled height, and reduced number of inflorescences in *E. purpurea* 'Bravado' (Hayashi et al., 2001); plants were shorter as total ethephon increased (1, 2, or 3 sprays of 500 or 1000 $mg \cdot L^{-1}$). While the height of *E. purpurea* 'White Swan' was not affected by treatment with BA, dikegulac sodium (Augeo, OHP, Inc., Mainland PA) or combinations of the two, *E. purpurea* 'Sundown' plants treated with 800 $mg \cdot L^{-1}$ dikegulac sodium or 800 $mg \cdot L^{-1}$ dikegulac sodium combined with 600 $mg \cdot L^{-1}$ BA were shorter compared to untreated plants between 3 and 9 weeks after treatment (WAT), although finished plants at 13 WAT were not shorter than untreated controls (B. Swanson and J. Latimer, unpublished data).

With the wide variety of PGRs to choose from in controlling plant height, growers must weigh which PGR to use, concentration, method of application and number of applications. Growth retardants vary in their period of activity in the plant; paclobutrazol and uniconazol may last for several months whereas daminozide is more short-lived (Rademacher, 2000). Although different PGRs have been shown to reduce height in *Echinacea*, cultivars vary in their response to PGRs (Latimer, 2004); growers and researchers will need to investigate the PGR response of newer *Echinacea* cultivars.

Nutrition in *Echinacea*

As a general recommendation, herbaceous perennials require 100 to 200 $mg \cdot L^{-1}$ N constant liquid feed (CLF) (Kessler, 2014). However, herbaceous perennials vary in their fertilizer requirements. Scoggins (2005) investigated the responses of ten taxa grown with 50, 150, 250 or 350 $mg \cdot L^{-1}$ N from 15N-7P-14K; effects varied by taxa; some taxa showed optimum growth with high levels of fertilizers, while others had better growth with lower rates. A study of the concentration and ratio of fertilizers in the production of *Hibiscus moscheutos* L. (hibiscus) and *Rudbeckia fulgida* var. *sullivantii* Ait. 'Goldsturm' (rudbeckia) determined that the optimum concentration for perennial production is 100 $mg \cdot L^{-1}$ with a ratio of 8N:1P:2K (Kraus and Warren, 2013).

Recommendations for fertilizing *Echinacea* vary. The technical guide for *Echinacea* Conefection™ series (including *E.* 'Marmalade') calls for 100 to 150 $mg \cdot L^{-1}$ N during active growth (GLPlants.com, 2012). Other fertilizer references include 100 $mg \cdot L^{-1}$ N CLF or 200

$mg \cdot L^{-1}$ N as needed (Pilon, 2013), 75 to 150 $mg \cdot L^{-1}$ N (Kaiser et al., 2015), and avoiding high ammonium forms (Schoellhorn and Richardson, 2006). Increasing rates of N up to 200 mg N/kg media led to greater vigor, number of flowers and shoot dry weight in greenhouse-grown *E. purpurea* (Davis et al., 2010). *E. purpurea* fertilized with NO_3^-/NH_4^+ ratio of 7:1 had greater leaf area, root weight, total weight, and root to shoot ratio compared with plants grown with a NO_3^-/NH_4^+ ratio of 5:1 or 3:1 (Zheng et al., 2006). In hydroponic production, the ratio of nitrate to ammonium (either 1:1 or 1:0) did not affect leaf weight, root weight, total plant weight or root to shoot ratio of *E. angustofolia* (Montanari et al., 2008).

In nursery production of perennials, growers often use controlled release fertilizer (CRF) (Kessler, 2014). *E. purpurea* grown with 5.3 or 7.1 kg/m^3 Osmocote (The Scotts Miracle-Gro Co., Marysville, OH) 14-14-14 CRF had greater quality ratings and flower production than plants grown with 0 or 3 kg/m Osmocote (Owings and Reed, 1994). In a field study to determine best practices in perennials CRF application, *Echinacea purpurea* responded linearly to a fertilizer application of 15N-3.9P-10 at rates of 0, 4.9, 9.8 or 19.5 g/m^2 (Chen et al., 2011). *Echinacea* 'Bright Star' grown with either of two CRFs (17N-7.4P-18.1K or 19N-2.2P-10K) had greater fresh weight than those grown with a 19N-4.4P-16.6K soluble fertilizer (Bir and Conner, 2001).

The growth of plugs and liners depends mainly on nitrogen, while phosphorus and potassium are less needed at this stage (van Iersel et al., 1998; van Iersel, 2000). The production of plugs and liners has been divided into stages based on growth; lower rates of fertility are recommended for early stages (0 to 50 $mg \cdot L^{-1}$ N) with higher rates for later stages (50 to 100 $mg \cdot L^{-1}$ N or more) (Cox, 2011; Dole and Hamrick, 2006). Similarly, during the acclimation of stage 3 tissue culture plantlets, 50 $mg \cdot L^{-1}$ N CLF is recommended 5 to 7 days after planting.

Overwintering

In nursery production, perennials can be held over the winter for early spring sales. While this method allows growers to plant in the summer or fall and provides plants with cold temperatures to satisfy any vernalization requirements, growers must protect plants in overwintering to ensure their survival and prevent plant losses (Pilon, 2006; Smith, 2016). Roots are more susceptible to cold damage than shoots (Kessler, 2014). Field grown plants benefit from the surrounding soil to buffer roots from ambient air temperature but container-grown plants are not insulated underground. Plastic pots provide little protection from cold (Kessler, 2014; Perry, 1998) so additional measures must be taken to protect containerized perennials from the cold.

Depending on expected minimum temperatures, different types of growing techniques can be used, including covering with insulating cloths, sandwiching straw between plastic, and, most commonly, using a polyethylene covered structure or cold frame (Perry, 1998). During periods of extreme cold temperatures, growers cover plants inside cold frames with insulating cloths or thermoblankets to provide additional protection (Perry, 1998). Plants should be covered when low temperatures are expected to consistently remain below 0°C and removed when temperatures warm above 4°C (Smith, 2016). While soil moisture should be maintained at an adequate level, moisture levels required for producing quality perennials during overwintering vary by species and cultivar (Kingsley-Richards and Perry, 2015).

Fertilizer guidance for overwintering perennials varies. During cool periods, Perry (1998) recommends applying 50 to 100 $mg \cdot L^{-1}$ N from a nitrate-based fertilizer to containerized perennials. As temperatures cool in the fall, growers can reduce fertilizer rates by half although stopping fertilizer in September is not recommended since plants are still actively growing (Pilon, 2006). High levels of fertilizer, up to 300 $mg \cdot L^{-1}$ N from 20N-4.4P-16.6K, applied as constant liquid feed until October results in increased growth before and after overwintering (Perry, 2006). Dan Heims (2009), of Terra Nova Nurseries, recommends fertilizing with 50 $mg \cdot L^{-1}$ N or less, and monitoring ECs over the winter months; EC should be maintained at a low level in overwintering, at or below 0.7 mS/cm (Pilon, 2006).

Controlled release fertilizer (CRF) may also be used, although if the rate is too high or applied too late in the season, damage may result (Perry, 1998). CRF can be an effective way to manage nutrient levels in plants for overwintering; nutrient release is slowed as temperatures fall and plants go into dormancy for the winter (Pilon, 2006). Of three perennial fountain grass cultivars, two had better survival with low fertility, 3.5 kg/m^3 from 15N-3.9P-10K CRF, compared to those grown with high fertility, 6.5 kg/m^3, from 15N-3.9P-10K CRF (Harris et al., 2015).

Containerized *Echinacea* is intolerant of wet conditions in overwintering in nursery production (Perry, 1998). Over-watering and poor drainage encourage the crown and root diseases (Pilon, 2014) and will cause plant losses; for this reason a bark media is recommended over a peat-based media (PanAmerican Seed, 2013). Due to significant winter losses in Canadian production of hybrid *Echinacea,* factors affecting overwintering were investigated in *E. purpurea* and three orange-colored hybrid cultivars (Lemaire et al., 2014). While flower pruning and earlier potting dates did not affect survival, stopping fertilization earlier in the season (in August as opposed to October) improved winter survival of hybrid cultivars (Lemaire et al., 2014).

Liner Production

Recent studies in liner production have advanced our understanding of optimal conditions to produce quality liners. Increased DLI during propagation led to higher shoot mass, root mass and quality of annual bedding plants; growers should use supplemental lighting if necessary to achieve 8 to 12 $mol \cdot m^{-2} \cdot d^{-1}$ (Currey et al., 2012). The importance of providing nutrients early in propagation was shown by Santos et al. (2011); constant fertigation with a complete fertilizer from the day of sticking increased shoot dry weight in *Petunia*. Bedding plant seedlings should be fertilized with low concentrations (25-50 $mg \cdot L^{-1}$ N) of CLF beginning in Stage 2 when cotyledons are open, with rates gradually rising up to 100 $mg \cdot L^{-1}$ N at transplant (Cox, 2011). Tissue culture plantlets should receive 100 $mg \cdot L^{-1}$ N at about day 21 of acclimation, gradually increasing to 200 $mg \cdot L^{-1}$ N at day 35 (Fifo, 2010).

Plant growth regulators (PGRs) are effective in increasing numbers of branches in liners before transplant. Five of six perennials studied showed increased numbers of branches after treatment with BA applied after rooting but before transplant (Grossman et al., 2012). Perennials treated with two applications of BA or dikegulac sodium (DS), once as liners and once after transplant, had a greater number of branches than those treated with a single application (Grossman et al., 2013). Controlling height of liners is important as overly tall liners can lead to finished plants with unwanted excessive height (Currey, 2016). Liner soaks, in which the root balls of rooted cutting liners or seedling plugs are soaked in a PGR solution, are effective in controlling height of vigorous annuals and perennials just before transplant (Latimer, 2014); however foliar sprays are the most convenient method of PGR application during propagation (Currey, 2016).

Production of liners through stage III tissue culture plantlets is increasing due to cost savings over shipping full size plugs (Heims and Sander, 2010). However, the acclimatization and growth of plantlets can be difficult due to the delicate nature of plantlets. Rooted plantlets must be gradually acclimated to humidity and light levels as they move from the sterile, environmentally controlled lab conditions to the greenhouse environment (Chandra et al., 2010).

Growers are combining best practices to create and market enhanced plugs and liners (Burkholder and Svob, 2016). These value-added young plants are treated with PGRs, given optimal lighting and fertility, and spaced so that input needs are reduced and crop time to finish is reduced. Numerous growers offer these liners and market them under different names: for example Four Star Greenhouse calls their enhanced liners "Supernovas" while Pleasant View Gardens markets size 72 and 84 "Enhanced Liners." The majority of enhanced liners on the market are for annuals, while a few perennials are offered in larger sizes (Burkholder and Svob, 2016). Westervelt (2016) of Saunders Brothers Inc. laments problems with poor quality *Echinacea* liners and discusses the need for enhanced *Echinacea* liners which are well rooted and branched, in a vegetative state, and actively growing.

Summary

New *Echinacea* cultivars present both a challenge and an opportunity for growers. The challenge is to grow these new cultivars which are hybrids and have different growth requirements and habits than the species. The opportunity is to use the new, exciting colors and forms of hybrids to capture a share of the growing perennial market. By examining growth requirements, such as nutrition, light, and growth regulators in hybrid cultivars, we hope to develop production protocols to allow growers to meet the challenges and take advantage of the opportunities that *Echinacea* hybrid cultivars present.

Literature Cited

Armitage, A.M. 2008. Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes. 3rd ed. Stipes, Champaign, IL.

Armitage, A.M., 2011. Armitage's Garden Perennials. Timber Press. Portland, OR.

Ault, J. and C. Thomas. 2014. Plant propagation for the breeding program at Chicago Botanic Garden. Acta Hort. 1055:265-268.

Ault, J.R. 2007. Coneflower, p. 801-824. In: Anderson, N.O. (ed.) Flower breeding and genetics. Springer, Dordrecht, The Netherlands.

Baggett, P. 2008. The Echinacea factor. Horticulture 105 (6):24-29.

Bergstrand, K.J. and H.K. Schüssler. 2012. Growth and photosynthesis of ornamental plants cultivated under different light sources. Acta Hort. 956:141-147.

Bir, R.E., and J.L. Conner. 2001. Color crop time to market is influenced by fertilizer form. Proc. Southern Nursery Assn. Conf. 46:18-20.

Burkholder, J. and J. Svob. 2016. One extra crop: Easier and more profitable. GrowerTalks. 80(1):32-34.

Carey, D. and T. Avent. 2014. Echinacea explosion - the coneflower chronicles. 14 September 2014. <http://www.plantdelights.com/Article/Echinacea-Coneflower>.

Carey, D., W. Buhler and B. Whipker. 2010. Stimulating plant growth with Configure, pp. 4-7. In: J. Latimer and B. Whipker (eds.) Configure product information and university trial results. Fine Americas, Inc., Walnut Creek, CA.

Castronuovo, D., A. Sofo, S. Lovelli, V. Candido, and A. Scopa. 2016. Light spectrum affects growth and gas exchange of common dandelion and purple coneflower seedlings. Intl. J. Plant Biol. *7*:11-14.

Chandra, S., R. Bandopadhyay, V. Kumar and R. Chandra. 2010. Acclimatization of tissue cultured plantlets: From laboratory to land. Biotechnol Lett. 32:1199-1205.

Chen, Y., R.P. Bracy, A.D. Owings and J.P. Quebedeaux. 2011. Controlled-release fertilizer type and rate affect landscape establishment of seven herbaceous perennials. HortTechnology 21:336-342.

Cox, D. 2011. Fertilizing bedding plant seedlings. 31 August 2014 < http://ag.umass.edu/fact-sheets/fertilizing-bedding-plant-seedlings>.

Currey, C.J. 2016. Preventing liner stretch. e-GRO Alert 5(4):1-5.

Currey, C.J. and R.G. Lopez. 2013. Cuttings of Impatiens, Pelargonium, and Petunia propagated under light-emitting diodes and high-pressure sodium lamps have comparable growth, morphology, gas exchange, and post-transplant performance. HortScience 48:428-434.

Currey, C.J., V.A. Hutchinson, and R.G. Lopez. 2012. Growth, morphology, and quality of rooted cuttings of several herbaceous annual bedding plants are influenced by photosynthetic daily light integral during root development. HortScience 47:25-30.

Davis, J.M., D. Reardon, A. Hamilton, V. Kandhi, A. Jarmusch, and N. Cech. 2010. Influence of nitrogen and pH on constituent levels and plant growth of greenhouse-grown *Echinacea purpurea*. HortScience 45:S217-S217.

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

Fifo, C. 2010. Know and grow: Success with tissue culture Echinacea. Grower Talks 74(6):56-60.

Frett, J. 2009. Coneflowers for the mid-Atlantic region. Mt. Cuba Center. Hockessin, DE.

Garland, K.F., S.E. Burnett, M.E. Day, and M.W. van Iersel. 2012. Influence of substrate water content and daily light integral on photosynthesis, water use efficiency, and morphology of *Heuchera americana*. J. Amer. Soc. Hort. Sci. 137:57-67.

GLPlants.com. 2012. Technical guide *Echinacea* Conefections series. 31 August, 2014 <http://www.glplants.com/system/cms/files/files/000/000/508/original/ECHINACEA_Cone-fectionsSeries.pdf>.

Grossman, M., J. Freeborn, H. Scoggins and J. Latimer. 2012. Benzyladenine increases branching but reduces root growth of herbaceous perennial liners. HortScience 47:1085-1090.

Grossman, M., J. Freeborn, H. Scoggins and J. Latimer. 2013. Timing of benzyladenine and dikegulac sodium application affects branching of liners and finished herbaceous perennial plants. HortScience 48:875-882.

Grossi, J.A.S., J.T. Baker, and H.B. Pemberton. 2003. Leaf photosynthesis, flower respiration and flower longevity of pot roses influenced by cultivar and growing environment. Acta Hort. 624:329-334.

Grossman, M.C., M. Aiken, H. Scoggins, and J. Latimer. 2015. Plant growth regulators affect branching and flowering in three *Echinacea* cultivars. Proc. Plant Growth Regulat. Soc. Amer. 42:127-133.

Ha, T.M. 2014. A review of plants' flowering physiology: The control of floral induction by juvenility, temperature and photoperiod in annual and ornamental crops. Asian J. Agr. Food Sci. 2:186-195.

Hall, C.R. 2016. Green industry is set for continued growth in 2016. Greenhouse Grower 13 September 2016. < http://www.greenhousegrower.com/business-management/green-industry-is-set-for-continued-growth-in-2016/>

Han, J., G.J. Huang, T. Wu, X.M. Sun, Y. Liu and R.F. Gao. 2015. Photoperiod affects morphology, flower productivity and photosynthesis of forced potted *Paeonia lactiflora* in greenhouses. Acta Hort. 1104:211-218

Harris, W.K., J.G. Latimer, J.F. Freeborn, M. Aiken, and H.L. Scoggins. 2015. Overwintering survival and vigor of container-grown fountain grass: Influence of substrate moisture content, protective covers, and fertilizer rate. HortTechnology 25:791-795.

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. 91:305-324.

Heide, O.M. 2004. Dual induction rather than intermediate daylength response of flowering in *Echinacea purpurea*. Physiol. Plant. 120:298-302.

Heims, D. 2009. Echinacea: Surviving old man winter. GrowerTalks 73(6):34.

Heims, D. and T. Sander. 2010. Terra Nova's Heims and Sander: Tissue culture tips. Greenhouse Grower. 31 Aug. 2014. <http://www.greenhousegrower.com/plant-culture/terra-novas-heims-sander-tissue-culture-tips>.

Hodges, A.W., C.R. Hall, M.A. Palma, and H. Khachatryan. 2015. Economic contributions of the green industry in the United States in 2013. HortTechnology 25:805-814.

Kaiser, C., R. Geneve, and M. Ernst. 2015. Echinacea. Univ. of KY Coop. Ext. Serv. 13 September 2016. <https://www.uky.edu/Ag/CCD/introsheets/echinacea.pdf>

Kazaz, S., M.A. Askin, S. Kilic, and N. Ersoy. 2010. Effects of day length and daminozide on the flowering, some quality parameters and chlorophyll content of *Chrysanthemum morifolium* Ramat. Scientific Res. and Essays 5:3281-3288.

Kessler, J.R., Jr. 2014. Herbaceous perennial production. 16 October 2014. <http://www.ag.auburn.edu/hort/landscape/herbaceousperennials.html.>

Kim, K.S., A. Cameron, and E.S. Runkle. 2005. *Echinacea purpurea* 'Magnus': Is it an intermediate-day or a short-day/long-day plant? HortScience 40:1100-1100.

Kindscher, K. 2016. A species by species overview of *Echinacea*, p. 55-80. In K. Kindscher (ed.) Echinacea Herbal Medicine with a Wild History. Springer Intl. Publishing, Switzerland.

Kingsley-Richards, S.L. and L.P. Perry. 2015. Influence of moisture on cold hardiness of six container-grown herbaceous perennials. J. Environ. Hort. 33:97-102.

Kraus, H.T. and S.L. Warren. 2013. Ratios and concentrations of nitrogen, phosphorus, and potassium affect production of woody perennials. Better Crops with Plant Food 97:11-12.

Lacy, L. 2010. Crop culture report: Powwow *Echinacea*. Greenhouse Product News 30 September 2016. < http://gpnmag.com/wp-content/uploads/036_0410gpn_0.pdf >.

Latimer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 31:1-4.

Latimer, J. 2014. Using PGR liner soaks for early growth regulation. e-GRO Alert 3(18):1-6.

Latimer, J. 2016. Growth regulators for containerized herbaceous perennial plants. Grower Talks 2016-2017 Guide to Growing Top-Quality Perennials.

Latimer, J., J. Freeborn and V. Groover. 2008. Benzyladenine increases branching of herbaceous perennials. Acta Hort. 886:163-166.

Latimer, J. 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.

Latimer, J. 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. and P.A. Thomas. 1997. Responses of nine containerized perennials to Sumagic. HortScience 32:593-593.

Latimer, J.G., P.A. Thomas and S.A. Baden. 1997. Effect of plant growth regulators on growth and landscape performance of perennial bedding plants. Proc. 42nd Annu. Southern Nursery Assn. Res. Conf. 42:283-285.

Lemaire, E., M. Trépanier, S. Simard, and M. Comtois. 2014. Evaluation of different crop management and overwintering techniques on winter survival of different *Echinacea* cultivars. Landscape Trades 36:9-13.

McKeown, K.A. 1999. A review of the taxonomy of the genus *Echinacea*, p. 482-498. In J. Janick (ed.) Perspectives on new crops and new uses. ASHS Press. Alexandria, VA.

Montanari, M., E. Degl'Innocenti, R. Maggini, S. Pacifici, A. Pardossi and L. Guidi. 2008. Effect of nitrate fertilization and saline stress on the contents of active constituents of *Echinacea angustifolia*. Food Chem. 107:1461-1466.

Netto, A.T., E. Campostrini, J.G. de Oliveira, and R.E. Bressan-Smith. 2005. Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. Scientia Hort. 104:199-209.

Owings, A.D. and P. Reed. 1994. Purple coneflower production as influenced by incorporated rates of osmocote and dolomite. Proc. Southern Nursery Assn. 39:142-143.

Padhye, S. and J. Groninger. 2010a. Echinacea liners - improved liner quality by increased basal branches, pp. 12. In: J. Latimer and B. Whipker (eds.) Configure product information and university trial results. Fine Americas, Inc., Walnut Creek, CA.

Padhye, S. and J. Groninger. 2010b. The influence of benzyladenine on basal branching of *Echinacea* cultivars. Unpublished manuscript. Department of Environmental Horticulture, University of Florida.

Padhye, S., J.K. Groninger and A.M. Davis. 2010. Benzyladenine application increased basal shoot production in four *Echinacea* cultivars. HortScience 45:S298-S298.

Padhye, S. and C. Whitman. 2008. *Echinacea* 'Sunrise' and 'Harvest Moon'. Greenhouse Grower 26(13):84-88.

PanAmerican Seed. 2013. Culture research *Echinacea* ‘Pow Wow Wild Berry’ and ‘Cheyenne Spirit’: Obtaining flower uniformity for fall sales. 31 August 2014 <http://www.panamseed.com/media/Culture/PAS/EchinaceaPowWowResearch.pdf>.

Perry, L.P. 1998. Herbaceous perennials production: A guide from propagation to marketing. Natural Resource, Agr., and Eng. Serv. Coop. Ext. Ithaca, NY.

Perry, L.P. 2006. Herbaceous perennials-container overwintering and hardiness. 24 August 2015 <www.uvm.edu/pss/ppp/pubs/coh31hardy.pdf>.

Perry, L.P. 2015. Vermont coneflower trials, 2009-2015. 26 September 2016 <http://pss.uvm.edu/ppp/coneflowers15.pdf>.

Pilon, P. 2006. Perennial solutions: A grower's guide to perennial production. Ball Publishing. Batavia, IL.

Pilon, P. 2011. Enhancing perennial production. Greenhouse Product News. 30 September 2016 <http://www.gpnmag.com/article/enhancing-perennial-production-0/>.

Pilon, P. 2013. Perennials demystified: Taking the fear out of premium cultivars. Green Profit 77(4):36.

Pilon, P. 2014. *Echinacea* 'Cheyenne Spirit'. Greenhouse Product News 24(8):44-46.

Pilon, P. 2016. Bulking *Echinacea* and decreasing plant losses. 31 August 2014 <http://www.perennialsolutions.com/index.cfm/fuseaction/articles.detail/articleID/87/index.htm>

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annu. Rev. Plant Biol. 51:501-531.

Runkle, E. 2010. *Echinacea purpurea*. Herbaceous perennial production articles. 31 August 2014 <http://www.hrt.msu.edu/perennialresearch/Perennial/Summary/Echinacea_purpurea.pdf>.

Runkle, E.S., R.D. Heins, A.C. Cameron, and W.H. Carlson. 1998. Flowering of herbaceous perennials under various night interruption and cyclic lighting treatments. HortScience 33:672-677.

Runkle, E.S., R.D. Heins, A.C. Cameron, and W.H. Carlson. 2001. Photocontrol of flowering and stem extension of the intermediate-day plant *Echinacea purpurea*. Physiol. Plant. 112:433-441.

Runkle, E.S., and R.D. Heins. 2005. Manipulating the light environment to control flowering and morphogenesis of herbaceous plants. Acta Hort. 711:51-60.

Santos, K.M., P.R. Fisher, T. Yeager, E.H. Simonne, H.S. Carter and W.R. Argo. 2011. Timing of macronutrient supply during cutting propagation of petunia. HortScience 46:475-480.

Schoellhorn, R., and A.A. Richardson. 2006. Warm climate production guidelines for *Echinacea*. Univ. of FL IFAS Commercial Floriculture Update ENHFL04-008.

Scoggins, H.L. 2005. Determination of optimum fertilizer concentration and corresponding substrate electrical conductivity for ten taxa of herbaceous perennials. HortScience 40:1504-1506.

Tackett, M., J. Freeborn, H. Scoggins and J. Latimer. 2010. Echinacea - timing of configure application, pp. 11. In: J. Latimer and B. Whipker (eds.) Configure product information and university trial results. Fine Americas, Inc., Walnut Creek, CA.

Torres, A.P. and R.G. Lopez. 2010. Measuring daily light integral in a greenhouse. 5 September 2016. < https://www.extension.purdue.edu/extmedia/ho/ho-238-w.pdf>.

Thomas, B. and D. Vince-Prue. 1996. Photoperiodism in plants. Academic Press. San Diego, CA.

USDA. 2014. Plant fact sheet: Eastern purple coneflower. 31 August 2014. <http://plants.usda.gov/factsheet/pdf/fs_ecpu.pdf.>

U.S. Department of Agriculture (USDA). 2015. Census of horticultural specialties (2014). 31 August 2016.

<https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Census_of_Horticulture_Specialties/HORTIC.pdf>

U.S. Department of Agriculture (USDA). 2016. Floriculture crops 2015 summary. 13 September 2016. <http://usda.mannlib.cornell.edu/usda/current/FlorCrop/FlorCrop-04-26-2016.pdf>

van Iersel, M. 2000. For plug nutrition, nitrogen matters. GMPro 20(3):35-41.

van Iersel, M., R. Beverly, P. Thomas, J. Latimer and H. Mills. 1998. Fertilizer effects on the growth of impatiens, petunia, salvia, and vinca plug seedlings. HortScience 33:678-682.

Warner, R., E. Runkle, S. Padhye, and C. Whitman. 2013. Controlling flowering of *Echinacea*. GrowerTalks 76(10):66-70.

Westervelt, P. 2016. Receiving starter plants. GrowerTalks 79(12):32.

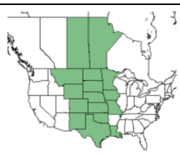
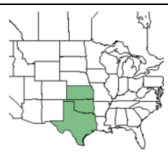
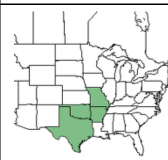
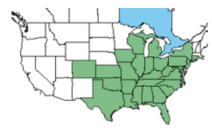
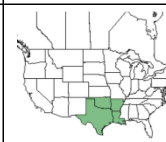
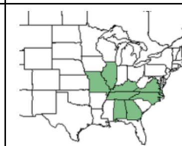
Whitman, C., S. Padhye, A. Cameron, E. Runkle and N. DuRussel. 2007. Evaluating new *Echinacea* cultivars. Greenhouse Product News 22(9):54-57.

Whitman, C.M. and E.S. Runkle. 2013. Flowering of newly introduced herbaceous perennial ornamentals in response to photoperiod and low-temperature treatments. Acta Hort. 1000:353-360.

Zheng, Y., M. Dixon and P. Saxena. 2006. Greenhouse production of *Echinacea purpurea* (l.) and *E. angustifolia* using different growing media, NO3-/NH4+ ratios and watering regimes. Can. J. Plant Sci. 86:809-815.

Tables and Figures

Table 1.1 Scientific name, common name, description, and native range of *Echinacea* species.[z]

Species	*angustifolia*	*atrorubens*	*laevigata*	*pallida*	*paradoxa*	*purpurea*	*Sanguinea*	*simulata*	*tennesseensis*
authority	DC	Nutt.	(C.L. Boynt. & Beadle) S.F. Blake	(Nutt.) Nutt.	(J.B.S. Norton) Britton	(L.) Moench	Nutt.	R.L. McGregor	(Beadle) Small
common name	blacksamson Echinacea or narrow leaf purple coneflower	Topeka purple coneflower	smooth purple coneflower	pale purple coneflower	Yellow coneflower	eastern purple coneflower or purple coneflower	sanguine purple coneflower	wavyleaf purple coneflower	Tennessee purple coneflower
USDA hardiness zone	3-8	6-9	3-8	3-10	4-7	3-8	7-9	5-8	5-6
native region									
habit	One to several hairy stems	Sturdy stems, hairy, rarely branched	Rarely branched	Stiff stems	Smooth stems	Stiff stems, rough, hairy	Stiff, upright, slender stems	Purple stems	Sturdy stems, compact, multiple flowering stems
height	1-3’	1-3’	3-5’	3-4’	2-3’	2-3	1.5-3’	2-3’	1.5-2’
foliage	Alternate, simple, narrow, entire 4-6” leaves	Smooth, lance shaped, entire margins	Smooth leaves, up to 3” long, never cordate	Hairy stems and leaves, leaves 3-5” long	Narrow, hairy leaves, entire margins	Hairy, serrated or entire, dark green leaves, 4-8” long	Hairy, narrow leaves, 4-10” long and .5” wide, entire	Narrow leaves, entire, 4-10” long, dark green	Dark green, linear leaves
flower form	Drooping, short ray flowers	Reflexed ray flowers	Narrow, reflexed ray flowers	Brown cones, narrow, reflexed ray flowers	Purple/brown cone, reflexed ray flowers	Purple to brown cone, drooping ray flowers	Reflexed ray flowers, cone purple with green center	Reflexed, narrow ray flowers, copper cones	Upturned ray flowers
flower color	Pink to creamy white	Deep magenta to purple	White to deep magenta	Pink to white (pale purple)	yellow	Pink to purple	Rose pink to pale purple	reflexed, narrow pale pink to deep magent	Mauve, rose to purple
root	Woody taproot	Taproot	Forked taproot	Taproot	Taproot	Fibrous root	Taproot	Taproot	Taproot
cultural notes	Performs better in the west than on the east coast	Rare, occurs in deep soil and rocky habitats	Rare, found in wooded or grassy areas	Tolerates poor soils, not long lived	Not vigorous	Tolerant of drought, heat, humidity, poor soil	Prefers sandy, acidic soils	Tolerant of drought, poor soils	Long lived, adaptable, needs well-draining soil,
image	 wildflower.org	 wildflower.org	 wildflower.org	 wildflower.org	 wildflower.org	 plants.usda.gov	 wildflower.org	 wildflower.org	 plants.usda.gov
other notes	Most northern range	Large seedhead	Listed as endangered species	White pollen, only tetraploid in the genus	fragrant	Common in home gardens and landscapes	Most southern range	Yellow pollen, fragrant	Removed from endangered species list in 2011

[z] Armitage, 2008; Kindscher, 2016; McKeown, 1999.

Table 1.2 Vegetatively-propagated *Echinacea* hybrid cultivars as of 24 October 2016

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
1	After Midnight	Big Sky	USPP18768 P2	magenta	Richard Gregg Saul	ItSaul Plants	short
2	Alaska		USPP17547 P2	white	Dirk de Winter	Compass Plants B.V.	med
3	All That Jazz		USPP21771	quilled (rolled) pink petals	Walters Gardens, Inc	Kevin Hurd	short
4	Aloha	Prairie Pillars	US20130081180 P1	yellow	Harini Korlipara	Terra Nova	med
5	Amazing Dream	Dream	USPP23019	deep pink	Harini Korlipara	Terra Nova	med
6	Amber Mist	Mistical	USPP21811 P2	yellow	C.M. van den Aardwegh	C.M. van den Aardwegh	short
7	Avalanche	Confections	USPP18597 P2	white	Arie Blom	AB-Cultivars	med
8	Big Kahuna	Prairie Pillars	US PP26159 P3	orange	Harini Korlipara	Terra Nova	med
9	Blackberry Truffle		PPAF	pink, double flower	Arie Blom	AB-Cultivars	short
10	Blushing Mountain Mama	Meadow Mama	PPAF	cream with pink center	Arie Blom	AB-Cultivars	med
11	Burgundy Fireworks	Meadowbrite	USPP23691 P2	red	James Robert Ault	Chicagoland Grows	tall
12	Buttercream		PPAF	yellow, double flower	Arie Blom	AB-Cultivars	short
13	Butterfly Kisses	Conefections	USPP24458 P2	pink, double flower	Arie Blom	AB-Cultivars	short
14	Cara Mia Rose	Cara Mia	PPAF	red, double flower	Harini Korlipara	Terra Nova	short
15	Catharina		USPP22000 P3	pink, double flower	Cornelis van der Meer	Cornelis van der Meer	short
16	Champagne Bubbles		PPAF	white petals	Arie Blom	AB-Cultivars	med
17	Cherry Fluff	Conefections	PPAF	green to pink, double flower	Arie Blom	AB-Cultivars	short
18	Chiquita	Prairie Pixies	USPP24505 P3	light yellow	Harini Korlipara	Terra Nova	short
19	Cinnamon Cupcake	Cupcake	US20140075633 P1	orange/red, double flower	Harini Korlipara	Terra Nova	short
20	Cleopatra	Butterfly	USPP24631 P2	orange	Arie Blom	AB-Cultivars	med
21	Coconut Lime	Confections	USPP18617 P2	white, double flower, green cone	Arie Blom	AB-Cultivars	med
22	Colorburst Orange	Colorburst	USPP24524 P3	orange, double flowe, green center	Harini Korlipara	Terra Nova	tall
23	Coral Reef	Prairie Pixies	USPP21888 P2	orange, double flower	Harini Korlipara	Terra Nova	med
24	Cotton Candy		PPAF	pink, double flower	Arie Blom	AB-Cultivars	med
25	Cranberry Cupcake	Cupcake	USPP23020 P3	pink, double flower	Harini Korlipara	Terra Nova	short
26	Crazy Pink	Big Sky	USPP21023	pink	Richard Gregg Saul	ItSaul Plants	short
27	Crazy White	Big Sky	USPP21024 P2	white	Richard Gregg Saul	ItSaul Plants	short
28	Daydream	Dream	USPP23086 P2	yellow	Harini Korlipara	Terra Nova	med
29	Dixie Belle	Dixie	USPP26111 P3	pink	Harini Korlipara	Terra Nova	Short

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
30	Dixie Blaze	Dixie	USPP26109 P3	orange	Harini Korlipara	Terra Nova	short
31	Dixie Scarlet	Dixie	USPP26110 P3	orange	Harini Korlipara	Terra Nova	short
32	Dixie Sun	Dixie	USPP26160 P3	yellow	Harini Korlipara	Terra Nova	short
33	Double Pink	Big Sky	USPP22102 P2	pink, double row petals	Richard Gregg Saul	ItSaul Plants	med
34	Double Scoop Bubblegum	Double Scoop	USPP23103 P2	pink, double flower	Jianping Ren	Ball Horticultural Co.	short
35	Double Scoop Cranberry	Double Scoop	USPP24769 P2	red, double flower	Jianping Ren	Ball Horticultural Co.	short
36	Double Scoop Lemon Cream	Double Scoop	PPAF	yellow, double flower	Jianping Ren	Ball Horticultural Co.	short
37	Double Scoop Mandarin	Double Scoop	US20160044851 P1	orange, double flower	Jianping Ren	Ball Horticultural Co.	short
38	Double Scoop Orangeberry	Double Scoop	USPP23145 P2	pink to orange, double flower	Jianping Ren	Ball Horticultural Co.	short
39	Double Scoop Raspberry	Double Scoop	USPP23117 P2	rose red, double flower	Jianping Ren	Ball Horticultural Co.	short
40	Eccentric		US PP23979 P2	red, double flower	Marco van Noort	Marco van Noort	short
41	Eleagance		US PP24926 P3	pink	Harini Korlipara	Terra Nova	short
42	Elton Knight		USPP18133 P2	pink	Anthony Brooks	Anthony Brooks	short
43	Evening Glow		PPAF	yellow to pink			short
44	Fancy Frills		USPP17209 P2	pink, multiple rows of petals	Harini Korlipara	Terra Nova	med
45	Fatal Attraction		USPP18429 P2	pink with burgundy stems	Piet Oudolf	Future Plants B.V.	med
46	Ferris Wheel		USPP24330 P2	white, quilled (rolled) petals	Harini Korlipara	Terra Nova	med
47	Fiery Meadow Mama	Meadow Mama	PPAF	gold with red center	Arie Blom	AB-Cultivars	short
48	Firebird	Bird	USPP22775 P3	red	Harini Korlipara	Terra Nova	short
49	Flame Thrower	Prairie Pillars	USPP21932 P2	orange/yellow	Harini Korlipara	Terra Nova	med
50	Fourth Of July		USPP26075 P3	pink, rolled petals	Adorján Rákosi	Adorján Rákosi	med
51	Fragrant Angel	Prairie Pillars	USPP16054 P2	white	Harini Korlipara	Terra Nova	med
52	Glowing Dream	Dream	US PP24329 P2	pink	Harini Korlipara	Terra Nova	med
53	Golden Skipper	Butterfly	PPAF	golden yellow	Arie Blom	AB-Cultivars	med
54	Green Envy		PPAF	green to pink	Mark Veeder	Mark Veeder	med
55	Green Eyes		USPP17172 P2	pink with green centers	Harini Korlipara	Terra Nova	med
56	Green Jewel		USPP18678 P2	green	Piet Oudolf	Future Plants B.V.	med
57	Green Queen		USPP20911 P2	green	Mark Veeder	Mark Veeder	Med
58	Greenline		USPP24800 P2	green, double flower	Dionysius F. M. de Bont	Dionysius F. M. de Bont	short

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
59	Guava Ice	Conefections	USPP23473 P2	salmon pink double flower	Arie Blom	AB-Cultivars	tall
60	Gum Drop		USPP22132	dark pink, double flower	Harini Korlipara	Terra Nova	med
61	Harvest Moon	Big Sky	USPP17652 P2	golden yellow	Richard Gregg Saul	ItSaul Plants	med
62	Heavenly Dream		USPP21957 P2	white	Harini Korlipara	Terra Nova	med
63	Honeydew	Conefections	USPP24630 P2	white to green double flower	Arie Blom	AB-Cultivars	med
64	Hope	Prairie Pillars	USPP17194 P2	light pink	Harini Korlipara	Terra Nova	med
65	Hot Lava	Prairie Pillars	USPP22807 P3	red	Harini Korlipara	Terra Nova	short
66	Hot Papaya	Conefections	USPP21022 P2	orange double flower	Arie Blom	AB-Cultivars	short
67	Hot Summer		USPP20687 P2	orange to red	Marco van Noort	Marco van Noort	short
68	Innocent Meadow Mama	Meadow Mama	PPAF	white	Arie Blom	AB-Cultivars	short
69	Jade		USPP13769	green to white	H. G. Oudshoorn	Future Plants B.V.	med
70	Julia	Butterfly	USPP24629 P2	orange	Arie Blom	AB-Cultivars	med
71	Jupiter	Big Sky	USPP22688 P2	peach	Richard Gregg Saul	ItSaul Plants	med
72	Kim's Knee High		USPP12242 P2	purple-rose	Kim Hawks	Kim Hawks	med
73	Kims Mophead		USPP13560 P2	white	Pierre R. Bennerup	Pierre R. Bennerup	med
74	Kismet Intense Orange	Kismet	PPAF	orange	Harini Korlipara	Terra Nova	short
75	Kismet Raspberry	Kismet	PPAF	pink	Harini Korlipara	Terra Nova	short
76	Laughing Meadow Mama	Meadow Mama	PPAF	orange	Arie Blom	AB-Cultivars	short
77	Leilani	Prairie Pillars	US20130074236 P1	yellow	Harini Korlipara	Terra Nova	med
78	Lemon Drop	Conefections	PPAF	yellow, double flower	Arie Blom	AB-Cultivars	short
79	Lilliput		USPP18841 P3	pink	Harini Korlipara	Terra Nova	short
80	Little Angel		USPP21780	white	Harini Korlipara	Terra Nova	short
81	Little Annie		PPAF	pink	Eric Stahlheber	Southernwood Gardens	short
82	Little Giant		USPP16183 P2	rose red	Harini Korlipara	Terra Nova	short
83	Little Magnus		USPP15973 P2	pink	Mart Vester	Green Works Intl.	med
84	Mac N Cheese		USPP19464	yellow	Harini Korlipara	Terra Nova	med
85	Mama Mia		USPP23172 P3	orange to pink	Harini Korlipara	Terra Nova	short
86	Mango Meadowbrite	Meadowbrite	USPP16636	orange to yellow	James Robert Ault	Chicago Botanic Garden	Med
87	Marmalade	Conefections	USPP22062	yellow orange double, flower	Arie Blom	AB-Cultivars	tall
88	Mars		USPP18412 P2	red-purple	Harini Korlipara	Terra Nova	short

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
89	Maui Sunshine	Prairie Pillars	USPP22808 P3	yellow	Harini Korlipara	Terra Nova	med
90	Meditation		USPP25602 P3	pink	Marco van Noort	Marco van Noort	short
91	Meditation White		USPP27015 P2	white	Marco van Noort	Marco van Noort	med
92	Meringue	Conefections	USPP20537 P2	white, double flower	Arie Blom	AB-Cultivars	short
93	Merlot	Prairie Pillars	USPP18814 P2	pink flowers, burgundy stems	Harini Korlipara	Terra Nova	short
94	Meteor Pink	Meteor	USPP25088 P3	pink, double flower	Harini Korlipara	Terra Nova	med
95	Meteor Red	Meteor	USPP25060 P3	red, double flower	Harini Korlipara	Terra Nova	short
96	Meteor Yellow	Meteor	USPP25149 P3	yellow, double flower	Harini Korlipara	Terra Nova	short
97	Milkshake	Conefections	USPP20594 P2	white, double flower	Arie Blom	AB-Cultivars	med
98	Mini Belle	Conefections	PPAF	pink double flower	Arie Blom	AB-Cultivars	med
99	Mistral		USPP20498 P2	pink	A. Johannes, M. Kempen	Inspiration Plant	med
100	Mount Hood		USPP19494 P2	white, double decker	Remy Lubbe	Molter B.V.	med
101	Now Cheesier		US20120192326 P1	yellow	Harini Korlipara	Terra Nova	med
102	Orange Meadowbrite	Meadowbrite	USPP15090	orange	James Robert Ault	Chicago Botanic Garden	med
103	Orange Skipper	Butterfly	PPAF	orange	Arie Blom	AB-Cultivars	med
104	Panther Pink		USPP20107 P2	pink	Michael Farrow	Cp Delaware, Inc.	short
105	Paranoia		USPP16587 P2	yellow	Tony Avent, Richard Saul	Tony Avent, Richard Saul	med
106	Passion Flute		PPAF	yellow, quilled (rolled) petals	Walters Gardens, Inc	Kevin Hurd	med
107	Peacock	Butterfly	PPAF	pink	Arie Blom	AB-Cultivars	med
108	Phoenix		US20120304353 P1	yellow	Harini Korlipara	Terra Nova	short
109	Pica Bella			pink	Jan Spruyt	Compass Plants B.V.	short
110	Piccolino		USPP23348 P2	pink, double flower	Marco van Noort	Marco van Noort	short
111	Pineapple Sundae	Conefections	PPAF	yellow, double flower	Arie Blom	AB-Cultivars	short
112	Pink Bon Bon	Conefections	PPAF	pink, double flower	Arie Blom	AB-Cultivars	short
113	Pink Double Delight	Conefections	USPP18803	pink, double flower	Arie Blom	AB-Cultivars	med
114	Pink Mist	Mistical	PPAF	pink	C. M. van den Aardwegh	C. M. van den Aardwegh	short
115	Pink Passion		USPP24799 P2	pink	Dionysius F. M. de Bont	Dionysius F. M. de Bont	Short
116	Pink Poodle		USPP19428 P2	pink, double flower	Daniel M. Heims	Terra Nova	short
117	Pink Shuttles		USPP18583 P2	pink, double flower	Arie Blom	AB-Cultivars	short
118	Pink Sorbet	Conefections	USPP18817 P2	pink, double flower	Arie Blom	AB-Cultivars	short

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
119	Pixie Meadowbright	Meadowbrite	USPP18546 P3	pink	James Robert Ault	Chicagoland Grows, Inc.	med
120	Playful Meadow Mama	Meadow Mama	PPAF	pink with white tips	Arie Blom	AB-Cultivars	short
121	Polar Breeze		USPP21630 P2	white	A. Johannes, M. Kempen	Gootjes-Allplant B.V.	short
122	Postman	Butterfly	PPAF	orange/red	Arie Blom	AB-Cultivars	med
123	Prairie Frost		PPAF	pink, variegated foliage	Harini Korlipara	Terra Nova	tall
124	Puff Vanilla	Puff	PPAF	white, double flower	Harini Korlipara	Terra Nova	short
125	Purity		USPP19441 P2	white	Harini Korlipara	Terra Nova	med
126	Purple Emperor	Butterfly	USPP24459 P2	magenta	Arie Blom	AB-Cultivars	med
127	Purple Fantasy		USPP20620 P3	red-purple	M. Nevin Smith	Cp Delaware, Inc.	med
128	Quills And Thrills	Carnival	PP23241	pink, rolled petals	Harini Korlipara	Terra Nova	short
129	Rainbow Marcella	Butterfly	PPAF	orange to pink	Arie Blom	AB-Cultivars	med
130	Raspberry Tart		USPP18933 P2	dark pink	Harini Korlipara	Terra Nova	short
131	Raspberry Truffle	Conefections	USPP22612 P2	peach to pink double flower	Arie Blom	AB-Cultivars	med
132	Razzmatazz		USPP13894 P2	pink, double flower	Marco van Noort	Marco van Noort	med
133	Red Baron		USPP23819 P2	pink, double flower	Dick Degenhardt	Compass Plants B.V.	tall
134	Red Knee High		PPAF	pink, magenta		Sunny Border Nurseries	short
135	Rosita	Prairie Pixies	USPP24392 P3	pink	Harini Korlipara	Terra Nova	short
136	Ruby Giant	Prairie Pillars	PPAF	pink	Harini Korlipara	Terra Nova	med
137	Satin Nights	Prairie Pixies	USPP22999 P3	pink	Harini Korlipara	Terra Nova	short
138	Secret Affair	Secret	USPP24354 P2	pink, double flower	Harini Korlipara	Terra Nova	short
139	Secret Desire	Secret	USPP23085	pink/orange, double flower	Harini Korlipara	Terra Nova	med
140	Secret Glow	Secret	USPP25061 P3	orange, double flower	Harini Korlipara	Terra Nova	med
141	Secret Joy	Secret	USPP23627	yellow, double flower	Harini Korlipara	Terra Nova	med
142	Secret Love	Secret	US20140075636 P1	red, double flower	Harini Korlipara	Terra Nova	med
143	Secret Lust	Secret	USPP23060	orange, double flower	Harini Korlipara	Terra Nova	med
144	Secret Passion	Secret	USPP23018	pink, double flower	Harini Korlipara	Terra Nova	Med
145	Secret Pride	Secret	US20130081178 P1	white, double flower	Harini Korlipara	Terra Nova	med
146	Secret Romance	Secret	US20120210480 P1	pink, double flower	Harini Korlipara	Terra Nova	med
147	Snowcone		PPAF	white		Intrinsic Perennial Gardens	short
148	Solar Flare	Big Sky	USPP22133 P2	red	Richard Gregg Saul	ItSaul Plants	short

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
149	Sombrero Adobe Orange	Sombrero	USPP26639 P3	orange	Jianping Ren	Ball Horticultural Co.	short
150	Sombrero Baja Burgundy	Sombrero	PPAF	red	Jianping Ren	Ball Horticultural Co.	short
151	Sombrero Blanco	Sombrero	PPAF	white	Jianping Ren	Ball Horticultural Co.	short
152	Sombrero Flamenco Orange	Sombrero	USPP22523	orange	Jianping Ren	Ball Horticultural Co.	short
153	Sombrero Hot Coral	Sombrero	USPP23097 P2	orange	Jianping Ren	Ball Horticultural Co.	short
154	Sombrero Hot Pink	Sombrero	PPAF	pink to orange	Jianping Ren	Ball Horticultural Co.	short
155	Sombrero Lemon Yellow	Sombrero	USPP24768 P2	yellow	Jianping Ren	Ball Horticultural Co.	short
156	Sombrero Salsa Red	Sombrero	USPP23105 P2	red	Jianping Ren	Ball Horticultural Co.	short
157	Sombrero Sandy Yellow	Sombrero	USPP23104 P2	yellow	Jianping Ren	Ball Horticultural Co.	short
158	Southern Belle	Conefections	USPP23493 P2	pink double flower	Arie Blom	AB-Cultivars	tall
159	Sparkler		USPP17298	pink	Harini Korlipara	Terra Nova	med
160	Strawberry Shortcake		PPAF	white to pink, double flower	Arie Blom	AB-Cultivars	med
161	Summer Salsa		USPP23996 P2	orange double flower	Marco van Noort	Marco van Noort	med
162	Summer Sky	Big Sky	USPP18783	orange to pink	Richard Gregg Saul	ItSaul Plants	short
163	Summer Sun		USPP22197 P2	orange to red	Kees van de Aardwegh	Kees van de Aardwegh	med
164	Sunbird	Bird	USPP24802 P3	orange	Harini Korlipara	Terra Nova	short
165	Sundown	Big Sky	USPP17652 P2	orange	Richard Gregg Saul	ItSaul Plants	med
166	Sunny Meadow Mama	Meadow Mama	PPAF	yellow	Arie Blom	AB-Cultivars	short
167	Sunrise	Big Sky	USPP16235 P2	yellow	Richard Gregg Saul	ItSaul Plants	med
168	Sunset	Big Sky	USPP16424 P2	orange	Richard Gregg Saul	ItSaul Plants	short
169	Supreme Cantaloupe	Supreme	USPP24897 P3	orange, double flower	Harini Korlipara	Terra Nova	med
170	Supreme Elegance	Supreme	USPP24926	pink, double flower	Harini Korlipara	Terra Nova	med
171	Supreme Flamingo	Supreme	USPP24898	pink, double flower	Harini Korlipara	Terra Nova	med
172	Sweet Meadow Mama	Meadow Mama	PPAF	pink	Arie Blom	AB-Cultivars	short
173	Sweet Sixteen	Conefections	PPAF	deep pink double flower	Arie Blom	AB-Cultivars	Short
174	Tangerine Dream	Dream	USPP21773 P2	orange	Harini Korlipara	Terra Nova	med
175	Tiki Torch	Prairie Pillars	USPP18839	orange	Harini Korlipara	Terra Nova	med
176	Tomato Soup		USPP19427 P2	red	Harini Korlipara	Terra Nova	med
177	Twilight	Big Sky	USPP17651	rose red	Richard Gregg Saul	ItSaul Plants	short
178	Vanilla Cupcake	Cupcake	USPP24506 P2	white, double flower	Harini Korlipara	Terra Nova	short

	Cultivar	Series	Plant Patent	Flower Color and Morphology[z]	Breeder	Introducer/Patent Holder[y]	Height[x]
179	Vintage Wine		USPP13893 P2	red-purple	Piet Oudolf	Future Plants B.V.	short
180	Virgin		USPP18684 P2	white with green cone	Piet Oudolf	Future Plants B.V.	med
181	White Double Delight	Conefections	USPP23472 P2	white double flower	Arie Blom	AB-Cultivars	med
182	White Mist	Mistical	USPP21790 P2	white	C. M. van den Aardwegh	C. M. van den Aardwegh	short
183	White Natalie		USPP19398 P2	white	Monique Dumas-Quesnel	Norseco Inc.	med

[z]Morphology given if other than single flower
[y]Addresses of patent holders with more than 10 cultivars: AB-Cultivars, Zuidwolde, Drenthe, Netherlands; Ball Horticultural Co., Chicago, IL; ItSaul Plants, Alpharetta, GA; Terra Nova Nurseries, Canby, OR
[x]Height based on height given by supplier, small = less than 2’ tall, med = between 2 and 3’ tall, tall = over 3’ tall

Table 1.3 *Echinacea* seed cultivars as of 24 October 2016

	Name	Flower color and morphology[z]	Height[y]
1	Alba	white	tall
2	Amado	white	med
3	Baby swan pink	pink	med
4	Baby swan white	white	med
5	Bravado	pink/purple	tall
6	Bright Star	rose/purple	short
7	Cheyenne Spirit	orange, yellow, red	med
8	doppleganger	pink, two tiered flowers	med
9	Doubledecker	pink, double flower	med
10	Feeling Pink	pink	short
11	Feeling White	white	short
12	Happy Star	white	tall
13	Hula Dancer *(E.* Pallida)	white to pink	med
14	Lucky Star	white	med
15	Magnus	rose pink	tall
16	Magnus superior	rose pink	tall
17	Overton	pink	short
18	Pow Wow White	white	med
19	Pow Wow Wildberry	pink	med
20	Prairie Splendor	pink	med
21	Primadonna deep rose	pink	med
22	Primadonna white	white	med
23	Rocky Top (*E.* tennesseensis)	pink	med
24	Ruby Star	pink	tall
25	Warm Summer	pink, orange, yellow	med
26	White Swan	white	med

[z]Morphology given if other than single flower

[y] Height based on height given by supplier, small = less than 2' tall, med = between 2 and 3' tall, tall = over 3' tall

Chapter 2. Plant growth regulators affect branching and flowering in three *Echinacea* cultivars

Abstract

Echinacea purpurea (L.) Moench, eastern purple coneflower, is a perennial plant in the Asteraceae family which is native to most of North America. This species, along with several others, has been utilized extensively in the hybridization of new, high-value cultivars. These hybrid cultivars vary significantly in their growth habits and requirements from the species. Foliar applications of plant growth regulators were applied in order to evaluate the effects on branching and flowering in hybrid *Echinacea* cultivars which have not yet been studied extensively. Liners of *Echinacea* 'Hot Papaya,' 'Marmalade,' and 'Harvest Moon' received two applications of PGRs, the first approximately one week after transplant and the second two weeks later. Treatments included: 400 $mg \cdot L^{-1}$ dikegulac sodium, 500 $mg \cdot L^{-1}$ ethephon, 600 $mg \cdot L^{-1}$ benzyladenine, and two experimental compounds. 'Marmalade' treated with benzyladenine had an increased number of branches, shoot dry weight, and marketability rating at 13 weeks after initial treatment (WAIT) compared to controls. 'Hot Papaya' treated with benzyladenine had more branches than controls at 6 WAIT; while there were no differences in branching when plants were finished at 14 WAIT, benzyladenine increased the number of flower stalks (4 compared to 1.7 in controls). At 14 WAIT, 'Harvest Moon' treated with benzyladenine had more basal branches than plants treated with dikegulac sodium but did not differ from controls. These three hybrid cultivars were responsive to benzyladenine, although their response to the other PGRs tested varied.

Introduction

Echinacea purpurea (L.) Moench, eastern purple coneflower, is a perennial plant in the Asteraceae family which is native to most of North America, and is hardy in USDA hardiness zones 3-8 (Armitage, 2008). *Echinacea* is a top selling perennial in the U.S., popular with consumers for being a drought tolerant and low maintenance plant. A 2014 Greenhouse Management survey (Jancsurak, 2014), lists *Echinacea* as one of the top 15 plants offered by growers surveyed, with 30% of those polled planning to increase production of *Echinacea* in the coming year. Breeders began introducing new hybrid *Echinacea* cultivars to market beginning in

1997, developing many new flower forms and colors (Carey and Avent, 2014). These hybrid cultivars vary significantly in their growth habits and cultural requirements from the species; many branch poorly due to a tendency to flower prematurely (Pilon, 2011).

Spray applications of benzyladenine (BA) have been successful in increasing branching of *Echinacea*. Six *Echinacea* cultivars, when sprayed with 600 $mg \cdot L^{-1}$ BA (Configure, Fine Americas, Inc., Walnut Creek, CA) 2 weeks after transplant, had significantly more branches than untreated controls at 4 weeks after treatment (Latimer and Freeborn, 2009).

The objective of this study is to evaluate the effects of foliar applications of plant growth regulators on branching and flowering in hybrid *Echinacea* cultivars which have not yet been studied extensively.

Materials and Methods

Three hybrid *Echinacea* cultivars, selected on the basis of their popularity in the marketplace, were studied: ‘Hot Papaya,’ ‘Marmalade,’ and ‘Harvest Moon.’ Size 72 liners were obtained from commercial sources and transplanted into trade gallon containers (2.8 L) filled with a peat and pine bark media (Fafard 3B, SunGro Horticulture, Vancouver, BC, Canada). One week after transplant, the liners received one of the following spray applications: 400 $mg \cdot L^{-1}$ dikegulac sodium (DS, Augeo, OHP, Mainland, PA), 600 $mg \cdot L^{-1}$ benzyladenine (BA, Configure, Fine Americas, Inc., Walnut Creek, CA), 500 $mg \cdot L^{-1}$ ethephon (ETH, Collate, Fine Americas, Inc., Walnut Creek, CA), 250 $mg \cdot L^{-1}$ experimental compound 1 (EXP1), 100 $mg \cdot L^{-1}$ experimental compound 2 (EXP2), or untreated control (CONT). Treatments were repeated 2 weeks after the initial treatment (WAIT).

Plants were transplanted between May 6th and June 9th, 2014 and grown in a coldframe in Blacksburg, Virginia until they reached a marketable size, between 13 and 14 WAIT. Every 2 weeks, plant height, width, and number of branches were measured. At the end of the study, plants were rated for marketability, and flowering data and shoot dry weight measurements were taken. Data were analyzed using analysis of variance ($P \leq 0.05$, Student's t-test) JMP Pro 10 (SAS Institute Inc., Cary, NC).

Results

The plant growth regulators tested affected branching and flowering in each of the three *Echinacea* cultivars. In ‘Marmalade,’ BA increased branches, shoot dry weight, and marketability rating in finished plants at 13 WAIT compared to controls (Table 2.1, Figure 2.1).

Plants treated with DS, ETH, and EXP1 had significantly fewer branches than controls. Flowering was uneven in this cultivar; only plants treated with ETH had more than 50% of plants flowering.

In ‘Hot Papaya,’ BA increased the number of branches in plants at 6 WAIT although there were no significant differences in branching at 14 WAIT (Table 2.2). In finished plants at 14 WAIT, BA increased the number of flower stalks, 4.0 compared to 1.7 in controls. EXP1 reduced the percentage of plants which flowered. Shoot dry weight was not affected by PGR application in this cultivar (data not presented).

In ‘Harvest Moon,’ plants treated with BA had more basal branches than plants treated with dikegulac sodium but did not differ from controls (Table 2.3). Percentage of plants flowering, shoot dry weight, and marketability were not significantly affected by treatments with PGRs. Two treatments were eliminated from the study due to infection with Impatiens Necrotic Spot Virus.

Discussion

The three hybrid *Echinacea* cultivars were responsive to PGRs, although each responded somewhat differently. ‘Marmalade’ was the most responsive to BA, with significant increases in branches at every data measurement after treatment. ‘Harvest Moon’ and ‘Hot Papaya’ had increased branches with BA, although there were no significant differences in finished plants. ‘Hot Papaya’ or ‘Harvest Moon’ treated with DS, ETH, EXP1, or EXP2 did not significantly differ in number of branches as compared to controls. ‘Marmalade’ treated with DS or ETH had fewer branches than controls.

In ‘Hot Papaya,’ BA increased the number of flower stalks, while EXP1 decreased flowering. PGRs did not affect flowering in ‘Harvest Moon.’ Flowering was inconsistent in ‘Marmalade’ in this study.

These cultivars responded to foliar applications PGRs, with increased branching in response to BA over the course of production. Further studies, including studies on additional hybrid cultivars and studies evaluating growth retardants, would help us to understand the differences between the hybrid cultivars and their needs during production.

Literature Cited

Armitage, A.M. 2008. Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes. 3rd ed. Stipes, Champaign, IL.

Carey, D. and T. Avent. 2014. Echinacea explosion - the coneflower chronicles. Retrieved 14 September, 2014, from http://www.plantdelights.com/Article/Echinacea-Coneflower.

Jancsurak, J. 2014. Top 15 plants. Greenhouse Management 02 April 2015 <http://www.greenhousemag.com/article/gm0114-top-plants-of-year/>

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

Pilon, P. 2011. Tweak your growing style to succeed with problem perennials: *Echinacea*. Presented at OFA Short Course, July 9, 2011.

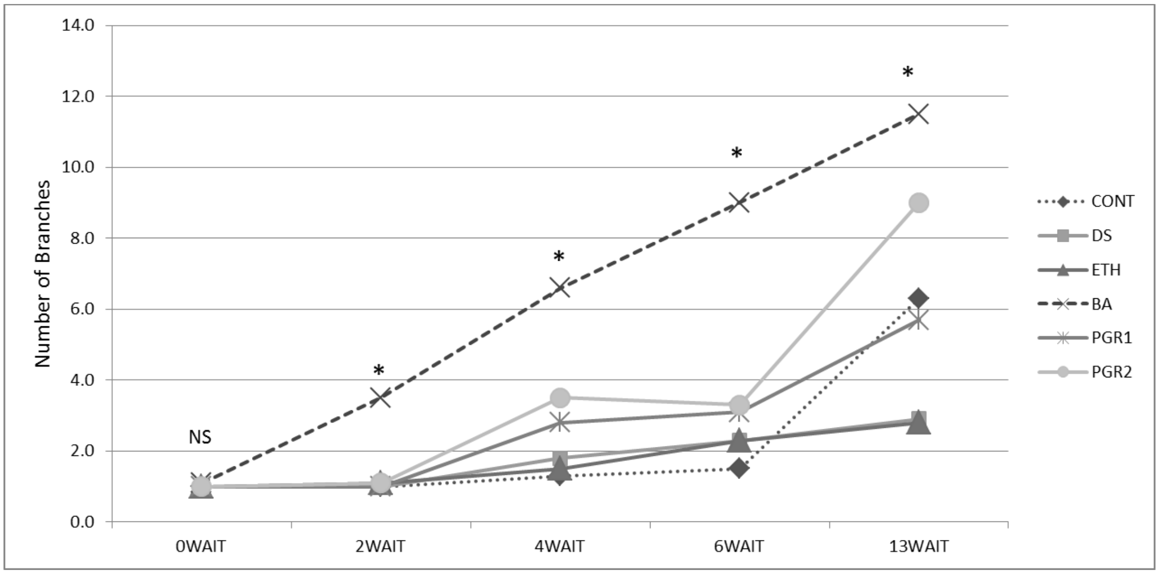
Tables and Figures

Table 2.1 Number of branches, percentage of plants flowering, shoot weight, and marketability rating of *Echinacea* 'Marmalade' at 13 weeks after initial treatment (WAIT). Plants were treated with 400 mg·L^{-1} dikegulac sodium (DS), 600 mg·L^{-1} benzyladenine (BA), 500 mg·L^{-1} ethephon (ETH), 250 mg·L^{-1} experimental compound 1 (EXP1), 100 mg·L^{-1} experimental compound 2 (EXP2), or untreated control (CONT) one week after transplant. Treatments were repeated 2 WAIT.

PGR	No. of branches	% flowering	Shoot dry weight (g)	Marketability^{y}
CONT	6.3b^{z}	13	18.7b	2.0b
DS	2.9c	50	18.9b	2.1b
ETH	2.8c	63	22.4b	2.1b
BA	11.5a	25	27.3a	2.9a
EXP1	5.7bc	0	19.4b	2.0b
EXP2	9.0ab	13	18.2b	2.3b
P value	<0.0001	0.0204	0.0173	0.0205

^{z}Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, n=8).
^{y}Marketability scale: 1. Unmarketable. Severe stunting. Very poorly branched. 2. Not well branched. More media showing than covered. 3. Not flowering or flower stalks not upright. Well branched. 4. Flowering or budding. Well branched. Little to no media showing. Upright flower stalks. 5. Well branched. No media showing. Good color. Good flowering with multiple flowers.

Figure 2.1 Number of branches of *Echinacea* 'Marmalade' treated with 400 mg·L^{-1} dikegulac sodium (DS), 600 mg·L^{-1} benzyladenine (BA), 500 mg·L^{-1} ethephon (ETH), 250 mg·L^{-1} experimental compound 1 (EXP1), 100 mg·L^{-1} experimental compound 2 (EXP2), or untreated control (CONT) counted at 2 week intervals after the initial PGR application (WAIT)^{z}.



^{z}NS, * nonsignificant or significant at P≤0.05.

Table 2.2 Number of branches at 6 and 14 weeks after initial treatment (WAIT) and percentage of plants flowering and number of flower stalks of *Echinacea* 'Hot Papaya' at 14 WAIT with 400 mg·L^{-1} dikegulac sodium (DS), 600 mg·L^{-1} benzyladenine (BA), 500 mg·L^{-1} ethephon (ETH), 250 mg·L^{-1} experimental compound 1 (EXP1), 100 mg·L^{-1} experimental compound 2 (EXP2), or untreated control (CONT).

PGR	No. of branches at 6 WAIT	No. of branches at 14 WAIT	% flowering	No. of flower stalks
CONT	4.8b[z]	6.5	83.3	1.7bc
DS	5.9ab	7.4	71.4	2.6bc
ETH	5.0b	6.6	87.5	2.1bc
BA	7.8a	9.5	87.5	4.0a
EXP1	6.3ab	7.5	50	1.0c
EXP2	5.9b	8.6	100	2.1bc
P value	0.0472	0.2086	0.1505	0.0020

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, n=8).

Table 2.3 Number of branches, percentage of plants flowering, shoot dry weight, and marketability rating of *Echinacea* ‘Harvest Moon’ at 14 weeks after initial treatment (WAIT) treated with 400 $mg \cdot L^{-1}$ dikegulac sodium (DS), 600 $mg \cdot L^{-1}$ benzyladenine (BA), 250 $mg \cdot L^{-1}$ experimental compound 1 (EXP1), or untreated control (CONT).

PGR	No. of branches	% flowering	Shoot dry weight (g)	Marketability rating[y]
CONT	12.7ab[z]	83	23.9	3.5
DS	9.2b	67	20.7	3.5
BA	15.1a	86	26.1	4.0
EXP1	9.7b	71	24.3	3.0
P value	0.0041	0.8186	0.5668	0.1018

1. Unmarketable, stunted, very poorly branched. 2. Not well branched. More media showing than covered. 3. Not flowering or flower stalks not upright. Well branched. 4. Flowering or budding. Well branched. Little to no media showing. Upright flower stalks. Well branched. No media showing. Good color. Good flowering with multiple flowers.

Chapter 3. Controlling height in *Echinacea* hybrid cultivars

Abstract

Hybrid cultivars of *Echinacea purpurea* (L.) Moench, eastern purple coneflower, vary significantly in their growth habits and production requirements from the species. Some *Echinacea* cultivars can grow to be very tall and leggy. Our objective was to examine the effects of plant growth regulators (PGRs) on height in two different cultivars of hybrid *Echinacea*. We wanted to determine if different concentrations and application methods were effective in controlling plant and flower height. Liners of *Echinacea* 'Marmalade' and 'Harvest Moon' were received in March 2015 and transplanted into trade gallon pots filled with peat/pine bark media (Fafard 3B, SunGro Horticulture, Vancouver, CA). Plants were kept under short days for six weeks. After short days ended, the following PGRs were applied as foliar sprays: daminozide (Dazide) 5000 $mg·L^{-1}$ (2 applications); uniconazole (Concise) 30 $mg·L^{-1}$ (1 application); uniconazole (Concise) 15 $mg·L^{-1}$ (2 applications); paclobutrazol (Piccolo 10 XC) 80 $mg·L^{-1}$ (1 application); paclobutrazol (Piccolo 10 XC) 40 $mg·L^{-1}$ (2 applications); or, as a single drench application (10 fl. oz. per pot): uniconazole (Concise) 2 $mg·L^{-1}$ or paclobutrazol (Piccolo 10 XC) 4 $mg·L^{-1}$. All PGR treatments were compared to an untreated control. The second application was applied 2 weeks after the first. Plants were grown until they reached marketable size (4 weeks after initial treatment for 'Marmalade' and 5 weeks after initial treatment for 'Harvest Moon'). At this time plant height, flower stalk height, plant width, days to flower, number of flowers, market rating, and shoot dry weight were measured. The effectiveness of height control PGRs varied by cultivar. 'Marmalade,' which has very vigorous growth, showed height control only with daminozide. However, daminozide had the unwanted effect of reducing the number of flowers in 'Marmalade.' With this cultivar, possibly earlier application of height control PGRs would be more effective; more work will need to be done to determine optimal timing. 'Harvest Moon' plants, which have a more compact growth habit compared to 'Marmalade,' were shorter in response to all of the height control PGRs applied as compared to untreated control plants, with the best results seen in plants treated with uniconazole or daminozide sprays, or the paclobutrazol drench.

Introduction

Echinacea purpurea (L.) Moench, eastern purple coneflower, is a perennial plant in the Asteraceae family which is native to most of North America. This species, along with several others, has been used in the hybridization of new, high-value cultivars with exciting new flower colors and forms. These hybrid cultivars vary significantly in their growth habits and production requirements from the species.

While hybrid cultivars differ in their flower color and morphology, they also vary significantly in their height. In research on 20 newer *Echinacea* cultivars, researchers at Michigan State University found that height at first flower varied between 30 cm and 99 cm (Whitman et al., 2007). Height ranged from 36 cm to 125 cm in 48 *Echinacea* species and cultivars grown over three years in trial gardens (Frett, 2009). As many of the newer *Echinacea* cultivars are relatively tall, growers will likely need plant growth regulators (PGRs) in order to produce compact plants (Whitman et al., 2007). Previous work has shown *E. purpurea* is responsive to a number of different commercially available PGRs including ancymidol, chlormequat chloride, daminozide, paclobutrazol, uniconazole, and flurprimidol (Latimer, 2016). *E. purpurea* plants treated with two applications of 5000 $mg \cdot L^{-1}$ daminozide was 20% shorter than controls; spray applications of 240 $mg \cdot L^{-1}$ paclobutrazol or 40 $mg \cdot L^{-1}$ uniconazole resulted in plants 50% or 70% shorter respectively than untreated plants (Latimer et al., 1997). While foliar sprays of 40 to 160 $mg \cdot L^{-1}$ uniconazole reduced height in *E. purpurea* at 8 weeks after potting (6 weeks after treatment), at 12 weeks after potting only plants treated with 120 or 160 $mg \cdot L^{-1}$ were significantly shorter than controls (Latimer and Thomas, 1997). Research at Michigan State University has shown spray applications of ancymidol, daminozide, chlormequat chloride, or uniconazole to be effective at reducing height of *Echinacea*; multiple applications are recommended as well as applying PGRs before significant flower stem elongation occurs (Runkle, 2010). A spray application tank mix of daminozide and chlormequat chloride (Fifo, 2010) or daminozide and uniconazole (Pilon, 2014) is recommended to reduce height of *Echinacea*.

With the wide variety of PGRs to choose from in controlling plant height, growers must weigh which PGR to use, concentration, method of application and number of applications. Growth retardants vary in their period of activity in the plant; paclobutrazol and uniconazol last for several months whereas damniozide is much more short-lived (Rademacher, 2000). Although different PGRs have been shown to reduce height in *Echinacea*, cultivars vary in their response to PGRs (Latimer, 2004); growers and researchers will need to investigate the PGR response of newer *Echinacea* cultivars.

Our objective was to examine the effects of PGRs in controlling height in two different cultivars of hybrid *Echinacea*. We wanted to determine if different concentrations and application methods were effective in controlling plant and flower height.

Methods and Materials

Trays of commercially grown liners of *Echinacea* 'Marmalade' and 'Harvest Moon' (cell size height 5.71 cm, volume 35.4 mL) were received in March 2015 and transplanted into 2.8 L pots filled with peat and pine bark media (Fafard 3B, SunGro Horticulture, Vancouver, CA). One week after transplant, the liners were sprayed with 600 $mg \cdot L^{-1}$ BA (Configure, Fine Americas, Inc., Walnut Creek, CA). In order to prevent premature flowering, plants were kept under short days with a day length of 11 h and flower stalks were removed for the first six weeks (Heide, 2004). Short days were maintained by covering and uncovering the plant benches with blackout cloth daily. After short days ended, the following PGR applications were made:

- Untreated control
- Daminozide (Dazide, Fine Americas, Inc.) 5000 $mg \cdot L^{-1}$ (2 spray applications)
- Uniconazole (Concise, Fine Americas, Inc.) 30 $mg \cdot L^{-1}$ (1 spray application)
- Uniconazole (Concise, Fine Americas, Inc.) 15 $mg \cdot L^{-1}$ (2 spray applications)
- Uniconazole (Concise, Fine Americas, Inc.) 2 $mg \cdot L^{-1}$ (1 drench application, 10 oz.)
- Paclobutrazol (Piccolo 10 XC, Fine Americas, Inc.) 80 $mg \cdot L^{-1}$ (1 spray application)
- Paclobutrazol (Piccolo 10 XC, Fine Americas, Inc.) 40 $mg \cdot L^{-1}$ (2 spray applications)
- Paclobutrazol (Piccolo 10 XC, Fine Americas, Inc.) 4 $mg \cdot L^{-1}$ (1 drench application, 10 fl. oz.)

The second application was applied 2 weeks after the first. 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 with average daily high temperatures of 29.7°C, average daily low temperatures 18.4°C, and average daily light integral (DLI) 10.7 $mol \cdot m^{-2} \cdot d^{-1}$ in Blacksburg, Virginia until they were flowering (4 weeks after initial treatment for 'Marmalade' and 5 weeks after initial treatment for 'Harvest Moon'). At this time plant height

(height measured from the rim of the pot to the top of the plant foliage), flower stalk height (measured from the rim of the pot to the top of the tallest flower), average width (the average of the width measured at the widest point of the plant and again perpendicular to this point), days to flower, number of flowers, marketability, and shoot dry weight were measured. Marketability was rated on a scale of 1 (poor), 2 (fair), 3(average), 4 (good), to 5 (premium quality) based on quality of plant growth and flowering characteristics.

The experimental design was a completely randomized design with 16 replications per treatment; each cultivar was analyzed as a separate experiment. Statistical analysis was performed by JMP (Version 12; SAS Institute Inc., Cary, NC), with the means of treatments compared by the Students t-test at $P<0.05$.

Results

‘Marmalade’

Only daminozide significantly controlled plant height and flower stalk height, but reduced number of branches (Table 3.1, Figure 3.1). Width was reduced in plants treated with uniconazole drench or daminozide. While days to flower was not affected by PGR treatment (data not shown), the number of flowers was less in plants treated with uniconazole or daminozide sprays, or paclobutrazol applied as a drench or 40 $mg \cdot L^{-1}$ spray. Market rating was reduced by daminozide sprays or paclobutrazol drench. All PGR treatments resulted in less shoot dry weight, with the smallest plants being those treated with daminozide (17.7 grams compared to controls 44.0 grams).

‘Harvest Moon’

All PGR treatments resulted in shorter plants and flower stalks as compared to untreated control plants (Table 3.1, Figure 3.2), with uniconazole 30 $mg \cdot L^{-1}$ spray and paclobutrazol 4 $mg \cdot L^{-1}$ drench resulting in the shortest plants. Width was less in plants treated with uniconazole 30 $mg \cdot L^{-1}$ spray, daminozide, or paclobutrazol applied as a drench or an 80 $mg \cdot L^{-1}$ spray. Number of branches, number of flowers, and shoot dry weight were not different in plants treated with height control PGRs compared to controls. The number of days to flower was not affected by PGR treatment (data not shown). Market rating of plants treated with uniconazole sprays or paclobutrazol drench was higher than controls.

Discussion

In this study we saw a different response to height control PGRs in different *Echinacea* cultivars. Plant growth regulators are known to have cultivar specific responses (Latimer, 2004). ‘Marmalade,’ which has very vigorous growth, showed height control only with daminozide. However, daminozide had the unwanted effect of reducing numbers of branches and flowers in ‘Marmalade.’ Daminozide can cause stunting of flower stalks and flower delay if applied late in production (Whipker et al., 2001). In ‘Marmalade,’ earlier treatment with height control PGRs might be more effective without the negative effects of reduced flowering; more work will need to be done to determine optimal timing. ‘Harvest Moon,’ which has a more compact growth habit compared to ‘Marmalade,’ had decreased height in response to all of the height control PGRs applied, with the best results seen in plants treated with uniconazole sprays, daminozide, or paclobutrazol drench.

PGRs can be used to effectively control height in *Echinacea* cultivars; however their response is cultivar specific. Two application methods were tested; both sprays and drenches were effective in controlling height of *Echinacea* ‘Harvest Moon.’ Paclobutrazol and uniconazole sprays controlled height in ‘Harvest Moon’ either when sprayed at a high rate once or a lower rate twice. Growers will need to conduct trials to determine best PGR rates and application methods in the cultivars they grow.

Literature Cited

Fifo, C. 2010. Know and grow: Success with tissue culture Echinacea. Grower Talks 74(6):56-60.

Frett, J. 2009. Coneflowers for the mid-Atlantic region. Mt. Cuba Center. Hockessin, DE.

Heide, O.M. 2004. Dual induction rather than intermediate daylength response of flowering in *Echinacea purpurea*. Physiol. Plant. 120:298-302.

Latimer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 31:1-4.

Latimer, J. 2016. Growth regulators for containerized herbaceous perennial plants. Grower Talks 2016-2017 Guide to Growing Top-Quality Perennials.

Latimer, J.G. and P.A. Thomas. 1997. Responses of nine containerized perennials to Sumagic. HortScience 32:593-593.

Latimer, J.G., P.A. Thomas and S.A. Baden. 1997. Effect of plant growth regulators on growth and landscape performance of perennial bedding plants. Proc. 42nd Annu. Southern Nursery Assn. Res. Conf. 42:283-285.

Pilon, P. 2014. *Echinacea* 'Cheyenne Spirit'. Greenhouse Product News 24(8):44-46.

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annu. Rev. Plant Biol. 51(1):501-531.

Runkle, E. 2010. *Echinacea purpurea*. Herbaceous perennial production articles. 31 August 2014 <http://www.hrt.msu.edu/perennialresearch/Perennial/Summary/Echinacea_purpurea.pdf>.

Whipker, B., J. Gibson, and T. Cavins, T. 2001. Diagnosing problems due to plant growth regulators. NC State Univ. Floriculture Res.: Floriculture Rx.001

Whitman, C., S. Padhye, A. Cameron, E. Runkle and N. DuRussel. 2007. Evaluating new *Echinacea* cultivars. Greenhouse Product News 22(9):54-57.

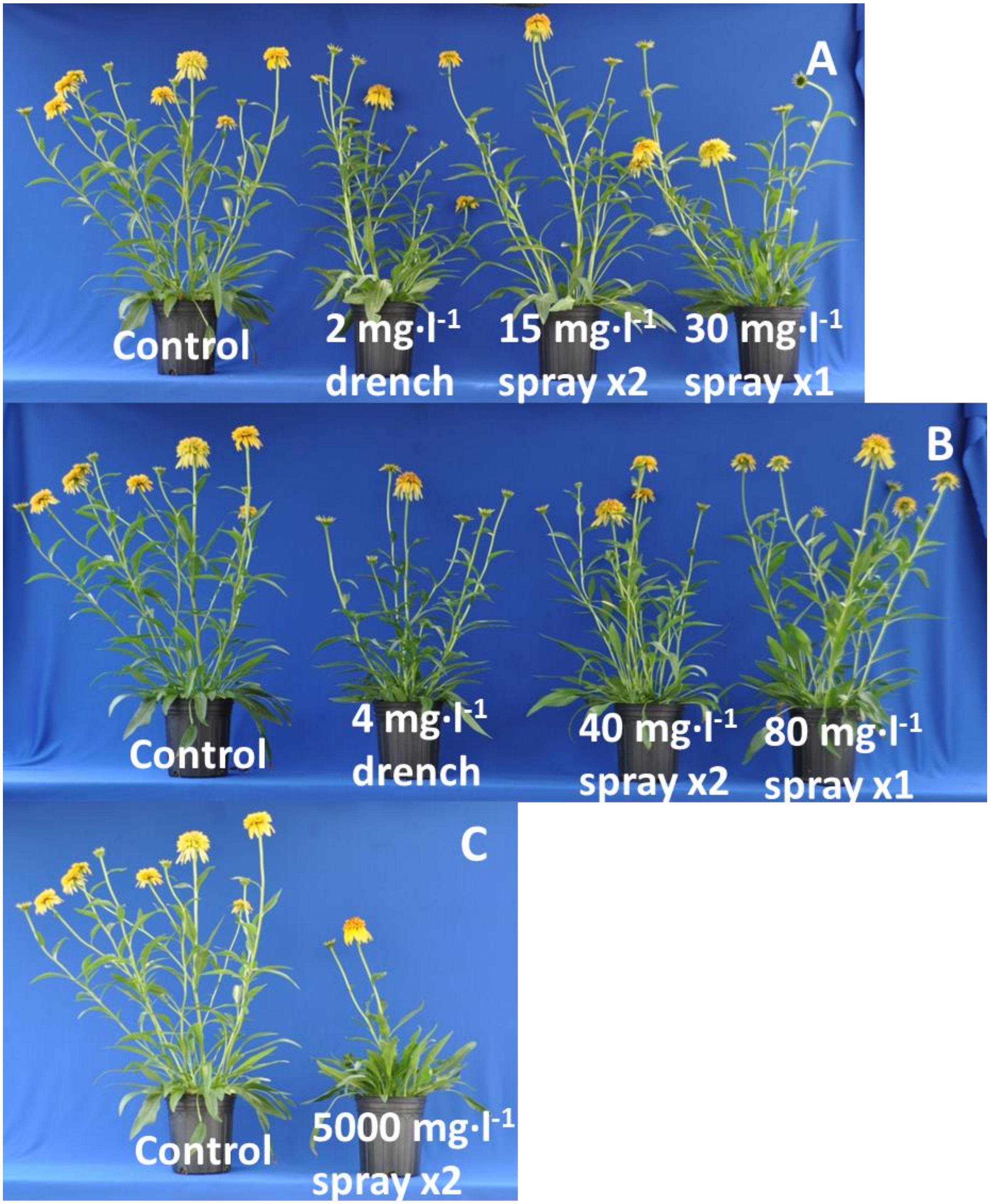
Tables and Figures

Table 3.1 Effect of PGR treatment on plant height, flower stalk height, plant width, number of branches, number of flowers, market rating and shoot dry weight of *Echinacea* 'Harvest Moon' and 'Marmalade' finished plants at 4 to 5 weeks after treatment, n=16.

Cultivar	PGR ($mg \cdot L^{-1}$) x number of applications, method of application	Plant height (cm)	Flower stalk height (cm)	Width (cm)	Number of branches	Number of flowers	Market rating	Shoot dry weight (g)
Marmalade	Control	60.2ab[z]	73.5ab	51.0ab	9.8a	10.0a	4.0a[y]	44.0a
	Uniconazole 2 X 1, drench	53.0bc	70.0ab	45.8c	8.0ab	8.8ab	3.8a	34.7b
	Uniconazole 15 x 2, spray	56.7ab	71.3ab	52.7a	8.5a	6.5b	3.7a	32.6b
	Uniconazole 30 x 1, spray	61.7a	79.2a	51.5a	8.7a	6.7b	3.7a	33.2b
	Daminozide 5000 x 2, spray	46.8c	55.7c	40.8d	6.2b	3.0c	3.0b	17.7c
	Paclobutrazol 4 x 1, drench	53.5bc	71.0ab	46.4bc	8.8a	7.3b	3.2b	33.2b
	Paclobutrazol 40 X 2, spray	55.2ab	66.0b	48.8abc	9.2a	7.2b	3.8a	31.9b
	Paclobutrazol 80 x 1, spray	61.3a	78.8a	49.1abc	8.7a	8.5ab	4.0a	36.2ab
	Significance	**	***	***	NS	***	***	***
Harvest Moon	Control	44.2a	48.2a	34.9ab	10.4	7.0	3.2c	19.7
	Uniconazole 2 X 1, drench	33.5bc	40.0b	32.4abc	9.0	6.3	3.3c	19.5
	Uniconazole 15 x 2, spray	32.0bcd	40.0b	31.8bc	11.0	5.0	4.2ab	18.8
	Uniconazole 30 x 1, spray	28.3d	29.5d	29.2c	7.5	6.5	4.5a	15.8
	Daminozide 5000 x 2, spray	32.8bcd	39.2b	30.3c	9.3	7.0	3.5bc	17.2
	Paclobutrazol 4 x 1, drench	28.8d	33.5cd	29.9c	9.2	6.3	4.2ab	19.6
	Paclobutrazol 40 X 2, spray	36.0b	37.4bc	36.3a	12.8	4.8	3.6bc	20.1
	Paclobutrazol 80 x 1, spray	31.2cd	37.7bc	29.5c	8.7	6.8	3.8abc	17.0
	Significance	***	***	*	NS	NS	*	NS

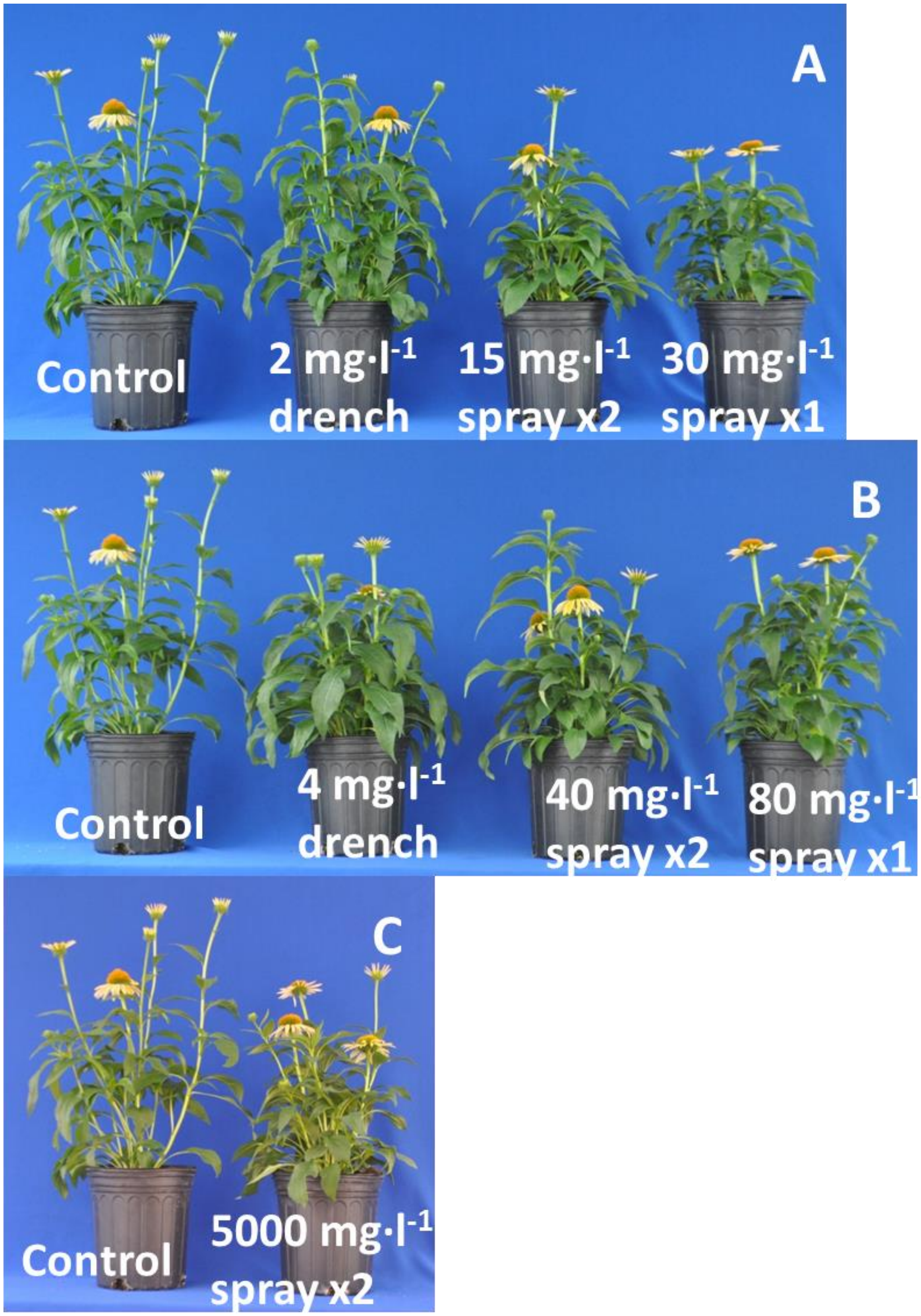
[z] NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.
[y]Marketability was rated on a scale of 1 (poor), 2 (fair), 3 (average), 4 (good), to 5 (premium quality) based on quality of plant growth and flowering characteristics.

Figure 3.1 *Echinacea* ‘Marmalade’ finished plants at 10 weeks after transplant treated with A) uniconzaole, B) paclobutrazol, and C) daminozide[z].



[z]Plant growth regulators were applied 6 weeks after transplant.

Figure 3.2 *Echinacea* 'Harvest Moon' finished plants at 11 weeks after transplant treated with A) uniconzaole, B) paclobutrazol, and C) daminozide[z].



[z]Plant growth regulators were applied 6 weeks after transplant.

Chapter 4. Fertilizer Affects Growth and Overwinter Survival of *Echinacea* Hybrid Cultivars

Abstract

New hybrid *Echinacea* cultivars, based on crosses of *Echinacea purpurea* (L.) Moench with several other *Echinacea* species, have generated interest and excitement in the marketplace due to novel flower colors and forms. However, these cultivars vary in their growth habits and requirements from *E. purpurea*. Our objectives were to examine the nutritional requirements of hybrid *Echinacea* cultivars to develop fertilization protocols for producing *Echinacea*. To examine the effect of fertilizer concentration on the growth of three popularly grown *Echinacea* hybrid cultivars, fertilizer concentrations of 50, 125, or 250 $mg \cdot L^{-1}$ N from 15N-2.2P-12.5K were applied at every irrigation to *Echinacea* 'Hot Papaya,' 'Marmalade,' and 'Harvest Moon' beginning immediately after transplant. For 'Marmalade,' shoot dry weights were highest in plants grown with 150 $mg \cdot L^{-1}$ N while tissue N was highest in those grown with 200 $mg \cdot L^{-1}$ N. Growth of 'Harvest Moon' and 'Hot Papaya' was not affected by fertilizer concentration. Flowering was less in 'Marmalade' grown at lower N concentrations. A subsequent study was conducted to isolate the effects of N on *Echinacea* growth in which we provided 'Harvest Moon' and 'Marmalade' liners with 50, 150, 250, or 350 $mg \cdot L^{-1}$ N based on 50 $mg \cdot L^{-1}$ 5N-5.2P-21.6K with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 and ammonium nitrate added to reach desired N rates. Plant height decreased in both cultivars with increasing N rates while shoot dry weight peaked between 150 and 200 $mg \cdot L^{-1}$ N. Number of flowers was reduced in 'Harvest Moon' with higher N rates. Supplying N at 150 $mg \cdot L^{-1}$ during the growing season provided *Echinacea* cultivars adequate nutrition and maximized numbers of branches and flowers and shoot dry weight. An experiment to examine the effects of fertilizer on the

overwintering survival of *Echinacea* hybrid cultivars was conducted in which three cultivars were grown with low, medium and high rates of 15N-3.9P-10K controlled release fertilizer (CRF) or a water soluble fertilizer at 150 $mg \cdot L^{-1}$ N using 15N-2.2P-12.5K until 1 Oct. 2016. Fertilization treatments that resulted in low substrate electrical conductivity going into dormancy, the low rate of CRF or the water soluble fertilizer 150 $mg \cdot L^{-1}$ N, resulted in the highest survival rates of *Echinacea* cultivars. Although SPAD measurements have been used to monitor leaf N status in many plant species, they were not successful in predicting tissue N levels in these *Echinacea* hybrids.

Introduction

Echinacea purpurea (L.) Moench, eastern purple coneflower, is a popular, long-blooming garden plant which is also used as a cut flower (Armitage, 2008). *Echinacea* is a top selling perennial; with $15.7 million in sales in 2014, it is the fifth highest selling perennial in the United States (USDA, 2015). Recently, breeders have developed many new hybrid cultivars, with new flower colors and forms, based on breeding of *E. purpurea* with other species in the genus (Armitage, 2011). Resulting hybrids have different growth habits, hardiness, and heat and drought tolerance than parent plants (Ault and Thomas, 2014).

The recommended nitrogen (N) fertilization rate for herbaceous perennials is 100 to 200 $mg \cdot L^{-1}$ N applied using constant liquid feed (CLF) (Kessler, 2014); however, herbaceous perennials vary in their fertilizer requirements (Scoggins, 2005). For ten taxa grown under fertilizer concentrations of 50 to 350 $mg \cdot L^{-1}$ N from 15N-7P-14K, optimal growth was found when substrate electrical conductivity levels ranged from 1.5 to 5.1 $mS \cdot cm^{-1}$, which corresponded to fertilizer concentrations between 100 and 350 $mg \cdot L^{-1}$ N (Scoggins, 2005).

Recommendations for fertilizing *Echinacea* vary. While Terra Nova Nurseries lists 50 to 100 mg·L^{-1} N applied using CLF in its *Echinacea* Grower Tips (Terranovanurseries.com, 2016), Proven Winners advises 75 to 100 mg·L^{-1} N applied as CLF for Big Sky^{TM} 'Sunrise' (Provenwinners.com, 2016), and Green Leaf Plants recommends CLF of 100 to 150 mg·L^{-1} N for the Conefection^{TM} Series (GLplants.com, 2012). Other *Echinacea* fertilizer guidelines include 100 mg·L^{-1} N applied using CLF (Pilon, 2013), 75 to 150 mg·L^{-1} N applied using CLF (Kaiser et al., 2015), and avoiding high ammonium forms of N (Schoellhorn and Richardson, 2006).

In nursery production, perennials can be grown through the winter for early spring sales. While this method produces plants which are well-branched for spring sales, growers have reported high levels of plant losses in overwintering *Echinacea* (Lemaire et al., 2014). Kessler (2014) recommends reducing fertilizer rates for containerized perennials in the fall before dormancy and eliminating fertilization during the winter. Controlled release fertilizers (CRFs) are often used during overwintering; because nutrient release is slowed with low temperatures, this can be an effective method of fertilizing perennials over the course of production (Pilon, 2006).

Photosynthesis is dependent on N in the plant (Marchese et al., 2005) and is highly correlated with chlorophyll concentration (Netto et al., 2005). Measuring the effect of fertilizer on photosynthesis can relate the effectiveness of the input on plant growth. Soil plant analysis development (SPAD) meters have been used to measure leaf greenness which is closely correlated with chlorophyll concentration (Netto et al., 2005); however, SPAD measurements are more closely associated with tissue N in some species than in others (Xiong et al., 2015). No information is available in the literature on the effect of N on *Echinacea* photosynthesis or on the utility of the SPAD meter in estimating tissue N in *Echinacea*.

Our goals were to examine nutritional requirements of hybrid *Echinacea* cultivars to develop production fertilization protocols for *Echinacea*. The specific objectives were, 1) to examine the effect of fertilizer concentration on the growth and tissue nutrient status of *Echinacea* cultivars, 2) to determine the optimal N rate for *Echinacea* cultivars, 3) to evaluate the SPAD meter as a tool to estimate N status in *Echinacea* cultivars, and 4) to examine the effect of fertilizer on the overwintering survival of *Echinacea* cultivars.

Materials and Methods

Fertilizer concentration:

Our goal in this study was to examine the effect of fertilizer concentration on the growth of three commonly grown *Echinacea* hybrid cultivars. We tested fertilizer concentrations, both higher and lower than those recommended by previously noted research and commercial references, to determine the suitability of a range of fertilizer concentrations in *Echinacea* production. Liners of *Echinacea* 'Harvest Moon,' 'Hot Papaya,' and 'Marmalade,' in trays of cells with a height of 5.71 cm and a volume of 35.4 mL (AG3, Inc., Eustis FL; North Creek Nurseries, Landenberg, PA; and Green Leaf Plants, Lancaster, PA, respectively), were transplanted into containers, with a height of 18.4 cm, diameter of 16.2 cm, and volume of 2.8 L, filled with a commercial bark-based soilless substrate containing a starter nutrient charge consisting of Canadian sphagnum peat moss, bark, perlite, and dolomitic limestone, (Fafard 3B, SunGro Horticulture, Agawam, MA). Fertilizer treatments included constant liquid feed (CLF) of 15N-2.2P-12.5K containing micronutrients (Jack's Professional Calcium + Magnesium LX Water Soluble Fertilizer, J.R. Peters, Inc., Allentown, PA) applied at every irrigation event at the following concentrations, 50, 125, or 250 $mg \cdot L^{-1}$ N. Fertilizers solutions were mixed and stored in 121 L containers; plants were irrigated by hand-watering daily or as needed to container capacity. The experimental design was a completely randomized design with sixteen replications per treatment; each cultivar was analyzed as a separate experiment. Plants were transplanted between 6 May and 9 June 2014 ('Hot Papaya' on 6 May, 'Marmalade' on 2 June, and 'Harvest Moon' on 9 June) and grown in a quonset-style coldframe covered with a single layer of 4-mil opaque white polyethylene in Blacksburg, Virginia (lat. 37.23N, long. 80.42W) until they were in flower, between 13 and 14 weeks after transplant (WAT).

At the end of the study, plant height, width, and number of branches were measured. Days to flower and number of flowers were recorded. A SPAD meter (SPAD 502, Spectrum Technologies, Aurora IL) was used to measure the greenness or relative chlorophyll concentration of the leaves. For each plant, three readings were taken on newly expanded leaves, and the results were averaged. Finished plants were harvested and dried; leaf tissue from mature leaves of new growth (Bryson, 2014) of three plants per treatment was analyzed for tissue nutrient content (Quality Analytical Laboratories, LLC, Panama City, FL), while the remaining thirteen plants were dried for 48 h at 66°C for shoot dry weights. Statistical analysis was performed by JMP Pro 12.0 (SAS Institute Inc., Cary, NC). All data were subjected to analysis of variance and regression analysis.

Nitrogen rate:

In the previous experiment, we compared the effects of increasing fertilizer concentrations of 15N-2.2P-12.5K on the growth of *Echinacea* cultivars. However, fertilizers with different N-P-K ratios are frequently used in commercial production. In this experiment, we focused our fertilizer comparison on N only, holding all other elements constant, to isolate the effects of N on *Echinacea* growth and provide N guidelines for growers in *Echinacea* production not based on any one fertilizer formulation.

Commercially-grown liners of *Echinacea* 'Harvest Moon' and 'Marmalade' (North Creek Nurseries, Landenberg, PA), were received in trays with cells with a height of 5.71 cm and volume of 35.4 mL. Liners were transplanted, 'Harvest Moon' on 3 Mar. 2015 and 'Marmalade' on 23 Mar. 2015, into containers with a height of 18.4 cm, diameter of 16.2 cm, and volume of 2.8 L, filled with a bark based soilless substrate containing a starter nutrient charge and consisting of bark, Canadian sphagnum peat moss, perlite, vermiculite, and dolomitic limestone (Fafard 52, SunGro Horticulture, Agawam, MA). Plants were grown in a double polyethylene greenhouse (average daily high temperature 26.6 °C, average daily low temperature 18.4 °C) located in Blacksburg, VA (lat. 37.23N, long. 80.42W) from Mar. through June 2015. The study was concluded 12 WAT, when most plants were flowering.

Nitrogen treatments consisted of 50, 150, 250, or 350 $mg \cdot L^{-1}$ N applied as CLF based on 50 $mg \cdot L^{-1}$ 5N-5.2P-21.6K (5% nitrate N with micronutrients, Jack's Professional 5-12-26 Hydroponic, J. R. Peters, Inc., Allentown, PA) with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 (calcium chloride dehydrate, Fisher Scientific, Pittsburgh, PA) and ammonium nitrate (Fisher Scientific) added to reach desired N rates. All plants received the same level of P, K and micronutrients, while N levels varied by treatment. Fertilizer solutions were mixed and stored in 121-L containers; plants were hand watered.

The experimental design was a randomized complete block with four replications; each cultivar was a separate experiment. Treatments in each replicate contained four plants (subsamples).

Volumetric water content (VWC) was measured daily in one plant from each replication in each cultivar with a Waterscout SM 100 soil moisture sensor (Spectrum Technologies, Plainfield, IL). Plants were irrigated to maintain a 20% leaching fraction when the mean VWC taken from four plants per treatment (one from each replication) fell below a threshold; the threshold for irrigation began at 17% VWC and increased to 25% VWC as plants grew during the study. The amount of irrigation to reach 20% leaching fraction was reassessed every two weeks. Every two weeks, pH and electrical conductivity (EC), a measure of the soluble salts which indicates level of plant available nutrients, were monitored through the pour-through method (Camberato et al., 2009).

To determine the effects of N treatments on gas exchange, leaf photosynthetic activity was measured 10 WAT using a portable photosynthesis system (LI-COR LI-6400XT, LI-COR Inc., Lincoln, NE). The third mature leaf from the top of the plant was measured in each plant, in each replicate (n=4, based on 4 subsamples). The reference CO_2 concentration was set to 400 $\mu mol \cdot mol^{-1}$; the air temperature, leaf temperature, and relative humidity averaged 30.8°C, 28.7°C, and 56%, respectively.

In previous research, we have seen uneven rates of flowering in finished plants and premature flowering in liners. To promote uniform flowering, plants were kept under short days (SD) with a daylength of 10 h, and flower stalks were removed for the first six weeks; previous research has shown flowering in *Echinacea* to be inhibited under SD (Heide, 2004; Warner et al., 2013). Short days were maintained by covering and uncovering the plant benches with blackout cloth daily. After the first 6 weeks, plants were grown under natural daylength (14 h).

Data were collected as in the previous experiment. Substrate was washed off of roots by hand using a screen to prevent loss of roots. Leaf tissue from one plant from each replicate was analyzed for tissue nutrient content (Quality Analytical Laboratories, LLC). Shoots and roots of the remaining plants were dried for 48 h at 66°C and weighed. Data were analyzed as in the fertilizer concentration experiment.

Overwintering survival:

Our objective in this experiment was to determine the effects of fertilizer on the overwintering survival of *Echinacea* hybrid cultivars. Commercially-grown liners of *Echinacea* 'Evening Glow,' 'Marmalade,' and 'Pow Wow White' (Creek Hill Nursery, Leola, PA) were received and transplanted into containers, with a height of 18.4 cm, diameter of 16.2 cm, and volume of 2.8 L, filled with Fafard 52 substrate on 20 Aug. 2015. Fertilizer treatments included low (5.0 $kg \cdot m^3$), medium (7.7 $kg \cdot m^3$), and high (10.7 $kg \cdot m^3$) rates of controlled release fertilizer (CRF) (Osmocote Plus 15N-3.9P-10K 8-9 months, Everris NA Inc., Dublin, OH) incorporated into the substrate with a soil mixer (Twister I Batch Mixer, Bouldin & Lawson, LLC, McMinnville, TN), as well as a water soluble fertilizer (WSF) treatment consisting of 150 $mg \cdot L^{-1}$ N using 15N-2.2P-12.5K with 3.00% ammoniacal nitrogen and 12.00% nitrate nitrogen (Jack's Professional 15-5-15 Calcium + Magnesium LX, JR Peters, Inc.) applied at every irrigation event using a fertilizer injector until 1 Oct. 2015 and again after 1 Apr. 2016. In the WSF treatment, fertilization was stopped when minimum temperatures were projected to remain below 7°C (Kessler, 2014). Plants in the WSF treatment received unfertilized water only between 1 Oct. 2015 and 1 Apr. 2016. Plants in the low, medium, and high CRF treatments received unfertilized irrigation water throughout the study. All plants were hand watered using municipal water (pH 5.8, EC 0.15 $mS \cdot cm^{-1}$).

In the previous experiments we treated each cultivar as a separate experiment. However, because we saw differences in the cultivar response to treatments, in this study we chose to compare cultivars to one another to quantify differences. The experiment was a randomized complete block design in a 4 (fertilizer) by 3 (cultivar) factorial arrangement with four blocks, each consisting of three pots. Pots filled with substrate surrounded each block and treatments within each block as buffers. Statistical analysis was performed by JMP Pro 12.0 (SAS Institute Inc., Cary, NC). Nominal logistic regression was used to analyze plant survival.

Plants were grown in a coldframe in Blacksburg, VA, as described in the fertilizer concentration experiment, from 20 Aug. 2015 through 24 June 2016. The coldframe was covered 1 Nov. 2015. At this time, sides were left raised and only closed on nights when temperatures were projected to be below 0°C. Sides were closed for the season 10 Jan. 2016. Sides were raised in 9 Mar. 2016. Plants were covered with thermoblankets (1.5 oz. per square yard, FrostGuard Heavy Weight Row Cover, Growers Supply, Dyersville, IA) when low temperatures were consistently expected to remain below 0°C. Blankets were removed when temperatures reached 4°C (Smith, 2016). Data loggers (WatchDog A-Series Loggers, Spectrum Technologies, Plainfield, IL) were used to continually monitor air temperature and rootzone temperature inside the coldframe during the experiment.

Plant survival was noted on 22 Apr. 2016. Substrate pH and EC were monitored as in N rate experiment biweekly during active growth, and monthly during dormancy. Liquid flowable lime (Limestone F Liquid Flowable Limestone, Cleary Chemical, Dayton NJ) was applied according to label rates using a 1:100 injector to raise substrate pH as needed.

Results and Discussion

Growth effects of fertilizer concentration

Fertilizer concentration affected growth of ‘Marmalade,’ but not ‘Harvest Moon’ and ‘Hot Papaya’ (Table 4.1 and Fig. 4.1). Fertilizer concentration affected height, number of branches, number of flower stalks, and shoot dry weight in ‘Marmalade’; height, number of branches, number of flower stalks, and shoot dry weight increased with increasing fertilizer concentration up to 250 $mg \cdot L^{-1}$ N.

Similarly, other studies have reported increased shoot dry weight in response to fertilizer concentration. *Echinacea purpurea* grown with N rates up to 200 $mg \cdot L^{-1}$ N had increased biomass at higher rates of N (Davis et al., 2010). Fertilizer concentrations from 50 to 500 $mg \cdot L^{-1}$ N affected shoot dry weight and plant height of *Oxalis regnellii* Miq.*;* rates below 100 $mg \cdot L^{-1}$ N and above 300 $mg \cdot L^{-1}$ N reduced growth (Miller et al., 2011). Total dry weight of *Rudbeckia fulgida* Ait.'Goldsturm' increased with increasing N concentration when grown with 50, 100, or 200 $mg \cdot L^{-1}$ N (Kraus et al., 2011).

Although growth was affected by fertilizer concentration in 'Marmalade,' shoot dry weight and other growth measurements were not affected by fertilizer concentration in 'Harvest Moon' and 'Hot Papaya'. Likewise, of ten herbaceous perennial taxa treated with increasing fertilizer concentration, shoot dry weight was affected in only six (Scoggins, 2005). In this study although the percentage of plants which flowered was not affected by fertilizer concentration in 'Hot Papaya' or 'Harvest Moon,' lower fertilizer concentration reduced flowering percentage in 'Marmalade': 79% of plants treated with 250 $mg \cdot L^{-1}$ N flowered, but only 8% of plants treated with 50 $mg \cdot L^{-1}$ N or 38% of plants treated with 125 $mg \cdot L^{-1}$ N flowered (data not shown). Likewise, flowering of *Begonia ×semperflorens-cultorum* Hort. and *Petunia ×hybrida* Hort. Vilm-Andr. was reduced in plants grown with a fertilizer EC of less than 0.85 and 1.3 $dS \cdot m^{-1}$ respectively (James and van Iersel, 2001).

Growth effects of N rate.

For *Echinacea* 'Harvest Moon,' N rate affected height, number of flowers, and SPAD but did not affect width, days to flower, root dry weight or shoot dry weight (Table 4.2). Nitrogen rate did not affect the number of branches in either cultivar (data not shown). In 'Marmalade' height, width, number of flowers, days to flower, SPAD, root weight and shoot weight (Fig. 4.2) were affected by N rate.

Height and number of flowers of ‘Harvest Moon’ and height, plant width, and root dry weight of ‘Marmalade’ decreased linearly with increasing N rate (Table 4.2). In both ‘Harvest Moon’ and ‘Marmalade’ SPAD measurements had a quadratic response to N rate. Days to flower and number of flowers had a quadratic response to N rate in ‘Marmalade.’

In this study, plants grown under higher N rates were smaller (Fig. 4.3), perhaps caused by high substrate EC (Fig. 4.4). Substrate EC rose while pH fell over the course of the study in all plants. Substrate EC was relatively high, above 4.00 $mS \cdot cm^{-1}$, for substrates in all treatments, and was greatest in the highest N rates. High substrate EC also reduced leaf area and shoot dry weight of pansies (*Viola ×wittrockiana* Gam.) treated with fertilizer solution with EC between 0.6 to 3.6 $mS \cdot cm^{-1}$; optimal growth occurring between 164 and 256 $mg \cdot L^{-1}$ N (van Iersel, 1999). Substrate pH in plants treated with 50 $mg \cdot L^{-1}$ N was in the normal range for *Echinacea* (5.5 to 6.5) (Kaiser et al., 2015; Pilon, 2006) while substrate pH in plants with higher N rates was low, below 5.5, by the end of the study. Plants treated with 50 $mg \cdot L^{-1}$ N received N in the form of nitrate only, those treated with higher levels of N received additional N in the form of ammonium nitrate, which has been shown to acidify substrate pH (Bryson et al., 2014).

Tissue nutrient content.

In the fertilizer concentration experiment, foliar tissue N and P content were not affected by fertilizer concentration in ‘Harvest Moon’; however, tissue levels of N and P increased with increasing fertilizer concentration in ‘Marmalade’ and ‘Hot Papaya’ (Table 4.3). Tissue N content was strongly correlated with fertilizer concentration in ‘Marmalade’ (Fig. 4.1B). Tissue K levels had a quadratic response to fertilizer concentration in ‘Harvest Moon’ and increased in a linear manner in ‘Marmalade’; however, tissue K was not affected by fertilizer concentration in ‘Hot Papaya’ (Table 4.3). Nutrients can be present in different concentrations among related cultivars cultivated in the identical growing media (Bryson et al., 2014). Similarly, tissue N and

P increased with increasing N fertilizer concentration in *Rudbeckia fulgida* ’Goldsturm,’ however, K was unaffected by N concentration (Kraus et al., 2011).

In all three cultivars, tissue percentage of N, P, and K were in the nutrient sufficiency range or above (Bryson et al., 2014), regardless of fertilizer concentration. Calcium amounts were below the nutrient sufficiency range for all treatments in all cultivars, despite the application of a fertilizer containing 4% Ca (Jack’s Professional Calcium + Magnesium LX Water Soluble Fertilizer, J.R. Peters, Inc.). This indicates that the *Echinacea* cultivars in this study had relatively high Ca needs which may need additional supplementation to reach the tissue nutrient sufficiency range. Ca was not affected by fertilizer concentration in ‘Harvest Moon’ but increased in a linear manner in response to fertilizer concentration in ‘Marmalade’ and ‘Hot Papaya.’ Levels of Mg decreased as fertilizer concentration increased in ‘Harvest Moon’ but was not affected by fertilizer concentration in ‘Marmalade’ or ‘Hot Papaya.’ Tissue Mg content was in the nutrient sufficiency range in all treatments in all cultivars.

Tissue content of Fe increased in a linear manner in ‘Harvest Moon’ and ‘Hot Papaya’ and responded in a quadratic manner to the increasing fertilizer rate in ‘Marmalade’ (Table 4.3). Manganese levels were unaffected by fertilizer concentration in ‘Harvest Moon’ while tissue Mn levels increased quadratically in ‘Hot Papaya’ and ‘Marmalade.’ Boron levels increased with increasing fertilizer concentration in all cultivars and were within the nutrient sufficiency range in all treatments. Tissue Cu content increased linearly with fertilizer concentration in all cultivars and was below the nutrient sufficiency range. In ‘Harvest Moon’, Zn increased with fertilizer concentration but levels of Zn were not affected by fertilizer concentration in ‘Marmalade’ or ‘Hot Papaya.’ Levels of Zn were below the nutrient sufficiency range in all plants except in ‘Harvest Moon’ grown with the two highest fertilizer concentrations. Molybdenum levels were higher than the nutrient sufficiency range in all fertilizer concentrations in all cultivars, but were not affected by fertilizer concentration.

In the N rate experiment, tissue N was strongly correlated with N rate in both 'Marmalade' and 'Harvest Moon' (Fig. 4.2B and 4.2F). In comparison, in the fertilizer concentration experiment, there was a strong correlation between tissue N and N concentration only in 'Marmalade' (Fig. 4.1B). Although only levels of N varied with fertilizer treatment, tissue N and P increased with increasing N rates in both cultivars (Table 4); a similar response was seen in *Rudbeckia fulgida* 'Goldsturm' (Kraus et al., 2011).

While tissue K levels were unaffected by N rate in 'Harvest Moon,' K had a quadratic response to N rate in 'Marmalade.' As in the fertilizer concentration study, levels of N, P and K are in the nutrient sufficiency range or above for plants in all treatments. In 'Harvest Moon,' tissue-Ca is not affected by N treatment and is below the sufficiency range for all plants; however in 'Marmalade,' Ca is in the sufficiency range in plants in all treatments and increases with increasing N rate. In 'Harvest Moon,' Mg had a quadratic response to N rate, while Mg in 'Marmalade' was not affected by N rate. Levels of S were below the sufficiency range for all 'Harvest Moon' and all 'Marmalade' except those treated with the highest N rate.

In 'Harvest Moon,' tissue Fe, Mn, and Cu levels increased with higher N rates, while levels of B and Zn were unchanged by N rate. Tissue content of Fe, Mn, and B increased with increasing N rates in 'Marmalade,' while amounts of Cu, Zn, and Mo were not affected by N treatment. In both cultivars levels of Cu were in the low range for plants of all treatments.

There were no visible nutrient deficiency symptoms noted during either experiment. In both experiments, tissue analysis indicated that levels of N, P, K, Mg, B, and Mo were within or above the sufficiency range for *Echinacea* even at low fertilizer concentration and N rates

(Tables 3 and 4). Likewise, begonias and petunias grown with 20N-4.4P-16.6K applied as CLF with fertilizer EC of 0.15, 0.6, 1.2, 1.8, 2.4, or 3.0 $mS \cdot cm^{-1}$ had tissue N, P, and K levels within the sufficiency range at all fertilizer concentrations (James and van Iersel, 2001). While fertilizers in the N rate experiment had constant levels of all nutrients except N, plant tissue showed significant differences in nutrients present in response to fertilizer application, suggesting possible nutrient interactions.

Photosynthesis.

The correlation between leaf photosynthesis and N rate was strong in 'Harvest Moon' but not in 'Marmalade' (Fig. 4.2D and 4.2H). In 'Marmalade' photosynthesis increased slightly with increasing N rate, whereas photosynthesis declined as N rate increased in 'Harvest Moon.' In contrast, photosynthesis of *Eustoma grandiflorum* (Raf.) increased with increasing N concentrations from 50 $mg \cdot L^{-1}$ N to 350 $mg \cdot L^{-1}$ N (Marchese, 2005). In *Echinacea angustifolia* DC. and *E. pallida* Nutt grown in hydroponic solutions with EC ranging from 0.6 to 2.4 $mS \cdot cm^{-1}$, photosynthesis was highest in both species at median rates of fertilization (in solutions of 1.5 $mS \cdot cm^{-1}$ for *E. angustifolia* and in a range from 0.9 to 1.8 $mS \cdot cm^{-1}$ for *E. pallida*) (Lee et al., 2006). Photosynthesis of the *Echinacea* cultivars in our study had different responses to N rate; photosynthesis of 'Harvest Moon' was reduced by high rates of N, whereas photosynthesis of 'Marmalade' was not affected by N rate.

SPAD.

In both the fertilizer concentration study and the N rate study, tissue N was highly correlated with applied N (Fig. 4.1B and 4.1E and Fig.4.2B and 4.2F). However, in both studies, SPAD measurements had a weak correlation with tissue N in both cultivars (Fig. 4.1C and 4.1F and Fig. 4.2C and 4.2G). SPAD meters measure the greenness of leaves which has been correlated with chlorophyll content and leaf N in horticultural and agronomic crops (Xiong et al., 2015). Although SPAD meters provide an instantaneous and non-destructive method to monitor N status in plants (Netto et al., 2005), the correlation between SPAD reading and tissue N content varies by species (Xiong et al., 2015). In these experiments, we found a weak correlation between SPAD readings and tissue N in both *Echinacea* 'Harvest Moon' and 'Marmalade.' Similarly, Martı´n et al. (2007) found that SPAD readings were not strongly correlated with leaf N in two of three ornamental species studied. Although SPAD measurements can be useful in determining N status in some species, we did not find evidence that the SPAD meter is valuable as a diagnostic tool with these two *Echinacea* cultivars.

Overwintering survival.

Fertilizer treatment had a significant effect on the winter survival of *Echinacea* 'Evening Glow,' 'Marmalade,' and 'Pow Wow White' (Table 4.5). Cultivar did not affect winter survival of these three cultivars and there was no significant interaction between fertilizer treatment and cultivar (Table 4.5). Winter survival percentage was highest with the WSF treatment (which consisted of 150 $mg{\cdot}L^{-1}$ N from 15N-2.2P-12.5K applied as CLF until Oct.); 92% of plants treated with WSF survived overwintering (data not presented). Winter survival percentage decreased with increasing rates of CRF fertilizers; 70% of plants in the low treatment survived, while only 25% and 3% survived the medium and high treatments, respectively (data not presented). Likewise, low CRF rates have increased the percentage of ornamental grasses which survived overwintering compared to high CRF rates (Harris et al., 2015).

Other studies have had similar results with stopping nutrient application in the fall. Perry (2006) reported that perennials which have been fertilized until mid-Oct. (300 $mg{\cdot}L^{-1}$ N applied as CLF from 20N-4.4P-16.6K) had increased growth after freezing. Kessler (2014) recommends reducing fertilization of perennials to be overwintered in late summer or early fall and stopping fertilization when temperatures fall below 7.2°C. Recent research in Quebec (Lemaire et al.,

2014) found that a higher percentage of *E. purpurea* survived overwintering when fertilization (200 mg·L^{-1} N applied as CLF from 20N-3.5P-16.6K) was stopped in Oct., compared to when fertilization was stopped or reduced in Aug. *Echinacea* 'Tiki Torch' and 'Tomato Soup' had higher survival rates when fertilization was stopped in August (Lemaire et al., 2014). In this study both cultivars had much lower survival rates than *E. purpurea*.

Substrate pH measurements began at normal levels of 5.5 to 6.2 at 4 WAT (Fig. 4.5A) but fell in plants treated with CRF over the next 8 weeks. Applications of lime to plants grown with CRF brought pH levels back to normal by Dec., before the coldest weather (Fig. 4.6). Plants treated with CRF had high substrate EC (3.0 to 4.6 mS·cm^{-1}) which fell over the first 14 weeks to 1.9 mS·cm^{-1} to 2.7 mS·cm^{-1} while plants treated with WSF began the study with normal substrate EC (1.2 mS·cm^{-1}) which dropped to 0.3 mS·cm^{-1} over 14 weeks (Fig. 4.5B).

For herbaceous perennials, substrate EC should be between 1.0 mS·cm^{-1} to 2.0 mS·cm^{-1} during the growing season but can drop to 1.0 mS·cm^{-1} going into dormancy (Gill, 2012). Pilon (2014) recommends that *Echinacea* 'Cheyenne Spirit' should have low EC, below 0.7 mS·cm^{-1}, before entering winter. In our study, substrate EC dropped between transplant and dormancy; however, only plants in the WSF treatment had substrate EC below 1.0 mS·cm^{-1} at 14 WAT while plants in the low CRF treatment had substrate EC of 1.9 mS·cm^{-1}. Plants in the medium and high CRF treatments, few of which survived overwintering, had substrate EC of 2.3 mS·cm^{-1} and 2.7 mS·cm^{-1}, respectively, before dormancy. High substrate EC in these treatments appeared to contribute to poor survival rates in *Echinacea* cultivars. Leaching to reduce high EC in the fall may have protected the plants from winter damage (LeBude et al., 2012).

Cultivar response to fertility treatments.

Response to fertilizer treatments varied by cultivar in both the fertilizer concentration and N rate experiments. 'Marmalade' had increased height, number of branches, number of flowers, and shoot dry weight with increasing fertilizer concentration in the fertilizer concentration experiment. On the other hand, growth of ‘Harvest Moon’ and ‘Hot Papaya’ was not influenced by fertilizer concentration. Similarly, in the N rate experiment, ‘Marmalade’ was more responsive to fertilizer treatment. In ‘Marmalade’ plant height, width, days to flower, number of flowers, SPAD, root dry weight and shoot dry weight were significantly affected by N rate. However, in the N rate experiment growth parameters decreased as N rates increased. In contrast, in ‘Harvest Moon’ only height, number of flowers and SPAD were affected by N rate. A cultivar-specific response to N was also seen in *Pelargonium* × *hortorum* Bailey (Wang et al., 2012), *Helianthus annuus* L. (Chen et al., 2005), *Ipomoea batatas* (L.) Lam. (Nin and Gilsanz, 1998), and *Rhododendron* L. cultivars (Hummel et al., 2013). While some cultivars are more responsive to higher fertilizer levels than others, in production growers need to monitor growth and substrate EC while applying the minimum amount of fertilizer needed to produce quality plants.

Conclusions

Although there were differences in cultivar response to fertilizer treatment, shoot dry weight of ‘Harvest Moon’ and ‘Marmalade’ was greatest when grown between 150 and 200 $mg \cdot L^{-1}$ N in the N rate experiment. Similarly, shoot dry weight of greenhouse-grown *E. purpurea* increased with increasing N rates up to 200 $mg \cdot L^{-1}$ N (Davis et al., 2010). Likewise, *E. pallida* and *E. angustifolia* grown hydroponically in solution with EC levels ranging from 0.6 $mS \cdot cm^{-1}$ to 2.4 $mS \cdot cm^{-1}$ had greatest shoot biomass when grown with an EC of 0.6 to 1.2 $mS \cdot cm^{-1}$ and 1.5 to 1.8 $mS \cdot cm^{-1}$ respectively (Lee et al., 2006).

Number of branches and number of flowers, also indicators of plant quality, were greater when plants were fertilized with 125 or 250 $mg \cdot L^{-1}$ N than compared to those fertilized with 50 mg·L^{-1} N in the fertilizer concentration experiment in ‘Marmalade’. Likewise, numbers of flowers were the same or greater at 150 mg·L^{-1} N in the N rate experiment than at 50 mg·L^{-1} N. All of the fertilization treatments, even the lowest level of 50 mg·L^{-1} N, led to tissue N levels in the nutrient sufficiency range or above (Bryson et al., 2014) in the fertilizer concentration and the N rate experiments. We found that providing *Echinacea* cultivars with 150 mg·L^{-1} N led to quality plants with adequate growth without excessive N, which can reduce growth as seen in ‘Marmalade’ in the N rate experiment.

A high quality perennial should be balanced, with a proportional height and width that is aesthetically pleasing, well-branched, and flowering (other than plants grown primarily for their foliage) (Pilon, 2006; 2011). The goal in fertilizing perennials is to apply enough fertilizer to achieve quality plants without applying too much which could encourage too much growth, reduce growth, or be leached into the environment. In this study we examined the response of hybrid *Echinacea* cultivars to fertilizer concentration and N rate during the growing season and to fertilizer during overwintering to determine fertilizer guidelines for growing these popular new cultivars.

Echinacea hybrid cultivars had cultivar-specific responses to fertilization. These cultivars are hybrids based on interspecific crosses from species which originate in different habitats (Ault, 2007); it is not surprising that cultivars would have varying growth and nutritional requirements based on their genetics. We found that supplying N at 150 mg·L^{-1} during the growing season provided *Echinacea* cultivars adequate nutrition and maximized numbers of branches and flowers and shoot dry weight. In overwintering, more *Echinacea* plants survived with fertilization treatments that resulted in low substrate EC going into dormancy compared to those which resulted in high substrate EC. As a monitoring tool, SPAD measurements were not successful in predicting tissue N levels in *Echinacea* hybrids. Photosynthesis was correlated with N rate in one cultivar but not the other; there was not a clear pattern of photosynthesis of *Echinacea* cultivars in response to N fertilization in this study. Tissue macronutrient levels (with the exception of Ca and S) were within or above the sufficiency range with all fertilizer treatments. This suggests that *Echinacea* can be grown at a range of fertilizer concentrations but that growers should look for formulations which provide added Ca and S. Providing enough N for optimal growth, but not too much which can reduce growth, is important in the production of hybrid *Echinacea*.

Literature Cited

Armitage, A.M. 2008. Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes. 3rd ed. Stipes, Champaign, IL.

Armitage, A.M. 2011. Armitage's garden perennials. Timber Press. Portland, OR.

Ault, J.R. 2007. Coneflower, p. 801-824. In: Anderson, N.O. (ed.) Flower breeding and genetics. Springer, Dordrecht, The Netherlands.

Ault, J. and C. Thomas. 2014. Plant propagation for the breeding program at Chicago Botanic Garden. Acta Hort. 1055:265-268.

Bryson, G.M., H.A. Mills, D.N. Sasseville, J.B. Jones, Jr., and A.V. Barker. 2014. Plant analysis handbook III: A guide to sampling, preparation, analysis, and interpretation and use of agronomic and horticultural crop plant tissue. Micro-Macro Publ., Athens, GA.

Camberato, D.M., R.G. Lopez, and M.V. Mickelbart. 2009. pH and electrical conductivity measurements in soilless substrates. Purdue Univ. Ext. Serv. Bul. HO-237-W.

Chen, Y., D. Merhaut, and J.O. Becker. 2005. Hydroponic sunflower production as influenced by cultivar, N fertilization, and root-knot nematode infestation. HortScience 40:1013 (abstr.).

Davis, J.M., D. Reardon, A. Hamilton, V. Kandhi, A. Jarmusch, and N. Cech, N. 2010. Influence of N and pH on constituent levels and plant growth of greenhouse-grown *Echinacea purpurea*. HortScience 45:S217 (abstr.).

Gill, S.A, K. Rane, and A. Ristvey. 2012. Key insects, diseases, and cultural problems by crop, p. 13-26. In: Gill, S.A. and D. Smith-Fiola (eds).Total plant management of herbaceous perennials. Univ. of MD Coop. Ext. Bul. 359.

GLPlants.com. 2012. Technical guide *Echinacea* Conefections series. 31 August, 2014 <http://www.glplants.com/system/cms/files/files/000/000/508/original/ECHINACEA_Cone-fectionsSeries.pdf>.

Harris, W.K., J.G. Latimer, J.F. Freeborn, M. Aiken, and H.L. Scoggins. 2015. Overwintering survival and vigor of container-grown fountain grass: Influence of substrate moisture content, protective covers, and fertilizer rate. HortTechnology 25:791-795.

Heide, O.M. 2004. Dual induction rather than intermediate daylength response of flowering in *Echinacea purpurea*. Physiol. Plant. 120:298-302.

Hummel, R.L., M. Elliott, G. Chastagner, R.E. Riley, K. Riley, and A. DeBauw. 2013. Nitrogen fertility influences growth and susceptibility of rhododendrons to *Phytophthora ramorum*. HortScience 48:601-607.

James, E.C. and M.W. van Iersel. 2001. Fertilizer concentration affects growth and flowering of subirrigated petunias and begonias. HortScience 36:40-44.

Kaiser, C., R. Geneve, and M. Ernst. 2015. Echinacea. Univ. of KY Coop. Ext. Serv. 13 September 2016. <https://www.uky.edu/Ag/CCD/introsheets/echinacea.pdf>

Kessler, J.R., Jr. 2014. Herbaceous perennial production. 16 October 2014. <http://www.ag.auburn.edu/hort/landscape/herbaceousperennials.html.>

Kraus, H.T., S.L. Warren, G.J. Bjorkquist, A.W. Lowder, C.M. Tchir, and K.N. Walton. 2011. Nitrogen: phosphorus: potassium ratios affect production of two herbaceous perennials. HortScience 46:776-783.

LeBude, A.V., T.E. Bilderback, H.T. Kraus, S.A. White, M. Chappell, and J. Owen. 2012. Preparing nursery plants for winter in the Southeastern United States. N.C. State Univ. AG-454. 24 August 2015. <http://www.nurserycropscience. info/cultural-practices/overwintering/extension-publications/preparingnursery-crops-for-winter-ag-454.pdf/view>.

Lee, Y.H., H.J. Lee, J.S. Seo, Y.B. Lee, S.E. Lee, and C.Lee. 2006. Photosynthesis and root biomass of *Echinacea* cultured at different nutrient concentration in hydroponics. 27th Intl. Hort. Congr. (abstr.)

Lemaire, E., M. Trépanier, S. Simard, and M. Comtois. 2014. Evaluation of different crop management and overwintering techniques on winter survival of different *Echinacea* cultivars. Landscape Trades 36(3):9-13.

Marchese, J.A., I. Katz, A.P. Sousa, and J.D. Rodrigues. 2005. Gas exchange in lisianthus plants (*Eustoma grandiflorum*) submitted to different doses of nitrogen. Photosynthetica 43:303-305.

Martı´n, I., N. Alonso, M.C. Lo´pez, M. Prieto, C. Cadahı´a, and E. Eymar. 2007. Estimation of leaf, root, and sap N status using the SPAD-502 chlorophyll meter for ornamental shrubs. Commun. Soil Sci. Plant Anal. 38:1785-1803.

Miller, C.T., N.S. Mattson, and W.B. Miller. 2011. Fertilizer composition, concentration, and irrigation method affect growth and development of *Oxalis regnellii* and *O. triangularis*. HortScience 46:1110-1115.

Netto, A.T., E. Campostrini, J.G. de Oliveira, and R.E. Bressan-Smith. 2005. Photosynthetic pigments, N, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. Scientia Hort. 104:199-209.

Nin, A. and J.C. Gilsanz. 1998. Growth analysis and performance of four sweetpotato cultivars under different levels of N and potassium. HortScience 33:443-443.

Perry, L.P. 2006. Herbaceous perennials-container overwintering and hardiness. 24 August 2015 <www.uvm.edu/pss/ppp/pubs/coh31hardy.pdf>.

Pilon, P. 2006. Perennial solutions: A grower's guide to perennial production. Ball Publishing. Batavia, IL.

Pilon, P. 2011. Enhancing perennial production. Greenhouse Product News. 30 September 2016 <http://www.gpnmag.com/article/enhancing-perennial-production-0/>.

Pilon, P. 2013. Perennials demystified: Taking the fear out of premium cultivars. Green Profit 77(4):36.

Pilon, P. 2014. Perennial solutions: *Echinacea* ‘Cheyenne Spirit’. Greenhouse Product News 24(8):44-46.

Provenwinners.com. 2016. Professional Growing Information Big Sky™ ‘Sunrise.’ 1 November 2016. <https://www.provenwinners.com/plant/44063/culture>.

Schoellhorn, R., and A.A. Richardson. 2006. Warm climate production guidelines for *Echinacea*. Univ. of FL IFAS Commercial Floriculture Update ENHFL04-008.

Scoggins, H.L. 2005. Determination of optimum fertilizer concentration and corresponding substrate electrical conductivity for ten taxa of herbaceous perennials. HortScience 40:1504-1506.

Smith, T.M. 2016. Overwintering containerized perennials. Univ. of Mass. 1 September 2015. <https://ag.umass.edu/greenhouse-floriculture/fact-sheets/overwintering-containerized-perennials>

Terranovanurseries.com. 2016.Echinacea Grower Tips. 1 November 2016 <http://www.terranovanurseries.com/growers/echinacea-c-82_22.html>.

U.S. Department of Agriculture (USDA). 2015. Census of horticultural specialties (2014). 31 August 2016. <https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Census_of_Horticulture_Specialties/HORTIC.pdf>

van Iersel, M. 1999. Fertilizer concentration affects growth and nutrient composition of subirrigated pansies. HortScience 34:660-663.

Wang, Y.W., B.L. Dunn, D.B. Arnall, and P.S. Mao. 2012. Use of an active canopy sensor and SPAD chlorophyll meter to quantify geranium nitrogen status. HortScience 47:45-50.

Warner, R., E. Runkle, S. Padhye, and C. Whitman. 2013. Controlling flowering of *Echinacea*. GrowerTalks 76(10):66-70.

Xiong D., J. Chen,T. Yu, W. Gao, X. Ling, Y. Li, S. Peng, and J. Huang. 2015. SPAD-based leaf N estimation is impacted by environmental factors and crop leaf characteristics. Scientific Rpt. 5(13389):1-12

Tables and Figures

Table 4.1 Effect of fertilizer concentration applied as constant liquid feed from 15N-2.2P-12.5K on height, number of branches, and number of flower stalks (n=16) of *Echinacea* 'Harvest Moon,' 'Hot Papaya' and 'Marmalade' finished plants at 13 to 14 weeks after transplant (WAT) in fertilizer concentration experiment.

Cultivar	Fertilizer concn ($mg \cdot L^{-1}$)	Height (cm)	No. of branches	No. of flower stalks
Marmalade	50	41.5	4.8	0.4
	125	57.0	9.8	0.8
	250	64.7	10.9	1.9
	Significance	L***[z]	L***	L***
	R^2	0.26	0.26	0.48
Harvest Moon	50	43.1	12.5	4.8
	125	46.3	15.3	5.3
	250	39.1	11.8	6.1
	Significance	NS	NS	NS
	R^2	0.1	0.02	0.07
Hot Papaya	50	55.6	6.4	1.4
	125	56.6	7.1	2.2
	250	52.3	6.9	1.6
	Significance	NS	NS	NS
	R^2	0.01	0.01	0.14

[z] NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; regression analysis indicating L=linear or Q=quadratic response.

Figure 4.1 Relationships between shoot dry weight and fertilizer concentration applied as constant liquid feed (CLF) from 15N-2.2P-12.5K (n=13), tissue N and fertilizer concentration (n=3), and soil plant analysis development (SPAD) and tissue N (n=16) in *Echinacea* 'Marmalade' (A), (B), (C), and *Echinacea* 'Harvest Moon' in (D), (E), (F), respectively. Solid line represents significant linear or quadratic regression, P ≤ 0.05. Measurements taken on finished plants at 13 to 14 weeks after transplant.

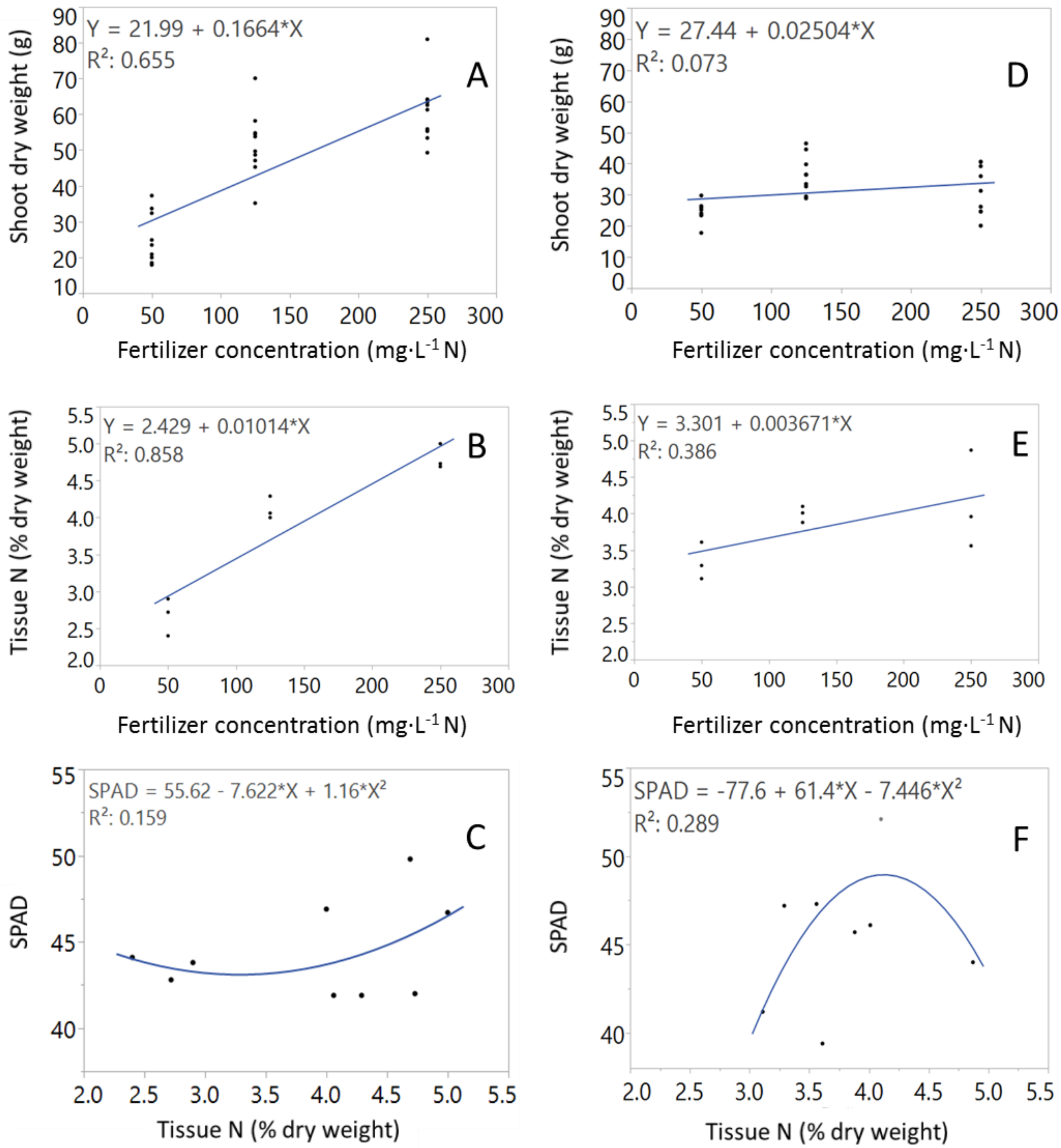


Table 4.2 Effect of nitrogen (N) rate treatments on plant height, width, number of branches, days to flower, number of flowers, SPAD, and root dry weight of *Echinacea* 'Harvest Moon' and 'Marmalade' finished plants at 13 to 14 weeks after transplant in N rate experiment; n=4. Nitrogen rate treatments were applied as constant liquid feed (CLF) and consisted of 50, 150, 250, or 350 mg·L^{-1} N based on 50 mg·L^{-1} 5N-5.2P-21.6K with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 and ammonium nitrate added to reach desired N rates.

Cultivar	N rate (mg·L^{-1})	Height (cm)	Width (cm)	No. of flowers	Days to flower	SPAD	Root dry weight (g)
Harvest Moon	50	37.6	26.2	4.29	92.6	47.3	1.16
	150	34.3	25.5	4.17	92.8	51.1	0.85
	250	34.2	25.3	3.88	93.7	51.6	1.03
	350	30.0	25.4	2.90	92.8	53.2	1.09
	Significance	L**	NS	L**	NS	Q*	NS
	R^2	0.41	0.02	0.42	0.04	0.39	0.14
Marmalade	50	65.3	49.3	4.4	72.0	42.3	6.6
	150	57.6	48.8	6.7	69.8	43.5	3.7
	250	49.4	43.0	6.3	68.1	42.3	4.0
	350	38.4	38.8	5.9	69.1	39.3	2.0
	Significance	L***	L***	Q*	Q*	Q**	L***
	R^2	0.92	0.74	0.40	0.44	0.63	0.60

[z] NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; regression analysis indicating L=linear or Q=quadratic response.

Figure 4.2 Relationships between shoot dry weight and nitrogen (N) rate, tissue N and N rate, SPAD and tissue N, and photosynthesis and tissue N (n=4) in *Echinacea* 'Marmalade' (A), (B), (C), (D) and *Echinacea* 'Harvest Moon' in (E), (F), (G), (H), respectively. Nitrogen rate treatments were applied as constant liquid feed (CLF) and consisted of 50, 150, 250, or 350 $mg \cdot L^{-1}$ N based on 50 $mg \cdot L^{-1}$ 5N-5.2P-21.6K with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 and ammonium nitrate added to reach desired N rates. Solid line represents significant linear or quadratic regression, $P \leq 0.05$.

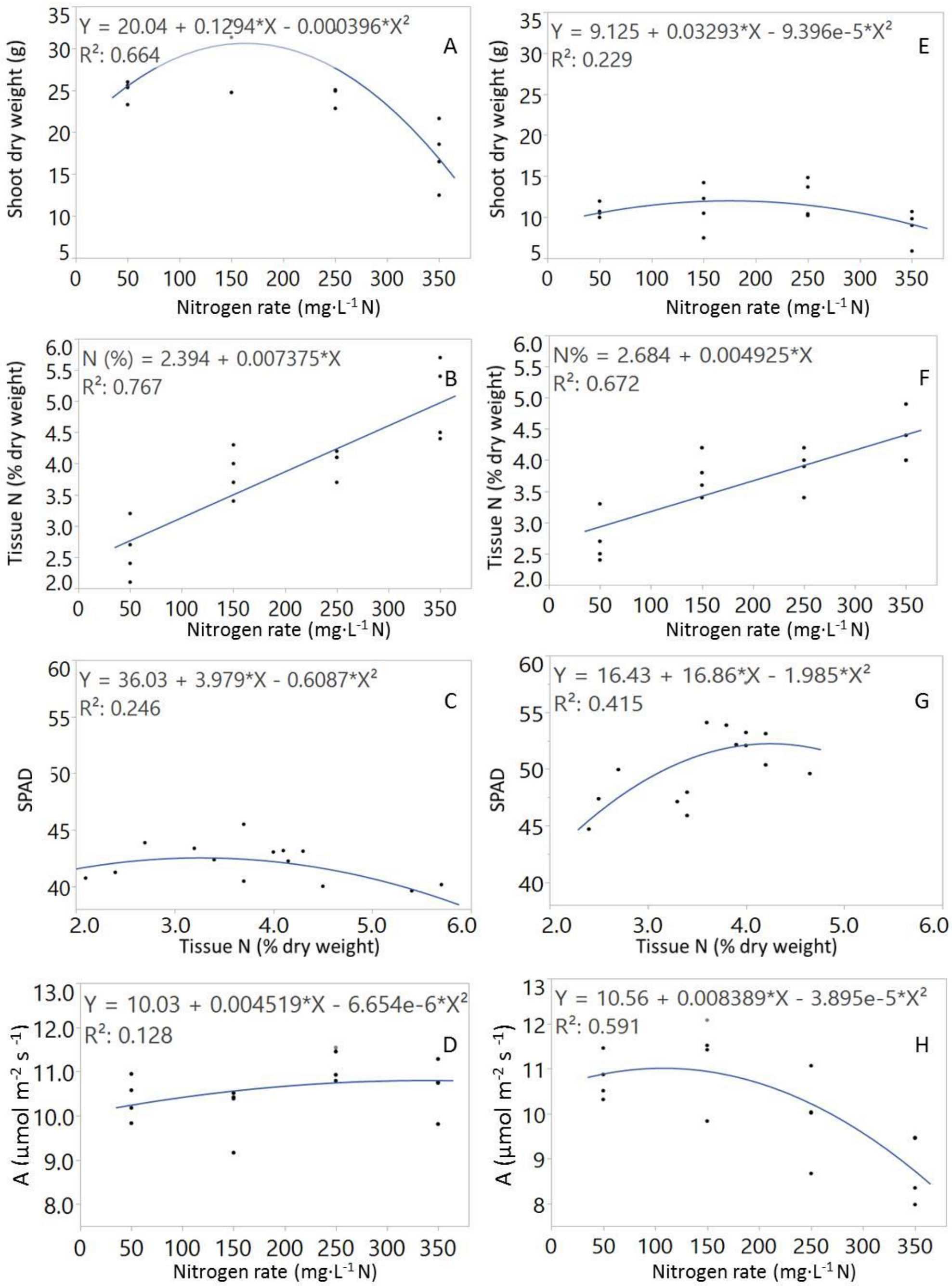


Figure 4.3 Finished *Echinacea* 'Marmalade' (top) and 'Harvest Moon' (bottom) at 12 weeks after transplant (WAT) grown under N rates from 50 to 350 mg·L^{-1} N applied as constant liquid feed (CLF) based on 50 mg·L^{-1} 5N-5.2P-21.6K with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 and ammonium nitrate added to reach desired N rates.

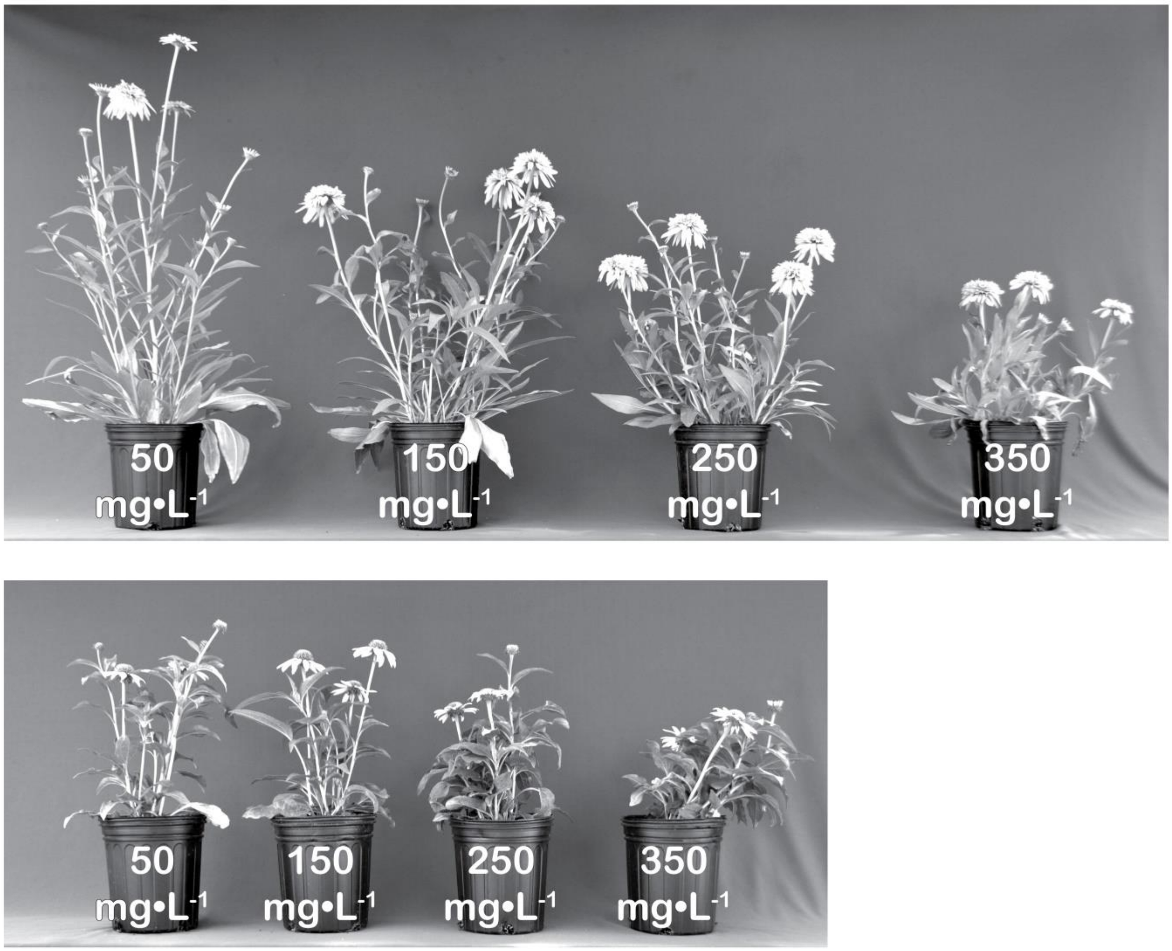


Figure 4.4 Substrate pH and EC response of *Echinacea* ‘Marmalade’ (A and C) and ‘Harvest Moon’ (B and D) to nitrogen (N) rate treatments from 0 to 10 weeks after transplant (WAT) in N rate experiment; n=4. Nitrogen rate treatments were applied as constant liquid feed (CLF) and consisted of 50, 150, 250, or 350 mg·L^{-1} N based on 50 mg·L^{-1} 5N-5.2P-21.6K with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 and ammonium nitrate added to reach desired N rates; data were analyzed by analysis of variance, Student’s T test, $P \leq 0.05$, n=4.

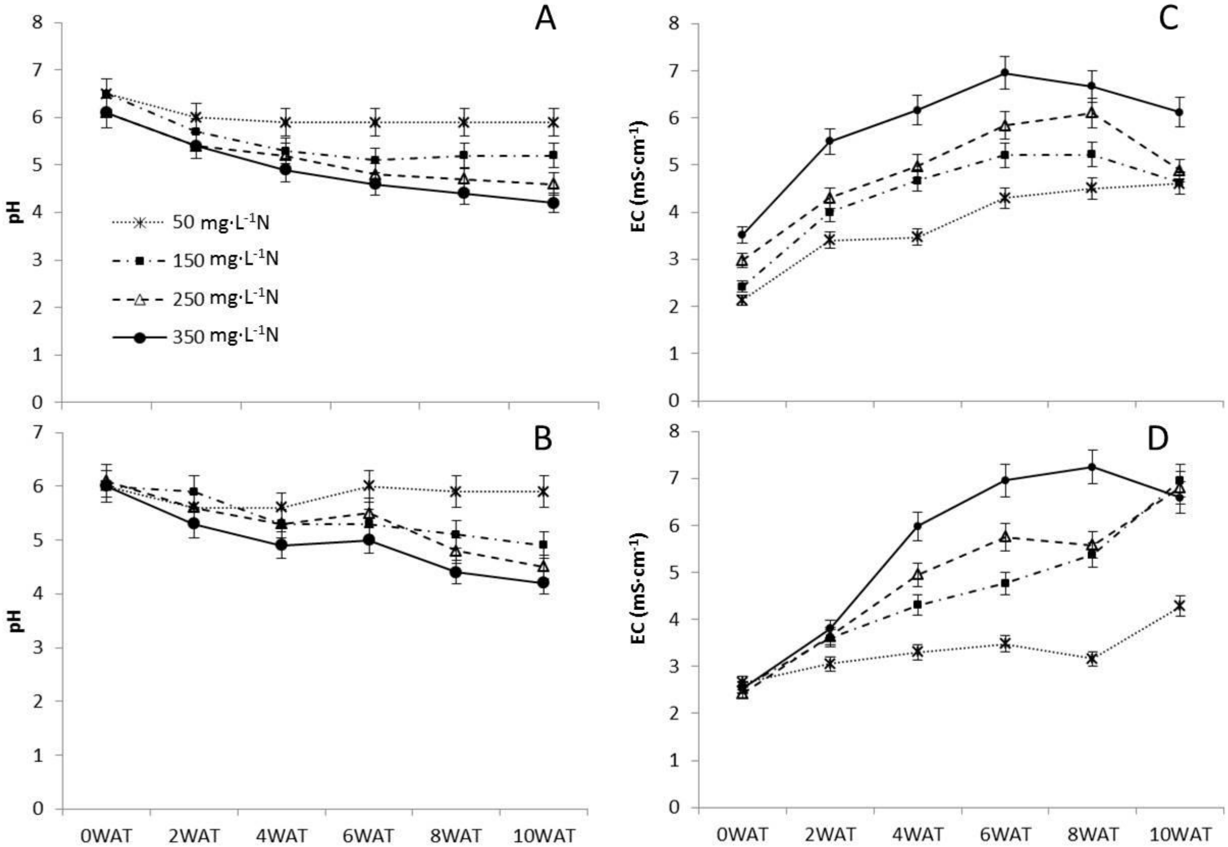


Table 4.3 Effect of fertilizer concentration applied as constant liquid feed (CLF) from 15N-2.2P-12.5K on major and micronutrient tissue nutrient levels of *Echinacea* 'Hot Papaya,' 'Marmalade,' and 'Harvest Moon' in fertilizer concentration experiment; n=3. Measurements taken from leaf tissue of finished plants at 13 to 14 weeks after transplant (WAT).

Cultivar	Treatment ($mg \cdot L^{-1}$ N)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ($mg \cdot L^{-1}$)	Mn ($mg \cdot L^{-1}$)	B ($mg \cdot L^{-1}$)	Cu ($mg \cdot L^{-1}$)	Zn ($mg \cdot L^{-1}$)	Mo ($mg \cdot L^{-1}$)
Harvest Moon	50	3.34	0.27	3.34	0.91	0.90	0.11	50.8	41.8	54.2	1.33	20.0	2.0
	125	4.00	0.33	4.38	0.97	0.76	0.14	68.2	29.9	87.1	1.73	25.6	1.6
	250	4.13	0.31	4.00	0.94	0.65	0.15	84.5	64.4	127.0	2.51	30.2	1.7
	Significance	NS	NS	Q*	NS	L**	NS	L*	NS	L***	L***	L**	NS
	R^2	0.51	0.35	0.65	0.11	0.68	0.34	0.49	0.63	0.82	0.89	0.65	0.57
Marmalade	50	2.67	0.35	3.89	1.06	0.75	0.10	34.2	21.1	56.3	1.01	20.7	2.4
	125	4.12	0.56	4.57	1.15	0.73	0.13	56.2	24.5	63.2	1.45	20.2	4.8
	250	4.81	0.72	4.89	1.44	0.70	0.11	51.5	54.5	110.3	2.27	20.5	2.0
	Significance	Q***	L**	L*	L*	NS	NS	Q**	Q***	L**	L***	NS	NS
	R^2	0.97	0.74	0.64	0.55	0.11	0.18	0.82	0.96	0.80	0.90	0.00	0.54
Hot Papaya	50	2.29	0.36	2.95	0.99	0.81	0.12	33.3	25.9	46.7	0.39	23.2	1.5
	125	3.36	0.42	3.18	1.02	0.77	0.12	44.8	32.6	56.3	0.54	24.0	1.3
	250	3.68	0.47	3.19	1.26	0.70	0.09	76.7	92.8	60.6	1.39	24.7	1.2
	Significance	L**	L***	NS	L*	NS	NS	L***	Q***	L*	L*	NS	NS
	R^2	0.64	0.83	0.17	0.46	0.34	0.38	0.83	0.98	0.56	0.59	0.03	0.22
	Sufficiency range[y]	2.25-3.0	0.25-0.34	2.26-3.84	1.45-2.17	0.35-0.90	0.19-0.28	42-78	55-81	31-93	5-15	25-41	0.09-0.12

[z] NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; regression analysis indicating L=linear or Q=quadratic response.
[y] Bryson et al., 2014

Table 4.4 Effect of N rate treatments on major and micronutrient tissue nutrient levels of *Echinacea* 'Marmalade' and 'Harvest Moon' in N rate experiment; n=4. Measurements taken from leaf tissue of finished plants at 12 weeks after transplant. Nitrogen rate treatments were applied as constant liquid feed (CLF) and consisted of 50, 150, 250, or 350 mg·L^{-1} N based on 50 mg·L^{-1} 5N-5.2P-21.6K with added calcium ions to supply a calcium:magnesium ratio of 2.5:1 and ammonium nitrate added to reach desired N rates.

Cultivar	N rate (mg·L^{-1})	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (mg·L^{-1})	Mn (mg·L^{-1})	B (mg·L^{-1})	Cu (mg·L^{-1})	Zn (mg·L^{-1})	Mo (mg·L^{-1})
Harvest Moon	50	2.73	0.25	3.98	1.06	1.11	0.09	43.2	73.6	190.6	1.98	31.0	1.29
	150	3.75	0.32	4.14	1.03	0.83	0.12	70.8	99.9	205.4	2.22	27.6	0.87
	250	3.88	0.35	3.75	1.09	0.8	0.17	81.5	103.7	204.1	2.87	32.5	1.06
	350	4.33	0.4	3.73	1.16	0.81	0.17	125.2	147.3	217.1	3.01	35.4	1.22
	Significance	L***[z]	L***	NS	NS	Q***	L**	L***	L**	NS	L**	NS	Q**
	R^2	0.67	0.73	0.19	0.29	0.70	0.54	0.57	0.48	0.14	0.53	0.30	0.53
Marmalade	50	2.6	0.65	5.5	1.52	0.91	0.12	38.6	21.5	199.1	3.5	27.4	1.4
	150	3.9	0.74	4.9	1.54	0.87	0.12	81.4	35.1	239.9	3.0	31.4	1.1
	250	4.0	0.82	4.7	1.9	0.94	0.16	219.3	93.1	267.8	3.4	24.8	1.7
	350	5.0	1.0	4.8	2.0	0.87	0.21	177.2	135.7	228.3	3.6	25.1	1.2
	Significance	L***	Q*	Q***	L***	NS	Q***	Q***	L***	Q*	NS	NS	NS
	R^2	0.77	0.48	0.70	0.63	0.01	0.71	0.71	0.88	0.45	0.11	0.13	0.02
	Sufficiency range[y]	2.25-3.0	0.25-0.34	2.26-3.84	1.45-2.17	0.35-0.90	0.19-0.28	42-78	55-81	31-93	5-15	25-41	0.09-0.12

[z] NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; regression analysis indicating L=linear or Q=quadratic response.
[y] Bryson et al., 2014

Table 4.5 Effect likelihood ratio test of winter survival in response to water soluble fertilizer (WSF) or low, medium, or high controlled-release fertilizer (CRF) treatments of *Echinacea* ‘Evening Glow,’ ‘Marmalade,’ and ‘Pow Wow White’ in overwintering experiment.

Source[z]	DF	Prob>ChiSq
Fertilizer Treat	3	<.0001
Cultivar	2	0.2113
Fertilizer Treat*Cultivar	6	0.0795
Block	3	0.0924

[z]Plant survival was analyzed by nominal logistic regression, n=4, $P \leq 0.05$.

Figure 4.5 Substrate pH response (A) and electrical conductivity (EC) response (B) of *Echinacea* cultivars to water soluble fertilizer (WSF) or low, medium, or high controlled release fertilizer (CRF) treatments from 6 to 31 weeks after transplant in overwintering experiment; data were analyzed by analysis of variance, Student's T test, P ≤ 0.05, n=4.

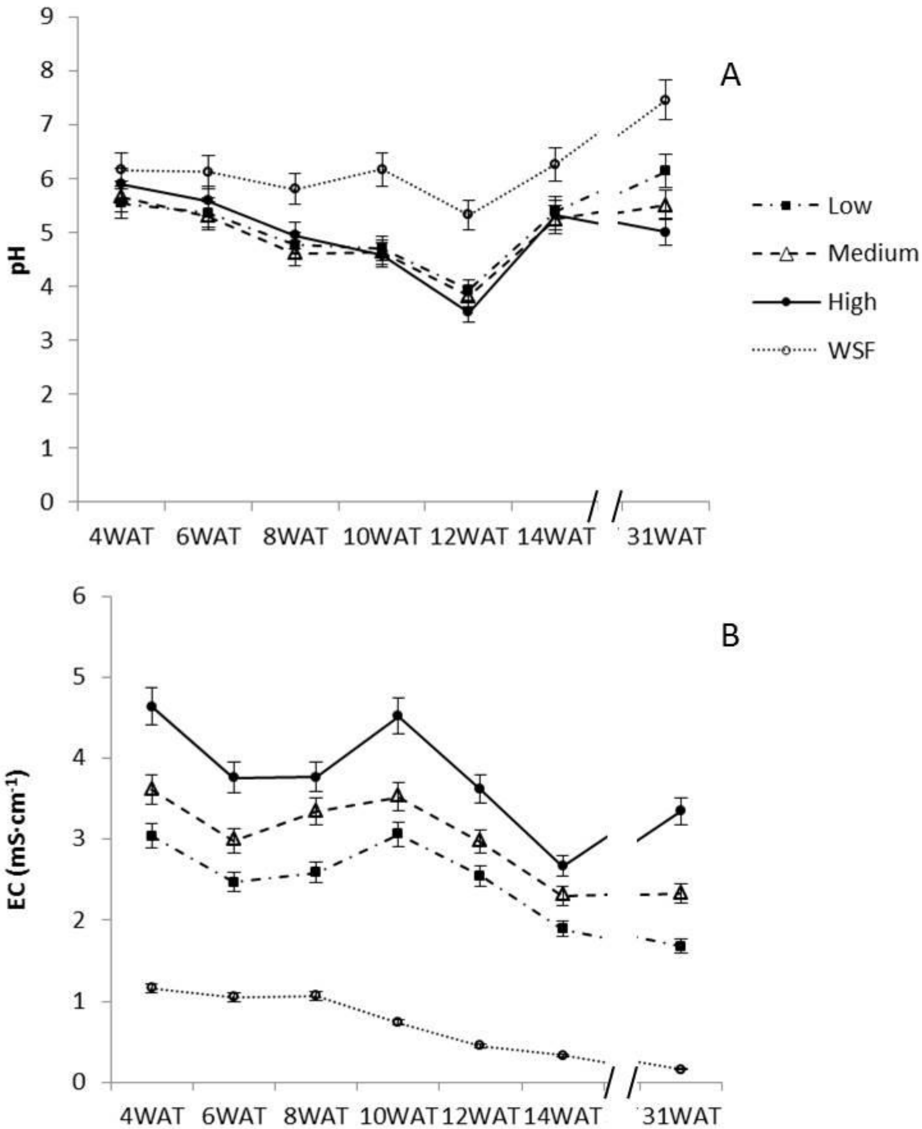
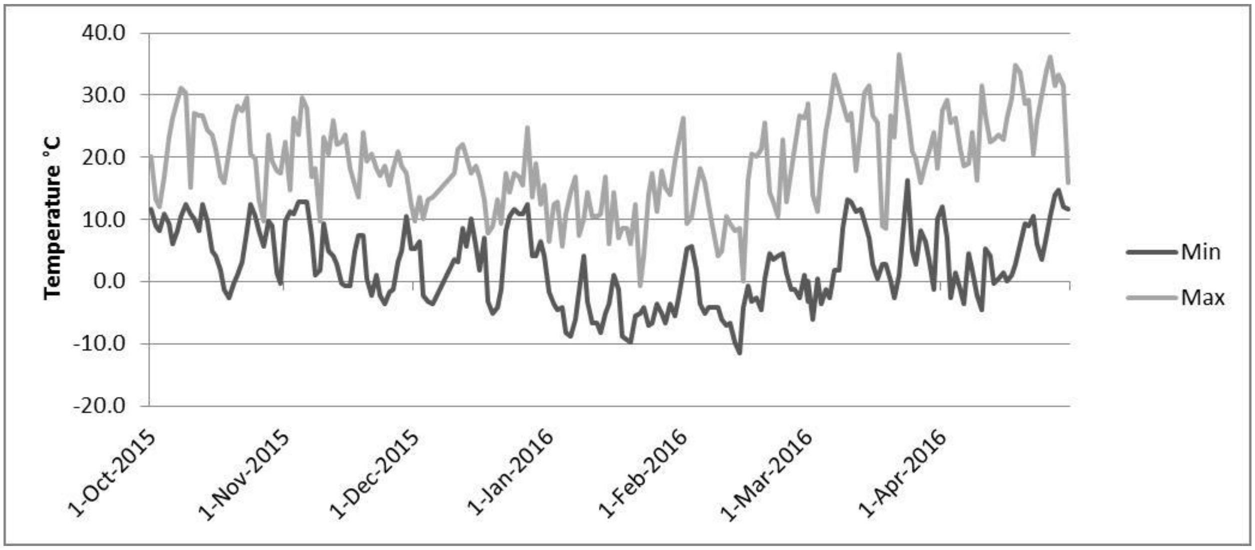


Figure 4.6 Average daily minimum and maximum air temperatures inside unheated coldframe in overwintering experiment conducted in Blacksburg, VA between Fall 2015 and Spring 2016.



Chapter 5. Photoperiod and PGRs affect growth in *Echinacea* hybrid cultivars

Abstract

Hybrid *Echinacea* cultivars, derived from crosses of *Echinacea purpurea* (L.) Moench and other *Echinacea* species, have diverse flower colors and forms that are popularly grown for the marketplace. Consumers and retailers prefer perennial herbaceous plants, such as *Echinacea*, to be compact and flowering. An experiment was conducted to examine the growth habits of 21 hybrid cultivars, the effect of photoperiod under which liners are grown on their growth and flowering, and their response to height control plant growth regulators (PGRs). Tissue culture plantlets were transplanted and these liners were grown under one of three photoperiods, with a 10 hour (h), 16 h, or 24 h daylength, for 10 weeks after which they were potted into final containers and grown under natural daylength (14 h) until plants flowered. Plants were grown in one of two height control PGR treatments, either with or without multiple foliar spray applications of 2,500 $mg \cdot L^{-1}$ daminozide and 15 $mg \cdot L^{-1}$ uniconazole, applied approximately every 2 weeks, beginning 6 weeks after tissue culture transplant, as needed. Liners grown in the 10 h photoperiod were shorter, less wide, and less rooted than those in longer photoperiods and liners in the 24 h photoperiod had reduced gas exchange measurements compared to liners in shorter photoperiods. Flowering in finished plants in the 10 h or 24 h photoperiods was delayed by 4 or 8 days, respectively, compared to those grown under the 16 h photoperiod. In some cultivars, fewer plants flowered under the 24 h photoperiod. Height control PGRs resulted in liners that were shorter and less wide and finished plants that were shorter with fewer branches and flowers, and less shoot dry weight and had increased days to bud and flower and a higher market rating than untreated plants. Cultivar and the interaction between cultivar and

photoperiod had a significant effect on growth measurements. *Echinacea* liners grown under a 16 h photoperiod flowered soonest without any negative effects on growth. While cultivar response and growth varied; overall, height control PGRs controlled height and increased market rating.

Introduction

Echinacea L. is a genus of nine species in the Asteraceae, which is native to most of North America (Ault, 2007).The most well-known of the species, *Echinacea purpurea* (L.) Moench, eastern purple coneflower, has both ornamental value as a popular garden plant and medicinal value as an herbal medical supplement commonly used to treat cold and flu symptoms (USDA, 2014). *Echinacea* is the 5th highest selling perennial in the United States with $15.7 million in sales in 2014 (USDA, 2015). The discovery that different *Echinacea* species readily cross with one another (Ault, 2007; Frett, 2009) has led to the introduction of many hybrid cultivars with new flower colors and forms (Armitage, 2008; Schoellhorn and Richardson, 2006).

The introduction of novel colors, forms, and even fragrance has resulted in a revolution in the genus (Baggett, 2008), but new cultivars have proven challenging for growers to produce. Some of the difficulties include: achieving uniform and consistent flowering (Warner et al., 2013), determining greenhouse crop times for new introductions (Whitman et al., 2007), achieving a well-branched plant (Latimer and Freeborn, 2009), and developing protocols for use of plant growth regulators (PGRs) to control height of taller cultivars (Whitman et al., 2007).

Echinacea cultivars have been bred for height and other size characteristics. Ideally, breeding *Echinacea* cultivars will result in compact plants with strong stems, along with attractive flower colors and types (Ault, 2007). In research on 23 cultivars, height ranged from

33 to 99 cm (Warner et al., 2013). Growers will need to use PGRs on the taller *Echinacea* cultivars to produce compact plants (Whitman et al., 2007).

Previous work has shown *E. purpurea* is responsive to commercially available growth retardants including ancymidol, chlormequat chloride, daminozide, paclobutrazol, uniconazole, and flurprimidol (Latimer, 2016). Although different PGRs have been shown to control height in *Echinacea*, cultivars vary in their response to PGRs (Latimer, 2004); as the number of new cultivars in the marketplace grows every year, so does the need for research into cultivar by PGR interaction.

Cultivar can also significantly influence time to flower in *Echinacea.* In 23 *Echinacea* cultivars, flowering occurred between 7 and 16 weeks after liner transplant in research at Michigan State University where starting material consisted of commercially propagated seedlings and liners (Warner et al., 2013). In previous research, we have found inconsistent and premature flowering in plants grown from commercially sourced liners (Grossman et al., 2015).

Investigations into photoperiod effect on flower induction in *Echinacea* have shed some light on flowering in the species. Runkle et al. (2001) found that *E. purpurea* 'Bravado' and 'Magnus' flowered fastest under intermediate photoperiods (13 h to 15 h) or when provided with a night interruption (NI), whereas flowering was inhibited by short days (SD) less than 12 h or under a 24 h photoperiod. Heide (2004) found that *E. purpurea* 'Bravado' flowers earliest in short days followed by long days (LD) whereas no plants flowered in continuous SD or LD. In addition, Heide (2004) found that photoperiods between 13 h and 16 h can meet both the SD and LD requirements; thus *Echinacea* can be considered either an intermediate flowering plant (IDP) or a dual induction SD/LD plant. While these two studies provide information on flowering requirements of *Echinacea*, the question of what photoperiod to keep liners under prior to transplant to induce uniform and rapid flowering has not been addressed.

Basal branches are produced in *Echinacea* while the plant is in a vegetative (non-flowering) state; however premature flowering limits branching and is an issue with many of the newer varieties which are typically produced through tissue culture (Fifo, 2010; Pilon, 2011; Whitman et al., 2007). Growing *Echinacea* under SD before providing LD to encourage flowering allows the plants to develop lateral branches and fill the containers; however, when grown at times of the year when these conditions do not happen naturally, *Echinacea* may branch poorly (Padhye and Whitman, 2008). Pinching does not increase branching in *Echinacea* (Padhye and Whitman, 2008; Whitman et al., 2007). Spray applications of benzyladenine (BA) successfully increase branching of *Echinacea*, whether in a single application on well rooted liners (Padhye and Groninger, 2010), on plants after transplant (Latimer et al., 2008; Latimer and Freeborn, 2009), or in multiple applications (Carey et al., 2010).

The objectives of this study are to further our understanding of the growth characteristics of hybrid *Echinacea* cultivars during the liner stage and in finished plant production. Our goal is to study the effect of photoperiod on flowering to determine the optimal photoperiod under which to grow liners in order to produce well branched plants which flower consistently and prevent premature flowering. In doing this research we hope to better understand the growth and PGR responses of a number of newer hybrid cultivars, which have not previously been studied, in order to provide grower recommendations for growing conditions and PGR applications.

Materials and Methods

Stage three tissue culture plantlets, in gel, with shoots and roots between 1 cm and 4 cm in length (Figure 5.1), of 21 hybrid *Echinacea* cultivars (Table 5.1) were obtained from a commercial source (AB-Cultivars USA, LLC, Trumbauersville, PA). Gel was rinsed off the plantlets and they were transferred to a peat pine bark substrate (Fafard 3B, SunGro Horticulture, Agawam, MA) in size 72 cell trays (height 5.7 cm, volume 35.4 mL) on 2 March 2016. These liners were gradually acclimated over the following 2 weeks to ambient humidity levels; liners were kept under a 24 h photoperiod for the first week after transplanting. After acclimation, liners were irrigated with 150 ppm N using 15N-2.2P-12.5K (Jack's Professional LX, JR Peters Inc., Allentown PA). Treatments consisted of three photoperiods (plants were lit during the liner stage at 10 h, 16 h, or 24 h photoperiods), two height control conditions (height control PGRs were applied as described below [HC+] or no height control PGRs were applied [HC-]), and 21 cultivars (Table 5.1). A factorial arrangement of treatments was used in a randomized complete block design with three blocks.

One week after tissue culture transplant, liners were placed into one of three photoperiods: 10 h, 16 h or 24 h. Light emitting diode (LED) lights were used as supplemental lighting (Philips GreenPower LED production module GP LED production DR/B 120 LB, Philips North America Corporation, Andover, MA) in addition to natural daylight. There were three replications consisting of four subsamples apiece. Each replication was on a separate cart upon which cultivar/PGR combinations were randomized; each cart had one shelf of each photoperiod (Figure 5.2 and Figure 5.3). The cart was surrounded by a 6.7 mil reflective film, black on the outside, silver on the inside (Diamond Foil, HTG Supply, Traverse City, MI) to exclude outside light. The film was attached to each shelf, so no light was transmitted between shelves. The film was removed during the day. At the end of the 10 h photoperiod, the film was replaced so plants in the 10 h photoperiod (average daily light integral, DLI, 3.7 $mol \cdot m^{-2} \cdot d^{-1}$) were in the dark while plants in the 16 h (average DLI 5.2 $mol \cdot m^{-2} \cdot d^{-1}$) and 24 h photoperiods (average DLI 5.9 mol·m^{-2}·d^{-1}) remained lit by LED lights. After 16 h, the LED lights were turned off in the 16 h photoperiod while the lights remained on for the 24 h photoperiod. Photoperiod treatments continued until liners were transplanted to larger pots at approximately 10 weeks after tissue culture transplant. Temperature was monitored for the duration of the study by data loggers (WatchDog A-Series, Spectrum Technologies, Inc., Aurora, IL); temperature was not significantly affected by photoperiod treatment (data not shown).

Beginning at 6 weeks after tissue culture transplant, benzyladenine (BA, Configure, Fine Americas, Inc., Walnut Creek, CA) was applied to all liners to increase branching as needed every 2 weeks for up to three applications (see Table 5.2 for treatment dates by cultivar and photoperiod). Readiness for BA was determined by adequate root and shoot development and a need for further branching to fill the cell. Foliar sprays of 300 mg·L^{-1} BA were applied with a CO_2 backpack sprayer (R&D Sprayers, Inc., Opelousas, LA) at 210 mL·m^{-2}.

In addition to BA, liners in the HC+ treatment received daminozide (Dazide, Fine Americas, Inc., Walnut Creek, CA) if they were deemed ready, up to two applications before transplant. Readiness for daminozide was determined by evidence of shoot elongation. Foliar sprays were applied as above for BA, either separately or in a tank mix with BA, as needed.

Liners of each cultivar were moved out of photoperiod treatments and transplanted to either quart (1.13 L) or trade gallon (2.8 L) pots filled with substrate (Fafard 3B, SunGro Horticulture) based on expected finished size between 11 May and 18 May 2016. At this time all cultivars in all photoperiods were fully rooted and ready for transplant except for ‘Coconut Lime’ and ‘Pink Bonbon’ plants in the 10 h photoperiod; these needed additional time for rooting and were transplanted on 31 May 2016. Plants received up to three additional applications of height control PGRs after transplant (15 $mg \cdot L^{-1}$ uniconazole, [Concise, Fine Americas, Inc., Walnut Creek, CA]) as needed as plants and buds elongated.

Data were collected at 10 weeks after tissue culture transplant when liners were ready for transplant from cell pack to larger containers, including plant height, average width (based on two widths, with the second measurement taken at 90 degrees from the first), number of branches, and root rating. Roots were rated on a scale from 1 (no roots visible), 2 (roots visible on 2 sides), 3 (roots visible on 3 to 4 sides, plug does not hold together), 4 (rooted to all sides, plug holds together, some substrate visible), to 5 (well rooted and little substrate visible). In order to determine the effects of treatments on gas exchange, photosynthetic activity was measured in liners of six cultivars chosen to represent a variety of expected heights (Table 5.1) prior to transplant at 10 weeks after tissue culture transplant using a portable photosynthesis system (LI-COR LI-6400XT, LI-COR Inc., Lincoln, NE). The third mature leaf from the top of the plant was measured in one plant randomly selected from each replication in each treatment (n=3). The reference CO_2 concentration was set to 400 $\mu mol \cdot mol^{-1}$; the air temperature, leaf temperature, and relative humidity averaged 31.5 °C, 29.7 °C, and 56%, respectively.

After transplant, plants were grown in one of two locations, based on limited space available: six cultivars, Guava Ice, Hot Papaya, Marmalade, Postman, Raspberry Truffle, and Southern Belle, were grown in a double polyethylene greenhouse with 60% shade cloth (average DLI 9.2 $mol \cdot m^{-2} \cdot d^{-1}$, average high temperature 30.6 °C, average low temperature 19.1°C) while the remaining 15 cultivars were grown in a glass greenhouse with no shade (average DLI 24.4, average high temperature 29.4°C, average low temperature 19.5°C). Both greenhouses were located in Blacksburg, VA (lat. 37.23 N, long. 80.42 W); plants grew out after transplant between May and August 2016. Natural daylength at transplant was 14 h; no supplemental lighting was used.

Days to visible bud and days to flower were monitored daily. For each cultivar there were six treatment groups based on the factorial combination of three photoperiods (10 h, 16 h, and 24 h) and two height control conditions (HC+ and HC-). Final data were taken when at least 80% of plants in a treatment group were flowering. Data collected at finish included days to bud (calculated from date of transplant to final container), days to flower (calculated from date of transplant to final container), plant height (measured to the top of vegetative growth), flower height (measured to the top of the tallest flower), average width, number of branches, number of flower stalks, marketability rating, and shoot dry weight. Marketability was rated on a scale of 1 (poor), 2 (fair), 3(average), 4 (good), to 5 (premium quality) based on quality of plant growth and flowering characteristics. Flowering status was rated on a scale from 1 to 3, with 1 indicating that the plant did not initiate a bud, 2 indicating that the plant had a bud but did not flower during the study, and 3 indicating that the plant flowered during the study.

Statistical analysis was performed by JMP (Version 12; SAS Institute Inc., Cary, NC), with the means of treatments compared by the Students t-test at $P < 0.05$.

Results

Finished liners at 10 weeks after tissue culture transplant

Height

Height was affected by cultivar, photoperiod, and height control (Table 5.3). Liners of the following cultivars were among the tallest: ‘Hot Papaya,’ ‘Marmalade,’ ‘Mini Belle,’ ‘Postman,’ ‘Raspberry Truffle,’ and ‘Southern Belle,’ all measuring 13.5 cm or more. Among the shortest cultivars were ‘Butterfly Kisses,’ ‘Cleopatra,’ ‘Coconut Lime,’ ‘Julia,’ ‘Purple Emperor,’ ‘Rainbow Marcella,’ and ‘Sweet Sixteen,’ all 9.8 cm or less. Longer photoperiods resulted in taller plants. Height control PGRs reduced the height of *Echinacea* cultivars.

The interaction between cultivar and photoperiod was significantwith respect to height (Table 5.4). While in most cultivars, the shortest photoperiod led to the shortest plants and the longest photoperiod led to the tallest plants, in ‘Blushing Meadow Mama,’ and ‘Raspberry Truffle’ there was no significant difference in height between the 16 h and 24 h photoperiod. With the significant interaction between photoperiod and height control PGRs, height was not affected by height control PGRs in the 10 h photoperiod, while in longer photoperiods height was less in plants treated with height control PGRs (Figure 5.4).

Width

Cultivar, photoperiod, and height control significantly affected plant width in *Echinacea* liners at 10 weeks after tissue culture transplant (Table 5.3). Among the widest cultivars were ‘Guava Ice,’ ‘Mini Belle,’ and ‘Postman,’ while the cultivars which were the least wide included ‘Avalanche,’ ‘Butterfly Kisses,’ ‘Coconut Lime,’ ‘Julia,’ ‘Orange Skipper,’ ‘Pink Bonbon,’ ‘Purple Emperor,’ and ‘Sweet Sixteen.’ Width increased under longer photoperiods. Liners treated with height control PGRs were only 0.9 cm less wide than untreated liners. The interaction between cultivar and photoperiod was also significant with respect to width (Table 5.4). In general, the widest plants were found in the 24 h photoperiod, although in about half of the cultivars there was no difference in width between plants in the 16 h and 24 h photoperiods.

Number of Branches

The number of branches in finished liners was affected by cultivar, photoperiod, and their interaction (Table 5.3). Branches filled the cell and could not be counted without damaging liners in cultivars Avalanche and Butterfly Kisses liners in all photoperiods, and in ‘Orange Skipper’ liners in the 10 h photoperiod. Other than those cultivars, the following were among those with the greatest number of branches: ‘Golden Skipper,’ ‘Guava Ice,’ ‘Julia,’ and ‘White Double Delight.’ ‘Blushing Meadow Mama,’ ‘Honeydew,’ ‘Postman,’ ‘Rainbow Marcella,’ and ‘Raspberry Truffle’ were among the cultivars with the fewest branches. With respect to the significant interaction between cultivar and photoperiod, plants in the 10 h photoperiod had the fewest branches in 18 of the 21 cultivars, while in eight cultivars, there was no difference in number of branches in response to photoperiod (Table 5.4). In ‘Blushing Meadow Mama,’ ‘Coconut Lime,’ ‘Pink Bonbon,’ and ‘Rainbow Marcella,’ liners in the 10 h photoperiod had fewer branches than those in longer photoperiods. In ‘Golden Skipper,’ ‘Marmalade,’ and ‘Raspberry Truffle,’ liners in the 10 h photoperiod had a greater number of branches than those in longer photoperiods.

Root Rating

Root rating in liners was affected by cultivar and photoperiod with a significant interaction between the two (Table 5.3). At 10 weeks after tissue culture transplant, most cultivars were well rooted and were rated between 4 (rooted to all sides, plug holds together, some substrate visible), to 5 (well rooted and little substrate visible). Cultivars Coconut Lime, Pink Bonbon, and Sweet Sixteen were among the less well rooted, and had ratings between 3 (roots visible on 3 to 4 sides, plug does not hold together) and 4. Root rating was lowest in plants in the 10 h photoperiod and increased with longer photoperiods. To look at the interaction between cultivar and photoperiod, although liners grown under the 10 h photoperiod had lower root ratings, those of the ‘Coconut Lime’ and ‘Pink Bonbon’ were rated between 2 (roots visible on 2 sides) and 3, much lower ratings than the other cultivars (Table 5.4). Liners of these two cultivars in the 10 h photoperiod were held in the plug trays an additional 2 weeks before rooting was sufficient for transplant.

Photosynthesis, stomatal conductance, and transpiration

Photosynthesis, stomatal conductance, and transpiration of *Echinacea* liners were affected by cultivar and photoperiod, and the interaction between cultivar and photoperiod was significant (Table 5.5). Photosynthesis rates were highest in ‘Guava Ice’ and lowest in ‘White Double Delight.’ Stomatal conductance was highest in ‘Golden Skipper’ and ‘Guava Ice’ and lowest in ‘White Double Delight.’ Transpiration was highest in ‘Honeydew’ and lowest in ‘Butterfly Kisses’ and ‘White Double Delight’. Liners in the 24 h photoperiod had lower photosynthesis, stomatal conductance, and transpiration compared to those in shorter photoperiods. Height control PGRs did not affect photosynthesis, stomatal conductance, or transpiration.

The interaction between cultivar and photoperiod was significant with respect to photosynthesis, stomatal conductance, and transpiration (Table 5.5). Photosynthesis was not affected by photoperiod in ‘Golden Skipper’ and ‘Guava Ice.’ However, in ‘Butterfly Kisses,’ photosynthesis was highest in plants in the 16 h photoperiod while photosynthesis of ‘Marmalade’ was highest in the 10 h photoperiod. Stomatal conductance was not affected by photoperiod in ‘Golden Skipper,’ while liners in the 16 h photoperiod had highest stomatal conductance in ‘Butterfly Kisses’ and ‘Guava Ice.’ Transpiration was not affected by photoperiod in ‘Golden Skipper,’ while liners of ‘Butterfly Kisses’ in the 16 h photoperiod had the highest transpiration, and liners of ‘Guava Ice’ in the 24 h photoperiod had the highest transpiration.

After transplant to final containers

Leaf damage

Signs of leaf damage, distorted or twisted leaves, were first noted at 12 weeks after tissue culture transplant (data not shown). The cause of damage to leaves is unclear as multiple chemicals, including PGRs, insecticides, and fungicides, were applied to plants during the study. Leaf damage was not directly attributable to PGRs; leaf damage was seen in plants with and without PGRs. In most plants leaf damage was slight to moderate during production with little evidence of damage in finished plants. Remaining leaf damage at finish was minimal and would not have affected the salability of affected plants.

Finished plants

In finished plants, cultivar significantly affected all growth parameters (Table 5.6). As cultivars are bred to have unique qualities, this is an expected result.

Height

Height was affected by cultivar and height control PGRs and their interaction was significant (Table 5.6). Among the tallest cultivars, measuring over 70 cm, were ‘Guava Ice,’ ‘Hot Papaya,’ ‘Marmalade,’ ‘Mini Belle,’ and ‘Southern Belle,’ while among the shortest cultivars, measuring less than 40 cm, were ‘Butterfly Kisses,’ ‘Pink Bonbon,’ and ‘Sweet Sixteen.’ Height was not affected by photoperiod. Plants treated with height control PGRs were 7 cm shorter than plants without height control PGRs. The interaction between cultivar and height control PGRs was significant. The height of the following cultivars was not significantly affected by height control PGRs at finish: ‘Avalanche,’ ‘Coconut Lime,’ Golden Skipper,’ ‘Mini Belle,’ ‘Pink Bonbon,’ ‘Raspberry Truffle,’ ‘Sweet Sixteen,’ and ‘White Double Delight’ (data not shown).

Width

Plant width was affected by cultivar and the interaction between cultivar and photoperiod was significant (Table 5.6). ‘Guava Ice,’ ‘Hot Papaya,’ ‘Marmalade,’ and ‘Postman’ were the widest cultivars, measuring over 47 cm. ‘Pink Bonbon,’ ‘Raspberry Truffle,’ and ‘Sweet Sixteen’ were the most narrow, measuring less than 35 cm in width. With respect to the interaction, plants in the 24 h photoperiod were wider than plants in shorter photoperiods in 'Butterfly Kisses,' 'Coconut Lime,' 'Hot Papaya,' 'Rainbow Marcella,' 'Raspberry Truffle,' and 'White Double Delight' (Table 5.7). In 'Guava Ice,' 'Honeydew,' and 'Orange Skipper,' plants were widest in the 16 h photoperiod, while plants in the 10 h photoperiod were widest in 'Mini Belle' and 'Golden Skipper'.

Number of branches

Number of branches was affected by cultivar and height control PGRs, and the interaction between cultivar and photoperiod was significant (Table 5.6). Cultivars with the most branches included 'Butterfly Kisses,' 'Coconut Lime,' and 'Avalanche,' while cultivars with the fewest number of branches included 'Postman,' 'Hot Papaya,' 'Raspberry Truffle,' 'Rainbow Marcella,' and 'Blushing Meadow Mama.' Plants treated with height control PGRs had 1.6 fewer branches than those with no height control PGRs. In the interaction between cultivar and photoperiod, 14 of the 21 cultivars exhibited no significant difference in the number of branches in response to photoperiod (Table 5.7). However, 'Avalanche,' 'Golden Skipper', 'Guava Ice', 'Pink Bonbon', and 'White Double Delight' had more branches in plants in the 10 h photoperiod compared to those in longer photoperiods. 'Honeydew' had the most branches in plants in either the 16 h or 24 h photoperiods, while 'Marmalade' had the most branches in the 24 h photoperiod.

Number of flower stalks

Number of flower stalks was influenced by cultivar and height control PGRs, and the interaction between cultivar and photoperiod was significant (Table 5.6). 'Butterfly Kisses,' 'Mini Belle,' and 'Southern Belle' had the most flower stalks, while 'Blushing Meadow Mama,' 'Guava Ice,' 'Hot Papaya,' 'Marmalade,' and 'Postman' had the fewest flower stalks. Photoperiod did not affect the number of flower stalks. Plants treated with height control PGRs had 0.5 fewer flower stalks than those without height control PGRs. In the interaction between cultivar and photoperiod, the number of flower stalks was not affected by photoperiod in 11 cultivars. However, ‘Butterfly Kisses,’ ‘Golden Skipper,’ ‘Honeydew,’ ‘Mini Belle,’ ‘Pink Bonbon,’ ‘Rainbow Marcella,’ and ‘Sweet Sixteen’ had more flower stalks in plants in the 10 h photoperiod compared to those in longer photoperiods while ‘Raspberry Truffle’ had the fewest flower stalks in the 16 h photoperiod (Table 5.7).

Days to bud

Days to bud, which was measured by days after liners were transplanted from cell packs to larger containers, was affected by cultivar, photoperiod and height control, and the interaction between cultivar and photoperiod was significant (Table 5.6). The following cultivars were among those that set buds soonest, in less than 22 days after liners were transplanted: ‘Golden Skipper,’ ‘Mini Belle,’ ‘Pink Bonbon,’ ‘Raspberry Truffle,’ and ‘Sweet Sixteen.’ The following cultivars were among those that took the longest to set buds, all more than 40 days: ‘Avalanche,’ ‘Blushing Meadow Mama,’ ‘Cleopatra,’ ‘Guava Ice,’ and ‘Hot Papaya.’ Plants in the 24 h photoperiod developed buds 7 days later than plants in shorter photoperiods. Height control PGRs delayed budding by 5 days compared to plants with no height control PGRs. In the interaction between photoperiod and cultivar, ‘Butterfly Kisses,’ ‘Coconut Lime,’ ‘Guava Ice,’ and ‘Southern Belle’ plants in the 16 h photoperiod set buds sooner than plants in other photoperiods (Table 5.7). Plants in the 10 h photoperiod set buds later than those in longer photoperiods in ‘Mini Belle,’ ‘Pink Bonbon,’ and ‘Sweet Sixteen.’ ‘Marmalade’ plants in the 16 h or 24 h photoperiods did not bud at all.

Days to flower

The number of days to flower was affected by cultivar, photoperiod, and height control, and the interaction between cultivar and photoperiod was significant (Table 5.6). ‘Avalanche,’ ‘Cleopatra,’ and ‘Guava Ice’ were among those that took the most days to flower, over 63 days, while ‘Mini Belle,’ ‘Pink Bonbon,’ and ‘Sweet Sixteen’ were among those that flowered soonest, in less than 39 days. Plants in the 16 h photoperiod flowered soonest (49.6 days), while plants in the 24 h photoperiod flowered latest (57.8 days). Plants with no height control PGRs flowered in an average of 50.7 days while those with height control PGRs flowered in 56.2 days. In the interaction between cultivar and photoperiod, the number of days to flower was not affected by photoperiod in ‘Julia,’ ‘Purple Emperor,’ and ‘Rainbow Marcella’ (Table 5.7). However, ‘Mini Belle,’ ‘Pink Bonbon,’ and ‘Sweet Sixteen’ plants in the 10 h photoperiod took longer to flower than plants in either the 16 h or 24 h photoperiods whereas in ‘Blushing Meadow Mama,’ Honeydew,’ ‘Hot Papaya,’ and ‘Postman’ plants in the 10 h photoperiod flowered sooner than plants in either the 16 h or 24 h photoperiods.

In ‘Butterfly Kisses,’ ‘Coconut Lime,’ ‘Golden Skipper,’ and ‘Southern Belle’ plants in the 16 h photoperiod flowered before plants in either the 10 h or 24 h photoperiods, while in ‘Avalanche,’ ‘Cleopatra,’ ‘Guava Ice,’ and ‘Orange Skipper’ plants in the 10 h or 16 h photoperiods flowered before those in the 24 h photoperiod.

Market rating

Market rating was affected by cultivar and height control PGRs, and the interaction between cultivar and photoperiod was significant (Table 5.6). ‘Butterfly Kisses,’ ‘Julia,’ and ‘Orange Skipper’ were among the cultivars that had the highest market ratings while ‘Hot Papaya,’ ‘Marmalade,’ and ‘Raspberry Truffle’ were among those with the lowest market ratings. Photoperiod did not affect market rating. Plants treated with height control PGRs had higher ratings than those without height control PGRs. In the interaction between cultivar and photoperiod, the market rating of 15 cultivars was not significantly affected by photoperiod. However, ‘Blushing Meadow Mama’ and ‘Orange Skipper’ plants in the 10 h photoperiod had lower market ratings compared to those in longer photoperiods (Table 5.7). ‘Butterfly Kisses’ had the highest rating in plants in the 10 h photoperiod while ‘Raspberry Truffle’ had higher ratings in either the 10 h or 24 h photoperiods compared to the 16 h photoperiod.

Shoot dry weight

Shoot dry weight was affected by cultivar and photoperiod and their interaction was significant (Table 5.6). Among the cultivars with the greatest shoot weight were ‘Avalanche’ and ‘Guava Ice’ while ‘Mini Belle,’ ‘Pink Bonbon,’ and ‘Sweet Sixteen,’ were among those with the lowest shoot weights. Shoot weight was lowest in plants treated as liners with a 10 h photoperiod and highest in plants treated as liners with a 24 h photoperiod. In the interaction between cultivar and photoperiod, the shoot weight of ‘Guava Ice,’ ‘Julia,’ and ‘Sweet Sixteen’ was not affected by photoperiod while ‘Golden Skipper’ and ‘Mini Belle’ had greatest shoot weight in plants treated as liners with a 10 h photoperiod, and ‘Purple Emperor’ had the greatest shoot weight in the 16 h photoperiod (Table 5.7).

Flower status

Flower status, rated on a scale from 1 to 3, measured whether the plant flowered (3), budded (2) or did not bud (1) during the study. Flower status was affected by cultivar and photoperiod, and their interaction was significant (Table 5.6). ‘Blushing Meadow Mama,’ ‘Cleopatra,’ ‘Hot Papaya,’ and ‘Marmalade’ had comparatively low flower status, below 2.8, indicating a small number of those plants did not bud or flower. Flower status was highest in the 10 h photoperiod and lowest in the 24 h photoperiod. Height control PGRs did not affect flower status. In the interaction between cultivar and photoperiod, although photoperiod did not affect flowering status in most cultivars, ‘Blushing Meadow Mama’ and ‘Hot Papaya’ had reduced flower status in plants in the 24 h photoperiod and flower status was lowest in ‘Marmalade’ plants in the 16 h or 24 h photoperiods, which did not bud or flower during the study (Table 5.7).

Discussion

Photoperiod

Photoperiod, which is an important factor in flower induction in *Echinacea*, significantly altered growth of liners and had a persistent effect on the growth and flowering of finished plants in this study.

Many new cultivars are propagated by tissue culture which most growers purchase as liners (Pilon, 2006). With commercially sourced liners, it is difficult to know what photoperiod plants were under prior to shipping. In our previous research we have seen issues with premature flowering and uneven flowering, even when plants are kept under short days followed by long days after receipt, as research has shown to be optimal for *Echinacea* (Heide, 2004). Articles in trade publications have mentioned the effect of photoperiod in liner production of tissue culture *Echinacea*. In an article in Grower Talks magazine, Chris Fifo (2010) of Swift Greenhouses recommends 24 h lighting immediately after transplanting tissue culture plantlets of *Echinacea* in order to prevent premature flowering and long day photoperiod after liner transplant to final containers encourage flowering. Paul Pilon (2013) of Perennial Solutions Consulting advises 24 h lighting immediately after transplanting tissue culture plantlets continuing after liner transplant until plants are sufficiently bulked with long days of 14 h after bulking to encourage flowering.

In this study it took approximately 10 weeks to produce finished liners after tissue culture transplant. Those liners produced in the 10 h photoperiod were shorter, less wide, and rooted more slowly than those in longer photoperiods. Liners in the 24 h photoperiod had reduced gas exchange measurements compared to plants in shorter photoperiods. ‘Coconut Lime’ and ‘Pink Bonbon’ liners in the 10 h photoperiod (average DLI 3.7 $mol \cdot m^{-2} \cdot d^{-1}$) grew more slowly than other cultivars and needed an additional 2 weeks before liners were ready for transplant. Photoperiod is an important factor in growth of many plants; of 40 seed-propagated herbaceous ornamental species studied, photoperiod affected mean dry weight gain per day in 30 species (Mattson and Erwin, 2004). *Chrysanthemum morifolium* Ramat, a SD plant, had greater stem length and diameter under LD as compared to those grown under SD (Kazaz et al., 2010). Mattson and Erwin (2004) found that both LD and SD plants had greater weight gain under LD as compared to those under SD. In our study, *Echinacea*, which is a dual induction SD/LD plant or an intermediate flowering plant, had greatest height and width as liners and greatest shoot dry weight as finished plants when liners were produced under longer photoperiods (16 h or 24 h) as compared to those grown under 10 h photoperiods. While compact plants are desirable in both liners and finished plants, vigorous growth is also important. Increasing DLI improves plant size and quality (Runkle and Heins, 2005) while plants grown under low light conditions have delayed development (Torres and Lopez, 2010). The 10 h photoperiod applied to *Echinacea* liners resulted in less rooting and growth in liners (Figure 5.4) compared to those under 16 h and 24 h photoperiods (DLI of 5.2 $mol\cdot m^{-2}\cdot d^{-1}$ and 5.9 $mol\cdot m^{-2}\cdot d^{-1}$, respectively).

Photosynthesis, stomatal conductance and transpiration were significantly less in *Echinacea* liners in the 24 h photoperiod. Similarly, in three *Rosa* L. cultivars, photosynthesis was less in plants grown under a 14 h photoperiod compared to a 10 h photoperiod with no differences among cultivars (Grossi et al., 2003). Of two *Peonia lactiflora* Pall. cultivars grown under 9 h, 14 h, or 18 h photoperiods, photosynthesis was less in one cultivar grown under the 18 h photoperiod compared to those grown under shorter photoperiods (Han et al., 2015) while photosynthesis was not affected by photoperiod in the other cultivar. In contrast, in *Chrysanthemum morifolium*, a short day plant, chlorophyll concentration, which is highly correlated with photosynthesis (Netto et al., 2005), was higher under LD conditions as compared to SD conditions (Kazaz et al., 2010). Higher photosynthetic rate benefits plant growth and flowering (Han et al., 2015). Some plants grown under continuous light exhibit leaf damage and less growth including lower photosynthesis and respiration levels (Velez-Ramirez, et al., 2011). While *Echinacea* hybrid liners grown under the 24 h photoperiod had lower gas exchange measurements, other growth measurements such as height, width, number of branches and root rating were greater under the 24 h photoperiod. In this case, lower gas exchange measurements in liners did not negatively affect plant growth.

In finished plants, the photoperiod the liner was grown under significantly affected days to bud, days to flower, shoot dry weight and flower status. Other growth measurements such as height, width, number of branches, market rating and number of flowers were not affected by photoperiod. Plants flowered and were considered finished between approximately 5 and 10 weeks after liner transplant to final containers. After flower initiation occurs in plants sensitive to photoperiod, flowering will continue even under non-inductive photoperiods (Runkle and Heins, 2005). In our study, plants in the 16 h photoperiod as liners flowered soonest, while flowering of plants in the 10 h or 24 h photoperiods was delayed by 4 or 8 days, respectively. Likewise, percentage of plants which flowered was highest in *Peonia lactiflora* cultivars grown under 14 h photoperiods compared to those grown under 9 h or 18 h photoperiods (Han et al., 2015). In contrast, SD plant *Chrysanthemum morifolium* flowered 42 days sooner under SD compared to LD (Kazaz et al., 2010).

Earlier studies on the effect of photoperiod on flowering in *Echinacea* applied photoperiod conditions at a later stage, 8 to 9 weeks after germination. Runkle et al. (2001) found that *Echinacea* flowered soonest when exposed to intermediate photoperiods (13 to 16 h) or night interruption; seedlings in this study were kept under intermediate photoperiod until 8 weeks after germination when they were transplanted and different photoperiods were imposed.

A low percentage (10-15%) of plants in 10 h or 24 h photoperiods flowered, which the authors ascribe to exposure to inductive photoperiod during seedling growth. Heide (2004) found consistent earliest flowering under short days (10 h) for 4 weeks followed by long days (24 h); however, treatments in this study began 9 weeks after germination when plants had 4 to 5 leaves and were ready for transplant to larger (0.9 L) pots; prior to this germinated seedlings were all kept under a 24 h photoperiod.

In our study, photoperiods were applied at an earlier stage of development, from just after transplanting tissue culture plantlets for 10 weeks, in the liner phase only. After liner transplant to final containers, all plants were exposed to a 14 h photoperiod. The effect of early photoperiod on time to flower was persistent in finished plants.

Photoperiod plays an important role in the growth and development of many plants, but it is not the only factor involved; temperature, light quality and intensity, and plant maturity are also involved (Ha, 2014). One of the goals of our study was to determine if photoperiod could prevent premature flowering, i.e. flowering in the liner stage or very soon after, which prevents adequate bulking in *Echinacea*. We did not see any premature flowering in this study; thus we believe that premature flowering seen in previous studies with commercially-sourced liners must have been caused by another factor such as age of plants, or temperature, and/or their interaction with photoperiod (Ha, 2014; Thomas and Vince-Prue, 1997).

Nevertheless, our results show that controlling photoperiod in the liner production stage can affect flowering in plants finished in LD, a daylength which is common in much of the United States during the late spring and summer growing season. The 10 h photoperiod limited growth too much in some cultivars, limited rooting in liners and resulted in less shoot dry weight in finished plants. Plants grown in the 10 h photoperiod required fewer applications of height control PGRs due to slower growth and flowered 4 days later than those in the 16 h photoperiod. The 24 h photoperiod resulted in taller and wider liners, and in finished plants with the greatest shoot dry weights which flowered 8 days later than those under the 16 h photoperiod. However, the 24 h photoperiod resulted in uneven flowering in some cultivars. The 16 h photoperiod resulted in liners which grew and rooted well, and in plants that flowered soonest.

Height control PGRs

Height control PGRs affected the growth of liners and finished plants in this study. Liners subjected to height control PGRs were shorter and less wide than untreated liners but number of branches, root rating or gas exchange measurements were not affected. Finished plants subjected to PGRs were shorter with fewer branches and flower stalks, and required longer to bud and flower. Market rating was higher in plants treated with height control PGRs. Other research has shown that *Echinacea purpurea* is responsive to height control PGRs. *Echinacea purpurea* treated with two applications of 5000 $mg \cdot L^{-1}$ daminozide was 20% shorter than controls; spray applications of 240 $mg \cdot L^{-1}$ paclobutrazol or 40 $mg \cdot L^{-1}$ uniconazole resulted in plants 50% or 70% shorter, respectively, than untreated plants (Latimer et al., 1997).

While overall, height control PGRs controlled height in *Echinacea* cultivars, not all cultivars were responsive to PGRs. Several of these cultivars were quite tall, notably: ‘Avalanche,’ ‘Mini Belle,’ ‘Southern Belle,’ and ‘White Double Delight,’ all over 65 cm. In the case of these and other vigorously growing cultivars, height control PGRs were applied as flower stalks were in the process of expanding; earlier application or higher rates may have been more successful in controlling the height of the finished plants. In *Echinacea purpurea* treated with foliar sprays of 40, 80, 120, or 160 $mg \cdot L^{-1}$ uniconazole 2 weeks after liner transplant, only plants treated with 120 or 160 $mg \cdot L^{-1}$ uniconazole were significantly shorter than untreated plants in finished plants at 12 weeks after transplant (Latimer and Thomas, 1997). Height control PGRs delayed budding (5 days) and flowering (6 days) in finished plants but there was no interaction between photoperiod and height control in finished plants. Similarly, while daminozide delayed flowering (statistically significant, but only by 0.6 days) in *Chrysanthemum morifolium*, there was no interaction between photoperiod and PGR (Kazaz et al., 2010).

Cultivar

Cultivar affected all growth parameters in both liners and finished plants. We found pronounced differences in days to flower among different cultivars, between 5 and 10 weeks after liner transplant (Table 5.6); similarly, Warner et al. (2013) saw flowering in *Echinacea* cultivars between 7 and 16 weeks under LD. Market ratings of 'Orange Skipper,' 'Julia,' and 'Butterfly Kisses' were the highest in the study, all averaged over 4.1, on a scale of 1 to 5, regardless of photoperiod or height control PGRs (Table 5.6). Cultivars Raspberry Truffle, Marmalade, and Hot Papaya had lowest market ratings, below 3.2. With the multitude of *Echinacea* cultivars available in the marketplace, market ratings of cultivars can provide growers with a tool in selecting which cultivars to grow.

In our study, the interaction between cultivar and photoperiod was significant in all growth parameters in both finished plants and liners except height in finished plants. Photoperiod can affect cultivars of the same species differently. Plants of *Peonia lactiflora* cultivar grown under a 9 h photoperiod were shorter and less wide compared to those grown under an 18 h photoperiod; however, the height and width of the other cultivar in this study were not affected by photoperiod (Han et al., 2015). Shoot dry weight of finished *Echinacea* plants was affected by photoperiod applied during the liner production stage in 18 of 21 cultivars studied.

Plant species as well as cultivars within the same species can have differing responses to plant growth regulators (Latimer, 2004). *Echinacea* cultivars had varying need for and response to PGRs in this research. Some cultivars were very tall even with height control applications (notably Southern Belle, Guava Ice and Hot Papaya, which were over 70 cm); newer cultivars in recent trials have grown over 95 cm tall (Warner et al., 2013; Whitman et al., 2007). While shorter cultivars are available, growers will need to conduct their own trials to develop growth control strategies for more vigorously growing cultivars.

Conclusions

Planning for flowering and managing growth are challenges producers face when growing newer varieties of *Echinacea*. This research has examined the growth and response to PGR and photoperiod in over 20 new and recently introduced cultivars to provide growers with additional tools in meeting the demands of the marketplace. Photoperiod reduced growth in liners grown under a 10 h photoperiod; liners were shorter, less wide, had fewer branches and were less well rooted than liners in longer photoperiods. Photoperiod delayed flowering in finished plants exposed to 10 h or 24 h photoperiods as liners, by 4 and 8 days respectively, but did not affect growth or quality in finished plants. Photoperiod did however slightly affect flowering in two cultivars in the 24 h photoperiod, and eliminated flowering in 'Marmalade' in the 16 h or 24 h photoperiod.

We found that providing *Echinacea* hybrid cultivars with a 16 h photoperiod during liner production resulted in plants which flowered soonest without any negative effects on growth. The need for height control PGRs varied by cultivar; however, overall, height control PGRs controlled height and increased market rating. Growers can use height control PGRs to control height in *Echinacea* hybrids liners and finished plants; however some compact cultivars may not need height control. We recommend growers keep liners under a 16 h photoperiod until bulked and use height control PGRs as needed in order to optimize the production of *Echinacea* hybrid cultivars.

Literature Cited

Armitage, A.M. 2008. Herbaceous perennial plants: A treatise on their identification, culture, and garden attributes. 3rd ed. Stipes, Champaign, IL.

Ault, J.R. 2007. Coneflower, p. 801-824. In: Anderson, N.O. (ed.) Flower breeding and genetics. Springer, Dordrecht, The Netherlands.

Baggett, P. 2008. The *Echinacea* factor. Horticulture 105(6):24-29.

Carey, D., W. Buhler and B. Whipker. 2010. Stimulating plant growth with Configure, pp. 4-7. In: J. Latimer and B. Whipker (eds.) Configure product information and university trial results. Fine Americas, Inc., Walnut Creek, CA.

Fifo, C. 2010. Know and grow: Success with tissue culture *Echinacea*. Grower Talks 74(6):56-60.

Frett, J. 2009. Coneflowers for the mid-Atlantic region. Mt. Cuba Center. Hockessin, DE.

Grossi, J.A.S., J.T. Baker, and H.B. Pemberton. 2003. Leaf photosynthesis, flower respiration and flower longevity of pot roses influenced by cultivar and growing environment. Acta Hort. 624:329-334.

Grossman, M.C., M. Aiken, H. Scoggins, and J. Latimer. 2015. Plant growth regulators affect branching and flowering in three *Echinacea* cultivars. Proc. Plant Growth Regulat. Soc. Amer. 42:127-133.

Ha, T.M. 2014. A review of plants' flowering physiology: The control of floral induction by juvenility, temperature and photoperiod in annual and ornamental crops. Asian J. Agr. Food Sci. 2(03):186-195.

Han, J., G.J. Huang, T. Wu, X.M. Sun, Y. Liu and R.F. Gao. 2015. Photoperiod affects morphology, flower productivity and photosynthesis of forced potted *Paeonia lactiflora* in greenhouses. Acta Hort. 1104:211-218

Heide, O.M. 2004. Dual induction rather than intermediate daylength response of flowering in *Echinacea purpurea*. Physiol. Plant. 120:298-302.

Kazaz, S., M.A. Askin, S. Kilic, and N. Ersoy. 2010. Effects of day length and daminozide on the flowering, some quality parameters and chlorophyll content of *Chrysanthemum morifolium* Ramat. Scientific Res. and Essays 5(21):3281-3288.

Latimer, J. 2016. Growth regulators for containerized herbaceous perennial plants. GrowerTalks. 2016-2017 Guide to Growing Top-Quality Perennials.

Latimer, J. 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.

Latimer, J., J. Freeborn and V. Groover. 2008. Benzyladenine increases branching of herbaceous perennials. Acta Hort. 886:163-166.

Latimer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 31:1-4.

Latimer, J.G. and P.A. Thomas. 1997. Responses of nine containerized perennials to Sumagic. HortScience 32:593-593.

Latimer, J.G., P.A. Thomas and S.A. Baden. 1997. Effect of plant growth regulators on growth and landscape performance of perennial bedding plants. Proc. 42nd Annu. Southern Nursery Assn. Res. Conf. 42:283-285.

Mattson, N.S. and J.E. Erwin. 2005. The impact of photoperiod and irradiance on flowering of several herbaceous ornamentals. Scientia Hort. 104(3):275-292.

Netto, A.T., E. Campostrini, J.G. de Oliveira, and R.E. Bressan-Smith. 2005. Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. Scientia Hort. 104(2):199-209.

Padhye, S. and C. Whitman. 2008. *Echinacea* 'Sunrise' and 'Harvest Moon'. Greenhouse Grower 26(13):84-88.

Padhye, S. and J. Groninger. 2010. *Echinacea* liners - improved liner quality by increased basal branches, pp. 12. In: J. Latimer and B. Whipker (eds.) Configure product information and university trial results. Fine Americas, Inc., Walnut Creek, CA.

Pilon, P. 2006. Perennial solutions: A grower's guide to perennial production. Ball Publishing. Batavia, IL.

Pilon, P. 2011. Enhancing perennial production. Greenhouse Product News. 30 September 2016 <http://www.gpnmag.com/article/enhancing-perennial-production-0/>.

Pilon, P. 2013. Perennials demystified: Taking the fear out of premium cultivars. Green Profit 77(4):36.

Runkle, E.S., R.D. Heins, A.C. Cameron, and W.H. Carlson. 2001. Photocontrol of flowering and stem extension of the intermediate-day plant *Echinacea purpurea*. Physiol. Plant. 112(3):433-441.

Runkle, E.S., and R.D. Heins. 2005. Manipulating the light environment to control flowering and morphogenesis of herbaceous plants. Acta Hort. 711:51-60.

Schoellhorn, R., and A.A. Richardson. 2006. Warm climate production guidelines for *Echinacea*. Univ. of FL IFAS Commercial Floriculture Update ENHFL04-008.

Thomas, B. and D. Vince-Prue. 1996. Photoperiodism in plants. Academic Press. San Diego, CA.

Torres, A.P. and R.G. Lopez. 2010. Measuring daily light integral in a greenhouse. 5 September 2016. < https://www.extension.purdue.edu/extmedia/ho/ho-238-w.pdf>.

U.S. Department of Agriculture (USDA). 2014. Plant fact sheet: Eastern purple coneflower. 31 August, 2014 <http://plants.usda.gov/factsheet/pdf/fs_ecpu.pdf>.

USDA. 2015. Census of horticultural specialties (2014). 31 August 2016. <https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Census_of_Horticulture_Specialties/HORTIC.pdf>

Velez-Ramirez, A.I., W. van Ieperen, D. Vreugdenhil, and F.F. Millenaar. 2011. Plants under continuous light. Trends in Plant Sci. 16(6):310-318.

Warner, R., E. Runkle, S. Padhye, and C. Whitman. 2013. Controlling flowering of *Echinacea*. GrowerTalks 76(10):66-70.

Whitman, C., S. Padhye, A. Cameron, E. Runkle and N. DuRussel. 2007. Evaluating new *Echinacea* cultivars. Greenhouse Product News 22(9):54-57.

Tables and Figures

Figure 5.1. *Echinacea* tissue culture plantlets prior to transplant.

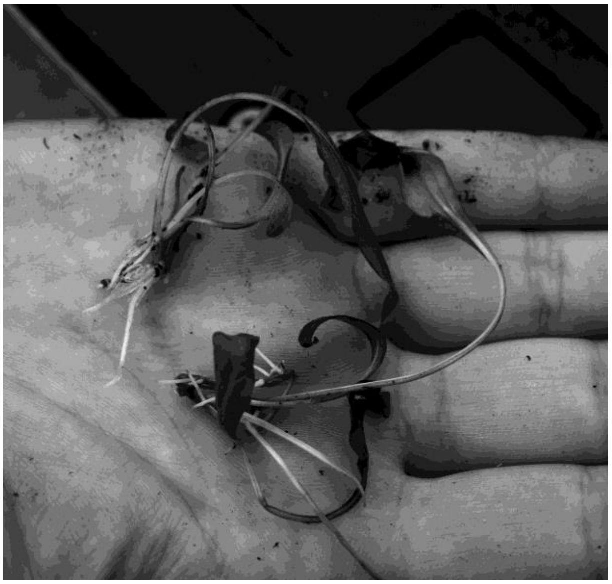


Figure 5.2 *Echinacea* liners growing on carts with LED lights on timers to create three photoperiods on each cart, a different one on each shelf[z].

[z]Photo shows light excluding film removed during daytime hours; film was replaced after 10 h photoperiod, and 16 h and 24 h photoperiods remained lit by LED lights. Lights were turned off after 16 h in the 16 h photoperiod while the 24 h photoperiod remained constantly lit.

Figure 5.3. Diagram of *Echinacea* cultivars (CV1-CV21) with PGR (HC+) or without (HC-)[z].

10 Hour

CV 3 HC-	CV 3 HC+	CV 1 HC-	CV 1 HC+	CV 17 HC-	CV 17 HC+	CV 4 HC-	CV 4 HC+
CV 11 HC-	CV 11 HC+	CV10 HC+	CV 10 HC-	CV 16 HC+	CV 16 HC-	CV 14 HC-	CV 14 HC+
CV 5 HC-	CV 5 HC+	CV 15 HC+	CV 15 HC-	CV 8 HC+	CV 8 HC-	CV 12 HC+	CV 12 HC-
CV 9 HC+	CV 9 HC-	CV 7 HC-	CV 7 HC+	CV 20 HC+	CV 20 HC-	CV 13 HC+	CV 13 HC-
CV 18 HC+	CV 18 HC-	CV 6 HC-	CV 6 HC+	CV 21 HC-	CV 21 HC+	CV 2 HC+	CV 2 HC-
CV 19 HC+	CV 19 HC-						

16 Hour

CV 14 HC-	CV 14 HC+	CV 21 HC-	CV 21 HC+	CV 19 HC+	CV 19 HC-	CV 6 HC-	CV 6 HC+
CV 13 HC+	CV 13 HC-	CV 7 HC+	CV 7 HC-	CV 3 HC-	CV 3 HC+	CV 2 HC+	CV 2 HC-
CV 17 HC-	CV 17 HC+	CV 12 HC+	CV 12 HC-	CV 15 HC-	CV 15 HC+	CV 18 HC+	CV 18 HC-
CV 9 HC+	CV 9 HC-	CV 16 HC-	CV 16 HC+	CV 20 HC+	CV 20 HC-	CV 4 HC-	CV 4 HC+
CV 11 HC-	CV 11 HC+	CV10 HC+	CV10 HC-	CV 5 HC-	CV 5 HC+	CV 8 HC+	CV 8 HC-
						CV 1 HC-	CV 1 HC+

24 Hour

CV 8 HC+	CV 8 HC-	CV10 HC+	CV10 HC-	CV 18 HC+	CV 18 HC-	CV 14 HC-	CV 14 HC+
CV 12 HC+	CV 12 HC-	CV 7 HC+	CV 7 HC-	CV 3 HC-	CV 3 HC+	CV 1 HC-	CV 1 HC+
CV 4 HC-	CV 4 HC+	CV 16 HC-	CV 16 HC+	CV 13 HC+	CV 13 HC-	CV 9 HC+	CV 9 HC-
CV 20 HC+	CV 20 HC-	CV 11 HC-	CV 11 HC+	CV 17 HC-	CV 17 HC+	CV 21 HC-	CV 21 HC+
CV 19 HC+	CV 19 HC-	CV 6 HC-	CV 6 HC+	CV 15 HC-	CV 15 HC+	CV 2 HC+	CV 2 HC-
		CV 5 HC-	CV 5 HC+				

[z]Cultivars were placed on carts and grown under 10 h, 16 h or 24 h photoperiods for 10 weeks after transplanting tissue culture plantlets. Cultivars were arranged randomly on each shelf. Each block of plants is made up of four plants grown in cell packs (height 5.71 cm, volume 35.4 mL) (subsamples). Diagram shows one cart (replicate).

Table 5.1 *Echinacea* cultivars used in the study with their height, finished pot size, and flower description.

Cultivar	Height (cm) [z]	Finish pot size[y]	Flower description
Avalanche	38-46	QT	White with yellow green cone
Blushing Meadow Mama	81	TG	Cream colored with pink near the yellow to green cone
Butterfly Kisses	30-38	QT	Double flowered, pink
Cleopatra	38-46	QT	Lemon yellow flower with a yellow cone
Coconut Lime	71	QT	Double flowered, white with lime green center
Golden Skipper	38-46	QT	Golden yellow flower with a yellow to green cone
Guava Ice	61-76	TG	Double flowered, salmon colored
Honeydew	46-61	QT	Double flowered, white ray petals with lime green cone
Hot Papaya	76-91	TG	Double flowered, red to orange
Julia	38-46	QT	Bright orange flower with a brown-orange cone
Marmalade	61-76	TG	Double flowered, yellow to orange
Mini belle	46-61	TG	Double flowered, bright magenta pink
Orange Skipper	38-46	QT	Bright orange flower with a brown-orange cone
Pink Bonbon	30-38	QT	Double flowered, pink pompom
Postman	46-61	TG	Red flowers with a brown cone
Purple Emperor	38-46	QT	Bright magenta purple flower with maroon cone
Rainbow Marcella	46	QT	Orange to pink with a brown cone
Raspberry Truffle	46-61	TG	Double flowered coral to pink
Southern Belle	76-91	TG	Double flowered, bright magenta pink
Sweet Sixteen	30-38	QT	Raspberry pink double pompom flowers
White Double Delight	46-61	QT	White double flowered

[z]Height listed is the height given by the supplier.
[y]Plants were transplanted into either quart (1.13 L) or trade gallon (2.8 L) pots.

Table 5.2 Benzyladenine (BA), daminozide (DZ), and uniconazole (UC) treatment dates listed by *Echinacea* cultivar and photoperiod[z].

Cultivar	Photo period	1st BA	2nd BA	3rd BA	1st DZ	2nd DZ	1st UC	2nd UC
Avalanche	10 hr	4/14	4/28					
Avalanche	16 hr	4/11	4/29		4/11	4/28	5/17	
Avalanche	24 hr	4/11	4/30		4/11	4/28	5/17	
Blushing Meadow Mama	10 hr	4/28	5/17				6/15	
Blushing Meadow Mama	16 hr	4/11	4/26	5/17	4/26		5/17	7/5
Blushing Meadow Mama	24 hr	4/11	4/26	5/17	4/26		5/17	7/5
Butterfly Kisses	10 hr	4/14	4/28					
Butterfly Kisses	16 hr	4/11	4/29		4/11	4/28		
Butterfly Kisses	24 hr	4/11	4/30		4/11	4/28		
Cleopatra	10 hr	4/28					6/17	
Cleopatra	16 hr	4/11	4/28		4/11	4/28	7/5	
Cleopatra	24 hr	4/11	4/28		4/11	4/28	7/5	
Coconut Lime	10 hr	5/17						
Coconut Lime	16 hr	4/11	4/26		4/11	4/26		
Coconut Lime	24 hr	4/11	4/26		4/11	4/26		
Golden Skipper	10 hr	4/14	4/28				6/17	
Golden Skipper	16 hr	4/11	4/29		4/11	4/28	5/5	
Golden Skipper	24 hr	4/11	4/30		4/11	4/28	5/5	6/21
Guava Ice	10 hr	4/14	4/28				6/15	
Guava Ice	16 hr	4/11	4/26		4/11	4/26	5/5	6/15
Guava Ice	24 hr	4/11	4/26		4/11	4/26	5/5	6/28
Honeydew	10 hr	4/28	5/17				6/15	
Honeydew	16 hr	4/11	4/26		4/11	4/26	5/5	7/5
Honeydew	24 hr	4/11	4/26		4/11	4/26	5/5	7/5
Hot Papaya	10 hr	4/14	4/28		4/28		6/15	
Hot Papaya	16 hr	4/11	4/26	5/10	4/11	4/26	5/5	6/21
Hot Papaya	24 hr	4/11	4/26	5/10	4/11	4/26	5/5	6/28
Julia	10 hr	4/28					6/15	
Julia	16 hr	4/11	4/28		4/11	4/28	6/15	
Julia	24 hr	4/11	4/28		4/11	4/28	6/15	
Marmalade	10 hr	4/14	4/28		4/28		6/15	
Marmalade	16 hr	4/11	4/26	5/10	4/11	4/26	5/5	
Marmalade	24 hr	4/11	4/26	5/10	4/11	4/26	5/5	
Orange Skipper	10 hr	4/14	4/28				6/17	
Orange Skipper	16 hr	4/11	4/28		4/11	4/28	6/21	
Orange Skipper	24 hr	4/11	4/28		4/11	4/28	6/21	
Pink Bonbon	10 hr	5/17						
Pink Bonbon	16 hr	4/11	4/28		4/11	4/28	5/17	
Pink Bonbon	24 hr	4/11	4/28		4/11	4/28	5/17	
Postman	10 hr	4/14	4/28		4/28		6/15	
Postman	16 hr	4/11	4/26	5/10	4/11	4/26	5/5	6/21
Postman	24 hr	4/11	4/26	5/10	4/11	4/26	5/5	6/21
Purple Emperor	10 hr	4/28					6/21	
Purple Emperor	16 hr	4/11	4/26		4/26	6/28		
Purple Emperor	24 hr	4/11	4/26		4/26	6/28		
Mini Belle	10 hr	4/14	4/28		4/28		6/17	
Mini Belle	16 hr	4/11	4/26	5/10	4/11	4/26	5/5	
Mini Belle	24 hr	4/11	4/26	5/10	4/11	4/26	5/5	
Rainbow Marcella	10 hr	4/28	5/17				6/17	
Rainbow Marcella	16 hr	4/11	4/28	5/10	4/11	4/28	5/5	6/21
Rainbow Marcella	24 hr	4/11	4/28	5/10	4/11	4/28	5/5	6/28
Raspberry Truffle	10 hr	4/14	4/28		5/17		6/15	
Raspberry Truffle	16 hr	4/11	4/28	5/17	4/11	4/28	5/5	
Raspberry Truffle	24 hr	4/11	4/28	5/17	4/11	4/28	5/5	
Southern Belle	10 hr	4/14	4/28				6/17	
Southern Belle	16 hr	4/11	4/26	5/10	4/11	4/26	5/5	
Southern Belle	24 hr	4/11	4/26	5/10	4/11	4/26	5/5	
Sweet Sixteen	10 hr	4/28						
Sweet Sixteen	16 hr	4/11	4/28		4/11	4/28		
Sweet Sixteen	24 hr	4/11	4/28		4/11	4/28		
White Double Delight	10 hr	4/14	4/28				6/15	

Cultivar	Photo period	1st BA	2nd BA	3rd BA	1st DZ	2nd DZ	1st UC	2nd UC
White Double Delight	16 hr	4/11	4/26		4/11	4/26	5/5	5/17
White Double Delight	24 hr	4/11	4/26		4/11	4/26	5/5	5/17[y]

[z]Liners received foliar sprays of PGRs beginning at 6 weeks after tissue culture transplant. All plants received 300 $mg{\cdot}L^{-1}$ BA to increase branching as needed every two weeks for up to three applications. Plants in the height control PGR treatment received 2500 $mg{\cdot}L^{-1}$ daminozide, up to two applications before liner transplant, and up to three applications of 15 $mg{\cdot}L^{-1}$ uniconazole as needed after liner transplant.
[y] ‘White Double Delight’ in the 24 h photoperiod received a 3rd UC treatment 5 July 2016.

Table 5.3 Effects of cultivar, photoperiod, and height control on height, width, number of branches and root rating of finished *Echinacea* liners at 10 weeks after tissue culture transplant, just prior to transplant to larger containers.

		Height (cm)	Width (cm)	No. branches	Root rating[x]
Cultivar (C)	Avalanche	11.5bcdef[zy]	11.2fg	na	4.2bcde
	Blushing Meadow Mama	12.7abcd	11.7ef	3.4ghi	4.4abcd
	Butterfly Kisses	9.8def	10.7fg	na	44.0de
	Cleopatra	9.8def	11.8ef	4.4def	4.5abc
	Coconut Lime	9.2ef	10.2fg	4.5de	3.9ef
	Golden Skipper	12.9abcd	11.9def	6.0b	4.6a
	Guava Ice	12.4abcde	14.5abc	5.7bc	4.7a
	Honeydew	10.7cdef	11.3ef	3.3hi	4.3abcd
	Hot Papaya	14.6ab	13.8cde	4.0efgh	4.6a
	Julia	9.6def	10.4fg	5.6bc	4.6ab
	Marmalade	15.3a	14.3bcd	5.5def	4.6a
	Mini belle	13.6abc	16.8a	4.2defg	4.7a
	Orange Skipper	11.4bcdef	11.0fg	7.7a	4.7a
	Pink Bonbon	10.7cdef	10.3fg	4.0efghi	3.6f
	Postman	14.6ab	16.2ab	3.2i	4.6ab
	Purple Emperor	8.5f	10.9fg	3.6fghi	4.1cde
	Rainbow Marcella	9.6def	14.2bcd	2.3j	4.7a
	Raspberry Truffle	13.6abc	12.5cdef	3.3hi	4.5abc
	Southern Belle	13.5abc	12.4cdef	4.0efghi	4.5abc
	Sweet Sixteen	8.6f	8.8g	4.9cd	3.5f
	White Double Delight	11.2bcdef	12.6cdef	5.9b	4.6ab
Photoperiod (P)	10-hour	5.1c	7.9c	3.9b	3.6c
	16-hour	13.3b	13.9b	4.8a	4.7b
	24-hour	16.4a	15.1a	4.4a	4.8a
Height control PGR (HC)	HC+	10.9b	11.8b	4.3	4.3
	HC-	12.4a	12.7a	4.5	4.4
Significance	Cultivar (C)	***	***	***	***
	Photoperiod (P)	***	***	*	***
	C*P	***	***	***	***
	Height control (HC)	***	***	NS	NS
	C*HC	NS	NS	NS	NS
	P*HC	*	NS	NS	NS
	C*P*HC	NS	NS	NS	NS

[z]Data for each cultivar are means of 18 plants (3 replicates x 2 height control conditions x 3 photoperiods). Data for photoperiods are means of 126 plants (3 replicates x 21 cultivars x 2 height control conditions). Data for height control PGR are means of 189 plants (3 replicates x 21 cultivars x 3 photoperiods). Each replicate represents the mean of 4

subsamples.
[y]Means within a column and main effect followed by different letters are significantly different (P<0.05, Student's t-test). NS, *, **, ***Nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.
[x]Roots were rated from 1 (no roots visible), 2 (roots visible on 2 sides), 3 (roots visible on 3 to 4 sides, plug does not hold together), 4 (rooted to all sides, plug holds together, some substrate visible), to 5 (well rooted and little substrate visible).

Table 5.4 Plant height, width, number of branches, and root rating of *Echinacea* cultivars as affected by photoperiod.

Cultivar	Photo period	Plant height (cm)	Width (cm)	No. branches	Root rating
Avalanche	10	4.0c[zy]	7.4c	na[x]	3.5c[w]
	16	12.6b	11.9b	na	4.1b
	24	17.9a	14.2a	na	5.0a
	Effect	<0.0001	<0.0001		<0.0001
	LSD	2.3	1.6		0.4
Blushing Meadow Mama	10	4.0b	7.7b	1.7b	3.2b
	16	17.0a	14.4a	4.8a	4.9a
	24	17.4a	13.1a	3.8a	5.0a
	Effect	<0.0001	<0.0001	0.0055	<0.0001
	LSD	2.1	1.9	1.6	0.5
Butterfly Kisses	10	5.2c	7.2c	na	3.5c
	16	11.1b	11.8b	na	4.0b
	24	13.0a	13.2a	na	4.6a
	Effect	<0.0001	<0.0001		0.0005
	LSD	1.4	1.0		0.4
Cleopatra	10	3.7c	6.7c	3.4b	3.6b
	16	11.6b	13.4b	5.7a	4.9a
	24	14.0a	15.1a	4.0b	5.0a
	Effect	<0.0001	<0.0001	0.0008	<0.0001
	LSD	2.6	2.1	1.0	0.2
Coconut Lime	10	2.13c	3.6b	1.3b	2.4c
	16	11.3b	12.8a	5.9a	4.3b
	24	14.3a	14.0a	6.4a	4.9a
	Effect	<0.0001	<0.0001	<0.0001	<0.0001
	LSD	1.9	1.5	1.0	0.3
Golden Skipper	10	5.8c	8.7c	7.8a	3.9b
	16	15.6b	14.3a	5.3b	4.9a
	24	17.3a	12.6b	4.9b	5.0a
	Effect	<0.0001	<0.0001	0.0003	<0.0001
	LSD	2.6	1.4	1.2	0.2
Guava Ice	10	6.3c	9.1c	5.6	4.0b
	16	12.5b	14.8b	5.3	5.0a
	24	18.5a	19.7a	6.0	5.0a
	Effect	<0.0001	<0.0001	0.1062	<0.0001
	LSD	1.7	2.6	0.8	0.1
Honeydew	10	4.1c	5.5b	1.7b	3.9b

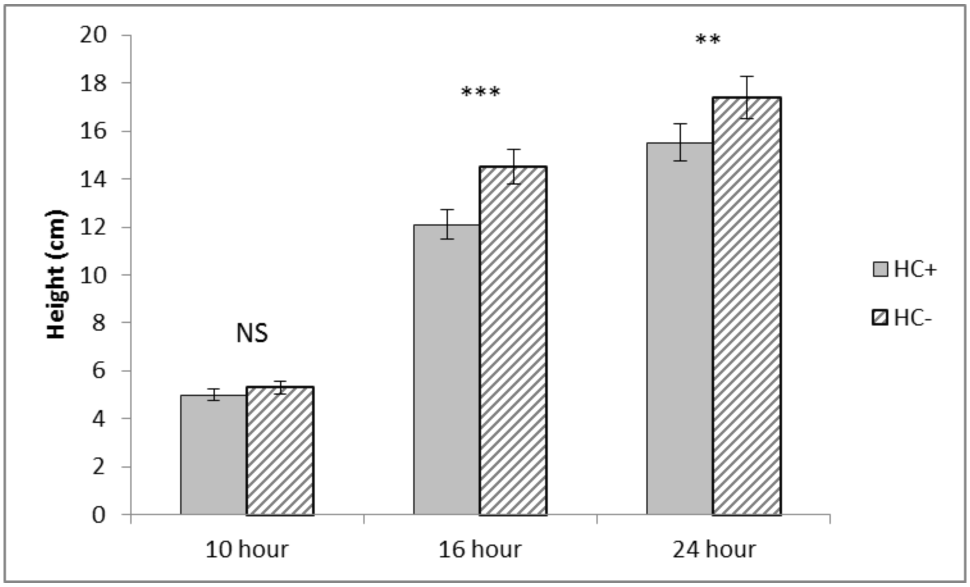
Cultivar	Photo period	Plant height (cm)	Width (cm)	No. branches	Root rating
	16	11.2b	13.2a	4.0a	4.4a
	24	16.6a	15.4a	4.3a	4.5a
	Effect	<0.0001	<0.0001	<0.0001	0.0141
	LSD	2.5	2.3	0.7	0.4
Hot Papaya	10	8.4c	10.5b	3.9ab	3.9b
	16	16.3b	15.1a	4.5a	5.0a
	24	19.1a	15.8a	3.7b	5.0a
	Effect	<0.0001	0.0002	0.0333	<0.0001
	LSD	1.8	2.0	0.7	0.1
Julia	10	4.5c	7.1c	4.9b	3.9b
	16	10.8b	10.9b	6.6a	4.8a
	24	13.4a	13.3a	5.4b	5.0a
	Effect	<0.0001	<0.0001	0.0196	<0.0001
	LSD	2.1	1.6	1.0	0.2
Marmalade	10	8.0c	10.8b	5.8a	4.0b
	16	17.3b	15.8a	4.3b	5.0a
	24	20.8a	16.4a	3.2b	4.9a
	Effect	<0.0001	<0.0001	0.0014	<0.0001
	LSD	3.1	1.7	1.1	0.1
Mini belle	10	6.0c	10.3c	3.4	4.1b
	16	14.8b	18.3b	4.6	4.9a
	24	20.0a	22.0a	4.6	5.0a
	Effect	<0.0001	<0.0001	0.1002	0.0029
	LSD	2.4	2.4	1.3	0.5
Orange Skipper	10	6.1c	7.6c	na	4.0b
	16	12.8b	11.8b	7.3	5.0a
	24	15.3a	13.4a	8.1	5.0a
	Effect	<0.0001	<0.0001	0.1832	<0.0001
	LSD	2.9	1.4	na	0.2
Pink Bonbon	10	2.6c	3.9c	1.9b	2.2c
	16	12.6b	12.4b	5.3a	3.9b
	24	17.0a	14.6a	4.7a	4.5a
	Effect	<0.0001	<0.0001	<0.0001	<0.0001
	LSD	1.1	1.8	0.6	0.4

Cultivar	Photo period	Plant height (cm)	Width (cm)	No. branches	Root rating
Postman	10	6.5c	12.7b	3.2	4.0b
	16	17.0b	18.7a	3.7	4.8a
	24	20.4a	17.4a	2.6	4.9a
	Effect	<0.0001	<0.0001	0.1962	<0.0001
	LSD	2.5	2.0	1.3	0.2
Purple Emperor	10	3.6c	7.2b	3.5	3.4b
	16	10.0b	13.1a	3.9	4.5a
	24	12.1a	12.4a	3.5	4.4a
	Effect	<0.0001	0.0001	0.4165	0.0001
	LSD	1.8	2.2	0.8	0.4
Rainbow Marcella	10	4.0c	8.7c	1.7b	4.1b
	16	10.4b	15.5b	2.6a	4.9a
	24	14.5a	18.5a	2.5a	5.0a
	Effect	<0.0001	<0.0001	0.0398	0.001
	LSD	2.3	2.0	0.7	0.4
Raspberry Truffle	10	7.5b	8.6b	4.5a	4.0c
	16	17.0a	14.7a	2.7b	5.0a
	24	16.4a	14.1a	2.6b	4.5b
	Effect	<0.0001	0.0006	0.0182	0.0024
	LSD	2.9	2.6	1.2	0.4
Southern Belle	10	6.0c	8.1b	4.3	3.6b
	16	14.8b	14.1a	4.3	4.9a
	24	19.7a	14.9a	3.3	5.0a
	Effect	<0.0001	0.0002	0.1139	<0.0001
	LSD	1.3	2.3	1.0	0.3
Sweet Sixteen	10	4.1c	5.2c	5.0	3.1b
	16	9.9b	9.7b	5.0	3.5a
	24	11.9a	11.4a	4.7	3.8a
	Effect	<0.0001	<0.0001	0.8612	0.0008
	LSD	1.2	1.5	1.3	0.3
White Double Delight	10	5.5c	8.1b	6.3	3.8b
	16	12.5b	14.5a	5.8	5.0a
	24	15.8a	15.1a	5.6	4.9a
	Effect	<0.0001	<0.0001	0.4378	<0.0001
	LSD	1.9	1.2	1.0	0.2

[z]Data for each cultivar are means of 6 plants (3 replicates x 2 height control). Each replicate represents the mean of 4 subsamples.
[y]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=3).
[x] Branches filled the cells and could not be counted in 'Avalanche', 'Butterfly Kisses', and in 'Orange Skipper' in the 10 h photoperiod without damaging the liners.
[w]Roots were rated from 1 (no roots visible), 2 (roots visible on 2 sides), 3 (roots visible on 3 to 4 sides, plug does not

hold together), 4 (rooted to all sides, plug holds together, some substrate visible), to 5 (well rooted and little substrate visible).

Figure 5.4 Effect of photoperiod (10-hour, 16-hour, or 24-hour) and height control PGRs (either with [HC+] or without [HC-] height control PGRS) on height of finished *Echinacea* liners at 10 weeks after tissue culture transplant[z].



[z]Error bars are the 95% confidence intervals of the mean. NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. Data are means of 63 plants (3 replicates x 21 cultivars). Each replicate represents the mean of 4 subsamples.

Table 5.5 Effects of cultivar, photoperiod, and height control on photosynthesis, stomatal conductance, and transpiration of *Echinacea* liners at 10 weeks after tissue culture transplant.

		Photosynthesis µmol·m^{-2}·s^{-1}			Stomatal conductance mol·m^{-2}·s^{-1}			Transpiration mol·m^{-2}·s^{-1}		
Cultivar (C)	Butterfly Kisses	10.0c[zy]			0.20bc			0.0019d		
	Golden Skipper	14.6b			0.35a			0.0039c		
	Guava Ice	19.0a			0.38a			0.0057ab		
	Honeydew	13.3b			0.23b			0.0058a		
	Marmalade	12.4bc			0.22bc			0.0049bc		
	White Double Delight	5.1d			0.16c			0.0025d		
Photoperiod (P)	10	14.3a			0.29a			.0046a		
	16	14.1a			0.30a			.0046a		
	24	8.7b			0.18b			.0032b		
Height control PGR (HC)	HC+	12.1			0.26			0.0042		
	HC-	12.8			0.26			0.0042		
		10 hour	16 hour	24 hour	10 hour	16 hour	24 hour	10 hour	16 hour	24 hour
C * P	Butterfly Kisses	9.7b[x]	14.2a	6.0c	0.19b	0.29a	0.11c	0.0020b	0.0026a	0.0010c
	Golden Skipper	13.8	17.4	12.5	0.40	0.35	0.31	0.0036	0.0040	0.0042
	Guava Ice	19.1	20.1	17.2	0.34b	0.43a	0.35b	0.0055b	0.0055b	0.0063a
	Honeydew	16.3a	14.8a	8.0b	0.24ab	0.28a	0.16b	0.0062a	0.0069a	0.0039b
	Marmalade	20.9a	12.9b	4.8c	0.35a	0.25a	0.07b	0.0075a	0.0056a	0.0017b
	White Double Delight	6.0a	5.5a	4.0b	0.24a	0.19a	0.08b	0.0030a	0.0029a	0.0018b
Significance	Cultivar (C)	***			***			***		
	Photoperiod (P)	***			***			***		
	C*P	***			***			***		
	Height control (HC)	NS			NS			NS		
	C*HC	NS			NS			NS		
	P*HC	NS			NS			NS		
	C*P*HC	NS			NS			NS		

[z]Data for each cultivar are means of 18 plants (3 replicates x 2 height control conditions x 3 photoperiods). Data for photoperiods are means of 36 plants (3 replicates x 6 cultivars x 2 height control conditions). Data for height control PGR are means of 54 plants (3 replicates x 6 cultivars x 3 photoperiods).
[y]Means within a column and main effect followed by different letters are significantly different (P<0.05, Student’s t-test). NS, *, **, ***Nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.
[x]For each cultivar in each growth parameter, different letters across columns equal significant differences (Student's t-test, P<0.05)

Table 5.6 Effects of cultivar, photoperiod, and height control on height, width, number of branches, number of flower stalks, days to bud, days to flower, market rating, shoot dry weight and flower status of *Echinacea* cultivars in flower at finish between 15 and 22 weeks after tissue culture transplant.

		Height (cm)	Width (cm)	No. branches	No. flower stalks	Days to bud[x]	Days to flower	Market rating[w]	Shoot dry weight (g)	Flower status[v]
Cultivar (C)	Avalanche	69.1d[zy]	40.3defg	12.3bc	4.4cde	44.4ab	70.0a	3.8b	47.2a	2.9abc
	Blushing Meadow Mama	60.7fg	42.5d	4.3jk	1.1j	40.7bc	61.8bcd	3.7bc	29.6bc	2.7de
	Butterfly Kisses	36.5jk	39.4efgh	21.5a	8.4a	28.4fgh	54.8f	4.4a	29.1bcd	2.9abc
	Cleopatra	54.7hi	36.8hijk	8.7fg	3.0ghi	42.0bc	65.5ab	3.8b	33.2b	2.6e
	Coconut Lime	59.8fgh	38.6fghi	13.2b	4.1def	22.7hi	46.6g	3.4de	20.5gh	2.9abc
	Golden Skipper	62.1ef	35.5jk	7.5gh	4.7bcd	21.5i	48.4g	3.4de	23.8efg	2.9abc
	Guava Ice	80.2b	50.6ab	8.2g	1.4j	50.2a	63.8bc	3.4de	42.6a	2.8bcde
	Honeydew	55.2ghi	36.3ijk	6.1hi	3.6efgh	31.4def	56.0ef	3.3e	24.1defg	2.8abcde
	Hot Papaya	77.5bc	48.8bc	5.4ij	2.4i	41.0bc	61.5bcde	3.2ef	32.3b	2.9abc
	Julia	51.5i	41.7de	11.4cd	3.0hi	33.7def	57.9def	4.2a	30.9bc	2.9abcd
	Marmalade	71.6cd	54.0a	7.0ghi	1.3j	22.3ghi	45.9gh	3.1ef	18.5ghi	1.6f
	Mini belle	70.4d	36.5hijk	9.8ef	5.4b	19.6i	38.5hi	3.3e	14.9ij	3.0a
	Orange Skipper	51.5i	37.8ghij	11.4cd	4.6cd	30.2efg	56.8def	4.2a	32.2b	3.0a
	Pink Bonbon	41.3j	25.9l	7.7g	3.1ghi	10.6j	36.5ij	3.6bcd	10.9jk	2.9abc
	Postman	62.1ef	47.5c	5.6ij	1.5j	35.8cde	59.3cdef	3.4de	28.9bcde	3.0a
	Purple Emperor	56.7fghi	41.4def	11.8bc	3.0ghi	36.6cd	59.1cdef	3.9b	30.2bc	2.9ab
	Rainbow Marcella	59.7fgh	40.8def	3.7k	2.4i	30.6defg	55.0f	3.7b	25.9cdef	2.9abc
	Raspberry Truffle	60.4fg	34.2k	5.4ij	3.4fgh	21.1i	45.3g	2.9f	17.2ij	2.9abcd
	Southern Belle	92.5a	39.8defg	7.2gh	5.0bc	28.5fgh	48.0g	3.4de	23.2fg	3.0a
	Sweet Sixteen	34.2k	21.6m	7.2gh	3.8efg	11.4j	32.7j	3.4de	7.5k	2.9abcd
	White Double Delight	67.5de	36.3ijk	10.2de	4.6cd	31.9def	54.6f	3.4cde	31.4b	3.0a
Photoperiod (P)	10-hour	60.3	38.2	9.1	3.8	28.6b	53.1b	3.5	21.9c	2.9a
	16-hour	60.0	38.6	8.7	3.3	27.8b	49.6c	3.6	26.8b	2.8b
	24-hour	60.5	39.8	8.9	3.5	35.3a	57.8a	3.6	31.5a	2.7c
Height control PGR (HC)	HC+	56.8	38.1	8.1	3.3	32.9	56.2	3.7	25.9	2.8
	HC-	63.8	39.7	9.7	3.8	28.1	50.7	3.5	27.4	2.8
Significance	Cultivar (C)	***	***	***	***	***	***	***	***	***
	Photoperiod (P)	NS	NS	NS	NS	***	***	NS	***	***
	C*P	NS	***	**	***	***	***	***	***	***
	Height control (HC)l	***	NS	***	*	**	***	***	NS	NS
	C*HC	*	NS	NS	NS	NS	NS	NS	NS	NS
	P*HC	NS	NS	NS	NS	NS	NS	NS	NS	NS
	C*P*HC	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Data for each cultivar are means of 18 plants (3 replicates x 2 height control conditions x 3 photoperiods). Data for photoperiods are means of 126 plants (3 replicates x 21 cultivars x 2 height control conditions). Data for height control PGR are means of 189 plants (3 replicates x 21 cultivars x 3 photoperiods). Each replicate represents the mean of 4 subsamples.
[y]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=3). NS, *, **, *** Nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

[x]Days to bud and days to flower were calculated from date of liner transplant to final container.
[w]Market rating was on a scale of 1 (poor), 2 (fair), 3(average), 4 (good), to 5 (premium quality) based on quality of plant growth and flowering characteristics.
[v]Flower status was rated on a scale from 1 to 3, with 1 indicating that the plant did not initiate a bud, 2 the plant had a bud but did not flower during the study, and 3 indicating that the plant flowered during the study.

Table 5.7 Plant height, width, number of branches, number of flower stalks, days to bud, days to flower, market rating, shoot dry weight, and flower status of finished, flowering plants of *Echinacea* cultivars as affected by photoperiod.

Cultivar	Photo period	Height (cm)[zy]	Width (cm)	No. branches	No. flower stalks	Days to bud	Days to flower	Market rating	Shoot dry weight (g)	Flower status
Avalanche	10	69.0	39.9	14.0a	4.5	39.5b	66.8b	3.8[x]	36.1b	2.9[w]
	16	71.6	42.5	11.9b	4.7	41.9b	67.5b	3.8	51.8a	3.0
	24	66.7	38.4	11.0b	4.0	51.7a	75.8a	3.8	53.7a	2.8
	Effect	0.2344	0.091	0.0021	0.6733	0.0002	0.0014	0.7564	0.0016	0.1436
	LSD	5.2	4.2	3.5	1.6	5.2	4.7	0.3	10.0	0.3
Blushing Meadow Mama	10	59.9	41.0	3.8	1.3	29.1c	51.0c	3.4b	22.5b	2.8a
	16	60.2	43.5	4.3	1.0	41.7b	63.5b	3.8a	32.3a	2.9a
	24	60.2	44.5	4.7	1.0	56.1a	71.0a	3.7a	32.3a	2.4b
	Effect	0.9934	0.2902	0.4829	0.095	<0.0001	<0.0001	0.0317	0.0018	0.0268
	LSD	24.7	7.5	2.6	0.3	5.5	4.6	0.4	9.3	0.4
Butterfly Kisses	10	35.8b	37.2b	23.9	9.2a	32.8a	59.8a	4.9a	24.7b	3.0
	16	31.1c	38.6b	20.7	6.7b	21.7b	46.5b	4.3b	23.1b	2.9
	24	41.6a	42.0a	21.1	8.5ab	35.4a	58.1a	4.0c	39.3a	2.9
	Effect	<0.0001	0.0025	0.1268	0.045	0.0143	0.0024	<0.0001	0.0025	0.5645
	LSD	4.7	3.2	3.4	1.8	9.5	7.7	0.5	8.1	0.2
Cleopatra	10	56.2	35.3	7.7	3.3	39.8b	61.7b	3.8	22.4b	2.7
	16	52.5	39.3	9.5	2.5	45.6ab	66.2ab	3.7	39.6a	2.7
	24	47.5	38	9.2	2.5	52.5a	71.3a	3.6	36.1a	2.6
	Effect	0.1637	0.0549	0.1975	0.1655	0.014	0.0162	0.6519	0.0021	0.7842
	LSD	10.8	3.3	2.1	1.1	10.0	8.1	0.5	7.7	0.4
Coconut Lime	10	54.4b	32.9c	10.8	2.9b	28.8a	53.3a	3.2	13.3b	3.0
	16	60.2ab	38.3b	13.1	4.1ab	11.9b	36.8b	3.4	19.0b	2.9
	24	64.8a	44.6a	15.7	5.3a	27.4a	50.6a	3.5	29.1a	2.9
	Effect	0.0155	0.0004	0.0933	0.0054	0.0006	0.0043	0.5042	0.0008	0.8516
	LSD	6.0	4.2	4.1	1.1	7.4	9.2	0.6	6.3	0.2
Golden Skipper	10	63.3	37.7a	9.6a	5.6a	22.4b	52.1a	3.2	27.1a	3.0
	16	63.5	33.5b	6.1b	4.1b	15.2c	38.7b	3.4	20.2b	2.9
	24	58.1	35.5b	7.0b	4.4b	28.5a	54.4a	3.6	23.8ab	2.8
	Effect	0.3312	0.0026	0.0017	0.007	<0.0001	<0.0001	0.3092	0.0055	0.1328
	LSD	8.8	4.0	2.0	0.8	9.0	9.0	0.6	4.0	0.2
Guava Ice	10	78.5	49.7b	10.2a	1.5	39.2c	62.8b	3.3	40.1	3.0
	16	81.5	53.3a	6.8b	1.3	63.1a	57.9b	3.5	40.4	2.8
	24	78.3	48.9b	7.4b	1.4	51.8b	70.8a	3.3	45.5	2.5
	Effect	0.3228	0.0164	0.0007	0.74	<0.0001	0.0027	0.1979	0.2476	0.1058
	LSD	10.1	5.5	2.5	0.6	12.6	9.6	0.4	11.2	0.4

Cultivar	Photo period	Height (cm)^{zy}	Width (cm)	No. branches	No. flower stalks	Days to bud	Days to flower	Market rating	Shoot dry weight (g)	Flower status
Honeydew	10	54.4	30.3b	5.2b	4.3a	20.1c	47.8c	3.3ab	20.1b	3.0
	16	53.5	37.9a	6.6a	3.2b	35.3b	56.2b	3.1b	23.4ab	2.8
	24	55.0	40.2a	6.5a	3.2b	43.5a	64.0a	3.6a	27.1a	2.8
	Effect	0.8931	0.0003	0.0339	0.0196	<0.0001	0.0005	0.0214	0.016	0.3051
	LSD	11.6	5.0	1.5	1.4	12.7	13.0	0.5	7.4	0.3
Hot Papaya	10	75.6	46.2b	4.8	2.0	30.0c	52.2c	3.1	16.1c	3.0a
	16	82.2	47.9b	5.6	1.4	41.0b	61.5b	3.2	35.8b	2.8a
	24	75.4	52.4a	6.0	1.1	52.1a	71.2a	3.2	45.3a	2.5b
	Effect	0.123	0.0008	0.0545	0.0976	<0.0001	<0.0001	0.8589	<0.0001	0.0038
	LSD	9.2	5.0	1.0	0.8	7.3	6.3	0.4	8.0	0.3
Julia	10	48.7	40.4	12.4	2.6	35.3	57.4	3.8	25.6	2.8
	16	51.7	42.6	11.9	3.4	33.6	57.3	4.3	29.8	3.0
	24	51.2	41.7	11.0	2.8	34.8	59.0	4.4	36.4	2.9
	Effect	0.6406	0.5029	0.6099	0.2446	0.6899	0.5039	0.066	0.0987	0.3135
	LSD	10.3	4.2	3.4	1.1	4.3	3.3	0.5	12.1	0.2
Marmalade	10	71.6	54.0b	7.0b	1.25	23.0	45.9	3.1	18.5b	2.9a
	16	na	65.6a	6.9b	na^{v}	na	na	na	37.7a	1.0b
	24	na	65.8a	7.9a	na	na	na	na	34.7a	1.0b
	Effect	na	<0.0001	0.0313	na	na	na	na	0.0003	<0.0001
	LSD		6.1	1.2					12.8	0.1
Mini belle	10	69.9	41.3a	9.8	6.9a	26.3a	45.9a	3.4	17.0a	3.0
	16	73.6	35.2b	9.6	5.4ab	16.9b	35.1b	3.3	15.0ab	3.0
	24	67.2	33.6b	10.1	4.0b	16.3b	34.5b	3.2	12.9b	2.9
	Effect	0.2371	0.0005	0.8225	0.0124	0.0023	0.0002	0.5851	0.0122	0.2072
	LSD	6.9	4.0	1.8	1.7	8.3	7.8	0.6	2.7	0.1
Orange Skipper	10	51.4	37.2b	11.6	5.1	27.0b	55.5b	3.7b	27.8b	3.0
	16	51.8	39.1a	11.1	4.4	28.6b	54.9b	4.3a	30.1b	3.0
	24	50.8	36.9b	11.5	4.2	36.0a	59.9a	4.5a	37.9a	2.9
	Effect	0.9524	0.0318	0.883	0.3645	0.0003	0.0289	0.0009	0.0206	0.2072
	LSD	8.6	2.9	2.5	1.2	4.8	5.2	0.4	6.3	0.1
Pink Bonbon	10	46.5a	26.2	9.0a	4.3a	29.7a	52.6a	3.6	15.3a	2.9
	16	37.1b	24.8	7.4b	2.5b	1.0b	28.3b	3.7	8.7b	2.9
	24	40.3b	26.8	6.6b	2.5b	1.2b	28.6b	3.6	8.7b	3.0
	Effect	0.0009	0.1647	0.0058	0.0008	<0.0001	<0.0001	0.9535	0.0006	0.5135
	LSD	5.5	2.5	1.6	0.9	3.1	4.8	0.4	2.7	0.2
Postman	10	63.4	46.9ab	5.3	1.5	29.1c	52.7c	3.5	18.3b	3.0
	16	61.3	49.5a	6.3	1.3	36.8b	60.0b	3.4	33.7a	3.0

Cultivar	Photo period	Height (cm)[zy]	Width (cm)	No. branches	No. flower stalks	Days to bud	Days to flower	Market rating	Shoot dry weight (g)	Flower status
	24	61.5	46.1b	5.4	1.7	41.4a	65.2a	3.4	34.7a	3.0
	Effect	0.5357	0.0492	0.1858	0.3611	<0.0001	<0.0001	0.6077	<0.0001	0.6186
	LSD	15.7	2.8	1.2	0.5	8.3	7.8	0.6	6.4	0.1
Purple Emperor	10	51.3b	40.1	11.9	2.7	35	57.3	3.8	25.8b	2.9
	16	58.3a	43.4	11.5	3.0	37	58.2	3.8	30.8a	2.9
	24	59.3a	41.0	12.0	3.0	40.7	61.8	3.9	25.8b	2.9
	Effect	0.0052	0.1032	0.9253	0.7874	0.3191	0.2621	0.8964	0.0168	1.0
	LSD	6.6	3.6	3.4	0.9	7.9	5.8	3.9	4.1	0.2
Rainbow Marcella	10	60.0	36.5b	3.3	2.9a	25.4b	52.4	3.8	22.8b	2.9
	16	59.1	41.1ab	4.1	1.8b	29.0b	53.8	3.7	23.5b	2.9
	24	59.6	45.2a	3.6	2.5ab	38.0a	58.9	3.7	31.1a	3.0
	Effect	0.9668	0.008	0.1558	0.0143	0.0006	0.1738	0.7718	0.0277	0.8516
	LSD	10.2	4.7	0.9	0.7	6.3	7.1	0.4	5.9	0.2
Raspberry Truffle	10	61	32.9	5.5	3.7a	17.6b	43.6b	3.2a	11.5b	2.9
	16	53	30.1	4.8	2.2b	12.6c	33.9c	2.5b	12.8b	2.9
	24	67.3	39.7	5.6	4.1a	34.5a	58.4a	3.0a	26.9a	2.8
	Effect	0.3282	0.2256	0.4214	0.0003	<0.0001	<0.0001	0.0047	0.0005	0.6616
	LSD	18.4	11.6	2.9	2.1	6.4	5.8	0.5	8.4	0.4
Southern Belle	10	87.6b	38.9	7.1	4.1	29.8a	50.0a	3.2	18.1b	3.0
	16	93.3ab	38.5	7.5	5.1	25.0b	44.1b	3.5	23.8a	3.0
	24	96.2a	42.7	7.1	5.7	31.1a	50.0a	3.5	27.3a	2.9
	Effect	0.0294	0.0592	0.6655	0.0939	0.0271	0.0225	0.2394	0.0102	0.3966
	LSD	6.0	4.0	1.3	1.4	4.5	4.6	0.4	5.9	0.1
Sweet Sixteen	10	35.7	23.1	7.6	6.2a	23.3a	44.4a	3.4	8.9	2.9
	16	32.0	20.2	6.9	2.9b	9.3b	28.3b	3.3	6.6	2.9
	24	33.1	22.3	6.9	2.0b	7.6b	25.6b	3.4	6.7	2.8
	Effect	0.3245	0.1468	0.7583	<0.0001	0.0014	<0.0001	0.6742	0.0968	0.5971
	LSD	5.4	4.9	2.0	1,6	8.2	6.6	0.6	3.1	0.2
White Double Delight	10	66.1	36.6	12.6a	4.8	26.8b	51.9b	3.3	24.2c	2.9
	16	68.2	34.1	8.3b	3.8	24.4b	44.7c	3.5	29.6b	3.0
	24	68.7	38.4	10.0b	5.2	45.1a	67.1a	3.5	40.2a	3.0
	Effect	0.6489	0.0569	0.0065	0.1119	<0.0001	<0.0001	0.106	<0.0001	0.3966
	LSD	8.6	3.5	3.3	1.2	9.5	9.7	0.4	6.9	0.1

[z]Data for each cultivar are means of 6 plants (3 replicates x 2 height control). Each replicate represents the mean of 4 subsamples.
[y]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=3).
[x]Market rating was on a scale of 1 (poor), 2 (fair), 3(average), 4 (good), to 5 (premium quality) based on quality of plant growth and flowering characteristics.
[w]Flower status was rated on a scale from 1 to 3, with 1 indicating that the plant did not initiate a bud, 2 the plant had a bud but did not flower during the study, and 3 indicating that the plant flowered during the study.

[v]Number of flowers stalks, days to bud, days to flower, and market rating not available in 'Marmalade' in the 16- and 24-hour photoperiods as none of these plants set buds or flowered during the study.

Chapter 6. Summary: Controlling Growth in *Echinacea* Hybrids

Introduction

Echinacea is a popular ornamental perennial which is native to most of North America. Recent advances in breeding have led to the introduction of many hybrid cultivars with new flower colors and forms. Hybrid *Echinacea* cultivars present both a challenge and an opportunity for growers. Hybrids are challenging to grow and have different growth requirements and habits than the species. However, growers have the opportunity to use the new, exciting colors and forms of hybrids to capture a share of the growing perennial market. Over the past few years, our research has focused on examining growth requirements, such as nutrition, daylength, and growth regulators in hybrid *Echinacea* cultivars, to develop production protocols to allow growers to meet the challenges and take advantage of the opportunities that *Echinacea* hybrid cultivars present.

Increasing Branching in Hybrid *Echinacea* with Plant Growth Regulators (PGRs)

Many newer *Echinacea* cultivars don't branch well during production, resulting in a plant which is less desirable commercially. We tested a variety of PGRs to increase branching in three *Echinacea* hybrid cultivars. Benzyladenine (BA) was successful in increasing the number of branches in our study. The three hybrid *Echinacea* cultivars were responsive to PGRs, although each responded somewhat differently. 'Marmalade' was the most responsive to BA, with significant increases in branching at every data measurement after treatment. 'Harvest Moon' and 'Hot Papaya' had increased numbers of branches with BA, although there were no significant differences in finished plants. In 'Hot Papaya,' BA increased the number of flower stalks, while PGRs did not affect flowering in 'Harvest Moon.' Flowering was inconsistent in 'Marmalade' in this study.

Other PGRs tested were not successful in increasing branches in *Echinacea* hybrids. 'Hot Papaya' or 'Harvest Moon' treated with dikegulac sodium or ethephon had no more branches than untreated control while 'Marmalade' treated with dikegulac sodium or ethephon had fewer branches than controls.

Controlling Height in Hybrid *Echinacea* with PGRs

Echinacea hybrids vary in height significantly; some cultivars have been bred to be compact while other can grow overly tall in production. We examined the effects of three PGRs to control height, paclobutrazol, uniconazol, and daminozide, applied as either sprays or drenches. All PGRs controlled height in 'Harvest Moon,' either applied as sprays or drenches, with uniconazole 30 $mg \cdot L^{-1}$ spray or paclobutrazol 4 $mg \cdot L^{-1}$ drench resulting in the shortest plants. Only daminozide controlled height in 'Marmalade,' which is a cultivar with very vigorous growth. However, daminozide also had the unwanted effect of fewer branches and flowers in 'Marmalade' in our study. Growers will need to conduct trials to determine best PGR rates and application methods in the cultivars they grow.

Fertility needs of *Echinacea* hybrids

Echinacea hybrid cultivars had cultivar-specific responses to fertilization. We found that supplying N at 150 $mg \cdot L^{-1}$ during the growing season provided *Echinacea* cultivars adequate nutrition and maximized numbers of branches and flowers and shoot dry weight. In overwintering, more *Echinacea* cultivars survived with fertilization treatments that resulted in low substrate EC going into dormancy compared to those which resulted in high substrate EC. As a monitoring tool, SPAD measurements were not successful in predicting tissue N levels in *Echinacea* hybrids. Photosynthesis was correlated with N rate in one cultivar but not the other; there was not a clear pattern of photosynthesis of *Echinacea* cultivars in response to N fertilization in this study. Tissue macronutrient levels (with the exception of Ca and S) were within or above the sufficiency range with all fertilizer treatments. This suggests that *Echinacea* can be grown at a range of fertilizer concentrations but that growers should look for formulations which provide added Ca and S. Providing enough N for optimal growth, but not too much which can limit growth, is important in the production of hybrid *Echinacea*.

Controlling Growth and Flowering of *Echinacea* Hybrids with Photoperiod and Height Control PGRs: Putting It All Together

Planning for flowering and managing growth are challenges producers face when growing newer varieties of *Echinacea*. Research has shown that *Echinacea* flowers best when grown after transplant under short day photoperiods followed by long days; an intermediate photoperiod (12-14 hour photoperiod) can also induce consistent flowering in *Echinacea*. Due to premature flowering experienced in several of our studies, we were interested in examining the effect of photoperiod during liner production on the flowering and growth of *Echinacea* cultivars. We transplanted tissue culture plantlets into plug trays and grew them under 10-hour, 16-hour, or 24-hour photoperiods. After 10 weeks, liners were transplanted and grown under natural daylength (a 14 hour photoperiod).

In this study, we applied the results of earlier studies in order to produce high quality *Echinacea* liners and finished plants. We used foliar BA sprays to increase branching during liner production. Plants received 150 $mg \cdot l^{-1}$ N as constant liquid feed throughout the study. We compared the use of height control PGRs, daminozide while plants were in the liner tray and uniconazole after transplant, on the growth and quality of finished plants. We tested 21 hybrid cultivars in this study to examine the differences between the many *Echinacea* hybrids on the marketplace.

Photoperiod reduced growth in liners grown under a 10 h photoperiod; liners were shorter, less wide, had fewer branches and were less well rooted than liners grown under longer photoperiods. Flowering was delayed in finished plants exposed to 10 h or 24 h photoperiods as liners, by 4 and 8 days respectively, but photoperiod did not affect growth or quality in finished plants. However, photoperiod slightly limited flowering in two cultivars in the 24 h photoperiod, and eliminated flowering in 'Marmalade' in the 16 h or 24 h photoperiod.

We found that providing *Echinacea* hybrid cultivars with a 16 h photoperiod during liner production resulted in plants which flowered soonest without any negative effects on growth. The need for height control PGRs varied by cultivar; however, overall, height control PGRs resulted in shorted plants with higher market rating. We recommend growers keep liners under a 16 h photoperiod and use height control PGRs needed in order to optimize the production of *Echinacea* hybrid cultivars.

Growing Recommendations

The variety of colors and forms available in hybrid *Echinacea* cultivars today is stunning, and breeders are continually developing new cultivars. By following recommendations below, growers can take advantage of these exciting new cultivars.

- Apply BA in liners to increase branching. We found that 600 $mg \cdot L^{-1}$ BA applied once or twice led to more full, well-branched plants.

- Apply height control PGRs to control height in *Echinacea* hybrids; however some compact cultivars may not need height control. Avoid late applications of daminozide which may negatively affect flowering. Height control PGRs may be applied to liners or to plants after transplant, as either sprays or drenches. Cultivars respond differently to PGRs; growers will need to conduct their own tests.
- Apply moderate levels of N. We found that 150 $mg \cdot L^{-1}$ N applied as CLF maximized shoot growth and flowering. In overwintering, plants with low electrical conductivity going into dormancy had the highest survival rates.
- Provide a 16 h photoperiod during liner growth in order to adequately bulk plants and induce flowering in finished plants soonest.