Studies in floral crops production: effects of root-zone temperature on dahlia growth and optimizing graphical tracks for poinsettia height management

by

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Abstract

Dahlia (*Dahlia* x*hybrida* Hort.) is subject to 'dahlia decline,' a phenomenon in which a crop exhibits graying foliage, root decline, and plant death that has reportedly caused partial or total crop loss and has no known initiating factor. We hypothesized that plant exposure to supraoptimal root-zone temperatures (RZT) during production may initiate the decline. Two experiments were conducted to initiate dahlia decline where supraoptimal RZT were applied to 12 different dahlia cultivars in spring 2019 and 2020. Experiment 1 (Exp 1) exposed potted dahlia root-zones to 22, 35, 40, 45, or 50 °C via water-bath. Experiment 2 (Exp 2) evaluated the effects of exposure time (0-, 2-, 4-, or 6-hrs) during elevated RZT (45 °C). Plant and root conditions were rated before treatment and weekly, for three weeks (Exp 2) and four weeks (Exp 1) post-treatment. Neither experiment resulted in the reported dahlia decline. However, Exp 1 root ratings decreased between 40 to 50 °C in several cultivars after treatment. In Exp 2, root ratings decreased in the 2 to 6-hr treatments compared to the control. Several cultivars exhibited an increase in root rating in the final observations, indicating dahlias could recover from a high heat injury and still develop into a potentially marketable plant.

Poinsettias [*Euphorbia pulcherrima* (Willd. ex Klotzsch)] are the leading winter potted flowering crop in North American greenhouse operations. Markets dictate specific height requirements, so growers employ graphical tracking, a technique to monitor crop height development compared to a target range. These target curves were originally developed in the 1990's using popular cultivars at that time, but updates are needed for modern varieties produced today. The original curve allows for some customization, but there is no guidance on how to adjust the target range based on cultivar vigor.

In the S-shaped graphical tracking curve, there are three parts: the lag phase (~two weeks post-pinch), the linear phase (active growth and transition into the reproductive phase), and the plateau phase (bract expansion and color development). This research focuses on providing growers with information based on the growth of modern poinsettia cultivars of ‘Ferrara’, ‘Premium Marble’, ‘J’Adore Pink’, and ‘Christmas Spirit.’ To evaluate the need for curve adjustment, in 2019, these four poinsettia cultivars were grown in four different glass-greenhouses with early and late pinch dates under different temperature regimes, and heights were measured weekly. Heights were analyzed from two weeks after pinch till short-day initiation by finding the slope and intercept of this line which occurred during the linear phase of growth. Slopes are different depending on the cultivar’s vigor, but not based on pinch date. This response indicates that graphical tracking curves would be better suited for growers if they were modified based on cultivar vigor. This adjustment allows for better growth management during the linear phase and may, therefore, assist growers in meeting target heights at the end of production.

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Chapter 1 - Literature Review

Dahlia Culture

Dahlia (*Dahlia* species Cav.) is a tuberous-rooted geophytic plant (Figure 1-1, Figure 1-2) consisting of approximately 42 species and additional subspecies and native to Central America [American Dahlia Society; (dahlia.org**)**; Dole and Wilkins, 2005]. There are approximately 20,000 cultivars of hybrid dahlias (*Dahlia xhybrida* Hort.) in existence with more being added every year (Armitage, 2020). Hybrid dahlias are quite diverse in many aspects of their flowering characteristics. Inflorescences can range in overall size from 5 to 40 cm in diameter and can have single or multiple rows of ray florets with various petal shapes and sizes (Dole and Wilkins, 2005). The color combinations also vary, ranging across the full color spectrum, except for true blue and black, from solid colors to streaked and bicolors.

In the 1840s, the frenzy for dahlias in the United States and Europe had parallels to tulip mania of the 17th century (Armitage, 2020). Dahlias are a highly desirable and versatile flowering crop and are common as both cut flowers and potted production. They can be grown either as annuals or perennials, allowing them to reach the consumer in different avenues (De Hertogh, 1996; Sekerci and Gulsen, 2016). Recently, there has been a resurgence in demand for potted annual dahlias. New varieties have been selected to reduce or eliminate common greenhouse production challenges, including powdery mildew (*Erysiphe cichoracearum),* botrytis (*Botrytis* spp.), and varieties that bloom uniformly (Schoellhorn, 2015). Dahlias can be propagated by seed, un-rooted vegetative stem cuttings, tuberous root divisions, and less-commonly, through tissue culture (De Hertogh and Le Nard, 1993; Hetman, et al., 2017; Nau, 2011). In North America, seed has historically been the most common way to produce dahlias as potted crops; however, vegetative propagation through stem cuttings has emerged as a popular and successful form of commercial propagation (Dole and Wilkins, 2005; Schoellhorn, 2015).

Dahlia Diseases

Dahlias are susceptible to many different diseases. Dahlias are also notoriously susceptible to several viruses, including, tomato spotted wilt (TSWV; *Orthotospovirus* sp.), dahlia mosaic (DaMV; *Caulimovirus* sp.), and cucumber mosaic (CMV; *Cucumovirus* sp.). Other common foliage and plant diseases that affect greenhouse dahlia production include, botrytis (*Botrytis* spp.), powdery mildew (*Erysiphe cichoracearum),* aster yellows phytoplasma (*Candidatus* Phytoplasma asteris), and bacterial soft rot (*Pectobacterium carotovora*). In outdoor garden situations, in addition to pathogens noted above, dahlias are susceptible to verticillium wilt (*Verticillium dahliae*), southern wilt (*Sclerotium rolfsii*), root rot (*Armillaria mellea*), and leaf spots including (*Alternaria, Cercospora,* or *Phyllosticta*) (De Hertogh and Le Nard, 1993; Dole and Wilkins, 2005). Another primary group of pathogens are root rots; *Pythium* spp., *Rhizoctonia solani,* and *Sclerotinia sclerotiorum.* The three most common greenhouse *Pythium* species, known as the "Big Three," are *P. aphanidermatum, P. irregulare,* and *P. ultimum* (Moorman and Daughtrey, 2002). All three of these have different environmental conditions for ideal growth and development and result in varying degrees of plant damage. *Pythium* used to be classified as a water mold fungus, but DNA analysis helped show *Pythium* is closely related to known single-celled algae (Moorman and Daughtrey, 2002). It is still in the category of similar organisms called oomycetes which thrive in wet conditions and use water to move around (Moorman and Daughtrey, 2002) *P. irregulare* spreads easily in irrigation systems while it is in the zoospore stage (swimming spore), however, it is less aggressive than *P. aphanidermatum* which also has a zoospore stage (Moorman and Daughtrey, 2002). *P.*

irregulare was found to have the broadest host range in a study conducted by Munera and Hausbeck in 2016, but Moorman and Daughtrey (2002) state that it usually just causes stunting and rarely kills plants quickly. *P. ultimum* does not have a zoospore stage and is most introduced through poor medium pasteurization (Moorman and Daughtrey, 2002). Each of the three species grow at different optimum root-zone temperatures. *Pythium ultimum* grows between 5 °C and 35 °C (Moorman and Daughtrey, 2002). *P. irregulare* also prefers cooler temperatures from 1 °C to 35 °C (Biesbrock and Hendrix, 1970; Moorman and Daughtrey, 2002). A major difference of *P. aphanidermatum* is that the pathogen can survive to a low temperature of 10 °C and has an optimum temperature of 35 °C to 40 °C, making it prevalent in soils of warm regions, which happens to be where a significant amount of off-shore vegetative propagation occurs (Moorman and Daughtrey, 2002; Panova, et al., 2004). *Pythium* spp. infections can spread quickly, due to zoospore contamination in irrigation water and can be brought in unknowingly to a facility through contaminated media. It is uncommon for new soilless mixes to contain pathogens, but any contamination between producer and consumer could result in an outbreak (Daughtrey and Benson, 2005; Munera and Hausbeck, 2016).

Photoperiodism

Photoperiodism is important to many plants as it relates to their growth and development. Many floriculture production species are photoperiodic and light manipulation to manage their flowering is an important part of greenhouse plant production. However, not all plants respond to a specific photoperiod and many do not respond at all to day-length changes. Plant responses to photoperiod are characterized in three main categories including 1) plants that require shorter light periods to flower (short-day plants; SD); 2) plants that need longer periods of light to flower (long-day plants; LD), and 3) day-neutral plants that will flower under any day-length period conditions (Hakuzan and Fukai, 2019; Garner and Allard, 1923). A plant sensitive to the ratio of day and night lengths results in a specific response: either vegetative or reproductive growth (Garner and Allard, 1923). Plants can further be classified into facultative or obligate SD or LD plants (Dole and Wilkins, 2005). In facultative plants, the initiation response for reproductive tissue (flowers) is accelerated under a specific LD or SD, however not required for a response (Dole and Wilkins, 2005). Obligate plants absolutely require either a SD or LD and will not initiate flowers without it (Dole and Wilkins, 2005). Plants like poinsettia (*Euphorbia pulcherrima*) and chrysanthemum (*Chrysanthemum xmorifolium*) are obligate short-day plants and when grown under natural photoperiods, would not flower in time for specific markets (Dole and Wilkins, 2005; McMahon et al., 2011). One important technique greenhouse growers use to manipulate and control growth and development (e.g., flowering response), is using day-length extension or night interruption lighting. When a SD plant receives a short-day but experiences a flash of light during the night, it will not flower. However, if a LD plant experiences a night break of light, it will flower even though it is technically experiencing a short-day (Taiz and Zeiger, 2011).

Dahlias are considered to be facultative SD plants, that is, they can flower under most any day-length, but will flower earlier when given SD (Dole and Wilkins, 2005). Dahlias respond differently when exposed to either SD or LD. When dahlias are exposed to SD, especially during seed-propagation, they can initiate tuber formation (De Hertogh and Le Nard, 1993; Dole and Wilkins, 2005). If given less than 8-hr days, flowering can also be delayed (De Hertogh, 1996). Formation of tubers directs energy away from shoot growth, reallocating carbohydrates and away from the flower formation (Dole and Wilkins, 2005). Low light intensity can also influence flowering by reducing the number of florets as well as delaying floral bud initiation (De Hertogh, 1996; Dole and Wilkins, 2005). When dahlias are grown in the landscape, SD conditions in late summer into fall is critical to their survival, allowing them to form tubers to increase their likelihood of surviving until spring (McMahon, et al., 2011).

Root-Zone Temperature

Managing root-zone temperature (RZT) of potted crops from start to finish, either from seed or vegetative means, is an important consideration in plant growth and development (Dole and Wilkins, 2005; Odhiambo, et al., 2018; Olberg and Lopez, 2016; Solfjeld and Johnsen, 2005). Root-zone temperature management can be an effective way to reduce greenhouse heating costs, especially during the winter months when heating cold air (Dole and Wilkins, 2005; Olberg and Lopez, 2016). However, when plant root-zones are exposed to supraoptimal or suboptimal temperatures, plant growth and development can be seriously affected, including, altering water uptake, root damage, and in extreme cases can result in plant death (Dodd, et al., 2000; Ingram, et al., 2015; Nambuthiri, et al., 2015). Supraoptimal heating can occur from solar radiation reaching plant pots, and can be influenced by pot color, and from irrigation with hot water, (Dodd, et al., 2000; Markham, et al., 2011; Martin, et al., 1989; Nambuthiri, et al., 2015). Several studies on supraoptimal RZT have been reported in nursery crops such as holly (*Ilex* x *attenuata*) and elm (*Ulmus parvifolia*) (Martin, et al., 1989; Yeager, et al., 1991), southern magnolia (*Magnolia grandiflora*) (Martin, et al., 1991), and vegetable crops including cucumbers (*Cucumis sativus*) (Du and Tachibana, 1994), pepper (*Capsicum annuum*) (Dodd, et al., 2000), potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*) (Sattelmacher, et al., 1990). Studies on supraoptimal RZT effects on potted floriculture crops temperatures are limited. Information on suboptimal RZT modification for floriculture crop growth has been published on snapdragon (*Antirrhinum majus*) (Hood and

Mills, 1994; Wai and Newman, 1992) and poinsettia (*Euphorbia pulcherrima)* (Olberg and Lopez, 2016). However, these studies do not cover the supraoptimal RZT aspect of plant growth. Hood and Mills (1994) found that as root-zone temperatures increased, snapdragons improved their nutrient uptake and growth. Wai and Newman (1992) reported that time to flower for cut flower snapdragon was reduced when root-zone temperatures increased even when air temperatures were cool. Although neither of these snapdragon studies discusses supraoptimal RZTs, they demonstrated the impact of RZT on growth and development of floriculture crops. To our knowledge, no studies have been reported on the effects of extreme RZTs on greenhouse-produced dahlias.

Dahlia Decline

With increased dahlia interest and subsequent greenhouse production, a novel problem has emerged; dahlia decline (Figure 1-3, Figure 1-4). Growers report periodic, often sudden, and complete crop loss of vegetativly propagated dahlias in late spring (Gooder, personal communication; Hammer, personal communication). Several reasons for this phenomenon have been hypothesized including *Pythium* root rot and excessive potting media dry down. Both issues, with informal research studies, were not conclusive in their results, (Hammer, unpublished data, 2015). An alternative hypothesis suggests that supraoptimal RZT may be a causal factor in dahlia decline. Previous preliminary research showed cultivar-specific differences in RZT responses, but that all cultivars respond negatively to 45 °C and 50 °C RZTs (Hammer, unpublished data, 2015). Investigating supraoptimal RZT as a trigger to dahlia decline could help growers understand what is happening to dahlia crop production and how to prevent it.

Figure 1-1: Tuberous root formation (arrow) on a dahlia (*Dahlia* x*hybrida*) plant grown from vegetative cutting.

Figure 1-2: Examples of variability of inflorescence colors and forms in dahlia (*Dahlia xhybrida*).

Figure 1-3: Example of normal, healthy foliage (left) and foliar damage associated with dahlia decline (right) on dahlia (*Dahlia xhybrida*). Image courtesy of Dr. Hammer, Dümmen Orange.

Figure 1-4: Examples of dahlia (*Dahlia xhybrida*) rooting. The plant on the left shows an example of root damage associated with dahlia decline, while the plant on the right exhibits healthy rooting. Image courtesy of Dr. Hammer, Dümmen Orange.

Chapter 2 - Dahlia Root-Zone Temperature Experiments

Introduction

Dahlias (*Dahlia xhybrida* Hort.) are a common garden plant that provide a variety of color and interest to the landscape in the summer and early fall. There are over 42 dahlia species and subspecies native to Central America that exhibit different inflorescence forms and habits (Dole and Wilkins, 2005). They are an important part of the modern floriculture industry and in the last several years, potted annual dahlias have gained popularity due to their versatility in planters and garden bed arrangements (Dolce 2020; Schoellhorn, 2015). In 2019, the National Garden Bureau (ngb.org) named the dahlia as the Plant of the Year, further exemplifying the public interest and enjoyment this interesting plant garners. This surging interest in dahlias underscores the need to fully understand plant culture and growing requirements, which are essential for floriculture producers to meet market demands.

Increased vegetativly propagated annual potted production and new cultivar development has led growers to a new and challenging problem: dahlia decline. Dahlia decline occurs during dahlia production and has been reported in different dahlia series and breeding lines. Reported dahlia decline symptoms include plants showing reduced rooting quality, greying foliage, foliage wilting, and sudden plant death. Growers have indicated that plant symptoms affect significant numbers of plants (i.e., whole benches of crops). To date, no definitive cause or causes have been identified. Considering the symptoms described a root rot pathogen such as *Pythium* might be involved but reports from growers indicate inconclusive pathogen links to this decline (Hammer, personal communication). Another hypothesized explanation for dahlia decline is root damage induced by supraoptimal RZT (Hammer, personal communication). When plant root-zones are exposed to extreme ranges outside normal growing conditions, water uptake can be altered, roots can be damaged, and plant growth and development can be seriously affected. And in extreme cases, the phenomenon can result in plant death (Dodd, et al., 2000; Ingram and Martin, 2015; Nambuthiri, et al., 2015).

To better understand the potential mechanisms involved in dahlia decline, we investigated supraoptimal RZTs and their effects on several commercially available dahlia cultivars from different hybridized dahlia series over two years (2019 and 2020) with a goal do induce and further characterize the dahlia decline phenomenon. The experiments were conducted in glass greenhouses at Kansas State University (Manhattan, KS). Experiment One, (2019 and 2020) investigated the effects of exposing greenhouse grown potted dahlia root-zones to temperatures between 22 to 50 °C using a water bath. Experiment Two (2019) focused on the effects of dahlia root-zone exposure to 45 °C for significant periods of time; either 2-, 4-, or 6-hours. Plant growth and development, including plant height, foliage, and root quality data were recorded in each experiment to assess the impact of supraoptimal RZTs.

Materials and Methods

Several dahlia cultivars (~45 individual plants form each cultivar used for both experiments) from five dahlia series were used for this research. Dahlias were received based on availability, which resulted in forming three groups of experiment rounds per year (Table 2-1). Upon receipt, rooted liners were immediately transplanted into 11.4 cm azalea plastic pots with a peat-based medium (Sungro 3B Mix; Agawam, MA). In 2020, ‘Melody Sincerity’ was received as unrooted cuttings. Cuttings were stuck in peat-based medium and rooted under mist for three weeks, then transferred to the greenhouse when they were potted three weeks later.

Experiment plants were grown in a glass greenhouse with temperature set points of 21 °C day and 18 °C night temperatures controlled by Argus (Surrey, British Columbia) environmental controls. Actual recorded average temperatures were 25 °C day/18 °C night for 2020 (Figure 2-2). High-pressure sodium lights were used to create a 6-hr growing day extension, providing a 12-hr total day-length. Plants were fertigated, as needed (averaging every other day to daily as plants grew) using fertilizer injected municipal water (pH of ~9 and alkalinity of ~ 40 ppm) and ~200 ppm N from 20N-4.3P-16.6K fertilizer (JR Peters; Allentown, PA). Plain water was used once a week. Pests (e.g., thrips and powdery mildew) were managed as needed.

Dahlias were pinched two weeks after potting to leave two nodes, then spaced approximately 20 cm on center and staggered down the bench. After four or five weeks of growth, depending on a cultivar's root development, plants were sorted for uniformity. Then the dahlias were randomly assigned a treatment and grown for a set period of time depending on the experiment.

Experiment One

Experiment one was conducted in 2019 and 2020. The focus of this experiment was to evaluate different supraoptimal RZTs on dahlia rootzones, with a goal to induce dahlia decline. Twenty-five plants from each cultivar were pinched and then grown for four or five weeks before experiment initiation to develop sufficient roots for observation. The Dalaya series was given an extra week because it did not initially meet the threshold of sufficient rooting. Sufficient rooting was determined to be when white, healthy appearing roots, were fully visible at the edge of the pot. Individual plants were randomly assigned to treatments. Using a water-bath (Precision; Model 186 and 260; ThermoFisher Scientific, Waltham, MA) dahlias were exposed to supraoptimal root-zone temperatures. There were five temperature treatments in total: a control (room temperature, ~22 °C), and 35, 40, 45, and 50 °C. Five plants or replications of each cultivar were assigned to each temperature treatment. On treatment application day, plants were watered and allowed to drain to pot capacity (no free-water in medium) before water-bath treatments. Then, after root-ratings and other plant growth parameters were recorded, dahlia pots were individually put into gallon plastic bags. This was to prevent hot water from saturating the root-zone. The bag tops were left open to aid in ventilation and allow heat and steam to escape. Groups of plants were placed into water baths and heated until the root-zone reached the desired temperature. Root-zone temperatures were measured using soil probes (5976 Soil Thermometer; Taylor, Rochester, NY) inserted into the root medium mid-way between plant and edge of pot, roughly ~2.5 cm from the pot edge and ~5 cm deep. After reaching the desired set-point temperature, plants were immediately removed from the water bath and plastic bag. Control plants were placed in plastic bags and in a room-temperature water-bath for ~2-hrs, the average time it took to reach the desired supraoptimal temperatures of other treatments. After plants were treated, they were placed back into the greenhouse and maintained for four weeks post-treatment with root and other plant observations taken weekly.

Experiment Two

Experiment two was conducted in 2019. The greenhouse growing parameters used in this experiment followed protocols described in Experiment one. This experiment focused on the duration of supraoptimal RZT exposure. The treatments in this experiment were 0- (control) 2-, 4-, or 6-hrs in a water-bath maintained at 45 °C. This temperature was selected based on preliminary observations of supraoptimal RZT exposure that resulted in a response in dahlia growth (in 2019). Dahlia root-zones were allowed to heat until the soil probe (5976 Soil Thermometer; Taylor, Rochester, NY) reached 45 °C, then the dahlias were treated for the appropriate amount of time. After treatment, plants were removed from the water bath and placed back into the greenhouse for continued growth and development. Plant growth parameter observations were taken before the treatment and weekly, for three weeks post treatment.

Data Collection

The primary data collected in both experiments evaluated dahlia rooting quality. Dahlia plants were carefully removed from their pots and placed on overturned pots to assess root health based on an established root ratings scale (Figure 2-1). Root ratings were defined as 0 = poor rooting (no visible sign of roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (limited roots; primarily white roots visible), 2 = good rooting (limited number of roots with roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed rooting, wrapped around pot, more thicker developed roots compared to thin; no evidence of browning or root death), 4 = excellent rooting (roots are highly developed, white, no signs of death). Plant height was recorded based on height from bottom of the pot to top-most foliage growth. Flower development ratings were also collected and were based on a qualitative scale of 0 to 3; 0=no visible flower bud; 1= visible flower bud; 2=flower bud with outer petals showing color; and 3=inflorescence open with ray florets expanded. Plants were also evaluated for foliage quality. Foliage ratings were assigned using a scale 0 to 4; 0=dead/completely brown leaves, 1=more than 60% brown with green still on leaves, 2=drooping/flagging leaves with a less than 50% brown or greying, 3=drooping/flagging leaves, but otherwise green leaves, 4=turgid, healthy, bright green leaves.

Experimental Design and Statistical Analysis

The experimental design for both experiments was a completely randomized design. Statistical analyses were performed using JMP (Version Pro 14, SAS Institute Inc., Cary, NC, 1989-2019) statistical software. An analysis of variance (ANOVA) using general linear model

(GLM) was used and mean separations were determined using LSMeans Tukey's HSD at a significance level of $P \leq 0.05$.

Results

Experiment One

Plant Height and Foliage Rating

Year 1

Plant heights were significantly different for the main effects of RZT treatment and week for all cultivars (Table 2-2). A significant interaction of treatment and week was only observed in Dalaya 'Dalaya Red and White' (Table 2-2). Significant treatment main effects were only observed in three cultivars for flower development ratings; Dalaya 'Dalaya Red and White', 'Dalaya Yogi', and XXL 'XXL Veracruz' (Table 2-2), while the main effect of week was significant for all cultivars (Table 2-2). A significant interaction was observed in between Dalaya 'Dalaya Red and White' and 'Dalaya Yogi' (Table 2-2). Foliage rating observations indicated significant differences in treatment for all cultivars except, 'XXL Sunset' and 'XXL Veracruz'. (Table 2-2), while the main effect of week on foliage rating differences were observed for 'Dalaya Red and White', 'Dalaya Yogi', and 'Dark Angel American Pie' (Table 2-2). Three cultivars exhibited a significant interaction (Table 2-2).

Year 2

The main effects, treatment and week, were significant for plant height in all cultivars in 2020 (Table 2-3). A significant interaction between root zone treatment and week was observed in 'Dalaya Shiva' and 'XXL Sunset' (Table 2-3). Plant height was significantly shorter the 50 °C treatment in comparison to the control treatment for all cultivars for (Table 2-3). Plant height was significantly taller from the initial observation (pre-treatment) compared to four-weeks post treatment for all cultivars, except for, ‘Gallery Monet’ (Table 2-3). Flower development ratings were significantly affected by treatment and by weeks for all cultivars except for ‘Dalaya Yogi’ for the treatment effect (Table 2-4). For about half of the cultivars, ‘Dalaya Shiva’, ‘XXL Sunset’, ‘XXL Veracruz’, and ‘Melody Sincerity’ the interaction significant (Table 2-4). For all cultivars except for ‘Dalaya Yogi’, ‘Gallery Art Deco’, flower development was significantly less between the control group and the 50 °C treatment (Table 2-4). Flower development increased in plants at pre-treatment observations compared to four-weeks post treatment (Table 2-4). Foliage ratings showed that all cultivars were significant for the treatment main effect, but only ‘Dalaya Shiva’, ‘Dalaya Yogi’, ‘XXL Sunset’ and ‘Gallery Monet’ were significant for the week main effect (Table 2-5). The interaction of treatment by week was significant for ‘Dalaya Shiva’, ‘XXL Sunset’, ‘XXL Veracruz’ ‘Melody Sincerity’ (Table 2-5). Generally, foliage ratings only significantly decreased consistently when comparing control plants to plants treated at 50 °C (Table 2-5). Foliage quality decreased significantly from pre-treatment observations to one-week post treatment only for ‘Dalaya Shiva’, ‘Dalaya Yogi’, ‘XXL Sunset’, and ‘Gallery Monet’ (Table 2-5).

Root Rating

Year 1

All the main effects and interactions were significant for root ratings (Table 2-7, Table 2-8). Treatment had a significant effect on all cultivars except for ‘Melody Gypsy’ and week was significant for all cultivars at (Table 2-6). A significant interaction was observed in the following cultivars: ‘XXL Tabasco’, ‘XXL Veracruz’; ‘Dalaya Shiva’; ‘Melody Gypsy’; and ‘Dark Angel American Pie’ were significantly different (Table 2-6). Decrease in root ratings were observed in many cultivars from pre-treatment observations to one-week post-treatment, but only ‘Dark

Angel Pulp Fiction' significantly decreased in root-rating at 40 and 45 °C (Table 2-10, Table 2-11, Table 2-12). Several cultivars that exhibited root rating increases from one week post treatment to four weeks post treatment were: 'XXL Sunset' (45, 50 °C), 'XXL Tabasco' (control, 50 °C), 'XXL Veracruz' (control, 35, 40, 45, 50 °C) (Table 2-11); 'Dark Angel American Pie' (50 °C), 'Dark Angel Pulp Fiction' (45, 50 °C) (Table 2-12).

Year 2

For our 2020 experiment replication, all cultivars were significant for treatment and week main effects, except for 'Gallery Monet' in treatment effect. In interaction of treatment by week, all cultivars except for 'Melody Sincerity' and 'Gallery Monet', were significant (Table 2-9). Root ratings decreased significantly after initial treatment at 45 and 50 °C for 'Dalaya Red and White,' (Table 2 10); 'XXL Sunset' and 'XXL Veracruz'(Table 2-11; Figure 2-6). We observed significant decreases in root ratings for 'Gallery Monet' (Table 2-12), in all treatments, except for the control and 50 °C. In general, 'Gallery Monet' did not root very well. Root ratings increased significantly from one-week post treatment to four-weeks post treatment at 50 °C in Dalaya 'Dalaya Yogi' (Table 2-10); at 40, 45, and 50 °C for 'XXL Sunset' and 'XXL Veracruz' and 45 °C for 'XXL Tabasco' (Table 2-11); at 40, 45, and 50 °C for 'Melody Sincerity' and at 45 and 50 °C in 'Gallery Art Deco' (Table 2-12).

Experiment Two

Treatment had a significant effect on all cultivars except for 'Dalaya Shiva' and 'XXL Sunset' (Table 2-13). The number of weeks influenced root-rating significantly for all cultivars except for 'Dalaya Red and White' were affected by (Table 2-13, Figure 2-7). We did not observe an interaction of treatment by week for four selections, 'Dalaya Red and White', 'Dalaya Shiva', 'XXL Sunset', and 'Dark Angel American Pie' were not significant (Table 2-13).

Examining the treatment and week interaction, root-ratings decreased after treatment, compared to pre-treatment ratings, in ‘Dalaya Yogi’ at 4-hrs, and ‘Dark Angel Pulp Fiction’ at 2-, 4-, and 6-hrs. (Table 2-14). Significant increases in root-rating for plants three-weeks post treatment in comparison to one-week post treatment were ‘XXL Tabasco’ at 2- and 6-hrs, ‘XXL Veracruz’ at 2-, 4-, and 6-hrs (Figure 2-8), Dark Angel ‘Dark Angel Pulp Fiction’ at 2-hrs, Melody ‘Melody Gypsy’ and ‘Melody Sincerity’ at 6-hrs (Table 2-14).

Discussion

In Experiment One, we were unable to initiate a uniform display of the reported symptomology that would be described as dahlia decline. Plant death did not reliably occur even though there were decreases in root ratings for some cultivars (Table 2-10, Table 2-11, Table 2-12). The absence of widespread plant death suggests that dahlias can survive supraoptimal RZT, even when their roots are injured. Similar field observations of plant recovery were reported by Martin and Ingram (2015) when looking at *Magnolia grandiflora* ‘St. Mary’ exposed to supraoptimal temperatures between 30 and 42 °C. The root injury (shown by decreases in dahlia root-rating) suggests that plants are damaged, but the absence of death and subsequent root-rating increases support the idea that plants can recover even when their root-zones are injured. Significant decreases in root-rating show an impact on root health which could slow the plants growth and flower development (Table 2-3, Table 2-4). For example, in ‘XXL Veracruz’ flowering was reduced at 50 °C with only two replicates in bloom four-weeks post treatment, while the control had all five replicates in bloom (Table 2-4; Figure 2-3). Most of the other cultivars also had lower flower development at 50 °C, except for ‘Dalaya Yogi’ (Table 2-4). Increases in the final weeks of observation in some cultivars, even at the highest temperature (50 °C) show that when dahlias experience root damage from heat, it could be possible for some level of plant recovery (Table 2-10, Table 2-11, Table 2-12). However, although roots may recover, foliage damage or flower delay may prevent the plant from being ultimately marketable (Table 2-3, Table 2-4, Table 2-5).

Inconsistent reaction to the supraoptimal RZT among different cultivars could be due to specific cultivar's ability to respond to the temperatures or the necessity which is supported by Martin and Ingram (2015). For example, our research showed the Dalaya series, in general, developed poor, or low-vigor root growth in comparison to the XXL series (Table 2-10, Table 2-11; Figure 2-5). By the end of the experiment in either year, the highest root-rating average observed was 1.6 for the Dalaya 'Dalaya Yogi' control group in 2020, while the highest root-rating observed in the XXL series was 3.9 in 'XXL Veracruz' at the 45 °C treatment (Table 2-10, Table 2-11; Figure 2-4). Cultivar differences made finding statistically significant declines difficult in the Dalaya series when initial root-ratings were low to begin the experiment and remained low even, in the control group four-weeks post treatment (Table 2-10, Figure 2-5).

'Gallery Monet' (Year 2) was an outlier for all treatments. The plants did not grow and had poor root and shoot development after pinch, and after the initial treatment, declined immediately and severely, resulting in death. Due to the widespread death, even in the control group, we believe initial plant quality was poor or the low vigor contributed to poor rooting compared to the other cultivars in the time allowed. Similar low plant vigor was observed in 'Dalaya Red and White'. In early production, the cultivar started to exhibit symptoms of virus (distorted growth, stunted foliage), however, we did not test for virus. It is possible virus may have impacted overall plant development.

We were not successful in eliciting uniform symptoms of dahlia decline. However, there were replications that exhibited similar symptoms to dahlia decline and succumbed to death. The plant death observed was most likely due to individual cultivars having lower vigor roots or individual plants experiencing the supraoptimal temperature and simply not recovering like the others in the cultivar. Although there were decreases in root-ratings, plants were also able to recover to some level, by four-weeks after treatment.

Observations of root-rating decrease in the surveyed dahlia cultivars were not surprising; previous research has shown that when root-zones are exposed to temperatures >40 °C, root quality is impacted and death can occur (Martin and Ingram, 2015). We observed root-rating decreases, especially above 40 °C, in our experiment; this indicates a threshold for potential root damage, which was also reported by Martin and Ingram (2015). In our potted dahlia study, our treatments (40, 45, 50 °C) were sub-lethal with supraoptimal temperatures. In observing an increase in root-ratings over time that indicates improved root quality as time passed, even after supraoptimal heat damage has occurred, suggests that dahlias have some tolerance to high temperatures and can be resilient.

Beyond supraoptimal RZT as an explanation for dahlia decline, it is plausible that one may need to further consider rootzone pathogens as described in the introduction. The symptoms of dahlia decline include poor rooting or root decline, leaf-greying and wilting foliage, then complete plant collapse (Hammer, personal communication, 2015). The diseases that would most likely fit these symptoms are root rots, especially *Pythium* species. *Pythium* infection symptoms include stunted growth, dead root tips, sloughing of root cortex, and ultimately in severe cases, plant death (Beckerman, 2011). Considering that the most common greenhouse *Pythium* species are not able to survive at supraoptimal temperatures (i.e., 40 °C and higher), it is plausible that dahlia decline observed at elevated RZT is not attributed to *Pythium* due to the pathogen being killed off or at least greatly inhibited (Moorman and Daughtrey, 2002). If infection or reinfection were to occur after an elevated RZT situation, it might then be possible that *Pythium* could infect and damage the root system. Although *Pythium* could be a probable cause of dahlia decline, previous preliminary tests suggest that it is not a primary factor in dahlia decline. (Hammer, personal communication,). In our study, we did not find any evidence of pathogen interference in our treatments, even in plants that died. We can make this assertion because there was no consistent, widespread death in our supraoptimal treatments, and there was no death in the control treatment. If a pathogen like *Pythium* had infected our initial rooted cuttings, we would expect root decline in more than just our supraoptimal treatments, that is, our control plants would have declined.

Other cultural considerations that may influence root-ratings include watering and EC and pH. During our experiment dahlias were irrigated when they reached medium dry down right before leaves flagged. Perhaps this technique did not meet the needs of specific cultivars, but we tried to be as consistent as possible when it came to monitoring of water needs. It is possible that if a plant stayed too wet or was too dry, root-ratings could decrease. pH and EC were monitored during the production cycle and our observations were found to be within the normal recommended range for dahlia production (data not shown). No salt accumulation (increased EC) that could burn the roots was observed. With the consistencies with watering, EC and pH, and the unlikely possibility of pathogen influence, we can assume that the root-rating decreases observed were in fact due to the treatments applied and how the individual cultivars reacted to them.

Conclusion

Dahlia decline, at least on a broad scale, was not induced in any treatment for any cultivar with supraoptimal RZT exposure during our experiments. Even when dahlia cultivars experienced supraoptimal RZT and subsequent root-rating decreases, some cultivars still showed a significant root-rating increase, suggesting that a heat damaged root-zone may not be a primary factor that leads to dahlia decline. Moreover, even with damaging RZTs, dahlia plants can recover with potential market value. With this information, growers can make more educated decisions about their crops especially if the crop endures high temperature exposure. Some cultivars have the potential to handle elevated RZTs, while others may not. It is advised to avoid letting dahlia root medium reach temperatures above 40 °C or let plants experience elevated RZT for more than 2-hrs. The instances where dahlia root-zones could encounter these temperatures for periods of time may include hot water left in a hose or extreme greenhouse air temperatures. However, this would not reliably explain whole crop losses, as the quantity of potential hot water left in a hose, would not be sufficient to kill a whole greenhouse range of dahlia plants. Moreover, the possibility that large numbers of dahlia pots on a bench in a greenhouse would experience increased RZTs, based on solar radiation on the pot is probably not likely, at least to the temperatures tested in these experiments. Pot and media surface temperatures were taken one day during our experiment; the highest average temperature was 35 °C at 11:00 am for pots on perimeter, south-facing side of the bench (data not shown).

Dahlia decline appears to be a more complex combination of factors, including physiological or environmental causes or both. Future research is needed to investigate other plausible causes of decline but knowing supraoptimal RZT is likely not one of the primary causes is insightful.

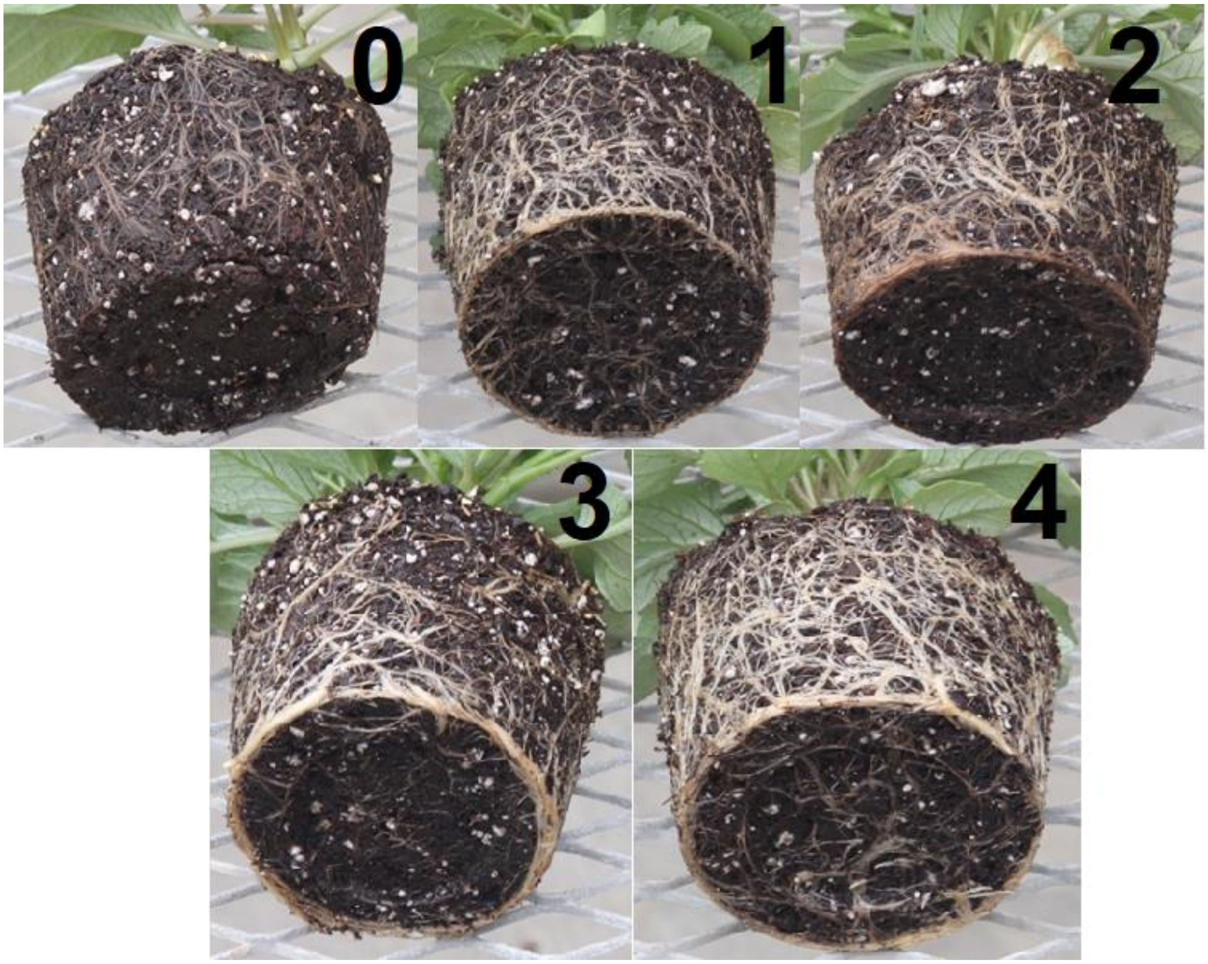


Figure 2-1: Root-rating scale [0-4], used to determine root condition and incidence of dahlia decline in Dahlia (*Dahlia xhybrida*).

Root Ratings: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)

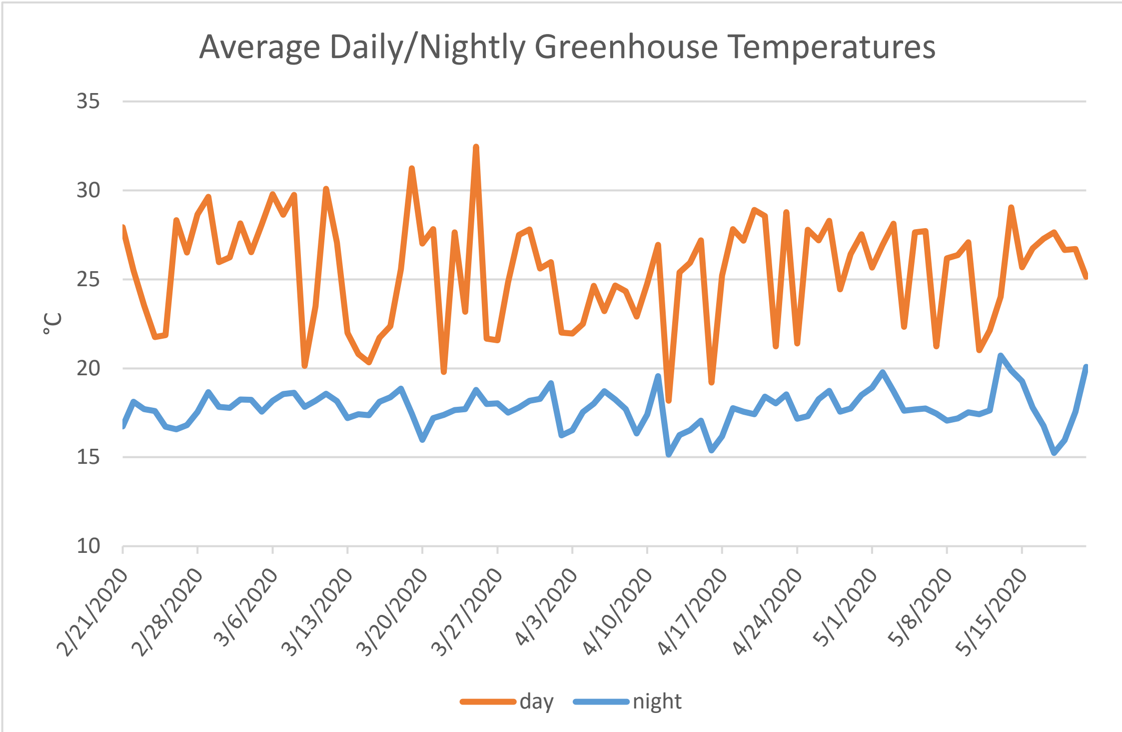


Figure 2-2: Average daily and nightly greenhouse temperatures for the duration of Experiment 1 from 21 Feb. 2020 to 21 May 2020. Averages calculated with temperature data from HOBO data logger (MX2202; Onset Computer Corporation; Bourne, MA). Day and night time length adjust for sunset/sunrise and daylight savings time.

Figure 2-3: Example of plant and root quality of ‘XXL Veracruz’ dahlia (*Dahlia xhybrida*) plants four-weeks post-treatment in Experiment 1 (Year 2). Panel A) are repetitions from control treatment and panel B) are repetitions from 50 °C treatment.

Figure 2-4: Examples of difference in overall root-rating between two cultivars of dahlia (*Dahlia xhybrida*) four-weeks post treatment in Experiment 1 (Year 2). Panel A) ‘Dalaya Yogi’ control repetitions. Panel B) ‘XXL Veracruz’ 45 °C repetitions.

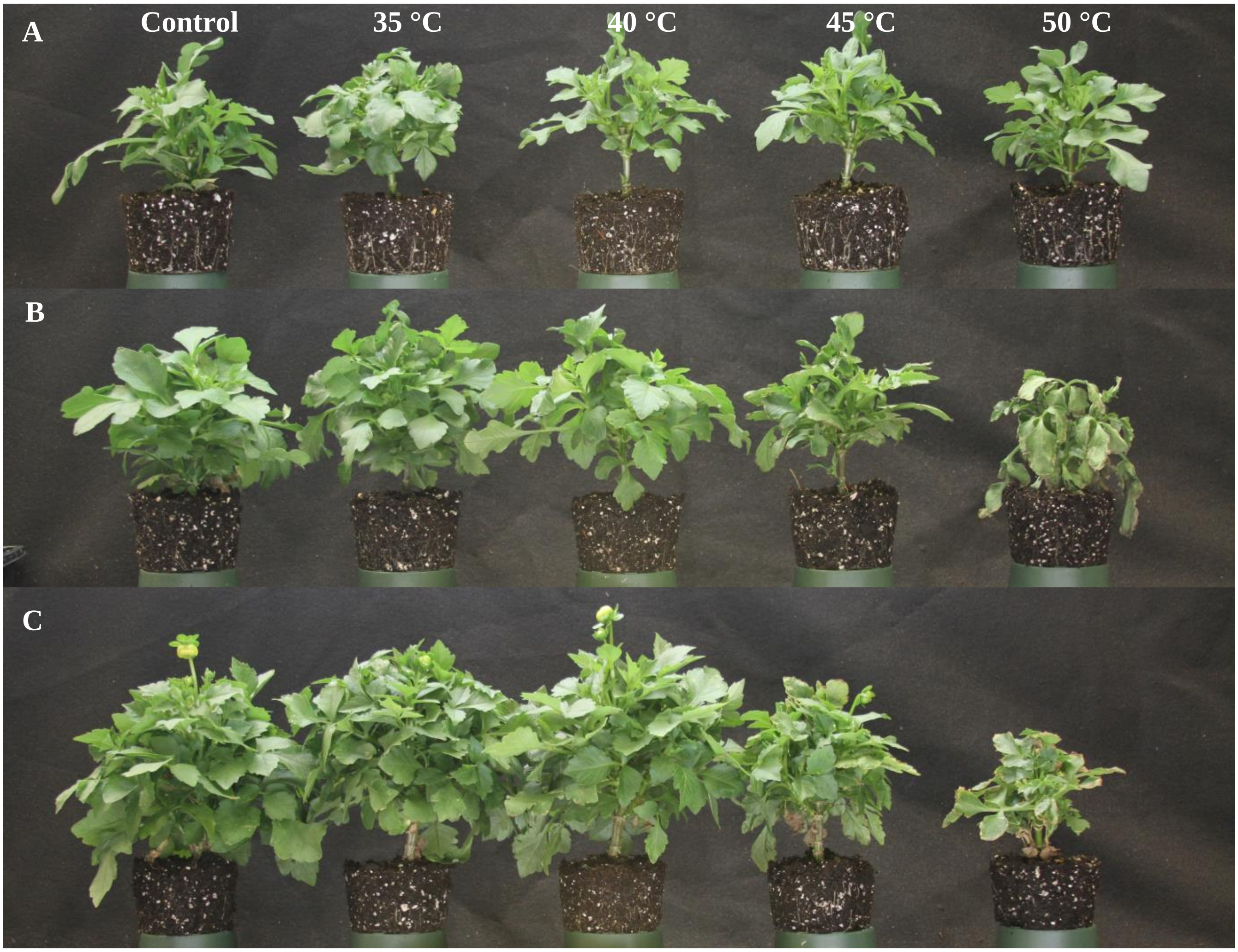


Figure 2-5: Treatment comparisons for ‘Dalaya Shiva’ dahlia (*Dahlia xhybrida*) from Experiment 1 (Year 2). Treatments are shown left to right in the photo; control, 35, 40, 45, 50 °C. Panel A) Pre-treatment observations. Panel B) One-week post treatment. Panel C) Four-weeks post treatment.

Figure 2-6: Treatment comparisons for 'XXL Veracruz' dahlia (*Dahlia xhybrida*) from Experiment 1 (Year 2). Treatments are shown left to right in the photo; control, 35, 40, 45, 50 °C. Panel A) Pre-treatment observations. Panel B) One-week post treatment. Panel C) Four-weeks post treatment.

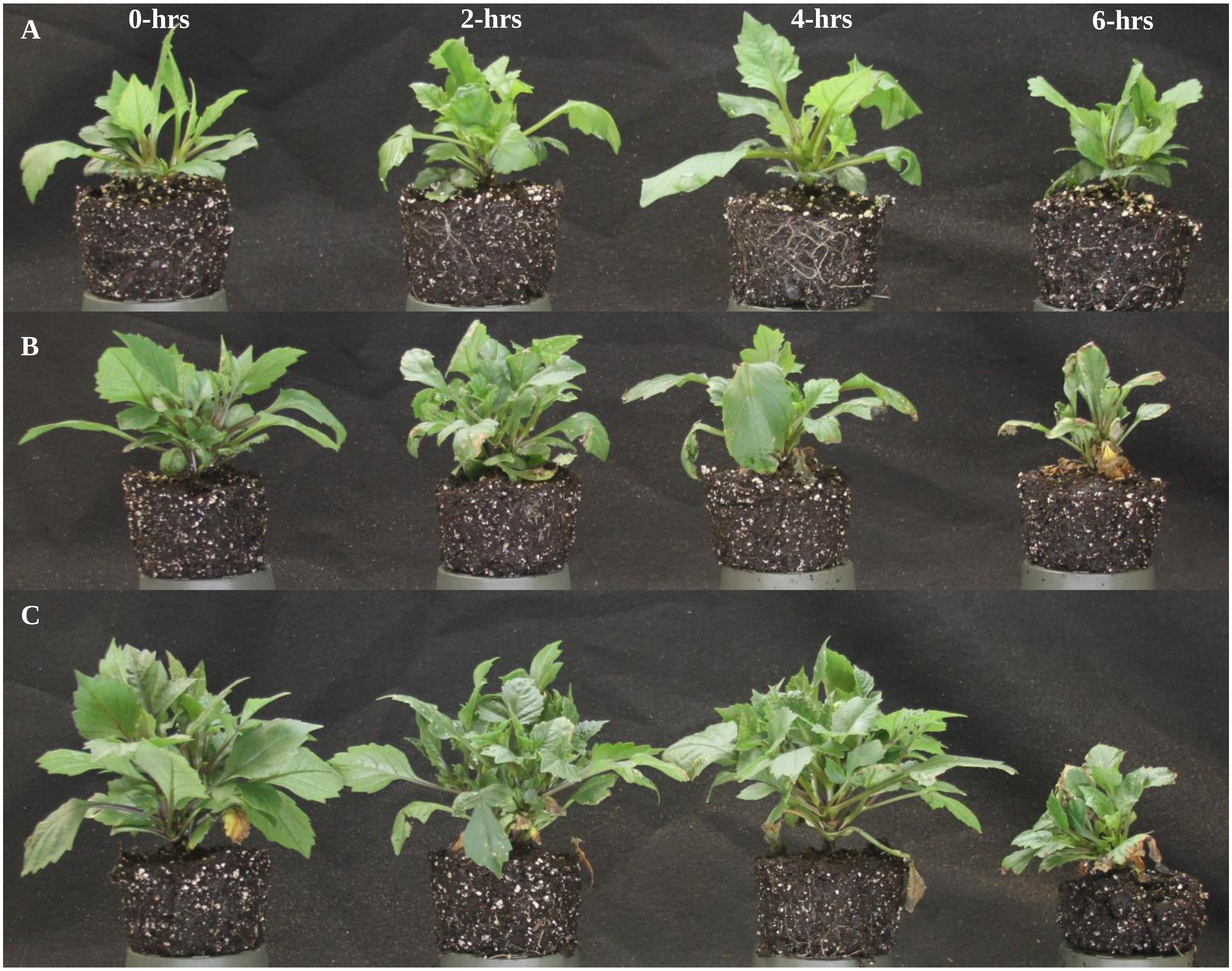


Figure 2-7**:** Treatment comparisons for ‘Dalaya Red and White’ dahlia (*Dahlia xhybrida*) from Experiment 2 (Year 1). Treatments are shown left to right in the photo; 0-, 2- 4, 6-hrs. Panel A) Pre-treatment observations. Panel B) One-week post treatment. Panel C) Three-weeks post treatment.

Figure 2-8: Treatment comparisons for 'XXL Veracruz' dahlia (Dahlia xhybrida) from Experiment 2 (Year 1). Treatments are shown left to right in the photo; 0-, 2- 4, 6-hrs. Panel A) Pre-treatment observations. Panel B) One-week post treatment. Panel C) Three-weeks post treatment.

Table 2-1: A list of the dahlia (*Dahlia xhybrida*) series and cultivars used in experiments to further characterize the dahlia decline phenomenon.

Series	**Cultivar**	**Group Number**	**Received**	**Pinch**	**Experiment**	**Year**
Dalaya	Red & White	1	6 Feb; 2 Feb	27 Feb; 20 Feb	1, 2	2019; 2020
Dalaya	Shiva	1	6 Feb; 2 Feb	27 Feb; 20 Feb	1, 2	2019; 2020
Dalaya	Yogi	1	6 Feb; 2 Feb	27 Feb; 20 Feb	1, 2	2019; 2020
XXL	Veracruz	2	22 Feb; 20 Feb	5 Mar; 20 Feb	1, 2	2019; 2020
XXL	Tabasco	2	22 Feb; 20 Feb	5 Mar; 20 Feb	1, 2	2019; 2020
XXL	Sunset	2	22 Feb; 20 Feb	5 Mar; 20 Feb	1, 2	2019; 2020
Melody	Sincerity	3	21 Mar; 20 Mar	1 April; 4 April	1, 2	2019; 2020
Melody	Gypsy	3	21 Mar	1 April	1, 2	2019
Dark Angels	Pulp Fiction	3	21 Mar	1 April	1, 2	2019
Dark Angels	American Pie	3	21 Mar	1 April	1, 2	2019
Gallery	Art Deco	3	20 Mar	4 April	1	2020
Gallery	Monet	3	20 Mar	4 April	1	2020

Table 2-2: Significance levels of growth measurements of main effects and interactions taken for all dahlia (*Dahlia xhybrida*) cultivars in Experiment 1; Year 1.

	Cultivar									
	Red & White	**Shiva**	**Yogi**	**Sunset**	**Tabasco**	**Veracruz**	**American Pie**	**Pulp Fiction**	**Gypsy**	**Sincerity**
Effects	**Significance**									
Plant Height (cm)										
Treatment	<0.0001	0.0014	<0.0001	0.0269	<0.0001	0.0036	<0.0001	<0.0001	<0.0001	<0.0001
Week	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Week	0.0009	0.0644	0.2875	0.0794	0.1562	0.7510	0.4544	0.1271	0.1420	0.1873
Flower Development Rating[z]										
Treatment	<0.0001	0.5847	<0.0001	0.6840	0.1267	<0.0001	--[x]	--	--	--
Week	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	--	--	--	--
Treatment*Week	<0.0001	0.9992	<0.0001	0.8984	0.1098	0.0882	--	--	--	--
Foliage Rating[y]										
Treatment	<0.0001	<0.0001	<0.0001	0.1003	--	0.2018	<0.0001	0.0012	0.1135	0.0007
Week	0.0051	0.0923	0.0018	0.5603	--	0.1824	0.0162	0.8521	0.7156	0.6658
Treatment*Week	0.0019	0.3784	0.2622	0.7365	--	0.8433	0.0002	0.9917	0.8750	0.9619

[z]Flower development rating: 0 to 3; 0=no flower bud, 1= flower bud present, 2=flower bud with outer petals showing color, and 3=inflorescence open with ray florets expanded

[y]Foliage rating: to 4; 0=dead/completely brown leaves, 1=more than 60% brown with green still on leaves, 2=drooping/flagging leaves with a less than 50% brown or greying, 3=drooping/flagging leaves, but otherwise green leaves, 4=turgid, healthy, bright green leaves.

[x]Dashes represent absence of ratings (average = 0)

Table 2-3: Plant height significance level and averages for all dahlia (*Dahlia xhybrida*) cultivars in Experiment 1; Year 2

	Cultivar								
	Red & White	**Shiva**	**Yogi**	**Sunset**	**Tabasco**	**Veracruz**	**Art Deco**	**Monet**	**Sincerity**
Effects	**Significance**								
Treatment	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0059	<0.0001
Week	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.0001	<0.0001
Treatment*Week	0.4741	0.0231	0.3789	0.0006	0.1964	0.2127	0.2212	0.9904	0.5381
	Plant Height (cm)								
Treatment									
Control	19.30 a[z]	19.42 a	19.82 a	23.12 a	20.84 a	21.26 b	26.94 a	11.92 b	21.18 a
35 °C	18.08 b	20.41 a	20.42 a	22.41 ab	20.84 a	22.23 a	25.08 b	13.04 a	21.34 a
40 °C	18.50 ab	18.18 b	18.18 b	21.72 b	20.18 a	20.78 b	25.10 b	11.98 b	21.26 a
45 °C	18.80 ab	17.60 b	17.60 b	21.48 b	18.76 b	20.30 b	22.78 c	12.46 ab	19.66 a
50 °C	16.29 c	16.30 c	16.30 c	18.98 c	17.80 b	19.12 c	21.24 c	12.92 ab	17.60 b
Week									
0	16.58 c	16.10 d	16.58 e	18.96 d	15.98 e	19.12 d	21.52 d	13.92 a	18.28 b
1	17.72 bc	17.42 c	17.96 d	20.36 c	17.68 d	19.96 cd	22.38 cd	12.94 ab	18.46 b
2	18.44 ab	18.30 bc	19.16 c	21.34 c	19.46 c	20.66 bc	23.42 c	12.63 bc	19.56 b
3	18.90 ab	19.38 ab	20.90 b	22.78 b	21.64 b	21.66 ab	25.60 b	11.70 c	21.52 a
4	19.41 a	20.44 a	22.16 a	24.00 a	23.66 a	22.38 a	28.23 a	11.40 c	23.22 a

[z]Letters after each value represent separation with a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-4: Flower development rating significance level and averages for all dahlia (*Dahlia xhybrida*) cultivars in Experiment 1; Year 2.

	Cultivar								
	Red & White	**Shiva**	**Yogi**	**Sunset**	**Tabasco**	**Veracruz**	**Art Deco**	**Monet**	**Sincerity**
Effects	**Significance**								
Treatment	0.0004	<0.0001	0.2753	<0.0001	<0.0001	<0.0001	0.0542	--[z]	<0.0001
Week	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0191	--	<0.0001
Treatment*Week	0.2283	0.0005	0.3216	0.0003	0.3546	0.0001	0.8372	--	<0.0001
	Flower Development Rating[y]								
Treatment									
Control	0.37 a[x]	0.80 a	1.60 a	1.68 a	0.80 a	1.80 a	0.24 a	--	0.28 a
35 °C	0.32 ab	0.60 a	1.58 a	1.52 a	1.16 a	1.80 a	0.00 b	--	0.20 a
40 °C	0.56 a	0.72 a	1.54 a	1.56 a	0.76 a	1.88 a	0.12 ab	--	0.00 b
45 °C	0.24 ab	0.32 b	1.50 a	1.78 a	0.28 b	2.00 a	0.04 ab	--	0.00 b
50 °C	0.00 b	0.20 b	1.48 a	1.16 b	0.28 b	1.24 b	0.12 ab	--	0.00 b
Week									
0	0.00 c	0.00 d	0.00 d	0.88 c	0.16 c	0.96 c	0.00 b	--	0.00 c
1	0.12 bc	0.08 d	0.92 c	0.92 c	0.20 c	1.00 c	0.00 b	--	0.00 c
2	0.36 ab	0.44 c	1.08 c	1.22 c	0.68 b	1.48 b	0.12 ab	--	0.00 c
3	0.43 ab	0.76 b	2.70 b	2.04 b	0.88 b	2.48 a	0.16 ab	--	0.12 b
4	0.58 a	1.39 a	3.00 a	2.64 a	1.36 a	2.80 a	0.24 a	--	0.36 a

[z]Dashes represent absence of ratings (average = 0)
[y]Flower development rating: 0 to 3; 0=no flower bud, 1= flower bud present, 2=flower bud with outer petals showing color, and 3=inflorescence open with ray florets expanded
[x]Letters after each value represent separation with a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-5: Foliage development rating significance level and averages for all dahlia (*Dahlia xhybrida*) cultivars in Experiment 1; Year 2.

	Cultivar								
	Red & White	**Shiva**	**Yogi**	**Sunset**	**Tabasco**	**Veracruz**	**Art Deco**	**Monet**	**Sincerity**
Effects	**Significance**								
Treatment	0.0172	<0.0001	0.0235	<0.0001	0.0021	<0.0001	0.0393	0.0072	<0.0001
Week	0.7459	<0.0001	0.0235	0.0241	0.4868	0.4751	0.7609	<0.0001	0.3643
Treatment*Week	0.9891	0.0002	0.1410	0.0036	0.1740	0.5864	0.9253	0.0540	0.8156
	Foliage Rating[z]								
Treatment									
Control	3.90 ab[y]	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	1.94 b	4.00 a
35 °C	3.98 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	2.42 a	4.00 a
40 °C	4.00 a	4.00 a	4.00 a	4.00 a	3.98 a	4.00 a	4.00 a	2.42 a	4.00 a
45 °C	4.00 a	3.66 b	3.88 b	3.96 a	4.00 a	4.00 a	3.82 a	2.08 ab	3.78 a
50 °C	3.44 b	3.08 c	3.96 ab	2.94 b	3.88 b	3.12 b	3.96 a	2.32 ab	2.92 b
Week									
0	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a	4.00 a
1	3.90 a	3.36 bc	3.88 b	3.58 b	3.96 a	3.76 a	3.98 a	3.24 b	3.66 a
2	3.84 a	3.58 c	4.00 a	3.70 ab	3.98 a	3.78 a	3.92 a	2.14 c	3.60 a
3	3.84 a	3.70 bc	3.96 ab	3.76 ab	3.98 a	3.76 a	3.94 a	1.02 d	3.66 a
4	3.74 a	3.86 ab	4.00 a	3.86 ab	3.94 a	3.82 a	3.94 a	0.78 d	3.78 a

[z]Foliage rating: to 4; 0=dead/completely brown leaves, 1=more than 60% brown with green still on leaves, 2=drooping/flagging leaves with a less than 50% brown or greying, 3=drooping/flagging leaves, but otherwise green leaves, 4=turgid, healthy, bright green leaves.
[y]Letters after each value represent separation with a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-6: Root-rating significance levels and averages of all dahlia (*Dahlia* xhybrida) cultivars used in Experiment 1; Year 1.

	Cultivar									
	Red & White	Shiva	Yogi	Sunset	Tabasco	Veracruz	Sincerity	Gypsy	Pulp Fiction	American Pie
Effects	**Significance**									
Treatment	<0.0001	<0.0001	<0.0001	<0.0001	0.0032	<0.0001	0.0012	0.1687	<0.0001	0.0004
Week	<0.0001	<0.0001	0.0008	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Week	0.2401	0.0418	0.1693	0.3510	0.0005	0.0039	0.3154	0.0093	0.0627	0.0119
	Root Rating[z]									
Treatment										
18 °C	0.60 a[y]	0.65 a	1.16 a	1.89 a	1.31 a	2.98 a	0.98 ab	0.50 a	0.40 bc	1.32 a
35 °C	0.45 a	0.76 a	1.20 a	2.09 a	0.96 ab	2.83 ab	1.29 a	0.54 a	0.58 a	1.32 a
40 °C	0.40 ab	0.58 ab	0.94 ab	1.51 ab	0.95 ab	2.38 b	1.29 a	0.50 a	0.56 a	1.02 ab
45 °C	0.53 a	0.42 bc	0.46 c	1.76 a	1.02 ab	2.27 b	0.97 ab	0.68 a	0.40 bc	0.70 b
50 °C	0.20 b	0.31 c	0.63 bc	0.90 b	0.78 b	1.65 c	0.83 b	0.62 a	0.36 c	0.78 b
Week										
0	0.64 a	0.62 ab	0.79 ab	1.34 bc	0.60 c	2.26 b	0.86 bc	0.46 bc	0.50 a	0.62 cd
1	0.28 c	0.30 c	0.62 b	0.89 c	0.61 c	1.28 c	0.59 c	0.36 c	0.30 b	0.42 d
2	0.37 bc	0.48 bc	0.97 a	1.57 b	0.96 bc	2.10 b	1.00 b	0.70 ab	0.54 a	1.30 ab
3	0.39 bc	0.56 ab	0.93 ab	1.91 ab	1.16 b	2.99 a	1.41 a	0.74 a	0.54 a	1.72 a
4	0.50 ab	0.76 a	1.08 a	2.44 a	1.69 a	3.48 a	1.50 a	0.58 abc	0.56 a	1.08 bc

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)

[y]Letters after each value represent separation with a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-7: Full factorial analysis for cultivar, treatment, and week effects and interactions on root ratings for dahlia (*Dahlia xhybrida*) for Experiment 1 in Year 1 and Year 2.

Parameter or Variable	Significance Level Year 1	Significance Level Year 2
Cultivar	<0.0001	<0.0001
Treatment	<0.0001	<0.0001
Week	<0.0001	<0.0001
Cultivar*Treatment	<0.0001	<0.0001
Cultivar*Week	<0.0001	<0.0001
Treatment*Week	<0.0001	<0.0001
Cultivar*Treatment*Week	0.0008	<0.0001

Table 2-8: Root-rating averages for cultivar across all treatments in Experiment 1; Year 1 and Year 2.

Cultivar	Root-Rating[z] Year 1	Root-Rating Year 2
Red and White	0.34 f[y]	0.52 e[y]
Shiva	0.40 ef	0.68 e
Yogi	0.57 de	1.18 d
Sunset	0.76 c	2.50 b
Tabasco	0.87 bc	1.13 d
Veracruz	1.92 a	2.92 a
Sincerity	0.70 cd	1.43 c
Gypsy	0.56 de	--[x]
Pulp Fiction	0.48 ef	--
American Pie	1.02 b	--
Art Deco	--	0.99 d
Monet	--	0.08 f

[z]Rating is an average of 5 replications, over 4 observations (weeks). Rating value is based on a scale of 0 to 4; 0=very poor rooting; roots brown, visibly in decline; to 4=very good rooting, roots are active and white, no signs of browning or graying roots.

[y]Letters after each value represent separation between cultivars using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

[x] Dashes indicate cultivars not used in that year.

Table 2-9**:** Root-rating significance levels and averages of all dahlia (*Dahlia* xhybrida) cultivars used in Experiment 1; Year 2.

	Cultivar								
	Red & White	**Shiva**	**Yogi**	**Sunset**	**Tabasco**	**Veracruz**	**Sincerity**	**Art Deco**	**Monet**
Effects	**Significance**								
Treatment	<0.000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0006	0.3890
Week	<0.000	<0.0001	0.0079	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Week	0.0091	0.0045	0.0009	<0.0001	0.0147	<0.0001	0.0686	0.0027	0.4841
	Root Rating[z]								
Treatment									
18 °C	0.80 a[y]	0.82 ab	1.48 a	3.14 a	1.40 a	3.68 a	1.36 ab	1.06 ab	0.04 a
35 °C	0.52 b	0.98 a	1.66 a	3.34 a	1.06 ab	3.32 ab	1.74 a	1.24 a	0.12 a
40 °C	0.46 b	0.72 ab	1.12 b	2.36 b	1.40 a	2.78 b	1.72 a	1.04 ab	0.08 a
45 °C	0.56 ab	0.54 bc	0.66 c	2.60 b	1.20 a	3.02 b	1.38 ab	0.80 b	0.10 a
50 °C	0.30 b	0.36 c	1.02 b	1.06 c	0.62 b	1.82 c	0.98 a	0.84 b	0.06 a
Week									
0	1.10 a	0.90 a	1.18 ab	2.34 c	0.74 b	3.20 a	1.08 bc	0.76 c	0.38 a
1	0.46 b	0.48 b	0.98 b	1.30 d	0.60 b	1.70 b	0.74 c	0.48 c	0.00 b
2	0.36 b	0.52 b	1.28 ab	2.56 bc	1.26 a	3.04 a	1.26 b	0.68 c	0.00 b
3	0.26 b	0.62 ab	1.12 ab	2.96 ab	1.42 a	3.28 a	1.96 a	1.22 b	0.00 b
4	0.45 b	0.90 a	1.38 a	3.34 a	1.66 a	3.40 a	2.14 a	1.84 a	0.00 b

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)
[y]Letters after each value represent separation within a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-10: The effects of temperature on root growth over a period of 4 weeks on dahlia (*Dahlia* xhybrida) Dalaya series for two crop cycles in Experiment 1; Year 1 and Year 2.

		Observation Week				
Cultivar	**Treatments**	**Initiation**	**Post Week 1**	**Post Week 2**	**Post Week 3**	**Post Week 4**
Year 1		**Root Rating[z]**				
Red & White	Control	0.10 bc[y]	0.10 bc	0.40 abc	0.60 ab	0.80 a
	35 °C	0.10 bc	0.20 bc	0.50 abc	0.50 abc	0.60 ab
	40 °C	0.20 bc	0.10 bc	0.40 abc	0.50 abc	0.50 abc
	45 °C	0.20 bc	0.10 bc	0.60 ab	0.80 a	0.80 a
	50 °C	0.30 abc	0.00 c	0.00 c	0.10 bc	0.10 bc
Shiva	Control	0.60 abc	0.20 abc	0.50 abc	0.50 abc	0.60 abc
	35 °C	0.30 abc	0.20 abc	0.70 ab	0.70 ab	0.80 a
	40 °C	0.20 abc	0.10 bc	0.60 abc	0.60 abc	0.70 ab
	45 °C	0.30 abc	0.10 bc	0.30 abc	0.40 abc	0.40 abc
	50 °C	0.30 abc	0.00 c	0.10 bc	0.30 abc	0.60 abc
Yogi	Control	0.40 abc	0.40 abc	1.00 abc	1.20 ab	1.20 ab
	35 °C	0.50 abc	0.50 abc	0.80 abc	0.90 abc	1.00 abc
	40 °C	0.30 abc	0.30 abc	1.30 a	1.10 abc	0.80 abc
	45 °C	0.20 abc	0.00 c	0.20 abc	0.30 abc	0.60 abc
	50 °C	0.60 abc	0.10 bc	0.00 c	0.20 abc	0.30 abc
Year 2						
Red & White	Control	1.10 ab	1.00 abc	0.90 abcd	0.40 bcde	0.60 abcde
	35 °C	1.00 abc	0.60 abcde	0.40 bcde	0.20 cde	0.40 bcde
	40 °C	1.10 ab	0.60 abcde	0.20 cde	0.20 cde	0.20 cde
	45 °C	1.40 a	0.10 de	0.30 bcde	0.50 bcde	0.50 bcde
	50 °C	0.90 abcd	0.00 e	0.00 e	0.10 de	0.50 bcde
Shiva	Control	0.90 abcd	0.80 abcd	0.80 abcd	0.70 abcd	0.90 abcd
	35 °C	1.20 a	1.20 a	1.00 abc	0.70 abcd	0.80 abcd
	40 °C	0.80 abcd	0.20 bcd	0.50 abcd	1.10 ab	1.00 abc
	45 °C	0.70 abcd	0.20 bcd	0.30 abcd	0.50 abcd	1.00 abc
	50 °C	0.90 abcd	0.00 d	0.00 d	0.10 cd	0.80 abcd
Yogi	Control	1.30 abcde	1.60 abcd	1.70 abc	1.20 abcde	1.60 abcd
	35 °C	1.40 abcde	1.90 ab	2.10 a	1.30 abcde	1.60 abcd
	40 °C	1.10 bcde	0.80 cdef	1.20 abcde	1.30 abcde	1.20 abcde
	45 °C	1.00 bcdef	0.10 f	0.50 ef	0.70 def	1.00 bcdef
	50 °C	1.10 bcde	0.50 ef	0.90 cdef	1.10 bcde	1.50 abcd

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)

[y]Letters after each value represent separation within a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-11: The effects of temperature on root growth over a period of 4 weeks on dahlia (*Dahlia* xhybrida) XXL series for two crop cycles, Experiment 1; Year 1 and Year 2.

		Observation Week				
Cultivar	**Treatments**	**Initiation**	**Post Week 1**	**Post Week 2**	**Post Week 3**	**Post Week 4**
Year 1		**Root Rating[z]**				
Sunset	Control	0.3 f[y]	0.5 def	0.5 def	0.7 bcdef	1.2 abcdef
	35 °C	0.4 ef	0.9 abcdef	0.8 bcdef	0.6 cdef	1.5 abcd
	40 °C	0.2 f	0.5 def	0.6 cdef	0.6 cdef	1.4 abcde
	45 °C	0.4 ef	0.3 f	0.6 cdef	1.6 abc	1.7 ab
	50 °C	0.4 ef	0.2 f	0.4 ef	0.8 bcdef	1.9 a
Tabasco	Control	0.5 c	0.9 c	1.0 c	1.1 bc	2.6 a
	35 °C	0.6 c	1.2 abc	0.6 c	0.7 c	1.2 abc
	40 °C	0.1 c	0.5 c	0.5 c	0.6 c	0.8 c
	45 °C	0.5 c	0.4 c	0.5 c	1.3 abc	1.5 abc
	50 °C	0.6 c	0.1 c	0.7 c	0.8 c	2.5 ab
Veracruz	Control	1.7 bcdef	1.6 bcdef	1.7 bcdef	2.4 abcd	4.0 a
	35 °C	1.2 def	1.6 bcdef	1.5 cdef	3.4 ab	4.0 a
	40 °C	1.3 def	0.6 def	1.2 def	3.4 ab	3.4 ab
	45 °C	1.0 def	0.4 ef	0.8 def	2.2 abcde	3.2 abc
	50 °C	1.4 cdef	0.1 f	0.6 def	2.1 bcde	3.2 abc
Year 2						
Sunset	Control	2.6 abcd	2.5 abcd	3.3 abc	3.5 a	3.8 a
	35 °C	2.8 abcd	3.1 abcd	3.4 ab	3.5 a	3.8 a
	40 °C	1.8 defg	0.5 fgh	2.9 abcd	3.3 abc	3.3 abc
	45 °C	2.5 abcd	0.4 gh	2.8 abcd	3.5 a	3.8 a
	50 °C	2.5 bcde	0.0 h	0.4 gh	1.0 efgh	1.9 cdef
Tabasco	Control	0.9 abcd	1.1 abcd	1.6 abc	1.4 abcd	2.0 abc
	35 °C	0.9 abcd	1.2 abcd	1.2 abcd	0.9 abcd	1.1 abcd
	40 °C	0.7 bcd	0.6 cd	1.8 abc	2.1 ab	1.8 abc
	45 °C	0.6 cd	0.1 d	1.1 abcd	2.0 abc	2.2 a
	50 °C	0.6 cd	0.0 d	0.6 cd	0.7 bcd	1.2 abcd
Veracruz	Control	3.5 ab	3.7 ab	3.8 ab	3.8 ab	3.6 ab
	35 °C	3.1 abc	3.2 ab	3.5 ab	3.4 ab	3.4 ab
	40 °C	2.5 abcd	0.9 de	3.3 ab	3.6 ab	3.6 ab
	45 °C	3.7 ab	0.4 e	3.4 ab	3.7 ab	3.9 a
	50 °C	3.2 ab	0.3 e	1.2 cde	1.9 bcde	2.5 abcd

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)
[y]Letters after each value represent separation within a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-12: The effects of temperature on root growth over a period of 4 weeks on dahlia Melody, Gallery, Dark Angel series for two crop cycles, Experiment 1; Year 1 and Year 2.

		Observation Week				
Series/Cultivar	**Treatments**	**Initiation**	**Post Week 1**	**Post Week 2**	**Post Week 3**	**Post Week 4**
Year 1		**Root Ratings[z]**				
Melody						
Sincerity	Control	0.5 abc[y]	0.5 abc	0.6 abc	0.7 abc	0.7 abc
	35 °C	0.6 abc	0.8 abc	0.8 abc	1.0 ab	1.0 ab
	40 °C	0.7 abc	0.8 abc	0.6 abc	1.0 ab	1.2 a
	45 °C	0.7 abc	0.0 c	0.7 abc	0.8 abc	0.6 abc
	50 °C	0.7 abc	0.1 bc	1.0 ab	0.8 abc	0.8 abc
Gypsy	Control	0.40 bc	0.50 abc	0.50 abc	0.50 abc	0.60 abc
	35 °C	0.40 bc	0.50 abc	0.70 abc	0.60 abc	0.50 abc
	40 °C	0.40 abc	0.50 abc	0.60 abc	0.40 bc	0.50 abc
	45 °C	0.50 abc	0.30 bc	0.90 ab	1.00 ab	0.70 ab
	50 °C	0.50 abc	0.00 c	0.80 ab	1.20 a	0.60 abc
Dark Angel						
American Pie	Control	0.7 cde	0.8 cde	1.5 abcd	2.5 a	1.1 abcde
	35 °C	0.6 de	0.6 de	2.1 abc	2.4 ac	0.9 cde
	40 °C	0.5 de	0.5 de	1.6 abcd	1.6 abcd	0.9 cde
	45 °C	0.6 de	0.2 de	0.6 de	1.1 abcde	1.0 bcde
	50 °C	0.7 cde	0.0 e	0.7 cde	1.0 bcde	1.5 abcd
Pulp Fiction	Control	0.5 a	0.5 a	0.5 a	0.6 a	0.6 a
	35 °C	0.5 a	0.5 a	0.7 a	0.6 a	0.6 a
	40 °C	0.5 a	0.5 a	0.6 a	0.6 a	0.6 a
	45 °C	0.5 a	0.0 b	0.5 a	0.5 a	0.5 a
	50 °C	0.5 a	0.0 b	0.4 ab	0.4 ab	0.5 a
Year 2						
Melody						
Sincerity	Control	0.8 cde	1.3 abcde	1.3 abcde	1.7 abc	1.7 abc
	35 °C	1.2 abcde	1.2 abcde	1.4 abcde	2.3 a	2.6 ab
	40 °C	1.2 abcde	0.9 bcde	1.6 abcd	2.4 a	2.5 a
	45 °C	0.9 bcde	0.2 de	1.4 abcde	1.9 abc	2.5 a
	50 °C	1.3 abcde	0.1 e	0.6 cde	1.2 abcde	1.7 abc
Gallery						
Art Deco	Control	0.8 defgh	0.9 cdefgh	0.9 cdefgh	1.1 bcdefg	1.6 abcde
	35 °C	0.7 efgh	0.7 efgh	0.8 defgh	4.7 abcd	2.3 a
	40 °C	0.8 defgh	0.8 defgh	0.9 cdefgh	1.1 cdefg	1.6 abcde
	45 °C	0.7 efgh	0.0 h	0.6 fgh	0.9 bcdefg	1.8 abc
	50 °C	0.8 defgh	0.0 h	0.2 gh	1.3 bcdef	1.9 ab
Monet	Control	0.0 bc	0.0 c	0.0 c	0.0 c	0.2 c
	35 °C	0.6 a	0.0 c	0.0 c	0.0 c	0.0 c
	40 °C	0.4 ab	0.0 c	0.0 c	0.0 c	0.0 bc
	45 °C	0.4 ab	0.0 c	0.0 c	0.0 c	0.1 c
	50 °C	0.3 abc	0.0 c	0.0 c	0.0 c	0.0 c

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots,

visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)

[y]Letters after each value represent separation within a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-13: Root-rating significance levels and averages for all dahlia (*Dahlia xhybrida*) cultivars used in Experiment 2; Year 1.

	Cultivars									
	Red & White	**Shiva**	**Yogi**	**Sunset**	**Tabasco**	**Veracruz**	**Sincerity**	**Gypsy**	**Pulp Fiction**	**American Pie**
Effects	**Significance**									
Treatment	<0.0001	0.1047	<0.0001	0.7366	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	0.0041
Week	0.0720	0.0166	<0.0001	0.0033	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Week	0.1592	0.2960	0.0062	0.6694	<0.0001	0.0096	<0.0001	0.0036	<0.0001	0.5087
	Root Rating[z]									
Treatment										
0-hrs	0.35 a[y]	0.37 a	0.47 a	0.52 a	0.65 a	2.17 a	0.66 a	0.47 ab	0.62 a	1.05 a
2-hrs	0.25 ab	0.22 a	0.20 b	0.67 a	0.62 a	1.17 b	0.62 a	0.35 bc	0.42 b	0.62 b
4-hrs	0.15 bc	0.22 a	0.225	0.52 a	0.27 b	0.87 b	0.25 b	0.20 c	0.22 c	0.55 b
6-hrs	0.02 c	0.17 a	0.10 b	0.57 a	0.85 a	1.17 b	0.65 a	0.60 a	0.20 c	0.52 b
Week										
0	0.17 a	0.37 a	0.50 a	0.47 b	0.45 bc	1.15 bc	0.65 ab	0.50 a	0.62 a	0.92 a
1	0.10 a	0.10 b	0.15 b	0.32 b	0.22 c	0.67 c	0.25 c	0.10 b	0.20 b	0.25 b
2	0.25 a	0.27 ab	0.17 b	0.60 ab	0.52 b	1.22 b	0.51 b	0.42 a	0.30 b	0.65 ab
3	0.25 a	0.25 ab	0.17 b	0.90 a	1.20 a	2.35 a	0.77 a	0.60 a	0.35 b	0.92 a

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)

[y]Letters after each value represent separation within a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 2-14: The effects of supraoptimal temperature duration on root growth over a period of three weeks on dahlia (*Dahlia xhybrida*) series XXL, Dalaya, Dark Angel, and Melody series for one crop cycle of Experiment 2; Year 1.

		Observation Time			
Cultivar	**Treatments**	**Initiation**	**Post Week 1**	**Post Week 2**	**Post Week 3**
XXL		Root Rating[z]			
Sunset	0-hrs	0.50 ab[y]	0.50 ab	0.60 ab	0.50 ab
	2-hrs	0.50 ab	0.30 ab	0.70 ab	1.20 a
	4-hrs	0.40 ab	0.10 b	0.60 ab	1.00 ab
	6-hrs	0.50 ab	0.40 ab	0.50 ab	0.90 ab
Tabasco	0-hrs	0.50 c	0.70 bc	0.70 bc	0.70 bc
	2-hrs	0.50 c	0.00 c	0.60 c	1.40 b
	4-hrs	0.30 c	0.00 c	0.30 c	0.50 c
	6-hrs	0.50 c	0.20 c	0.50 c	2.20 a
Veracruz	0-hrs	1.40 bcdef	1.90 abcd	2.90 ab	2.80 a
	2-hrs	1.00 def	0.40 ef	0.80 def	2.50 abc
	4-hrs	1.20 cdef	0.10 f	0.60 def	1.60 abcde
	6-hrs	1.0 def	0.60 ef	0.90 def	2.50 abc
Dalaya					
Red & White	0-hrs	0.10 ab	0.30 ab	0.50 a	0.50 a
	2-hrs	0.30 ab	0.10 ab	0.30 ab	0.30 ab
	4-hrs	0.20 ab	0.00 b	0.20 ab	0.20 ab
	6-hrs	0.10 ab	0.00 b	0.00 b	0.00 b
Shiva	0-hrs	0.30 a	0.20 a	0.50 a	0.50 a
	2-hrs	0.50 a	0.10 a	0.20 a	0.10 a
	4-hrs	0.30 a	0.00 a	0.30 a	0.30 a
	6-hrs	0.40 a	0.10 a	0.10 a	0.10 a
Yogi	0-hrs	0.40 abc	0.50 ab	0.50 ab	0.50 ab
	2-hrs	0.50 ab	0.10 bc	0.10 bc	0.10 bc
	4-hrs	0.70 a	0.00 c	0.10 bc	0.10 bc
	6-hrs	0.40 abc	0.00 c	0.00 c	0.00 c
Dark Angel					
American Pie	0-hrs	1.00 ab	1.00 ab	1.00 ab	1.20 a
	2-hrs	0.80 ab	0.00 b	0.70 ab	1.00 ab
	4-hrs	1.00 ab	0.00 b	0.40 ab	0.80 ab
	6-hrs	0.90 ab	0.00 b	0.50 ab	0.70 ab
Pulp Fiction	0-hrs	0.70 a	0.80 a	0.50 abc	0.50 abc
	2-hrs	0.70 a	0.00 d	0.50 abc	0.50 abc
	4-hrs	0.60 ab	0.00 d	0.10 cd	0.20 bcd
	6-hrs	0.50 abc	0.00 d	0.10 cd	0.20 bcd

Melody					
Gypsy	0-hrs	0.50 abc	0.40 bc	0.50 abc	0.50 abc
	2-hrs	0.50 abc	0.00 c	0.40 bc	0.50 abc
	4-hrs	0.50 abc	0.00 c	0.00 c	0.30 bc
	6-hrs	0.50 abc	0.00 c	0.80 ab	1.10 a
Sincerity	0-hrs	0.80 ab	0.70 bc	0.55 bcd	0.60 bcd
	2-hrs	0.80 ab	0.30 bcd	0.70 bc	0.70 bc
	4-hrs	0.50 bcd	0.00 d	0.10 cd	0.40 bcd
	6-hrs	0.50 bcd	0.00 d	0.70 bc	1.70 a

[z]Rating is an average of 5 replications. Root Ratings scale 0-4: 0 = poor rooting (no roots; significant browning of roots, visibly in decline or absent), 1 = fair rooting (primarily white roots visible), 2 = good rooting (roots wrapped around base of media, distributed throughout pot; no browning), 3 = very good rooting, (well distributed roots, wrapped around pot, more thicker developed roots compared to thin), no browning, 4 = excellent rooting (roots are highly developed, white, no signs of death)

[y]Letters after each value represent separation within a cultivar, across Treatment or Week using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Chapter 3 - Literature Review

The poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) is a beloved and well-recognized floriculture crop. It is synonymous with the Christmas holiday and wintertime and can be found in homes across the world. From a native shrub in Southern Mexico to internationally produced potted cultivation, the poinsettia has gone through many changes; traditional breeding, grafting discoveries, and genetic modification have all contributed to creating the poinsettia as it is recognized today. In 2018, this crop generated $149 million in wholesale value by producers in 17 U.S. states (USDA, 2019). There are hundreds of cultivars used in the industry sporting traditional red colors to pink, white, variegated, and even purple. Studying the poinsettia history, crop development, and cultural improvements with specific focus on the difference between day and night temperature (DIF) and graphical tracking, provide insight to background that sets the stage for the future trajectory of poinsettias.

History

The first instance of the poinsettia appearing in the United States (U.S.) occurred in 1828 when it was documented in Philadelphia (Taylor, et al., 2011). The story of its arrival is wrapped in myth and unsubstantiated claims, but the general accepted story is that Joel Roberts Poinsett, first American minister to Mexico, observed the plant and sent cuttings to Colonel Robert Carr in Pennsylvania (Taylor, et al., 2011). Carr then entered the plant in the Pennsylvania Horticulture Society show in 1829 where it was received with much delight (Taylor et al., 2011). After its arrival in Philadelphia, cuttings were taken to Scotland, and the nurseryman Robert Buis then gave it to one of his friends (Taylor, et al., 2011). Once in Europe, it made its way to Germany where the botanist Karl Willdenow named it *Euphorbia pulcherrima* in 1934 (Taylor et al., 2011). The name has stuck ever since despite an attempt to rename it to *Poinsettia pulcherrima* in 1936 (Taylor, et al., 2011). Although the poinsettias has a generally confusing path to the U.S., commercial production began as early as the 1900s and the crop has continued to be a crucial part of the floriculture industry ever since (Taylor, et al., 2011).

Experimentation and poinsettia improvement have taken place intensively at the industry and university level. Pennsylvania State University, the United State Department of Agriculture (USDA) in Beltsville, Maryland, and the University of Maryland have all been major players in breeding since the 1950s (Taylor, et. al., 2011). However, the largest breeding improvements came from private companies like Ecke in California, (now a part of Dümmen Orange) Azalealand in Nebraska, Mikkelsens in Ohio, Pinellas Park in Florida, Yoder Brothers in Ohio, and Fischer in Germany (Benson, 2002; Taylor, et al., 2011). The original poinsettia was undesirable when compared to today's modern cultivars. Key features of this were poor branching, poor bract longevity, scraggily bracts, and limited color range. All of these breeding programs worked hard to make the poinsettia a more desirable crop. The cultivar Oak Leaf, in 1923 became the first cultivar with a dwarfing habit that made it appropriate for potted crop production, and it also had longer-lasting bracts (Benson, 2002; Taylor, et al., 2011). This cultivar was the foundational cultivar for all modern plants and nearly all cultivars can be traced back to 'Oak Leaf,' (Benson, 2002; Taylor, et al., 2011). The next turning point in poinsettia culture development did not come until 1963 with the introduction of, 'Paul Mikkelsen,' which contributed characteristics of bract longevity and stiffer stems (Taylor, et al., 2011; Benson, et al., 2002). Next, in the late 80's and 90's, breeding work done by Ecke introduced characteristics of dark leaves, early flowering, consistent branching, stiffer stems, curly bracts and leaves, and new colors (Taylor, et al., 2011).

One of the biggest breakthroughs in poinsettia cultivation came with the discovery of what causes free-branching cultivars. Free-branching is when plants induce axillary shoots to create multiflowered canopies while restricted-branching plants produce very few stems and have poor structural integrity (Lee, 2000). In the 1980's, poinsettia breeder Gregor Gutbier found that when he grafted a branch-restricted plant onto a free-branching plant, cuttings taken from the branch-restricted scion had characteristics of the free-branching rootstock (Taylor, et al., 2011). In 1997, a partnership between Ball FloraPlant and the USDA discovered that a phytoplasma had induced free-branching in poinsettias and was being transferred from rootstock to uninfected scions (Lee, et al., 1997; Lee, 2000; Taylor, et al., 2011). Lee and Ball FloraPlant discovered the phytoplasma was not related to the poinsettia mosaic virus (PnMV) and all branching characteristics were induced by the phytoplasma (Lee, 2000). Today, this phytoplasma is found in all modern cultivars and it is customary practice to inoculate seedlings by grafting onto an infected stock plant to transfer the free-branching and dwarfing characteristics (Lee, 2000; Taylor, et al., 2011).

Defining the modern poinsettia

Modern poinsettia varieties are much better at branching than the old cultivars. The development of free-branching is due to the combination of phytoplasma and breeding that has changed the way they branch (Vollmer, 2020). In the past, poinsettias were pinched after roots reached the edge of the pot and started growing down; at this time, they were pinched hard and breaks would form (Dole and Wilkins, 2005; Vollmer, 2020). Modern poinsettias are different: they will branch whether they are pinched or not, which can result in uneven canopy formation, and small stems (Dole and Wilkins, 2005; Vollmer, 2020). Modern poinsettias branch based on age of the stem rather than proximity to the apical meristem like their predecessors, meaning branches will form below the medium line if not pinched (Vollmer, 2020). To prevent this, it is recommended that poinsettia pinching should occur within 12 to 14 days of potting, when the plant is showing active root and vegetative growth, not necessarily when roots are starting to grow down the edge of the pot like previously recommended (Dole and Wilkins, 2005; Vollmer, 2020).

Photoperiod

Photoperiodism is important to many commercial floriculture crops as it relates to their growth and development. Many floriculture species are photoperiodic and light manipulation is used to manage their flowering response. However, not all plants respond to a specific photo period. Plant responses to photoperiod are characterized in three main categories including 1) plants that respond to shorter light periods (i.e. longer dark periods) to flower (short-day plants; SD); 2) plants that respond to longer periods (i.e. shorter dark periods) of light to flower (long-day plants; LD), and 3) day-neutral plants that will flower under any day-length (Hakuzan and Fukai, 2019; Garner and Allard, 1923). A plant sensitive to the ratio of day and night lengths results in a specific response: either vegetative or reproductive growth (Garner and Allard, 1923). Plants can further be classified into facultative or obligate SD or LD plants (Dole and Wilkins, 2005). In facultative plants, the initiation response for reproductive tissue (flowers) is accelerated under a specific LD or SD, however not required for a response (Dole and Wilkins, 2005). Obligate plants absolutely require either a SD or LD and will not initiate flowers without it (Dole and Wilkins, 2005). Plants like poinsettia and chrysanthemum (*Chrysanthemum xmorifolium*) are obligate short-day plants and when grown under natural photoperiods, they would not flower in time for specific markets (Dole and Wilkins, 2005; McMahon et al., 2011). One important technique that greenhouse growers can use to manipulate growth and development (e.g. flowering response) is the use of day-length extension or night interruption lighting. When a SD plant receives a short-day but experiences a flash of light during the night, it will not flower. However, if a LD plant experiences a night break of light, it will flower even though it is technically experiencing a short-day (Taiz and Zeiger, 2011).

The ability to understand photoperiodism is what makes growing poinsettias possible; even a small amount of light during the night from a streetlight can disrupt bract color development in poinsettias.

The importance of pinching and vegetative growth

Pinching does more than help ensure well-branched plants. The timing of the pinch may influence final plant height, as well, because nearly all poinsettia vegetative growth occurs between pinching and short-day initiation (Dole and Wilkins, 2005). During this period, a grower has the most control over crop height (Ecke, et al., 2004). After short-days arrive, typically around the autumnal equinox, poinsettias enter a reproductive growth phase where growers have less control over height management because the apical meristems transition to reproductive growth. By pinching early, and at least 12 days after potting, growers ensure that a maximum amount of vegetative growth by providing the widest window to control height as needed. Cultivars can react differently to day-length, however, and begin reproductive growth a few days before the natural short-days begin. Knowledge of individual cultivar specifications or using supplemental light to support vegetative growth is important to create a marketable crop.

Height Control and Temperature

Hundreds of studies on managing poinsettia height and development have been conducted including research found on irrigation techniques, lighting, temperature, plant growth regulators (PGRs), growing media, pinching date, fertilizer, and CO_2 injection (Berghage and

Heins, 1991; Clifford, et al., 2004; Harkess, et al., 2002; Schnelle, et al., 2006; Moe, et al., 1992;). The most efficient and best methods of poinsettia production are frequently a hot topic and growers are always looking for more information on how to improve their crops. One of these techniques is called DIF, or the difference between day and night temperatures.

DIF is used by growers to alter the height of plants (Dole and Wilkins, 2005). Depending on how DIF is used, it can result in plants finishing shorter or taller. A positive DIF, where day temperatures are higher than night temperatures, results in a taller plant (Berghage and Heins, 1991; Cockshull, et al., 1995; Dole and Wilkins, 2005). Negative DIF, where day temperatures are cooler than night temperatures, creates a shorter plant but also has side effects if used through the entire production cycle (Berghage and Heins, 1991; Cockshull, et. al., 1995; Dole and Wilkins, 2005). DROP DIF is a technique growers use to shorten plants, but temperatures dip during the first 2-hours after sunrise rather than all day (Moe, et. al., 1992). The final DIF technique is Zero DIF where temperatures during the day and night are the same. This creates shorter plants and stalls internode elongation (Dole and Wilkins, 2005). Temperature management is an effective way to influence plant height and can be used as an alternative to PGR height management, however, in areas with high late summer temperatures and high humidity like many southern areas of the U.S., negative and zero DIF can be difficult or impossible to accomplish.

The rate at which plant leaves unfold is determined by average daily temperature (ADT). The base temperature at which nearly no leaf unfolding occurs has been determined to be 45 °F for poinsettia. The linear range where leaf unfolding rate is proportional to temperature is 45 °F to 76 °F. Above 76 °F, leaf unfolding slows; it decreases if ADT exceeds 90 °F (Erwin, 1995). This is the basis for a graphical track of a standard poinsettia growth response.

Graphical Tracking

To monitor height, growers use a tool called graphical tracking. Height measurements are taken weekly from sentinel plants, then input into a spreadsheet. This height data can then be tracked along a target growth curve to monitor if the plant is at the right height for a given week. The goal of graphical tracking is to produce a plant at the correct height for sale. If a plant is too tall or short on the curve, a grower can make the decision to change the DIF or perhaps apply a PGR. This predictive curve is helpful to see what trajectory plants may be on and how early a grower should make adjustments in the cultural practices to adjust the course of height development. Faust and Klein (1998) noted that 'Freedom Red' is a cultivar that develops considerable height after the appearance of first color in the bracts; this is referred to as 'late stretch'. A late-season graphical tracking curve has been developed to assist growers in anticipating this late stretch (Fisher et al., 1997). This is precisely the sort of information that is needed for modern cultivars that has not been completely explored.

Basics of developing growth models for industry use

Leith (1999) outlines a growth model development process, how to package a model, and issues in selecting the type of model or tool to be developed. The primary audience is the grower, so their needs and ease of use are the paramount considerations. Leith concludes that the more complex the model package, the more difficult it will be for it to be useful for growers; therefore, the model should be simple and easy to adapt to individual production operations (Leith, 1999).

Harwood and Hadley (2004) pose that graphical tracks for poinsettias have been based on basic ideal curves that allow for modification only via a Response Time parameter. As such, their use is limited to sites and cultivars closely matching those that were used to develop the ideal growth curves. The Horticultural Development Council Poinsettia Tracker (Harwood and

Hadley, 2009) is their developed software that allows growers to create their own curves, but this carries the risk of accidental misuse. They address this problem by not allowing new curves to deviate greatly from existing curves and ensuring that they mimic past crop records. This curve however is no longer accessible to growers.

Research and information for graphically tracking poinsettias

The original graphical tracking curves were created in the 1990's by Erwin and Heins (1995), Leith (1999), and Fisher, et al., (1996). However, the cultivars used in these studies are no longer in mass production today, therefore more customization for modern cultivars is needed. Early graphical tracking data with DIF on poinsettias was published in 1991 by Berghage et al. from research conducted in 1986 using the cultivar 'Annette Hegg Dark Red.' Moe et al. (1992) provided graphical tracking data for poinsettia 'Lilo' and 'Starlight.' Fisher et al. (1996) used 'Freedom' poinsettias to quantify the relationship between phases of stem elongation and flower initiation, and Liu and Heins (1998) used 'Freedom' poinsettias to model vegetative growth and development in evaluating the response to the ratio of radiant to thermal energy. From the cultivars previously mentioned, only 'Freedom' is still for sale (Dümmen Orange, 2020b).

Poinsettia growth models that have existed for the commercial greenhouse industry include The Greenhouse CARE System (Ehler et al., 1995; Fisher and Heins, 1995), University of New Hampshire FloraTrack (Fisher and Heins. 2002), and Ecke OnTarget™ (ontarget.dummenorange.com). In addition, The University of Florida Poinsettia Height Control (hort.ifas.ufl.edu) website has the greatest variety of cultivars actively displayed, but the results do not relate well to production environments in more northern latitudes. None of these sources of information are currently active, let alone up-to-date.

The most active and in use graphical tracking program is Dümmen Orange’s recently updated OnTarget™ website (Dümmen Orange, 2020a), rebranded from the Ecke OnTarget™ tracking site. This program allows for the input of dates and heights to be plotted against an automatically generated tracking curve. Growers can input starting height at pinch, desired finish date and minimum and maximum target heights. Next, the grower selects either a standard, late, or unpinched curve, or to create a custom curve. The three pre-programed curves only allow for minor modifications depending on growing environment. The custom curve setting is highly customizable but relies on the grower having an understanding on how a curve is made and how each cultivar is supposed to grow, going against the recommendations of Leith (1999). The challenge with these curves and the commonly presented standard curve is that it does not consider differences in growth patterns from lower vigor varieties such as Dümmen Orange’s ‘Premium’ series.

Based on the age of the original graphical tracking curves, updates could be needed to allow for better customization to meet grower needs. Investigating the slope of the linear phase of different cultivar vigor groups may help graphical tracking systems be better suited for grower needs.

Chapter 4 - Evaluating the Poinsettia Graphical Track for Modern Cultivars

Introduction

Poinsettias [*Euphorbia pulcherrima* (Willd. ex Klotzsch)] are a standard potted flowering crop found throughout the world. Poinsettias comprised $149 million out of the $877 million generated in the wholesale potted flowering indoor or patio plant category in the United States (USDA, 2019). Though flowering potted crops only account for 16% of the $4.62 billion wholesale floriculture industry (USDA, 2019), knowing how to grow poinsettias efficiently and cost effectively is essential for growers who produce thousands of pots for the holiday market.

One way growers ensure proper height management is by using a technique called graphical tracking. Graphical tracking requires growers to take weekly measurements of sentinel plants and input the data into a target growth curve. This growth curve helps guide grower decisions by indicating when a plant is too tall or too short at a specific stage in the production cycle. With their knowledge of the progress of their poinsettia crop compared to a standard growth curve, a grower can determine if a plant growth regulator (PGR) should be applied, changing the difference between day and night temperatures (DIF) should be instituted, or other height control measures should be employed.

Graphical tracking curves were originally developed in the 1990's by Erwin and Heins (1995), Leith (1999), and Fisher, et al., (1997). The original poinsettias used to create growth curve models, included 'Annette Hegg', the first free-branching cultivar (Berghage et al., 1986) 'Lilo', 'Starlight' (Moe et al., 1992) and 'Freedom' (Fisher et al., 1996). These plants are no longer dominant cultivars in the industry (Dümmen Orange, 2020b). The modern poinsettia has progressed from the early days of poinsettia breeding, becoming better branched, and selected for different growth characteristics (Dole and Wilkins, 2005; Vollmer, 2020). With a graphical tracking system created over 30-years ago, there is an opportunity to update their accuracy for modern poinsettia varieties and improve their ability to be customizable to groups of cultivars.

Poinsettias have three distinct growth phases from the time of pinch, when graphical tracking is initiated, to flowering; this is described as an S-shaped, sigmoidal growth pattern. The lag phase, Period 1, describes the initially slow growth as axillary buds begin to develop that occurs immediately after pinching, and lasts one to two weeks (Ecke et al., 2004). Next, the linear phase, Period 2, describes the period during which poinsettias elongate at their most rapid rate and presents the best possibility to manage crop height (Ecke et al., 2004). Finally, the plateau phase, Period 3, occurs as no new leaves are added and flowers are initiated and developed; this phase occurs about two weeks prior to market or earlier (Ecke et al., 2004). These periods were used to develop the, “phasic model” growth curve, a custom version of a sigmoidal curve (Lieth, et al., 1996). The duration (number of weeks) and manipulation of DIF during Period 2 sets the stage for height management of this crop. Therefore, the focus of adjusting the best slope for the target graphical tracking curve is during Period 2.

Poinsettias can be classified into three general vigor groupings: low, moderate, and high. Each of these groupings categorize poinsettias by the speed of their growth and can influence the final height of the plant (Styer, 2003). Each of the vigor groupings benefit from cultural practices to meet customer specifications. Current standard graphical tracking curves do not allow for a great deal of customization for different vigor groupings.

The objective of this research was to evaluate whether the target graphical track, which was developed with older poinsettia cultivars, should be modified for use with modern poinsettia cultivars. To do this, we 1) compared the slope of cultivars from different vigor groupings during the linear phase of growth to the standard curve; 2) evaluated whether y-intercept of the track is related to vigor of a variety, and 3) compared graphical track characteristics from the 2019 production season in Manhattan, Kansas, to the 2018 production season as well as other locations in North America to assess the broad applicability of this work.

Materials and Methods

Growth of multiple poinsettia cultivars that represent a range of vigor (Table 4-1) were tracked in 2019. Rooted cuttings were potted on July 19, 2019 in 16.5 cm diameter (677 ml vol) azalea pots (ITML; Myers Industries; Akron, OH) using a peat-based root medium (Pro-Mix BX; Premiere Tech; Quakertown, PA). Plants were grown in glass greenhouses of Kansas State University's Throckmorton Plant Sciences Center (Manhattan, KS) with a fan-and-pad cooling system and steam heat source. Arthropod and disease management occurred as needed with the following applications: Conserve SC (28 Aug), Safari (16 September), and Botanigard (10 October). RootShield (BioWorks; Victor, NY) was applied as a drench after transplanting rooted cuttings to help reduce incidence of root rot pathogens. Plants were fertigated at each watering using municipal water (pH of ~9 and alkalinity of ~ 40 ppm) and ~200 ppm N from 20N-4.3P-16.6K injected fertilizer (JR Peters; Allentown, PA). Two saturated medium extract (SME) readings were taken, once on 20 September, and at production finish, to determine pH and EC of the poinsettia crop (Table 4-2) (Accumet XL20 meter, ThermoFisher Scientific, Waltham, MA). Osmocote (14N-14P-14K; The Scotts Miracle-Gro Company, Marysville, OH) was applied on 22 September 2019 at a rate of ¼ teaspoon per pot as top-dress in response to low SME readings (Table 4-2) to increase the EC to an optimal range.

Temperature and Environmental Control. Temperature and light conditions were managed by Argus (Surrey, British Columbia) or Wadsworth Controls (Arvada, CO) environmental control systems, depending on the greenhouse room. Data loggers (MX2202; Onset Computer Corporation; Bourne, MA) were used within each replicated greenhouse environment to record real time temperature and light changes.

To generate information on the actual Average Daily Temperature (ADT) and DIF (day temperature average minus night temperature average) (Dole and Wilkins, 2005), daily sunset and sunrise time was used. In a spreadsheet (Microsoft Excel ver. 2010) sections of days were averaged by certain day and night lengths that were closest to a round time (i.e. 13 Sep 2018-25 Sep 2018; Day 7am-7:30pm; Night 7:30pm-6:30am); sunrise and sunset times were adjusted for daylight savings time. The ADT and DIF was then calculated from the averages captured from the adjusted time periods (Table 4-3; Figure 4-2).

High-pressure sodium lights were used for night interruption from 4 Sept to 20 Sept from 10pm to 2am to ensure all cultivars began short-day initiation on the same day of 21 Sept, the vernal equinox and traditional start of short days.

Treatments. In 2019, two pinch treatments and two DIF environments resulted in a two-way factorial treatment structure. Ten pots of each of the four cultivars were placed in four production environments for a total of 160 plants. There were two pinch treatments applied to each cultivar in each production environment: 80 total plants received the early pinch (EP) treatment, 12 days after potting (31 July); the final 80 plants received the later pinch (LP) treatment, 26 days after potting (14 Aug). Once pinched to leave 6 or 7 nodes, plants from each pinch treatment were equally and randomly divided between four greenhouses; two greenhouses (GHC and GHE) controlled by Argus had a target negative DIF with a -5 DROP where the temperature of the greenhouse was set to drop 5 °F below the daytime temperature during a period of 4-hours after sunrise. Greenhouse temperatures were set at 15.5 °C/18.3 °C outside of the DROP period. The other greenhouse environments (GHI and GHM) were controlled by Wadsworth Controls step-control systems with a target +10 DIF with temperatures set at 23.8 °C/18.3 °C. Table 4-3 shows the observed DIF and ADT for each greenhouse environment. Experimental design was completely random design (CRD) with replications randomly spaced on one bench in each greenhouse with spacing of at least 61 cm from centers.

Data Collection

Height measurements were taken twice weekly on each plant from bottom of the pot to the top of the tallest growing point. Height data were then inputted into a standard graphical tracking curve in Excel based on Erwin (1995). On 19 Sep 2019, before natural SD began, a leaf-count of fully expanded leaves was taken from all plants. Pollen development and anthesis were monitored and recorded during each data collection day using a floral development scale [1= all green leaves; 2= bracts starting to color; 3= bracts starting to color + cyathia visible; 4= bracts fully colored + cyathia visible; 5= bracts fully colored + some cyathia shedding pollen; 6= all cyathia shedding pollen; 7= seed pod formation] (Figure 4-1). Final data collection was taken as each cultivar reached anthesis, including average inflorescence widths (total width of two randomly selected inflorescence), canopy width (average of two measurements across top of the plant), inflorescence number, and a second leaf-count. This leaf-count at harvest did not include any bracts that had changed color. Destructive harvest was performed, and a fresh weight of the entire plant, minus the roots, was measured. The plants were then placed in a drying oven set to 70 °C for four days and then dry weights were recorded.

Statistical Analysis

Experimental design was a split plot with main plots as the greenhouse environments. The five replicate pots of each cultivar (experimental units) with equal representation of both pinch groups (factors) were completely randomized within each greenhouse environment. Measurements taken from each plant were input into a spreadsheet. We analyzed the slope and intercept of data measurements taken from two-weeks after pinch to short-day initiation (Figure 4-3). This period of time is when growers have the most control over height (Hammer, personal communication). This information, along with final measurements, the height two weeks after pinch, and height at short-day initiation were analyzed with JMP (Version Pro 14, SAS Institute Inc., Cary, NC, 1989-2019). A full factorial fit model was run for all inputted measurements. The ANOVA was recorded and examined to determine significance. For the effects that exhibited significance, we then ran an LSMeans Difference Tukey HSD for mean separations at significance level of $P \leq 0.05$.

The standard graphical track to which we compared our data was generated based on instructions from Erwin (1995) (Figure 4-4). For target finish height, we used 30 (lower target curve) to 36 (upper target curve) cm (12 to 14 in), which is based on industry specifications for the container size of our crop (Kurlich, 2019; personal communication).

Verification Data Collection

We compared our results from 2019 to 1) graphical tracking data for the same poinsettia cultivars produced in a different production year, 2018, in Manhattan, KS; and 2) to graphical tracking data for the same cultivars produced other locations in North America between 2017 and 2019. Dümmen Orange provided us with information from their OnTarget™ Graphical Tracking program (2020a) (Figure 4-5). This information contained growth measurements input by growers from across North America and was extracted for the specific cultivars that we were evaluating.

Different production year, same geographical location: In 2018, six pots of each of four poinsettia cultivars (Table 4-1) were potted in the same containers and substrate as used in 2019, then placed in two production environments for a total of 48 plants. Rooted cuttings of 'Ferrara' and 'Christmas Spirit' from PlantPeddler (Cresco, IA) were potted on 9 July and pinched on 1 August, after 23 days of growth, leaving six to seven nodes per plant. Rooted cuttings of 'Ferrara', 'Premium Marble', and 'J'Adore Pink' from Knox Nurseries (Winter Garden, FL) were potted on 27 July and pinched on 13 August, 17 days after planting, also leaving six to seven nodes per plant. After pinching treatment, plants were equally (6 plants per cultivar per greenhouse) divided between two greenhouses with setpoints for either 0 DIF or +10 DIF conditions. In the 0 DIF greenhouse controlled by Argus, day and night temperatures were set to a 20.5°C, however the measured ADT was 23.3°C/20.5°C (74°F/69°F) creating a +5 DIF environment (GH6E; Figure 4-6). The other half of the poinsettias were placed in a +10 DIF greenhouse controlled by a Wadsworth system with daytime set point at 23.8°C and 18.3°C for night. The actual ADT of this greenhouse was 24.4°C/19.4°C (76°F/67°F) creating a +9 DIF environment (GH2E; Figure 4-6). Temperatures were monitored with data loggers (UX100-003, Onset Computer Corporation; Bourne, MA). Plants were completely randomized and placed in final spacing position on one bench inside each greenhouse and at least 30.5 cm from center of each plant.

As with 2019, twice weekly, height measurements were taken of each plant and input into the standard graphical tracking curve. At the end of the experiment, average measurements were taken of inflorescence width, entire canopy width, and a floral development rating was assigned using the same procedures as in 2019.

Same and different production years, different geographical locations*:* Using the graphical track information provided by Dümmen Orange, we analyzed the cultivar Ferrara because it had the most complete data set to compare to our experiment. We used only data from 'Ferrara' that had +/- 2 days from either of our pinch 2019 pinch dates (31 July and 14 August) we also excluded any reports that had noted use of PGR. Then, we determined the date from two weeks after pinch and the short-day initiation for the specific year the data was from, following the same procedures as the 2019 data analysis. Slope and intercept were calculated from that specific time period to compare to results from 2019.

Results and Discussion

Cultivar Data. Final growth measurements were used to characterize and evaluate poinsettia growth across different greenhouse environments. Cultivar was the most consistently significant effect that affected all parameters based on vigor groupings, including: leaf-count one and two, canopy width, inflorescence width, fresh weight, dry weight, inflorescence number, final height, height at short-day initiation, and height two-weeks post pinch (Table 4-4, Table 4-5). Specifically, for final height in 2019, the most vigorous variety, 'Christmas Spirit', was tallest, followed by moderate-vigor 'Ferrara' and 'J'Adore Pink', then finally by the low-vigor cultivar 'Premium Marble' (Table 4-4). Similarly, leaf-counts one and two followed this grouping by vigor (Table 4-5). Fresh and dry weight results very clearly indicate a difference in plant mass based on cultivar, and interestingly, this significance does not divide predictably between vigor groupings (Table 4-5). Fresh and dry weights of 'Christmas Spirit' and 'Premium Marble' are not different which suggests similar mass accumulation despite different heights (Table 4-5). All of these parameters reveal the differences in plant characteristics that contribute to groups of different cultivars potentially requiring modified target graphical tracks to guide crop management. Differences were not due to fertilization or nutrient accumulation, as pH and EC were similar across treatments (Table 4-2).

Pinch Date Data. Pinch date was significant for leaf-count one and two, canopy width, fresh weight, dry weight, inflorescence number, final height, height at short-day initiation, and height two-weeks post pinch (Table 4-4, Table 4-5). Pinching early or later alters the amount of time a plant experiences long days which can affect the vegetative growth. The poinsettias pinched on 31 July 2019 were given 14 more long days compared to those pinched on 14 August 2019. This two-week difference was enough to significantly influence plant growth characteristics at harvest. This can be explicitly observed by comparing average fresh and dry weights for different pinch dates. The average fresh weight for earlier pinched plants was 255 g, and the dry weight was 42.3 g (Table 4-5). For later pinch, the fresh weight was 215 g and resulting dry weight was 36.1 g (Table 4-5). This biomass difference in pinch date was also found by Abdullah and Seng (2003) using 'Ecke's Red' poinsettia finding plants pinched two-weeks after potting (early pinch) had higher bract numbers and bract area (cm^2) in comparison to poinsettias pinched four-weeks after potting (late-pinch).

Although pinch date resulted in different finish heights, when we examine the cultivar by pinch interaction, there is no difference in height between pinch dates within the same cultivar (Table 4-4, Figure 4-7). For example, 'Ferrara' has a height of 36.52 cm for EP and 35.39 for LP which is not different from each other (Table 4-4)**.** This lack of significant difference shows that pinch does not significantly influence the finish height of poinsettias as much as it changes the biomass accumulation. Graphical tracks begin with pinch date which in turn predicts how plant growth should take place to reach the finish height target. When the vegetative growth period is extended or shortened with an earlier or later pinch, difference in finish plant height is not as marked as other quality aspects including leaf number and plant weight.

Greenhouse Environment Data. Greenhouse environment also influenced some growth measurements, including final height (Table 4-4, Figure 4-8), second leaf-count, canopy width, fresh weight, dry weight, and inflorescence number (Table 4-5). This is not surprising, given that the greenhouse environments were designed to evaluate different DIF and ADT (Table 4-3), which are known to influence plant growth characteristics such as height and rate of development (Dole and Wilkins, 2005). For example, greenhouse GHE, which provided the closet zero DIF environment from 1 October to 1 December 2019; resulted in these plants having the shortest final height (though not different from the next tallest plants in GHI) (Table 4-4). Results from the SME pH and EC readings were within the normal range for poinsettia production which reduces the possibility of any height difference due to nutritional deficiency (Table 4-2).

Several of the parameters also resulted in significant interactions, mainly within cultivar by pinch, greenhouse by cultivar, and greenhouse by pinch (Table 4-4, Table 4-5). Cultivar by pinch was significant for leaf-count one, canopy width, and final height (Table 4-4, Table 4-5). Greenhouse by cultivar was significant for canopy width, inflorescence number, final height, height at short-day initiation, and height two-weeks after pinch (Table 4-4, Table 4-5). Greenhouse by pinch was significant for only leaf-count two (Table 4-5). These interactions indicate that the different greenhouse environments also played a role in how plants finished.

Slope and Intercept Data. To determine how the slope of the standard graphical tracking curve's linear phase might need alteration for different cultivars and pinch times, we evaluated the slope and intercept of seven weeks for the earlier pinched poinsettias and five weeks for the later pinched plants during the linear phase of vegetative growth. Specifically, we chose the time period two-weeks after pinch to the initiation of short-days. The specificity of this time helped us exclude the lag-phase of growth on the tracking curve and focus on the period after the apical meristem became reproductive and flower bud development occurred.

We found that slope was significantly different only for cultivar (Table 4-4, Figure 4-9). The lowest vigor ‘Premium Marble’ had an average slope of 0.15 while the highest vigor cultivar, ‘Christmas Spirit’ averaged a slope of 0.29 (Table 4-4). The two moderate vigor cultivars, ‘Ferrara’ and ‘J’Adore Pink’ had different slopes from each other, 0.22 and 0.25 respectively (Table 4-4), but were the most closely grouped of the cultivars. Notably, slope was not different for pinch date or greenhouse environment. These results suggest that breeding companies might offer different graphical tracks based on cultivar vigor groupings. Following the vigor groupings that were demonstrated with the growth data, we recommend a high-vigor target curve for varieties such as ‘Christmas Spirit’, a moderate-vigor target curve for varieties such as ‘Ferrara’ and ‘J’Adore Pink’, and a low-vigor target curve for varieties such as ‘Premium Marble’.

Intercept was different for cultivar and pinch date (Table 4-4). The intercept itself represents the starting height of the poinsettias. In the linear equation, $y=mx+b$; y=independent variable, m=slope, x=dependent variable, and b=y-intercept. In our experiment, the equation for ‘Ferrara’ is $y=(0.22)x+13.19$, where x=time and y=height. When $x=0$, $y = 13.19$, or the average starting height for ‘Ferrara’ after the two weeks of lag phase when our calculations began (Table 4-4).

‘J’Adore Pink’ was the cultivar that resulted in a lesser intercept compared to the other varieties (Table 4-4), which connects back to height of the plants at pinch, where the graphical track begins. Although intercept was significant for cultivar, the fact that ‘J’Adore Pink’ was the only cultivar different from the others also suggests that intercept may not be directly related to the vigor of the plant, but again, an indication of starting height which can be different based on the source and quality of cuttings (Styer, 2003).

The average pinch date intercepts were 12.22 for early pinch and 13.15 for the later pinch (Table 4-4). This difference shows that even though both groups were pinched according to the same guideline of leaving 6 to 7 nodes per plant, the later pinch resulted in taller plants as the graphical track began. This result is not surprising because the plants pinched later had 14 additional days for internode elongation before their pinch. This initial height is also demonstrated by the height two-weeks after pinch as the plants were 15.5 cm for the early pinch and 16.5 cm at the late pinch (Table 4-4). This difference was eventually overcome and by the time short-day initiation occurred when the early-pinched poinsettias had an average height of 23.6 cm whereas the later pinch resulted in heights of 21.5 cm (Table 4-4). The early-pinched plants were already two-weeks ahead of the later-pinched plants, so they grew under the most long-days; this contributed to them being taller than the later-pinched plants, at least during the time period going into short-days (Table 4-4).

The interaction of greenhouse by cultivar by pinch was only significant for intercept and likely related to the different environmental set points that contributed to different internode elongation after potting.

Verification data from different production year, same geographical locations. To compare the results of our 2019 experiment, we looked back to extensive graphical tracking data collected in 2018. We only made statistical comparisons for pinch date in ‘Ferrara’ because it had two pinch dates within two DIF environments (Table 4-6).

Growth data. In 2018, 'Ferrara' had significant differences in final height in both the greenhouse and pinch parameter (Table 4-6). Width was significant for pinch, and inflorescence width was only significant for greenhouse by pinch (Table 4-6). The significance found at these parameters matches what we found in 2019, excluding the greenhouse by pinch interaction for inflorescence width.

For the other three cultivars, the cultivar effect is significant for final height, canopy width, and inflorescence width, which supports our findings in 2019 (Table 4-4, Table 4-5, Table 4-7). The greenhouse effect was only significant for canopy width, which was also the case in 2019 (Table 4-5, Table 4-7). There are three differences between 2018 and 2019 growth data. First, there is a lack of significance in final height between greenhouses and the cultivar by greenhouse interaction, and there is no difference in the cultivar by greenhouse interaction for canopy width (Table 4-7). In 2019, these three parameters were different (Table 4-4, Table 4-5). The differences might be explained by the more similar greenhouse environments that were compared in 2018 (Figure 4-6) compared to 2019 (Figure 4-2).

Pinch date. Slopes were comparable for 'Ferrara' between 2018 (0.22 to 0.23) and 2019 (0.21 to 0.22) (Table 4-4, Table 4-7). In 2018, slope was significant for pinch date, unlike our 2019 results (Table 4-6). This difference might be explained by the quality of plants received where plants used for the EP date had a lower quality in comparison to the LP group. This does not support the idea that we proposed based on the 2019 results in which the target graphical track could be the same regardless of pinch date, but the fact that there were initial health differences between the pinch dates could explain why we saw this result in 2018 but not 2019. Styer (2003) states that the quality of the cutting, including the source and size, can impact final poinsettia height, which is what we observed in 2018.

Intercept was not different for any effect in 2018 (Table 4-6). This difference from the pinch significance in 2019 could also be compared to plant quality and the fact that the two pinched groups came from two different growers at two different times creating an unequal elongation time period and differences based on plant health.

The other three cultivars were different for only the cultivar effect, and not greenhouse or greenhouse by cultivar, for slope and intercept (Table 4-7). The significance in cultivar and lack of significance in greenhouse environment and the cultivar by greenhouse interaction fits with what was found in 2019 (Table 4-4, Table 4-7). The actual slopes from 2018 were in the same range as those in 2019. 'Premium Marble' ranged from 0.17 to 0.18 in 2018 and 0.15 to 0.16 in 2019; 'Christmas Spirit' ranged 0.26 to 0.28 in 2018 and 0.28 to 0.30 in 2019; and 'J'Adore Pink' ranged 0.23 to 0.29 in 2018 and 0.28 to 0.31 in 2019 (Table 4-4, Table 4-8). The closeness in these ranges help support the idea of different slopes for different vigor groups and that cultivars are fairly consistent between years and greenhouse environment differences.

Verification data from same and different production years, different geographical locations. Information provided by Dümmen Orange (Table 4-8) focused on only 'Ferrara' because of the completeness of the information and multiple locations with pinch dates that aligned with our study could be extracted. The data provided was from anonymous users of the publicly available software, so the only details about environments and plant growth were self-reported in the program. There were unequal amounts of data available to gain a wide perspective on the differences between EP and LP, however, what we were able to collect assists in a level of verification.

Growth and Pinch data. Final height of 'Ferrara' produced in locations across North America in 2017, 2018 and 2019 resulted in final heights ranging from 25 cm to 57 cm, selected based on pinch dates similar to those in our study (Table 4-8). This compares to our final heights of 36 cm in 2019 and 34 cm in 2018.

Slope and Intercept data. The slope and intercept information from the industry varied widely, however using a t-test to compare the slope of EP vs LP, there was no significance found ($t(6)=-0.83$, $p=0.43$) (Table 4-8). The average of all the slopes found was 0.23 which falls very near the range reported in 2019 (0.21 to 0.22) (Table 4-4, Table 4-8). However, the large range in slopes (0.15 to 0.36) could still argue against our evidence that no matter what the environment is, the plant will follow the same linear growth pattern, but, there are other factors from this information we are not aware of. For example, we cannot know for sure whether PGR was applied, we do not know how different the environments were from our environments, as well as other parameters that might be useful when drawing a comparison between the industry data and 2019. Even though this information is lacking, the fact that a t-test comes out with no significance between EP and LP still helps validate our findings in 2019.

We demonstrated that slope and intercept of the linear phase of the graphical track are similar from year to year in the same geographical location, even with different production environments, but we cannot project that the results from one location will apply to all production locations. However, individual growers could generate modified target graphical tracks for their operation and have confidence in using them from year to year.

Conclusion

Graphical tracking is an important and crucial tool for managing poinsettia height. Adapting it to modern cultivars could help improve the quality of the tool and assist growers in making better management decisions. Pinch date did not influence ‘Ferrara’ final height in 2018 and while it was significant in 2019, the difference was only 1-cm, which is not a meaningful difference for growers. Therefore, while pinch date dramatically influences total plant growth, the impact in finish height was not extraordinary over two production years. Though our pinch dates differed by only two weeks, this is contrary to industry understanding in which pinch date is thought to dramatically impact finish plant height.

Pinching could still play a role in how different poinsettia vigor groups finish, however. That is, for less vigorous varieties, it is important to pinch earlier to achieve adequate vegetative growth; for more vigorous varieties, later pinch can help manage excessive vegetative growth. Styer (2003) recommends different levels of pinching (soft vs. hard) based on plant vigor to help them finish within specifications, as pinch level determines the number of nodes left on the plant and, therefore, axillary buds that will break. Vollmer (2020) however, recommends using more of a medium (not hard or soft pinch) on modern cultivars. Pinching earlier is usually better when a grower needs greater amounts of time to manipulate finish height or push a low-vigor cultivar to reach taller finish height specifications.

Slope during the linear phase was a useful tool to delineate how the target curve should be adjusted based on cultivar vigor grouping. Different and customized slopes during the linear growth phase for cultivar vigor groupings could help a grower visualize that some cultivars may need PGR earlier than others and will need to pay closer attention to specific vigor groups to help manage height. Customized curve slope based on vigor will better follow the growth of a plant and will help a grower see what changes need to be made faster to reach target heights. In particular, providing at least three different standard curves based on low, moderate, and high vigor groupings, would allow growers to modify cultural practices in time to meaningfully impact crop height development during a production season. If a grower does not want to change from using one standard curve, understanding that slopes of different vigor groups exist still help point to specific times where height management needs to occur. Based on our research, available tracking software would assist the grower by providing new curves tailored to the needs of different poinsettia vigor groups. For example, program adjustments made to the linear phase of the curve for low-vigor varieties would help spur early-production-cycle pushing of growth. These, “pre-packaged” curves help grower usability and create less room for error (Leith, 1999).

The modern poinsettia is different from its predecessors, and graphical tracking should be adapted to it. More research investigating the slope differences of cultivars and vigor groups, as well as a more customizable graphical tracking program will help form a more complete picture of the specific changes to the standard curve that need to take place.

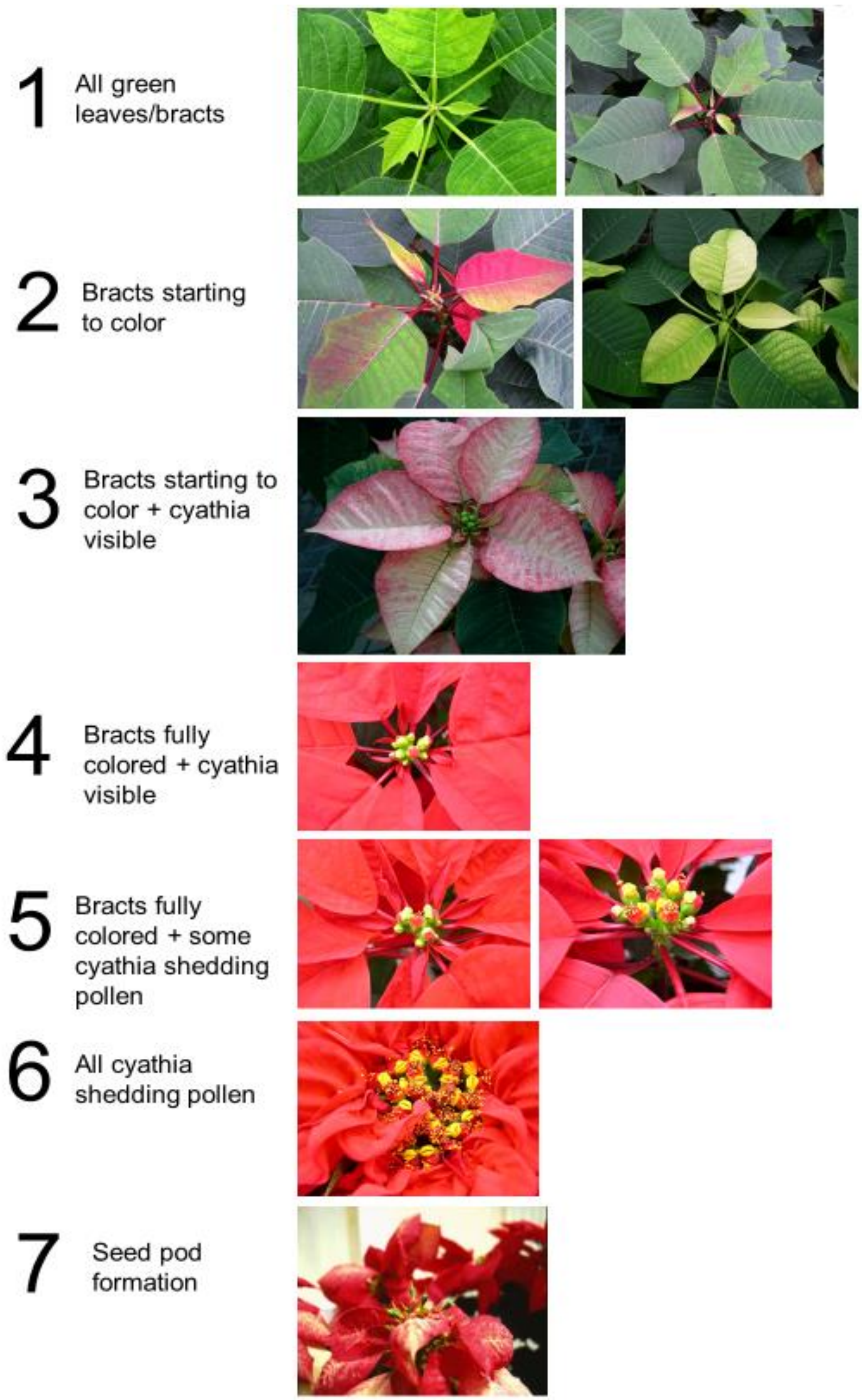


Figure 4-1: Poinsettia (*Euphorbia pulcherrima*) flower and bract development rating scale [1 to 7].

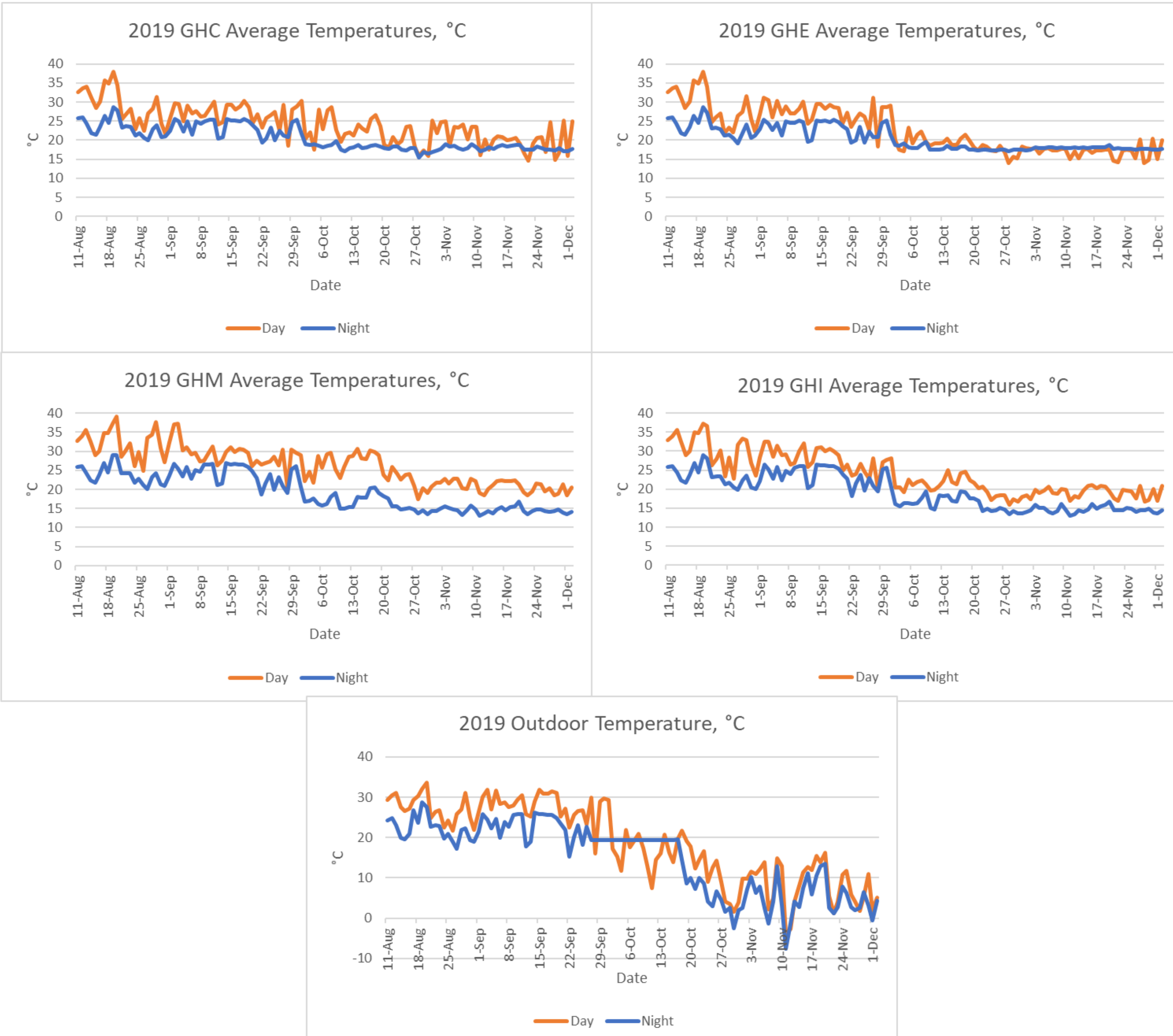


Figure 4-2: Average daily and nightly temperatures during poinsettia production in 2019. Averages calculated with temperature data from HOBO data logger (MX2202; Onset Computer Corporation; Bourne, MA). Day and nighttime length adjusted for sunset/sunrise and daylight savings time.

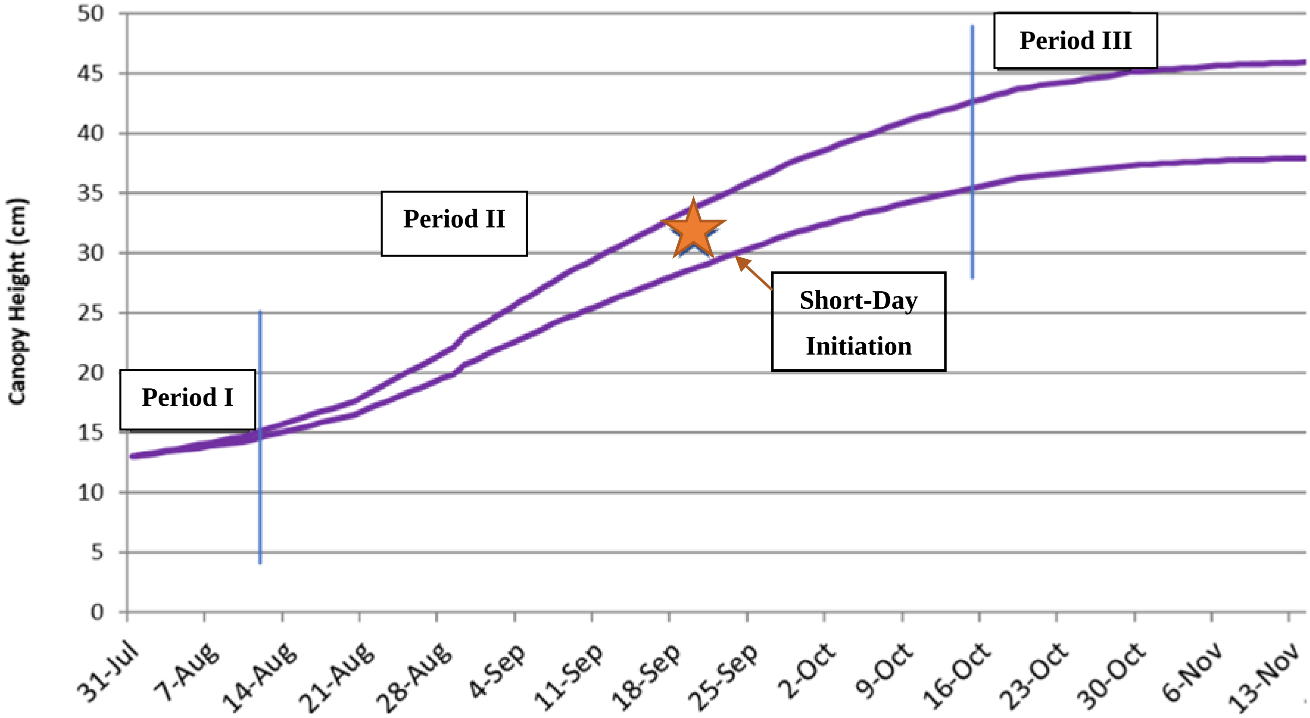


Figure 4-3: Standard curve separated into three periods: Period I (lag phase), Period II (linear phase), Period III (plateau phase). Short-day imitation, marked with a star, occurred 21 September 2019.

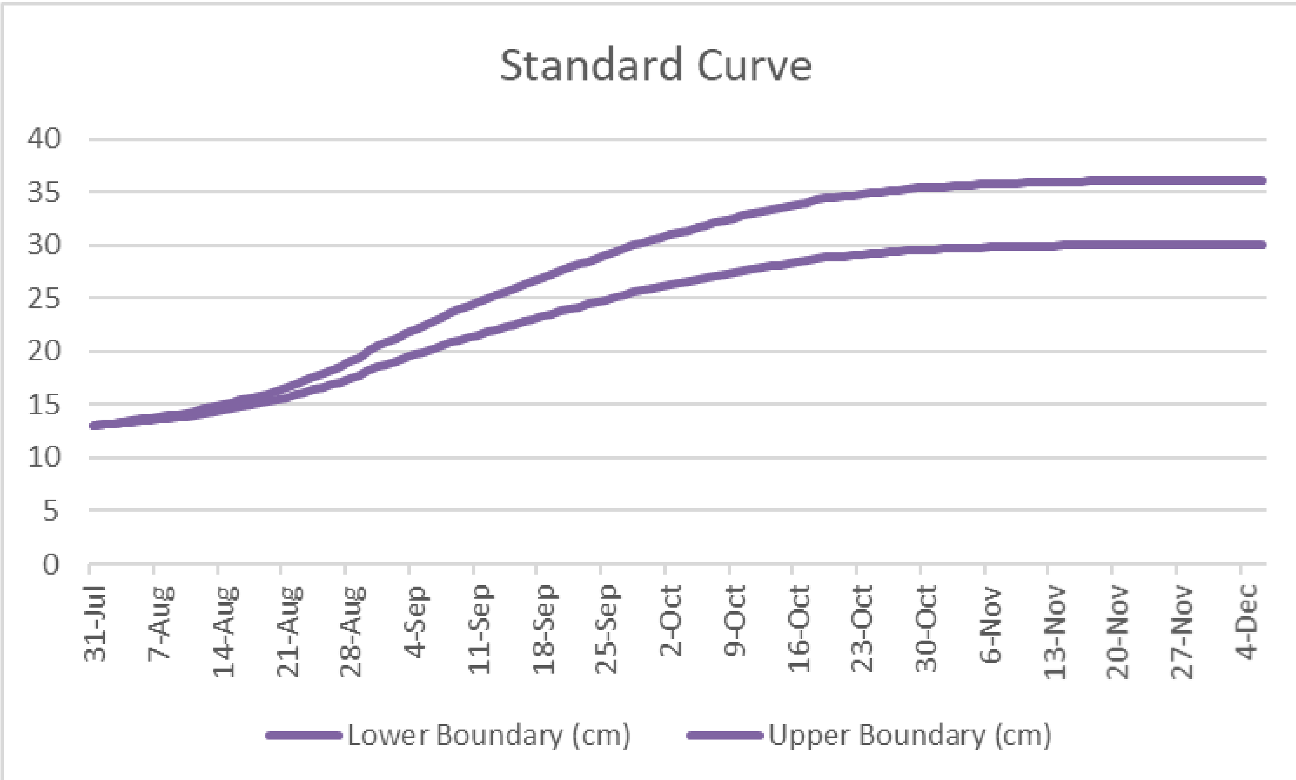


Figure 4-4: Standard curve used in 2019 graphical tracking experiments, generated from procedure outlined by Erwin (1995). Height at pinch is 13 cm, lower boundary final heigh is 30 cm, and upper boundary final height is 36 cm.

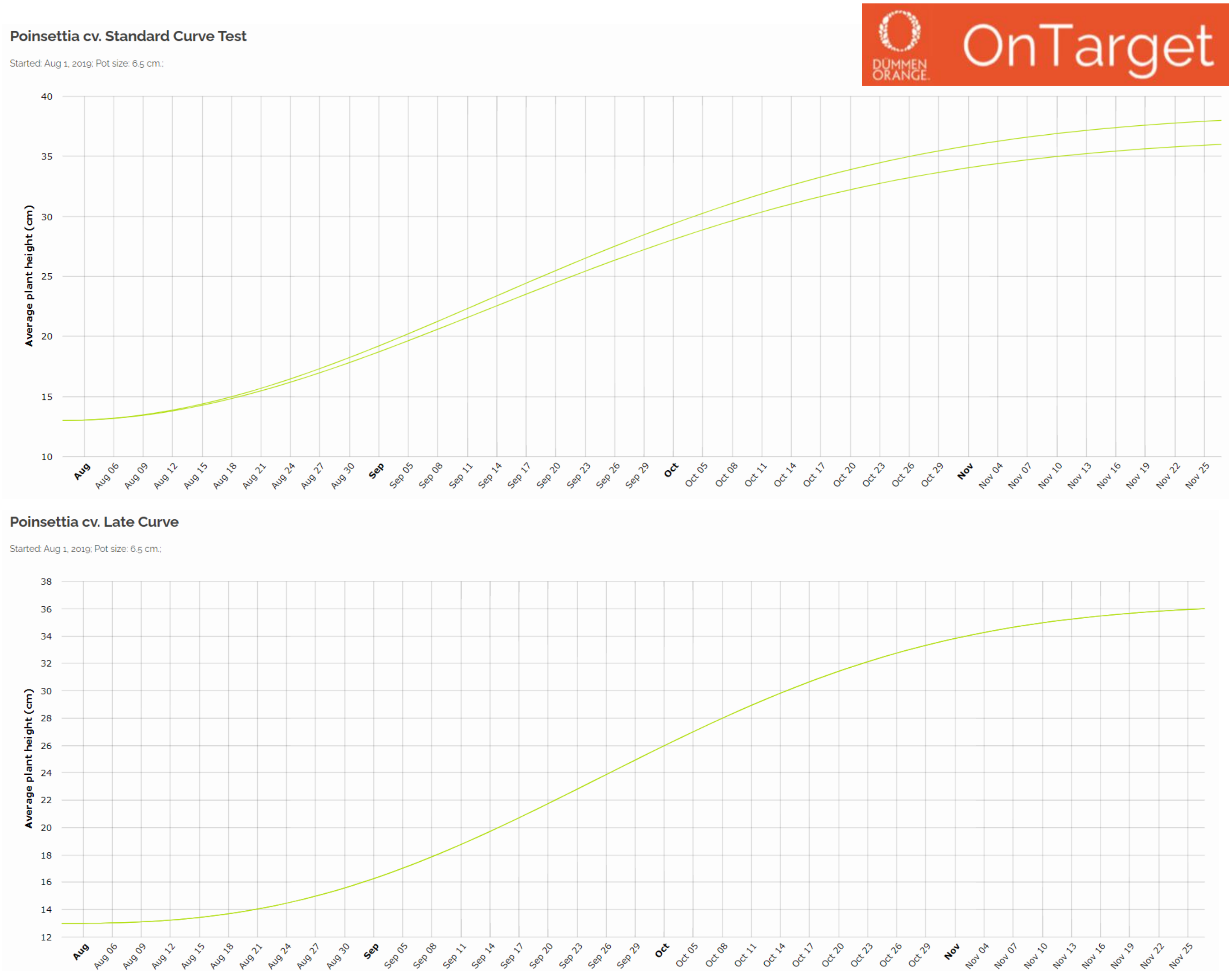
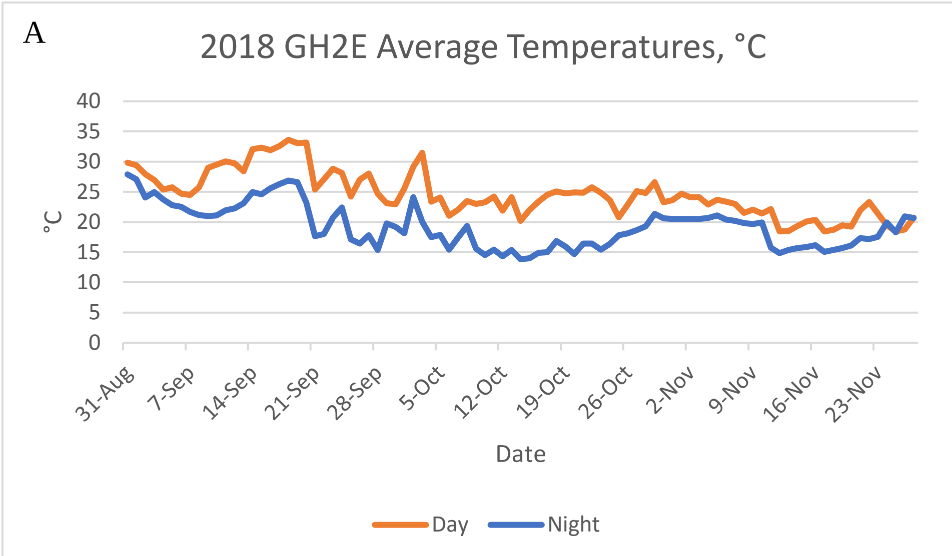


Figure 4-5: Two examples of graphical tracking curves generated in Dümmen Orange's OnTarget™ (ontarget.dummenorange.com) online program. The top image is a standard curve, and the lower image is a late curve.



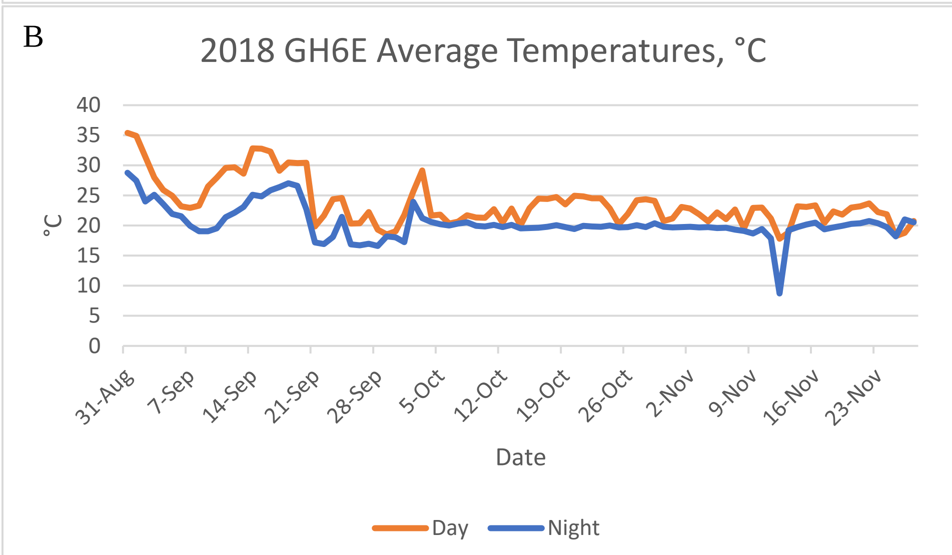


Figure 4-6: Average daily and nightly temperatures during poinsettia production in 2018. Averages calculated from data recorded with HOBO data loggers (UX100-003, Onset Computer Corporation; Bourne, MA). Day and night time length adjust for sunset/sunrise and daylight savings time. A) Actual temperature: 23.3°C/20.5°C (74°F/69°F) Actual DIF: +5. B) Actual temperature: 24.4°C/19.4°C (76°F/67°F) Actual DIF: +9.

Figure 4-7: Three poinsettia (*Euphorbia pulcherrima*) cultivars used in graphical track experiments in 2019 representing each vigor group (low, moderate, high). Early pinch (EP) groups are compared to later pinch (LP) groups from two separate DIF environments. 'Premium Marble' is low-vigor, 'Ferrara' is moderate-vigor, and 'Christmas Spirit' is high-vigor.

Figure 4-8: Poinsettia (*Euphorbia pulcherrima*) heights captured at each DIF environment (3, 7, 9, 12) used in 2019. Cultivar shown is early pinched (EP) ‘Christmas Spirit’.

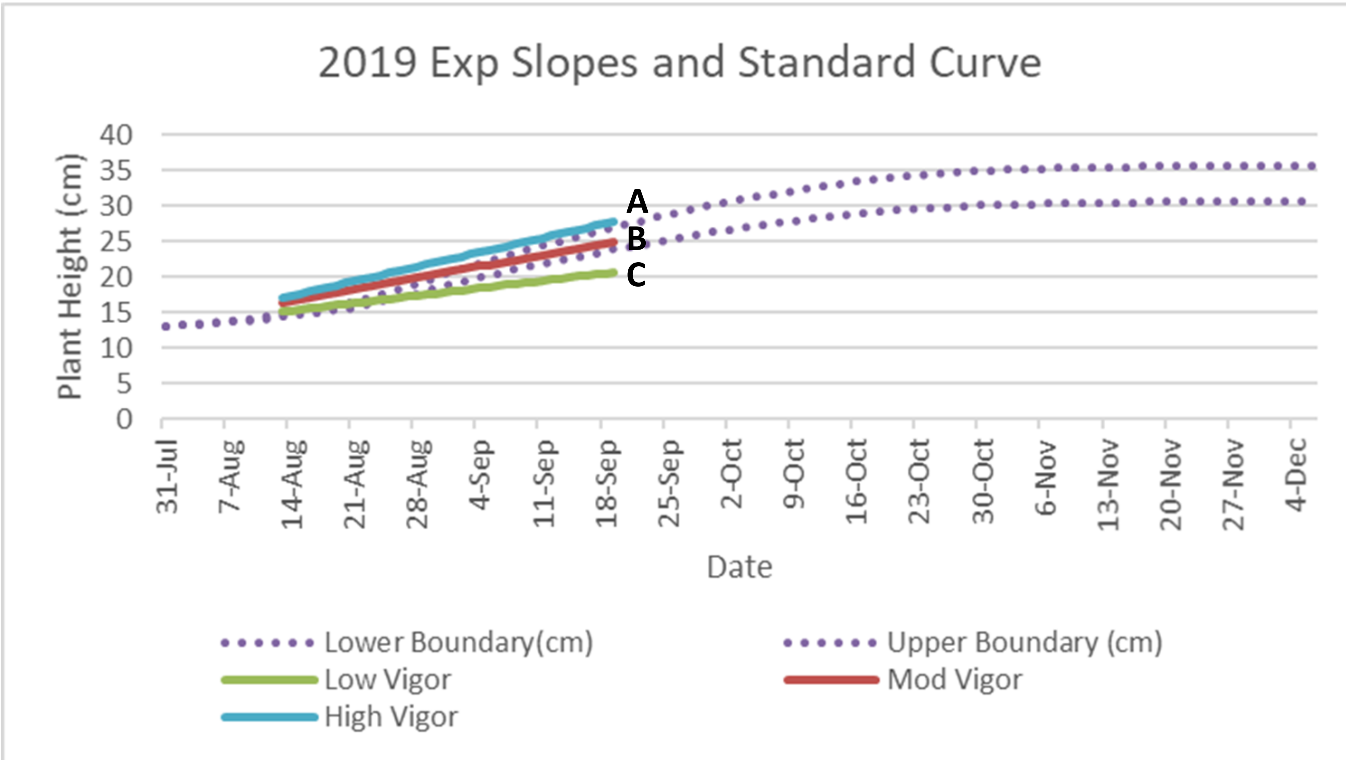


Figure 4-9: Individual slopes of different poinsettia (*Euphorbia pulcherrima*) vigor groupings found in 2019 from the time period two weeks after pinch to short day initiation compared against a standard curve. Each vigor is separated by a letter showing significant difference.

Table 4-1: Experimental poinsettia (*Euphorbia pulcherrima*) cultivars including breeding company, response groups, vigor, color, and where they were sourced in 2018 and 2019 to assess graphical track curve modifications

Breeder	**Cultivar**	**Response Group**[z]	**Vigor**[y]	**Color**	**Grower**
Selecta	Christmas Spirit	7.5– Early	High	Red	PP[x]
Dümmen	Ferrara	7– Early	Moderate	Red	PP/KN (2018) KN (2019)
Dümmen	J'Adore Pink	7.5– Early	Moderate	Pink	KN
Dümmen	Premium Marble	7– Early	Low	White/pink	KN

[z]Response groups are determined by how many weeks a cultivar takes to finish from initiation of short-days to anthesis.
[y]Vigor ratings taken from cultivar information.
[x]PP= PlantPeddler; KN= Knox Nursery.

Table 4-2: pH and EC readings taken by saturated medium extract in 2019 during production and at finish.

Location	EC 1[z]	pH 1	EC 2[y]	pH 2
GHE	1.07[x]	5.95	1.58	6.05
GHC	0.87	6.05	1.80	6.20
GHI	1.13	6.05	1.53	6.15
GHM	0.92	6.25	1.58	6.30

[z]EC and pH 1 taken 20 September 2019

[y]EC and pH 2 taken at cultivar finish.

[x]EC taken using saturated medium extract (SME). Multiple plants (n=10) in greenhouse used to determine average (Accumet XL20 meter, ThermoFisher Scientific, Waltham, MA).

Table 4-3: Observed daily and nightly temperatures, average daily temperature (ADT), and DIF between 11 Aug. 2019 to 2 Dec. 2019.

Greenhouse	**Day Temperature**[z]	**Night Temperature**	**ADT**	**DIF**[y]
GHC	24.4 °C (76 °F)	20.5 °C (69 °F)	22.45 °C (72.5 °F)	7
GHE	21.67 °C (71°F)	20.0 °C (68 °F)	20.8 °C (69.5 °F)	3
GHM	25.5 °C (78 °F)	18.9 °C (66 °F)	22.2 °C (72 °F)	12
GHI	23.9 °C (75 °F)	18.9 °C (66 °F)	21.4 °C (70.5 °F)	9

[z]Temperatures calculated from HOBO data loggers MX2202. Day-length was adjusted for changing sunset/sunrise and daylight savings.
[y] Difference of day and night temperatures (DIF) calculated by taken day °F – night °F.

Table 4-4: 2019 slope, intercept, height at two weeks post pinch (2 wks post pinch), short-day initiation (SD init), final height, average canopy width, and average inflorescence width for poinsettia (*Euphorbia pulcherrima*) cultivars; Significance and Effects

Effect	Slope	Intercept	2 wks Post Pinch (cm)	SD Init. (cm)	Final (cm)
Significance					
Greenhouse (GH)	0.2102	0.1500	0.1800	0.2195	<0.0001
Cultivar (Cv)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Pinch	0.4214	<0.0001	<0.0001	<0.0001	0.0052
GH*Cv	0.2924	0.0509	0.0049	0.0227	0.0011
GH*Pinch	0.9887	0.9665	0.8336	0.4389	0.4477
Cv*Pinch	0.5550	0.6162	0.3157	0.1511	0.0446
GH*Cv*Pinch	0.3972	0.0242	0.0621	0.7063	0.2104
Greenhouse					
GHC	0.22 a[z]	12.98 a	16.16 a	22.60 a	34.43 b
GHE	0.24 a	12.67 a	16.11 a	22.56 a	32.48 c
GHI	0.22 a	12.72 a	15.97 a	22.26 a	33.61 bc
GHM	0.24 a	12.36 a	15.58 a	22.85 a	38.52 a
Cultivar					
Ferrara	0.22 c	13.19 a	15.68 b	22.36 b	35.95 b
Prem. Marble	0.15 d	13.09 a	15.20 b	19.66 c	29.34 c
Xmas Spirit	0.29 a	12.97 a	17.82 a	25.98 a	37.80 a
J'Adore Pink	0.25 b	11.48 b	15.13b	22.26 b	35.95 b
Pinch					
Early Pinch	0.22 a	12.22 b	15.45 b	23.60 a	35.26 a
Late Pinch	0.23 a	13.15 a	16.47 a	21.53 b	34.26 b
Greenhouse*Cultivar					
GHC Ferrara	0.19 bcd	14.27 a	16.55 abcd	22.70 bc	36.63 bcd
GHC Prem. Marble	0.15 d	12.79 abc	14.85 de	19.35 e	29.40 gh
GHC Xmas Spirit	0.30 a	13.34 ab	18.25 a	26.50 a	37.20 bc
GHC J'Adore Pink	0.24 ab	11.53 bcd	15.00 de	21.85 bc	34.50 cdef
GHE Ferrara	0.24 ab	12.89 abc	16.42 abcd	23.00 bc	34.00 cdef
GHE Prem. Marble	0.15 d	13.34 ab	15.30 de	19.70 de	28.08 h
GHE Xmas Spirit	0.29 a	13.11 abc	17.85 a	25.95 a	35.35 cde
GHE J'Adore Pink	0.25 ab	11.37 bcd	14.90 de	21.60 bcd	32.50 feg
GHI Ferrara	0.21 bcd	12.87 abc	13.95 e	21.30 cd	33.50 def
GHI Prem. Marble	0.15 d	13.27 abc	15.50 cde	19.75 de	28.70 h
GHI Xmas Spirit	0.29 a	12.48 abcd	17.45 abc	25.70 a	37.10 bc
GHI J'Adore Pink	0.23 ab	12.29 bcd	15.45 cde	22.30 bc	35.15 cde
GHM Ferrara	0.23 abc	12.72 abc	15.80 bcde	22.45 bc	39.70 ab
GHM Prem. Marble	0.16 cd	13.01 abc	15.15 de	19.85 de	31.20 fgh
GHM Xmas Spirit	0.28 a	12.96 abc	17.75 ab	25.80 a	41.55 a
GHM J'Adore Pink	0.29 a	10.72 d	15.20 de	23.30 b	41.65 a
CV*Pinch					
Ferrara EP	0.22 c	12.72 abc	15.35 bc	23.42 c	36.52 b
Ferrara LP	0.21 c	13.65 a	16.02 b	21.30 d	35.39 b
Prem. Marble EP	0.15 d	12.44 bc	14.50 c	20.32 d	30.10 c
Prem. Marble LP	0.15 d	13.74 a	15.90 b	19.00 e	28.59 c
Xmas Spirit EP	0.28 ab	12.68 abc	17.52 a	27.27 b	38.80 a

Xmas Spirit LP	0.31 a	13.25 ab	18.12 a	24.70 b	36.80 ab
J'Adore Pink EP	0.25 bc	11.03 d	14.42 c	21.15 d	36.27 b
J'Adore Pink LP	0.26 abc	11.92 cd	15.85 b	21.15 d	36.27 b

[z] Letters after each value represent separation within effect using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 4-5: 2019 Final poinsettia (*Euphorbia pulcherrima***)** cultivar measurements including leaf-count, average canopy width, average inflorescence width, fresh and dry weight, and inflorescence number.

Effect	Leaf-count 1[z]	Leaf-count 2	Canopy Width (cm)	Inflor. Width (cm)	Fresh Weight (g)	Dry Weight (g)	Inflor. Number
			Significance				
Greenhouse (GH)	0.8467	0.0136	<0.0001	0.2665	<0.0001	0.0002	0.0170
Cultivar (Cv)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Pinch	<0.0001	<0.0001	<0.0001	0.4557	<0.0001	<0.0001	0.0031
GH*Cv	0.2700	0.4589	0.0025	0.2148	0.5026	0.4610	0.0033
GH*Pinch	0.8330	0.0467	0.4351	0.4600	0.4328	0.3842	0.1254
Cv*Pinch	0.0015	0.8297	0.0181	0.3937	0.3653	0.9253	0.8438
GH*Cv*Pinch	0.0784	0.5533	0.6461	0.4621	0.5688	0.8746	0.2520
Greenhouse							
GHC	28.72 a[y]	60.45 a	40.85 b	26.17 a	227.76 b	37.62 b	4.57 ab
GHE	28.31 a	58.73 ab	37.70 c	23.43 a	221.06 b	39.49 ab	4.74 a
GHI	28.34 a	55.21 b	39.08 c	30.51 a	218.10 b	37.01 b	4.33 b
GHM	29.05 a	59.77 a	43.23 a	28.11 a	272.72 a	42.69 a	4.65 ab
Cultivar							
Ferrara	29.83 b	67.30 b	43.76 b	27.97 ab	274.36 a	47.03 a	4.80 a
Prem. Marble	24.46 c	43.29 c	35.31 c	24.56 b	223.32 b	39.06 b	4.20 b
Xmas Spirit	26.02 c	47.42 c	46.46 a	37.11 a	241.27 b	38.10 b	4.71 a
J'Adore Pink	34.13 a	76.17 a	35.33 c	18.58 b	200.70 c	32.61 c	--
Pinch							
Early Pinch (EP)	32.09 a	62.74 a	41.20 a	25.51 a	255.23 a	42.28 a	4.71 a
Late Pinch (LP)	25.12 b	54.86 b	39.44 b	28.78 a	214.60 b	36.14 b	4.43 b
GH*Cv							
GHC Ferrara	29.40 abc	69.80 abc	42.56 cdef	28.11 ab	265.46 abcd	44.25 ab	4.41 bc
GHC Prem. Marble	23.70 bc	44.40 d	36.20 ghi	25.07 b	209.50 defg	38.37 bcd	4.35 bc
GHC Xmas Spirit	28.80 abc	48.80 d	49.45 a	32.42 ab	249.00 bcdef	38.37 bcd	4.95 ab
GHC J'Adore Pink	33.00 a	78.90 a	35.50 hi	19.10 b	187.10 g	29.49 d	--
GHE Ferrara	30.00 ab	70.30 abc	41.35 def	25.90 b	261.40 abcd	49.85 a	5.30 a
GHE Prem. Marble	24.96 bc	42.42 d	32.50 i	19.97 b	210.05 defg	38.54 bcd	4.28 bc
GHE Xmas Spirit	23.30 c	47.90 d	44.20 bcde	28.70 ab	223.30 cdefg	38.54 bcd	4.65 ab
GHE J'Adore Pink	35.00 a	74.30 ab	33.02 i	19.15 b	189.50 g	31.01 d	--
GHI Ferrara	30.10 ab	62.70 c	44.05 bcde	28.40 ab	259.20 abcde	43.43 ab	4.60 ab
GHI Prem. Marble	23.36 bc	37.86 d	32.65 i	24.30 ab	208.53 cdefg	37.94 bcd	3.73 c
GHI Xmas Spirit	25.70 bc	45.90 d	44.70 bcd	51.17 a	207.40 efg	34.11 bcd	4.67 ab
GHI J'Adore Pink	34.20 a	74.40 ab	34.95 hi	18.20 b	197.30 fg	32.55 cd	--
GHM Ferrara	29.80 abc	66.40 bc	47.10 abc	29.50 ab	311.40 a	50.60 a	4.90 ab
GHM Prem. Marble	25.80 bc	48.50 d	40.20 efg	28.90 ab	265.20 abc	41.39 abc	4.45 bc
GHM Xmas Spirit	26.30 bc	47.10 d	47.50 ab	36.15 ab	285.40 ab	41.39 abc	4.60 ab
GHM J'Adore Pink	34.30 a	77.10 ab	38.15 fgh	17.90 b	228.90 cdefg	37.40 bcd	--
GH*Pinch							
GHC EP	32.60 a	66.85 a	42.07 ab	25.77 a	242.90 b	39.25 bcd	4.70 ab
GHC LP	24.85 b	54.10 c	39.63 bc	26.58 a	212.63 bc	35.99 cd	4.44 c
GHE EP	32.03 a	63.36 ab	39.75 cd	23.25 a	239.32 b	42.70 ab	5.05 a
GHE LP	24.60 b	54.10 c	36.65d	23.61 a	202.80 c	36.27 cd	4.43 b
GHI EP	31.45 a	56.85 bc	40.10 bc	25.25 a	238.55 b	40.65 bc	4.43 b
GHI LP	25.23 b	53.58 c	38.07 cd	35.78 a	197.66 c	33.37 d	4.23 b
GHM EP	32.30 a	63.10 ab	43.50 a	27.50 a	300.15 a	46.47 a	4.66 ab
GHM LP	25.80 b	56.45 bc	42.97 a	28.72 a	245.30 b	38.92 bcd	4.63 ab
Cv*Pinch							

Ferrara EP	34.90 a	72.25 b	44.37 b	28.17 ab	299.75 a	50.07 a	4.97 a
Ferrara LP	24.75 de	62.35 c	43.15 b	27.78 ab	248.98 bc	43.99 b	4.63 ab
Prem. Marble EP	26.88 cd	47.06 de	35.32 c	24.03 b	235.87 bcd	41.67 bc	4.34 bc
Prem. Marble LP	22.03 e	39.53 e	35.30 c	25.08 b	210.76 de	36.46 cd	4.06 c
Xmas Spirit EP	30.60 bc	50.90 d	48.47 a	31.70 ab	265.25 b	41.67 bc	4.82 a
Xmas Spirit LP	21.45 e	43.95 de	44.45 b	42.52 a	217.30 cd	34.54 de	4.61 ab
J'Adore Pink EP	36.00 a	79.95 a	36.25 c	17.86 b	220.05 cd	35.67 d	--
J'Adore Pink LP	32.25 ab	72.40 b	34.42 c	19.31 b	181.35 e	29.56 e	--

[z]Leaf-count 1 taken 18 September 2019.

[y] Letters after each value represent separation within effect using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 4-6: 2018 poinsettia (*Euphorbia pulcherrima*) cultivar Ferrara, slope, intercept, height at two weeks post pinch (2 wks post pinch), short-day initiation (SD init), final height, average canopy width, and average inflorescence width; Significance and Effects

Effect	Slope	Intercept	2 wks Post Pinch (cm)	SD Init. (cm)	Final (cm)	Canopy Width	Inflor. Width
Significance							
Greenhouse	0.5485	0.1198	1.0000	0.8150	0.0307	0.1811	0.4708
Pinch	0.0005	0.0699	<0.0001	0.0397	0.0524	0.0127	0.8670
Greenhouse*Pinch	0.5767	0.2065	0.1360	0.5592	0.5747	0.6651	0.0092
Greenhouse							
GH2E	0.23 a	12.60 a	16.37 a	22.52 a	35.58 a	40.08 a	29.27 a
GH6E	0.22 a	13.29 a	16.37 a	22.75 a	33.37 b	38.37 a	28.45 a
Pinch							
EP	0.20 b	13.35 a	17.70 a	23.66 a	33.50 b	37.54 b	28.77 a
LP	0.25 a	12.54 b	15.04 b	21.61 b	35.45 a	40.91 a	28.95 a
Greenhouse*Pinch							
GH2E EP	0.21 ab[z]	12.73 a	17.41 a	23.83 a	34.33 a	38.66 ab[z]	27.58 a
GH2E LP	0.25 a	12.47 a	15.33 b	21.22 a	36.83 a	41.50 a	30.95 a
GH6E EP	0.19 b	13.97 a	18.00 a	23.50 a	32.66 b	36.41 b	29.95 a
GH6E LP	0.25 a	12.61 a	14.75 b	22.00 a	34.08 ab	40.33 ab	26.95 a

[Z] Letters after each value represent separation within effect using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 4-7: 2018 poinsettia (*Euphorbia pulcherrima*) 'Premium Marble', 'Christmas Spirit' and 'J'Adore Pink', slope, intercept, height at two weeks post pinch (2 wks post pinch), short-day initiation (SD init), final height, average canopy width, and average inflorescence width; Significance and Effects.

Effect	**Slope**	**Intercept**	**2 wks Post Pinch (cm)**	**SD Init. (cm)**	**Final (cm)**	**Canopy Width**	**Inflor. Width**
Greenhouse (GH)	0.1255	0.065	0.4871	0.0896	0.0619	0.0010	0.4304
Cultivar	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
GH*Cultivar	0.8048	0.5275	0.8584	0.3881	0.6431	0.218	0.7431
Cultivar							
Prem. Marble	0.17 b[z]	12.38 b	18.87 c	14.66 b	28.25 b	21.91 c	25.85 b
Xmas Spirit	0.27 a	16.59 a	30.58 a	22.45 a	33.70 a	42.20 a	50.04 a
J'Adore Pink	0.30 a	11.10 b	22.79 b	14.70 b	34.12 a	30.70 b	19.93 c
Greenhouse							
GH2E	0.26 a	12.95 a	24.22 a	17.00 a	32.81 a	33.13 a	31.44 a
GH6E	0.24 a	13.76 a	23.94 a	17.55 a	31.23 a	30.83 b	32.44 a
Cultivar*GH							
Prem. Marble GH2E	0.18 b	12.31 b	19.16 c	14.66 b	29.58 bc	23.41 d	25.87 b
Prem. Marble GH6E	0.17 b	12.44 b	18.58 c	14.66 b	26.91 c	20.41 d	25.83 b
Xmas Spirit GH2E	0.28 a	16.00 a	30.66 a	21.91 a	34.29 a	44.66 a	49.66 a
Xmas Spirit GH6E	0.26 a	17.18 a	30.50 a	23.00 a	33.12 ab	39.75 b	50.41 a
J'Adore GH2E	0.31 a	10.53 b	22.83 b	14.41 b	34.58 a	31.33 c	18.79 c
J'Adore GH6E	0.28 a	11.67 b	22.75 b	15.00 b	33.66 ab	30.08 c	21.08 bc

[Z] Letters after each value represent separation within effect using LSMeans Difference Tukey HSD at P =0.05. Values with different letters are different from each other.

Table 4-8: Final height, slope, and intercept calculations of poinsettia (*Euphorbia pulcherrima*) cultivar Ferrara from different industry locations.

Location	Pinch Date	Pinch	Final Height (cm)^z	Slope^y	Intercept
British Columbia 1	14 Aug 18	LP	40.64	0.22	16.87
British Columbia 2	14 Aug 18	LP	42.54	0.15	19.99
British Columbia 3	14 Aug 18	LP	40.64	0.18	17.05
British Columbia 4	12 Aug 18	LP	45.72	0.36	18.69
Michigan	16 Aug 17	LP	56.51	0.17	14.49
California	2 Aug 19	EP	38.60	0.27	14.06
Colorado 1	2 Aug 19	EP	38.60	0.29	13.84
Colorado 2	1 Aug 19	EP	24.99	0.22	10.51
		T.Test^x:	$t(6)=2.15$, $p=0.03$	$t(6)=-0.83$, $p=0.43$	$t(6)=3.08$, $p=0.02$

Industry data provided by Dümmen Orange, OnTarget™ Graphical Tracks. Locations were picked based on similarity to 2019 pinch dates of 31 July and 14 August +/- 2 days. Applications of plant growth regulators or other greenhouse characteristics are unknown.

^{z}Final height is the last number input into OnTarget™ by the growers. It is possible this is not the actual final height of the crop.

^{y}Slope and intercept calculated from data points occurring between two-weeks after pinch and initiation of short day for the specific year.

^{x}Two-sample, two-tailed T-Test compared measurements from LP and EP categories.

Chapter 5 - Literature Cited

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Appendix A - Experiment 3

Introduction

In 2020, we were introduced to the idea of day-length involvement in dahlia decline. In a study conducted by Sygenta Flowers, they found incidence of foliage decline when plants were exposed to short-days. From this, we decided to develop an experiment that would compare short-days and long days partnered with three different levels of soil moisture levels.

Materials and Methods

In 2020, 60 plants each of two cultivars, XXL 'XXL Veracruz' and Dalaya 'Dalaya Red and White' were grown under short-day (SD) or long day (LD) conditions replicated in two greenhouses. Uniform plants were selected and assigned to each treatment and placed into their assigned area immediately after pinching, which was two weeks after potting. The LD treatment was achieved using a high-pressure sodium light set to extend the day from 6 pm-12 am daily. For the SD treatment, plants were set in a polyvinylchloride (PVC) cube on a bench. Black cloth was pulled daily over the cube to block out light at 6 pm and removed at 9 am, creating a 9-hr SD.

Each cultivar was grown until flower buds showed visible color, which was roughly ~6 weeks after pinching. Once reaching this stage, plants were assigned to different dry down treatments with five plants per treatment (15 plants per day-length treatment). Dry down treatments (% media moisture content from field capacity) consisted of control (~40%), ~60%, or ~80% dry down. Before the treatment, plants were thoroughly watered, allowed to come to equilibrium for at least 2-hrs, then a baseline soil moisture content (SMC) measurement was taken with a WaterScout SM100 (Spectrum Technologies, Inc., Aurora, IL). Before the dry down treatments were initiated, observations were made to evaluate root quality, flower number and development. A water calibration curve was created for the experiment using details outlined by Spectrum Technologies. After initial observations, the dry-down period started and plants were taken back to their day-length treatments and monitored daily with the WaterScout probe until their respective dry down threshold was met. Once achieving the proper dry down level, plants were watered, then immediately taken for root rating observation. Normal growing conditions were resumed, and observations were taken for two additional weeks after the initial threshold was met to monitor plant changes.

Results and Discussion

Unfortunately, we do not have complete results to show from this experiment. We discovered that when taking readings with the WaterScout SM100, the probe created unrecoverable root damage because of its width and knife-like nature. Since we took readings every day of the plants, more roots became damaged. Initial observations did show a difference in plant growth and flower development between the SD and LD treatments, but the effect of water deficit cannot be determined. Before the water deficit treatment began, the plants did not exhibit consistent symptoms of dahlia decline. Dalaya 'Dalaya Red and White' started to decline to some level, but there was possible evidence of virus impacting the plants, therefore, dahlia decline again could not be confirmed or denied.