Improving Nursery Production by Reducing Root Zone Temperatures

by

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Abstract

The greenhouse and nursery industry in Alabama is a $294 million dollar industry that continues to grow and economically impacts each of the 67 counties in the state. Many challenges present themselves while growing containerized plants in the Southeastern United States, including heat stress, inadequate or excess moisture, and increased disease pressure. These challenges lead to reduced performance, poor plant health and plant decline. Many of the issues can be linked, directly or indirectly, to the intense heat that can be experienced by containerized plants during the optimal growing season in the Southeastern United States. The intent of this study was to identify easily implemented and economically feasible production techniques that can lower rootzone temperatures. By decreasing root zone temperatures, production can be increased, and labor inputs lowered by use of alternatively colored containers. The potential effects of root zone temperature on controlled release fertilizer were also evaluated along with the effects of reduced root zone temperatures on roots and overall growth of two commonly grown species of plants: 'Soft Touch' hollies and garden mums. Black containers were exposed to temperatures over 38°C an average of 55% more than white containers. Plants grown in white containers had 55% better root coverage ratings than those grown in black containers and had increased biomass and growth index measurements.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

RZT	Root zone temperatures
USDA	United States Department of Agriculture
OHRC	Auburn University Ornamental Horticulture Research Station
CRF	Controlled release fertilizer
NASS	National Agricultural Statistics Service
HSP	Heat shock proteins
ERS	Economic Research Service
DLI	Daily light integral
GI	Growth index
DAP	Days after planting
FW	Fresh Weight
DW	Dry Weight
FC	Flower Coverage

Chapter I

Literature Review

Introduction

History of Nursery Production in Alabama

Commercial production of nursery crops in containers began after World War II as returning soldiers, and the resulting economic prosperity of the 1940's and 1950's, led to a monumental rise in housing developments across the United States. Horticulturists across the U.S. responded to the need for plant material by growing more plant stock that was easily shipped long distances (Brass et al., 1996). Prior to this time, most nursery items were grown in the ground, dug and wrapped in burlap by hand, limiting the numbers sold due to time required to dig each plant and resulting in an increase in labor costs. Nursery stock grown in containers transplant more successfully, exhibit healthier root systems, have minimized mechanical damage and reduced transportation costs due to artificial substrates weighing less than native field soils. A severe uptick in plant production occurred in the so-called "Sunbelt States", stretching across the southern portion of the United States, including Alabama, Mississippi, Florida, and Georgia. This was due to several factors including affordability of land and a lengthened growing season (Chappell and Knox, 2012).

Alabama has been a long-time leader in nursery production in the United States. In 1852, Col. C.C. Langdon began offering plants at a nursery north of Citronelle, a small community in Mobile County, Alabama (Fain, 2009). Since that time, the warm climate of both Mobile and Baldwin Counties have made them ideal for ornamental plant production, though plant production is reported in all 67 counties of Alabama. In 2007, the United States Department of

Agriculture's (USDA) National Agricultural Statistics Service (USDA NASS) indicated that Alabama's Green Industry had an estimated $2.3 billion impact on the state, with over $256 million in receipts from greenhouse and nursery production (USDA NASS, 2015).

Plastic Nursery Containers in Ornamental Production

As an increase in container production continued after World War II and throughout the 1950's, horticulturalists and researchers moved from the breakable and heavy terracotta pots that had long been used and began utilizing metal food cans from restaurants, tar paper sacks and surplus egg cans (Fain, 2009). Overtime, the cans were more widely used, primarily for their durability, light weight, and larger sizes. As nursery container production increased in popularity, these cans were designed specifically for nursery production. As the production technique was further researched, other container types were used, including styrene, polyethylene plastic and U.V. stabilized plastics (Chappell and Knox, 2012).

Petroleum-based, plastic containers began to replace metal cans due to their affordability, light weight, easy transportation, and versatility. Due to lower costs, black, blow-molded polyethylene became the dominant container used in modern day production of nursery crops, ranging from annual bedding plants to large container grown trees and shrubs (Chappell and Knox, 2012).

While many alternative options, including biodegradable containers, have been used in the industry, black plastic containers continue to be the primary container in nursery production, though not without some complications (Brass et al., 1996). These complications include moisture inconsistencies, nutrient leaching, and temperature fluctuations. Despite these issues, above ground production is generally more efficient than field nurseries, with plants being grown at higher densities and reduced grow out times (Barr and Pellett, 1972). Additionally, increased quality of plant and improved establishment success rates of containerized plants have also been observed (Gilman and Beeson, 1996).

A significant disadvantage of black nursery pots is supraoptimal root zone temperatures (RZT) (Witcher et al., 2020). Most nursery containers are black in color, which increases RZT by converting solar radiation to thermal energy which is then transferred through the wall of the container and into the substrate. While research has shown that substrate types can reduce RZT, observations still show that high root zone temperatures can occur regardless of the substrate type or composition (Brass et al., 1996; Witcher et al., 2020). Root zone temperature is an important environmental factor that negatively impacts growth, productivity, and long-term health of nursery stock (Wright et al., 2007). Studies have shown that RZT greater than 38°C can cause root growth and development to cease and prolonged exposure above 48°C can cause permanent root damage (Barr and Pellett, 1972; Fretz, 1971; Gilman and Beeson, 1996; Ingram and Buchanan, 1981). This damage results in plant stress and decreases potential productivity or may cause plant decline and stock mortality (Benson, 1986).

Issues Associated with Supraoptimal Root Zone Temperatures

Abiotic disorders, or those issues that are not caused by living organisms, account for more than sixty percent of plant samples submitted to plant diagnostic clinics (Mathers et al., 2007). Previous studies have indicated that temperature extremes can cause severe losses in production. Temperature extremes were reported to increase the formation of Heat Shock Proteins (HSPs), especially in plants that were exposed to temperatures above 47°C (Veirling, 1991). While container nurseries are generally more productive than in-ground nurseries, temperature stress is a limiting factor in container production. Extreme temperature fluctuations in the winter can cause root injury and tissue desiccation. Similarly, prolonged exposure to high temperatures, or above the critical temperature of 38°C in the summer, can lead to root tissue damage and eventual plant decline (Fretz, 1971).

The optimal temperature range for root and shoot growth for many species if between 20°C to 30°C (Ingram and Buchanan, 1981). Nursery container production poses several issues for the producer, particularly in warm climates like the Southeastern United States, where temperatures commonly reach 35°C for multiple days at a time (Fretz, 1971). These high air temperatures, along with light intensity, and inadequate or inconsistent moisture, can increase the probability of supraoptimal RZT in containerized plant material. Supraoptimal RZTs an unseen and commonly overlooked factor in nursery health (Benson, 1986).

Root growth and development is slower at temperatures above 30°C and ceases in many woody species at temperatures above 39.4 °C (Gilman and Beeson, 1996). When root development ceases, top growth and development also ceases, reducing profitability and potentially increasing the number of growing days for susceptible crops (Johnson and Ingram, 1984). The potential for damage is heightened when high temperatures are combined with black containers, which absorb all light waves and convert light energy to thermal energy (Chappell and Knox, 2012). Due to this transformation of energy and the high surface to volume ratio of containers, nursery grown plants are subject to high RZT (Ingram and Buchanan, 1981). Furthermore, roots are more susceptible to high temperature fluctuations than shoots, potentially resulting in damage throughout the container or one-sided root ball growth (Barr and Pellett, 1972). For these reasons, trials indicate that white-on-black nursery containers, or containers that are white on the outside with a black interior container wall, can reduce the amount of thermal energy that is transferred through the pot wall and into the substrate, ultimately resulting in improved root growth and development (Brass et al., 1996; Fretz, 1971; Witcher et al., 2020).

Ingram and Buchanan (1981) demonstrated that root growth ceases when RZT are above 39.4°C and permanent damage can occur when exposed to temperatures above 46°C, even for short intervals of time. While production techniques vary, common issues can be observed across the industry. High root zone temperatures (RZT) have been reported to play a critical role in production (Ingram and Buchanan, 1981; Self et al., 1956; Witcher et al., 2020). Media type, container type, container color, and container size have all been observed to impact RZT (Ingram and Buchanan, 1981).

Container Color and Root Zone Temperature

Production practices have been evaluated as economical methods to reduce RZT. Pot-in-pot, irrigation scheduling and mulching are all effective, yet costly and somewhat labor-intensive practices (Brass et al., 1996; Fretz, 1971; Ingram and Johnson, 1981; Irmak et al., 2005). Container color, or the use of alternative-colored containers other than the traditional black container, has shown some promise in the reduction of temperature while using no more labor than traditional black containers and having a nominal cost per unit (Ingram and Johnson, 1981). Markham et al., (2011) reported that root density on the southern facing sides of containers were between 2.7 to 6.1 times greater in white, gloss white and silver containers when compared to the traditional black or green container. Markham et al., (2011) also observed that overall root density throughout the container was 2.3 to 3.8 times greater in white, gloss white and silver containers when compared to the black and green containers. This indicated that more reflective container colors can reduce RZT and encourage root development and density (Keever and

Cobb, 1984; Markam et al., 2011). Another factor that has been observed to impact RZT is the difference in all white containers when compared to those that have black liners with a white exterior. Due to the translucency of the white container, which allows solar radiation to pass through the side walls of containers and a buildup of heat occurs inside, substrates were observed to be even hotter than those in black containers. In contrast, containers that are white on the outside with a black liner reflect heat away from the root zone, reducing the observed temperatures (Whitcomb and Whitcomb, 2006).

Container Size and Root Zone Temperatures

While container color has long been recognized as being an effective and economical cooling strategy for RZT in nursery stock, few studies have identified the relationship between container color, container size, container spacing and the impacts on RZT. Brass et al. (1996) reported that temperature differences were observed in containers with small dimensions and volume, even when the container had been lined with a styrene lining (Brass et al., 1996). The Brass et al. (1996) study indicated that larger sized trade containers, 10.3 L, when compared to standard trade one gallon and three-gallon containers, provide a buffer for temperature fluctuations, thus reducing the potential for temperature stress, for both extreme cold and heat. This buffering was thought to arise from the increased amount of substrate and the potentially thicker side wall of the container. Nonetheless, substrate in all containers reached higher than ambient air temperatures due to the transformation of energy to heat (Brass et al., 1996). Martin and Ingram (1993) observed that small containers, and the substrate within, were more susceptible to extreme fluctuations in temperature. This study also indicated that while larger, 10.3 L containers and the increased amount of substrate buffered temperature fluctuation, the larger containers showed a consistent rise in temperature over an interval of time. Increased buffering associated with a larger mass of substrate with reduced temperature fluctuations also slows the substrate from cooling after each day's peak in temperature, thus substrate in larger containers would start warmer and stay warmer over a period of time than small containers (Martin and Ingram, 1993). This increase may lead to prolonged periods of exposure above critical temperature zones, or those temperatures that are above 38°C.

Spacing and Container Color Effect Root Development

Many considerations must be taken by nursery operators when deciding what spacing should be utilized in containerized production. Among those are space required for a given group, desired plant shape and canopy development, pest and disease prevalence, costs of spacing or respacing plants and potential for deleterious effects of temperature, both hot and cold (Fretz, 1971). Spacing of plants has been identified as a factor that can alleviate or contribute to supraoptimal root zone temperature in containers (Ingram and Johnson, 1981). Generally, nursery operators arrange plants in field plots in either jammed (containers touching on all sides) or spaced at the distance between each container that will be suitable for final growth of the plant. The distance will vary based on desired size of the final product, limitations of growing pad area or by the needs of the individual species (Laiche, 1985).

Jamming has been shown to reduce RZTs by providing shade to the sidewall of containers, specifically in plants that do not have an established canopy (Ingram and Johnson, 1981). Commonly, operators will jam containers at the onset of the growing season and then move containers to the final spacing after the establishment of some canopy that provides shade, thus reducing the temperature of the root zone. While this method is effective and allows for more growing area at times when growers may require additional growing pad space, this is a highly inefficient method as labor input costs have been estimated to represent approximately 43% of costs in nursery production (USDA ERS, 2021).

The need to move plants more than once to improve growing conditions increase labor per plant and decrease profits in an already small profit potential. Furthermore, in labor intensive commodity production, including nursery production, labor costs are at a 20-year high (USDA ERS, 2021). As labor costs continue to rise and labor availability continues to dwindle, finding effective yet economical techniques to reduce input costs will not only increase profit margins for growers by saved labor, but by also reducing the needed touches per plant, allowing for more time to work in other areas of the nursery.

Effects of Temperature on Controlled Release Fertilizers

Just as supraoptimal temperatures have been observed to cause decline and root death, excessive heat has been observed to reduce the time and efficacy of controlled release fertilizers (CRFs) (Kochba et al., 1990). In containerized nursery production, soluble fertilizers encapsulated in individual polymer or resin coated capsules, are commonly referred to as prills.

Time, soil moisture, thickness of the coating, water vapor and temperature all impact the efficacy and duration of optimal fertilizer release rates in CRFs. Time and temperature are the primary factors that determine duration (Lamont et al., 1987). Even with advances in polymer and resin coated technology, supraoptimal container temperatures, especially those noted in the south, can drastically decrease release times and render prills of CRFs ineffective months shorter than observed in laboratory settings (Kochba et al., 1990). In a study to determine the diurnal, or short term, effects of temperature on CRFs in laboratory settings, Husby et al., (2003) reported a significant interaction in product release and temperatures, with supraoptimal temperatures reducing release rates and cooler temperatures extending release rates. Furthermore, Husby et al., (2003) suspected that daily temperature changes in nursery settings would have a greater effect on nutrient release levels as well as on effective longevity of products. In their study, Kochba et al., (1990) observed that fertilizer release rates increased steeply as temperature rose.

Justification

While studies have shown that container color, container dimension, container spacing and substrate types can influence RZT, this continues to be an unseen and often undiagnosed issue that could be contributing to hundreds of thousands of dollars of loss per year across the state (Witcher et al., 2020). We believe that if this study results in data consistently showing that RZT can be reduced adequately by changing the color of the container and that there is an interaction with spacing, the findings will give growers an easily implemented and economically feasible method to reduce RZT. Our study will investigate release rates of CRFs related to RZT, giving a more adequate demonstration of how RZT could impact fertilizer efficacy. Additionally, data and observations may be utilized to encourage container manufacturers to offer more container sizes that are readily available in the white-on-black configuration to not only preserve or enhance root development, but also to reduce input costs for producers.

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Chapter II

Effects of Pot Spacing × Pot Color on Root Zone Temperatures in 'Soft Touch' Hollies

Abstract

Newly up potted 'Soft Touch' Japanese hollies (*Ilex crenata*) were grown in Mobile, AL in 1.47L containers to evaluate the effects on plant root growth from black or white pot colors and pot spacing in relation to root zone temperature. Two treatments, container color and container spacing were evaluated and root ratings were reported. An interaction was observed between pot color and spacing with jammed white and spaced white containers being approximately 11.5% larger in size than spaced black containers. White containers experienced 38% less time above 38°C when compared to black containers, resulting in 30% greater root rating for roots of plants grown in black containers.

Introduction

In an effort to reduce rootzone temperatures in containerized plants, nurseries commonly place containers in the field where each container is touching surrounding containers after planting to reduce exposed surface area to solar radiation. This spacing technique is commonly referred to as plants being "jammed." Plants are spaced later in the production cycle to provide room for expanding canopies. Depending on the species, canopies eventually provide shade and reduce solar radiation exposure to the container. Placing containerized plants after potting at their final spacing requirements would be desirable, considering current labor cost and availability, however this cultural practice leaves more of the container sides exposed to solar radiation (USDA ERS, 2021). Supraoptimal root zone temperatures (RZT) have been shown to reduce productivity in container nurseries (Ingram and Buchanan, 1981). Nursery containers or pots are commonly black polyethylene material. Solar radiation is quickly absorbed by these black pots (Chappell and Knox, 2012; Gilman and Beeson, 1996; Markham et al., 2011). Solar radiation is converted to heat energy and is absorbed by the substrate. As the substrate's heat capacity is greater than the surrounding air, heat is gained faster than it can be lost, resulting in rapid gains in RZT (Fretz, 1971).

Studies have shown RZT above 38°C can cause root growth and development to cease and prolonged exposure above 48°C can cause permanent root damage in woody plants (Ingram and Buchanan, 1981). Root damage from supraoptimal temperatures can lead to plant stress, decreased productivity, reduced quality and/or stock mortality (Benson, 1986). Previous studies have been conducted using multiple woody plant species, working to identify the advantages or disadvantages of lowering the RZT (Ingram and Buchanan, 1981; Self and Ward, 1956; Sibley et al., 1999; Wright et al., 2007; Witcher et al., 2020). Observations have been made on the reduction of RZT in containers by using alternative colors, including silver and white, when compared to the traditional container colors of black or green (Markham et al., 2011).

White on black containers have been shown to significantly reduce RZT when compared to the common black containers (Fretz, 1971; Husby et al., 2003; Ingram and Johnson, 1981; Markham et al., 2011; Witcher et al., 2020). Ingram and Buchannan (1981) reported increased or decreased RZT depending on color and reflection of solar reflectivity. Ingram and Johnson (1981) reported that spacing in nursery production could have an effect on temperatures, and also reported that jammed placings experience lower temperatures on all side walls when compared to those placed at final spacings for market. Additionally, root injury or death has been observed in rootzones when containers were originally jammed and then later placed at final spacings, reducing the healthy or live roots and reducing the overall root to shoot ratio (Fretz, 1971). Reduced roots have a direct relationship with size and health of containerized plants and can reduce overall plant health while reducing water and nutrient absorption capabilities (Ingram and Johnson, 1981; Fretz, 1971; Keever and Cobb, 1994).

The following study evaluates the impact of container color and container spacing on newly planted ‘Soft Touch’ Japanese hollies (*Ilex crenata* ‘soft touch’*).*

Materials and Methods

On 11 May, 2021, at the Auburn University Ornamental Horticulture Research Station (30°42'06.9"N 88°08'48.5"W), 324 rooted liners of ‘Soft Touch’ Japanese hollies (*Ilex crenata* ‘Soft Touch’) were potted into 1.47L containers (Yikush Inc. Shanghai, China). Containers were black or white-on-black depending on the treatment. Liners were previously grown in 50 cell count 1.9 cubic inch cell trays. Before planting, liners were blocked by size. Containers (1.47L) were each filled with a substrate consisting of 100% aged, milled pine bark incorporated with 8.2 kg/m^3 of 15–9–12 Osmocote® 12–14 month slow release fertilizer (ICL Specialty Fertilizers, Dublin Ohio), 2.71 kg/m^3 of lime and 0.68 kg/m^3 Micromax® Micronutrients (ICL Specialty Fertilizers, Dublin Ohio).

Plants were arranged in 2×2 factorial design with pot color × pot density. Experimental design was a randomized complete block design with 9 blocks. Each experimental unit consisted of nine plants arranged in three rows (Figure 1.1). Data was only collected on the center pot and surrounding pots (buffer pots) were used to simulate the environmental conditions in a nursery block. To evaluate the effects of plant density on root zone temperature, the spacing factor consisted of jammed and spaced plants. Jammed plants were arranged with containers touching on all sides. Spaced units were spaced at approximately 12.5 cm. Plants were pruned to an average of 7.5 cm seven weeks after planting with growth indices (GIs) being recorded before and after pruning. Growth index of each plant was measured at planting, 10 days after planting (DAP), 30 DAP, 60 DAP, 90 DAP and 120 DAP and at termination (141 DAP). Leachates from each unit were conducted using the Virginia Tech Extraction Method (VTEM) at 10 DAP, 30 DAP. 60 DAP, 90 DAP, 120 DAP (Wright, 1986). Other data collected included fresh and dry weights of the canopy of each plant. A subjective rating scale was developed to determine the percent coverage of roots on four quadrants of the root ball. North, South, East, and West sides of each container were marked, in respect to their orientation in the field, to determine if differences could be observed and quantified. The following scale was used to rate the percent root coverage of the area facing each cardinal direction: 0= 0% root coverage, 1= 1 to 25% root coverage, 2= 26 to 50% root coverage, 3= 51 to 75% root coverage and 4= 76 to 100% root coverage. Ratings were taken on each of the four marked quadrants of the root ball based on a visual estimation of total root coverage. Additionally, significant root death, or those areas where roots were visually determined to have been killed were also noted as (0= no root death observed) or (1= severe root death observed).

All containers in this study were spaced 112 DAP at 12.5 cm imitate the final spacing of the containers in a production nursery, allowing for canopy development (Ingram and Johnson, 1981). The purpose of this study was to determine if desired root development can be achieved without spacing by using white containers. Reduction in labor associated with spacing could increase profitability with regards to labor inputs.

Results and Discussion

No trends in pH or EC were observed across all main effect combinations. A difference among sampling dates was observed but this followed the anticipated release rate of the controlled release fertilizer (data not shown).

Generally, there was no significance in growth index (GI) for main effects (color or spacing) or their interactions until 141 DAP (Table 1.1). Differences in GI associated with container color was detected after pruning (48 DAP). At 141 DAP, an interaction was observed between spacing and color ($p > 0.0540$) for GI ($\alpha = 0.10$). Plants grown in jammed white and spaced white were approximately 11.5% larger in GI than the spaced black containers. Jammed black grown plants were similar to all other treatments (Table 1.1). This interaction is consistent with previous studies, indicating increase growth when containers are white or exhibit reduced RZT (Barr and Pellett, 1972; Ingram and Johnson, 1981; Johnson and Ingram, 1984; Laiche, 1985).

Biomass of trimmings, fresh weight (FW) and dry weight (DW)) were collected at 43 DAP after pruning. Total shoot biomass was collected at termination (141 DAP) (Table 1.2). No significance in main effects or their interaction was detected from FW and DW of trimmings at 43 DAP. Color was significant at termination for both FW (0.0250) and DW (0.0317); however, no significance was detected in spacing or the interaction of spacing and color. At termination, biomass collected from plants grown in white containers (29.6g) was 16% greater than those collected from black containers (24.8g). Dry weights of plant material from the white containers (11.3g) weighed 15% more than dry weights of plants collected from black containers. Increase in shoot weight in white containers is consistent with observations of increased biomass when there is increased root matter due to greater nutrient and water uptake (Barr and Pellett, 1972; Ingram and Johnson, 1981; Johnson and Ingram, 1984; Laiche, 1985).

Root ratings were not influenced by an interaction between spacing and container color for each quadrant with the exception of the east quadrant. As a main effect, color had a significant effect on root rating on the north, south and west quadrants, where white container grown plants exhibited 30, 52 and 55% greater root scores than black container plants. Pot spacing only had an effect on the south quadrant, resulting in 32% increase in jammed plants over spaced. The only interaction between spacing and container color was on east facing roots where plants from all other treatments were approximately 60% greater in root rating than spaced black containers. While not significant, treatments behaved similarly in other quadrants. Overall black spaced pots performed the poorest in root ratings across directional quadrants. The greater performance of other factor combinations is likely attributed to cooler RZT. These observations are similar to previous studies, indicted increased or decreased growth of plants due to RZT that is impacted by spacing or color of containers (Keever and Cobb, 1984; Ingram and Johnson, 1981; Fretz, 1971; Gilman and Beeson, 1996).

Critical temperatures have been established for a number of nursery crops (Ingram and Buchanan, 1981). These temperature points were primarily established through laboratory procedures. Laboratory established critical RZTs may not represent damage experienced in situ or in the nursery where other external factors (soil moisture, exposure time, and nutritional status) may further influence susceptibility to damage. The point in which RZT becomes damaging may also be dependent on other external factors such as moisture content and exposure time. Exhaustive reviews of literature involving RZT in container nurseries summarized that “sublethal yet supraoptimal” RZT between 38°C and 42°C can reduce growth. (Mathers et al., 2007).

Time above critical temperatures

Time units (30 minutes) where temperatures were above 38° C on five random sunny days where daily light integral (DLI) ranged from 38 to 48 $mol \cdot m^{-2} \cdot d^{-1}$ (Table 1.4). An interaction between spacing and container color was only detected in the north quadrant. On sampled days, the main effects of spacing were significant across all quadrants where spaced containers were 100, 87, 96 and 89 % greater in time of 38°C for north, south, east and west, respectively. For each quadrant, color was significant in time above 38°C with the exception of the east quadrant. Time above 38°C in black containers (Table 1.4.) was 82, 58 and 55% greater than those in white for north, south and west, respectively. Generally, spaced-black containers experienced the greatest number of time intervals above 38°C on selected days. Figure 1.2 represents average temperature (n= 5 days) for each directional quadrant in each treatment combination. Black-spaced pots tended to have greater RZT than all other treatment combinations. Black-spaced containers represent the greatest RZT as solar radiation exposure and absorption would be greatest. This correlates with observations from Markham et.al., (2011) and Witcher et al., 2020).

Root coverage ratings followed trends associated with RZT for each quadrant with white pots exhibiting lower temperatures than black and jammed containers having lower RZT than spaced (Figure 1.2). South and west quadrants of the jammed black containers generally were 2–5° C greater in RZT than north and east.

Collectively, results suggest that spaced black containers were less productive in both shoot and root growth. For some species, final spacing of black containers in production is a conventional practice. Black containers dominate production, and, in many cases, containers are spaced to their final spacing after potting. This data suggest that ‘Soft Touch’ holly could be grown in white pots exclusively at final spacing throughout the production cycle and result in similar growth to jammed plants. These observations, that jammed containers reduce RZTs and increase root development are similar to previous studies (Mathers, 2007). Previous studies have also reported that white containers are effective in reducing RZTs and promoting root development (Fretz, 1971; Husby et al., 2003; Ingram and Johnson, 1981; Markham et al., 2011; Witcher et al., 2020). However, our study indicates that both jammed and spaced white containers are similar in their abilities to reduce RZTs, improve root development and increase plant size and biomass. Labor used in respacing ‘Soft Touch’ holly could be reduced or eliminated simply by utilizing white–on–black containers; however, results may vary depending on pot size, species and even cultivar.

Root death followed by spacing of plants grown in black-jammed pots was not experienced in white pots that were previously jammed, indicating a reduction in stress associated with spacing when white pots are used. Similar to labor savings, larger container sizes and plant canopy architecture could result in different results. Future work, including various pot sizes and species associated with spacing and pot color, would add a greater understanding of the potential impact on the industry, namely in labor savings.

Conclusion

This study suggests that in some cases, labor could be reduced by utilizing white containers over black containers. All treatments spaced or jammed, when in white containers performed better than either of the black treatments. Furthermore, when evaluating roots of jammed black containers that were later spaced, massive root death was observed in containers that had been jammed versus those that had not. No root death was observed in any white container treatment or in the black spaced containers. This indicates that while jamming black containers sufficiently reduces RZT below critical temperatures, roots that are developed early in the growing season could be later killed by supraoptimal RZT once plants are spaced. We hypothesize that these roots that are near the container side wall are not hardened off and are more sensitive to high temperature than those that have been exposed for the duration of the growing interval.

Due to the performance of white containers, we recommend that producers utilize white containers for root zone temperature sensitive crops, placed at final spacing at planting. Associated increased root and shoot develop may have the potential to reduce grow-out times, decreasing input costs and opening up more growing space for crops that follow. Future studies should investigate if a reduction in productivity is a response of spacing jammed plants late in the season.

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Tables and Figures

Figure 1.1 Experimental layout of fixed effect combinations, representing one block.

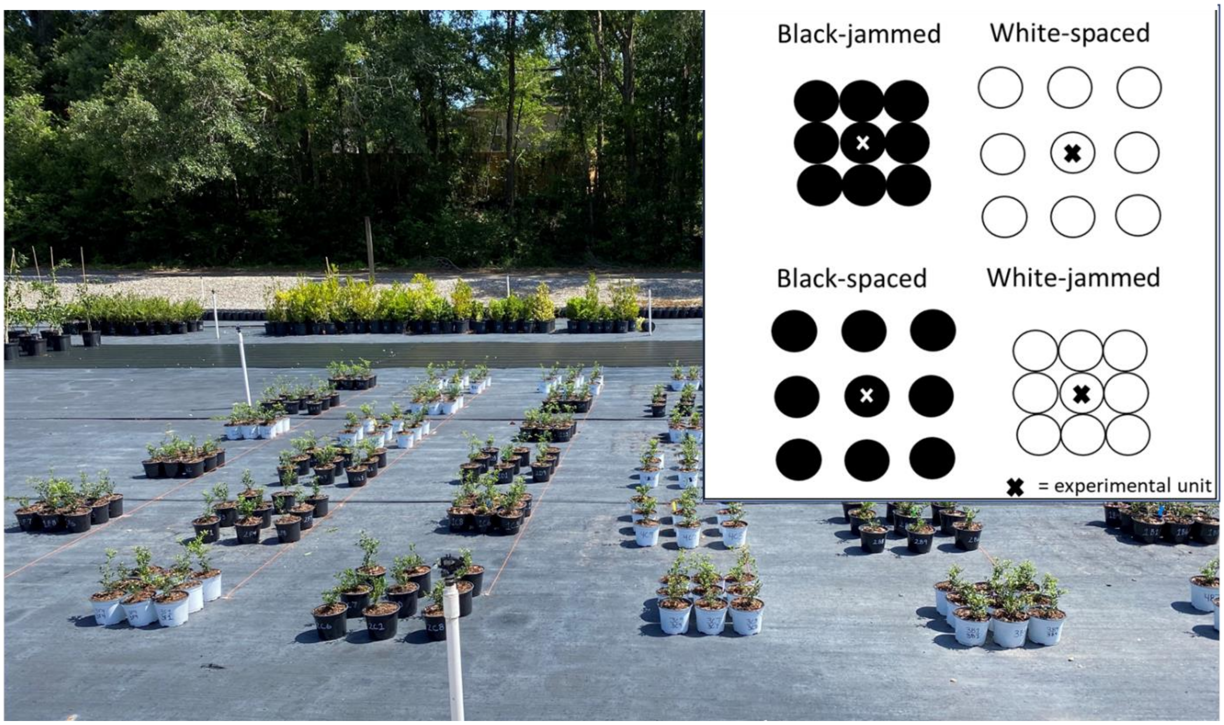

Table 1.1. Main effects and interactions of spacing and color on 'Soft Touch' holly growth index[Z] measured at five intervals after planting. Data collected at the Ornamental Horticulture Research station in Mobile, AL.

Least square means for main effect: container spacing[x]					
	9 DAP[Y]	43 DAP	48 DAP	122 DAP	141 DAP
Jammed	12.6	17.0	10.0	15.1	17.1
Spaced	11.6	16.0	10.2	15.8	16.3
Spacing (p-value)	0.0961	0.2792	0.4488	0.0771	0.0879

Least square mean for main effect: container color					
	9 DAP	43 DAP	48 DAP	122 DAP	141 DAP
Black	12.5	16.3	9.7 B	15.1	16.1
White	11.7	16.7	10.5 A	15.8	17.3
Color (p-value)	0.1427	0.6607	0.0388	0.0885	0.0292

Interaction least square means[w] :container color × container spacing						
Spacing	Color	9 DAP	43 DAP	48 DAP	122 DAP	141 DAP
Jammed	Black	13.4	17.2	9.3	15.6	17.1
Spaced	Black	11.6	15.3	10.0	14.5	15.3
Jammed	White	11.7	16.7	10.6	16.0	17.2
Spaced	White	11.6	16.6	10.4	15.6	17.3
Spacing x Color (p-value)		0.1582	0.3444	0.2442	0.4184	0.0540

[Z]Growth index = (height + width at widest point + perpendicular width) / 3.
[Y]DAP = Days after planting with a planting date of 5/11/2021.
[X]Main effects included the factors container spacing and container color. Spacing represents placed in a jammed fashion where containers are touching on all sides or spaced at 12.5 cm between containers. Jammed containers were spaced to 12.5 cm 112 DAP. Container color included either white or black containers (1.7L).
[W]When interaction terms (spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Table 1.2. Effect of container color and spacing on biomass (g) of 'Soft Touch' holly (n =9).

		Biomass of trimmings after pruning[y]		Total shoot biomass at termination	
Least square means for main effect: container spacing[X]					
Spacing		FW 43 DAP[W]	DW 43 DAP	FW 141 DAP	DW 141 DAP
Jammed		14.0	3.1	28.0	10.6
Spaced		12.7	2.7	26.3	10.2
Significance		0.1293	0.2123	0.4038	0.5615
Least square mean for main effect: container color					
Color		FW 43 DAP	DW 43 DAP	FW 141 DAP	DW 141 DAP
Black		13.4	2.9	24.8 B	9.6 B
White		13.3	2.8	29.6 A	11.3 A
Significance		0.9426	0.6808	0.0205	0.0317
Interaction treatment least square means: container spacing × container color[X]					
Spacing	Color	FW 43 DAP	DW 43 DAP	FW 141 Dap	DW 141 DAP
Jammed	Black	14.9	3.3	26.8	10.2
Spaced	Black	11.9	2.5	22.7	9.0
Jammed	White	13.2	2.7	29.2	11.2
Spaced	White	13.5	2.9	30.0	11.4
Significance		0.0682	0.0919	0.2201	0.3316

[Z]Main effects included the factors container spacing and container color. Spacing represents placed in a jammed fashion where containers are touching on all sides or spaced at 12.5 cm between containers. Jammed containers were spaced to 12.5 cm 112 DAP. Container color included either white or black containers (1.7L).

[Y]All experimental units were pruned to 7.5 cm in height at 43 DAP. Biomass represents weight of trimmings after pruning.

[X]When interaction terms (spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

[W]DAP = Days after planting with a planting date of 5/11/2021.

Table 1.3. Effects[Z] of color and container spacing on root ratings[Y] of 'Soft Touch' holly grown in combinations of container color and spacing (n =8).

Least square means for main effect: container spacing				
Spacing	North	South	East	West
Jammed	2.3	1.8 A	2.2	1.8
Spaced	2.2	1.4 B	1.6	1.5
Spacing (p-value)	0.8369	0.0358	<0.0001	0.2140
Least square mean for main effect: container color				
Color	North	South	East	West
Black	1.8 B	1.0 B	1.4	1.1 B
White	2.6 A	2.3 A	2.4	2.3 A
Color (p-value)	0.0601	<0.0001	0.0001	<0.0001

Interaction treatment least square means: container spacing × container color[X]					
Spacing	Color	North	South	East	West
Jammed	Black	2.0	1.3	2.0 A	1.4
Spaced	Black	1.7	0.7	0.9 B	0.7
Jammed	White	2.5	2.4	2.4 A	2.2
Spaced	White	2.7	2.1	2.4 A	2.3
Spacing x Color (p-value)		0.2459	0.4056	0.0038	0.0591

[Z]Main effects included the factors container spacing and container color. Spacing represents placed in a jammed fashion where containers are touching on all sides or spaced at 12.5 cm between containers. Jammed containers were spaced to 12.5 cm 112 DAP. Container color included either white or black containers (1.7L).

[Y]Root ratings were based off of percent coverage of roots on outside of root ball. 0 = 0 roots; 1= 1% to 25%; 2 = 26% to 50%; 3 = 51% to 75%; 4 = 76% to 100%

[X]When interaction terms (spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Figure 1.2 Effects of container color and spacing on root zone temperature by directional quadrants.

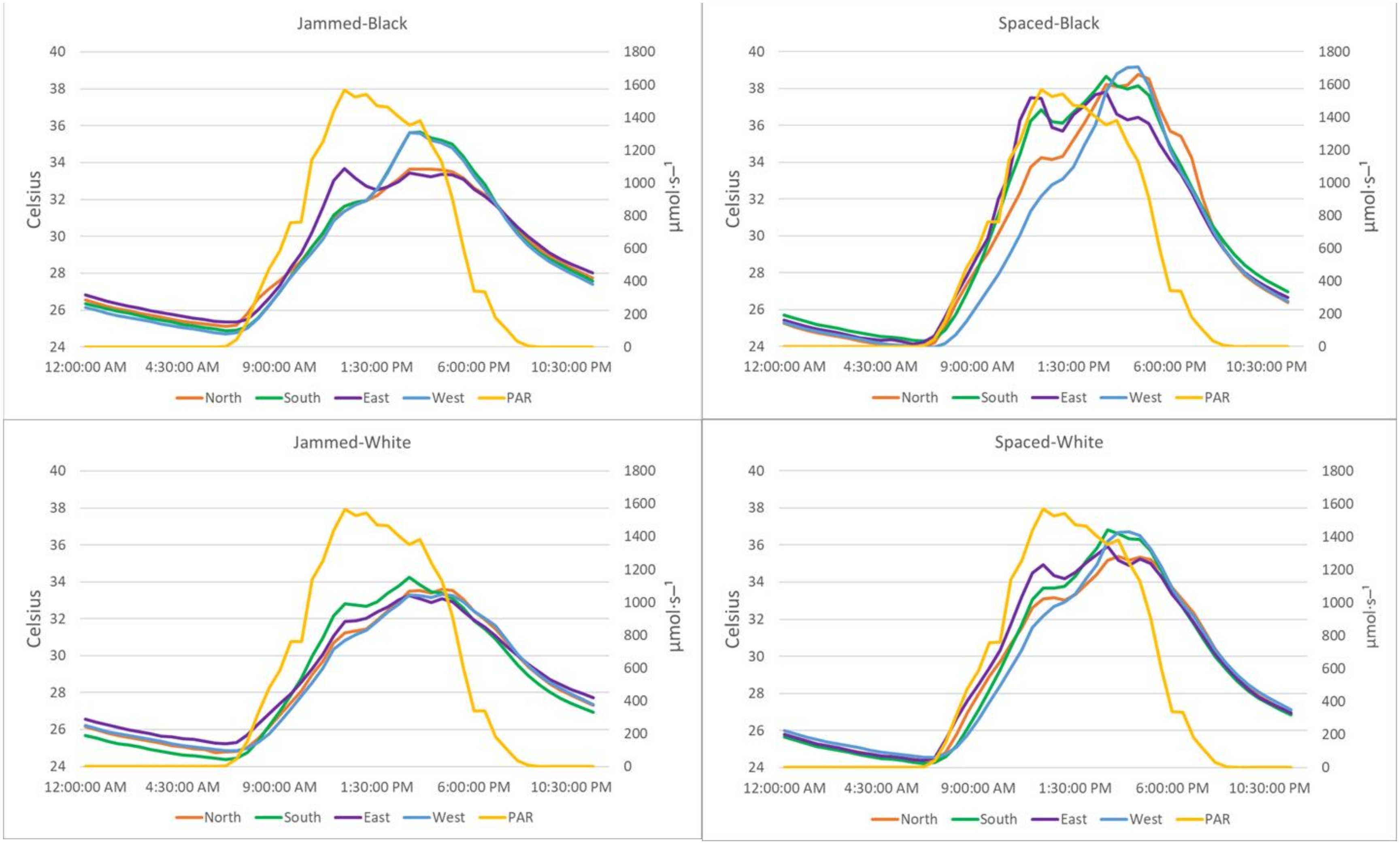

Table 1.4. Comparisons of time over 38° C associated with container color by directional root ball quadrants (n =5 days).

		North	South	East	West
Least square means for main effect: container spacing[Z]					
Color		North	South	East	West
Jammed		0.0 B	0.5 B	0.1 B	0.3 B
Spaced		3.4 A	3.9 A	2.6 A	2.9 A
Spacing (p-value)		0.0004	0.0007	0.0017	0.0004
Least square mean for main effect: container color					
		North	South	East	West
Black		2.9 A	3.1 A	2.70	2.2 A
White		0.5 B	1.3 B	1.40	1.0 B
Color (p-value)		0.0048	0.0325	0.2059	0.0473
Interaction treatment least square means: container color × container spacing[Y]					
Spacing	Color	North	South	East	West
Jammed	Black	0.0 B	0.80	0.20	0.60
Spaced	Black	5.8 A	5.40	5.20	3.80
Jammed	White	0.0 B	0.20	0.00	0.00
Spaced	White	1.0 B	2.40	0.20	2.00
Spacing x Color (p-value)		0.0048	0.1332	0.2799	0.2906

[Z]Main effects included the factors container spacing and container color. Spacing represents placed in a jammed fashion where containers are touching on all sides or spaced at 12.5 cm between containers. Jammed containers were spaced to 12.5 cm 112 DAP. Container color included either white or black containers (1.7L).

[Y]When interaction terms (spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Chapter III

Fertilizer Rate and Root Zone Temperature in Chrysanthemum Production

Abstract

Three trials were conducted to determine if lower rootzone temperatures that have been associated with white nursery production containers would allow for reduced controlled released fertilizer rates in Chrysanthemum (*Chrysanthemum ×morifolium* Ramat) production. All experiments utilized the following factorial design with main effects being container color, (black and white) and three fertilizer type (3 to 4 month, 5 to 6 month, and 6 to 8 month). Trial one was conducted at the Ornamental Horticulture Research Center, Mobile AL and utilized 11.3L containers. Trials two and three utilized 1.47L containers and were conducted at Paterson Greenhouse Complex at Auburn University, Auburn AL and the Ornamental Horticulture and Research Center, Mobile, AL., respectively. Container color reduced exposure to supraoptimal RZTs (Root Zone Temperatures) (>38°C) of white containers by 80% and increased root ratings by 33-55%. Fertilizer type impacted root rating when containers had a higher moisture content. Fertilizer longevity and container color generally impacted growth indices, increasing size of plants by up to 36%. Fertilizer type had an effect on flower coverage, with delayed flowering in 5 to 6 month and 8 to 9 month treatments, when compared to 3 to 4 month treatments. Overall, plants in white containers out-performed those in black containers by 10-36%.

Introduction

Commercial production of garden chrysanthemum is a high input crop that requires an abundance of water and fertilizer during the early stages of vegetative growth. Growers commonly use liquid fertilizer at 200 to 300 ppm soluble nitrogen applied daily, to achieve the desired size of the final product (Mattson and Bridgen, 2009). While effective, fertilizer injectors and drip irrigation can be cost prohibitive for small growers. In addition to cost, liquid fertilization is limited to irrigation schedules. In areas with heavy rainfall, controlled release fertilizers (CRFs) can continue to provide nutrients regardless of irrigation schedules. Controlled release fertilizers have been shown to be a viable option to reduce fertilizer inputs and to reduce nutrient leaching from containers while reducing labor as application is typically applied only once (Cox, 1993).

High temperatures have been observed to reduce the time and efficacy of CRFs (Kochba et al., 1990). Time, soil moisture, water vapor and temperature all impact the efficacy and duration of optimal fertilizer release rates in CRFs. Time and temperature are the primary factors that determine duration (Lamont et al., 1987).

Though strides have been made with advances in both polymer and resin coated technology, supraoptimal container temperatures, especially those noted along the Gulf Coast of the United States, can drastically decrease release times, rendering prills of CRFs useless months shorter than observed in laboratory settings (Kochba, 1990). In a study to determine the diurnal, or short term, effects of temperature on CRFs in laboratory settings, Husby et al. (2003) reported a significant interaction in product release rate and temperature. When temperature is higher or lower than the manufacturer recommended temperature, release rates can be increased or decreased. Furthermore, Husby et al., (2003) suspected that daily temperature changes in nursery settings would have a greater effect on nutrient release levels as well as on effective longevity of products. In their study, Kochba et al., (1990) observed the rate fertilizer release rates increased steeply as temperature rose.

In addition to reducing efficacy rates of CRFs, supraoptimal root zone temperatures (RZT) have been shown to reduce productivity in container nurseries by reducing root development though root injury. Ingram and Buchanan (1981) reported that temperatures above 38°C cause root growth and development to cease and temperatures above 48°C can cause long term root damage or death. This damage can impact nutrient and water uptake, causing reduced plant growth and a decline in plant health (Dodd et al., 2000; Mathers, 2007; Nambuthiri et al., 2014). Other studies that have focused on plant damage caused by supraoptimal RZT in nursery crops such as foster holly (*Ilex ×attenuata*), southern magnolia [(*Magnolia grandiflora*) (Martin et al., 1993)], and vegetable crops including pepper [(*Capsicum annuum* (Dodd et al., 2000)], potato (*Solanum tuberosum)*, sweet potato (*Ipomoea batatas*) and Dahlia [(Dahlia ×hybrid) (Schneck et al., 2021)].

White-on-black containers have been shown to significantly reduce RZT when compared to the common black containers (Fretz, 1971; Husby, 2003; Ingram and Johnson, 1981; Markham et al., 2011; Witcher et al., 2020). Ingram and Buchannan (1981) reported container color either increased or decreased RZT depending on color and solar reflectivity.

Summer temperatures commonly exceed 35°C for many days at a time in the Southeastern United States (Fretz, 1971). Nighttime minimums can remain above 21°C, resulting in elevated, often supraoptimal RZT (Ingram and Buchanan, 1981). RZT is an important environmental factor that affects growth, productivity, release rates of CRFs and long–term health of nursery stock, often resulting in an unrealized loss of production (Wright et al., 2007).

While container color has been shown to impact RZTs, previous studies have not explored the potential for extending release rates of CRFs by utilizing white containers. This study was implemented to determine if reduced RZTs associated with white containers will allow for use of shorter–term release rate CRFs and increased plant root health, thus reducing the cost of production.

Materials and Methods

Trial 1

On June 30, 2021 a study was installed at the Auburn University Ornamental Horticulture Research Station, Mobile, AL (30°42'06.9"N 88°08'48.5"W). Rooted C*hrysanthemum* ×*morifolium* Ramat 'Beverly gold' garden mum plugs [(Yoder Garden Mums®) (North Carolina Farms Inc, Indian Trial, NC)] were transplanted into black and white 11.3 containers (PF1200; Nursery Supplies Inc., Kissimmee, FL, USA), depending on treatment. Transplanted rooted plugs had been previously grown in 100 cell count flats (20 cm^3). Each container received three evenly spaced plugs. Each container was filled with a substrate consisting of 4:1(v:v) aged milled pine bark: peatmoss and amended with 3.6 $kg \cdot m^3$ of lime and 0.9 $kg \cdot m^3$ of Micromax (ICL Specialty Fertilizers, Dublin, Ohio). The containers in this study were spaced at 60 cm on center to imitate the final spacing of the containers in a production nursery, allowing for canopy development (Mattson and Brigdon, 2009). Treatments consisted of black or white nursery pots with three fertilizer treatments. The factor for fertilizer release rates included 3 to 4 month, 5 to 6 month and 8 to 9 month using Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio). Fertilizers were incorporated at the labeled high rates for each product 5.4, 6.6, 8.2 kg/m^3 for 3 to 4, 5 to 6 and 8 to 9 months, respectively.

Plants were arranged in 2×3 factorial design with pot color × fertilizer type. Experimental design was a randomized complete block design with ten blocks. Electrical conductivity (EC) measurements were collected at 15, 29, 48, 107 days after planting (DAP) using a Blue–Lab© Pulse Multimedia EC/MC meter (Bluelab Industries, Tauranga, New Zealand). Container pH and EC were also collected biweekly using the pour-through ethod (LeBude and Bilderback, 2019). Growth index (height + width at widest point + perpendicular width) / 3) for all plants were measured and recorded weekly.

Root zone temperatures were recorded with HOBO U12 Stainless 5” Probe Temp Logger (Onset Computer Corp., Bourne, MA). Probes were placed in each directional quadrant of containers on sunny days (n=5). Root zone temperature data was only collected across the container color factor (white or black).

Flower percent coverage was documented via visual rating of percentage at 86, 92 and 106 Days after planting (DAP). Fresh and dry weights of the canopy of each plant were reported at termination of the project. Roots were evaluated with plants carefully removed from their container and evaluated using a rating scale. The following scale was used to rate the percent root coverage of the entire root area: 0= 0% root coverage, 1= 1 to 25% root coverage, 2= 26 to 50% root coverage, 3= 51 to 75% root coverage and 4= 76 to 100% root coverage. Root ratings were given to each plant based on a visual observation of total root coverage.

Trials 2 and 3.

On 21 July and 23 July, 2021 two studies were installed at the Paterson Greenhouse Complex at Auburn University, Auburn AL (32°35'49.2"N 85°29'16.9"W), and the Auburn University Ornamental Horticulture Research Station, Mobile, AL (30°42'06.9"N 88°08'48.5"W). For each study, 72 rooted *Chrysanthemum ×morifolium* Ramat ‘Katie White’ garden mum plugs [(Yoder Garden Mums®) (North Carolina Farms Inc, Indian Trial, NC)] were transplanted into 1.47 containers (Yikush Inc. Shanghai, China). Transplanted rooted plugs were grown in 100 cell count flats (20 cm^3). The substrate mix was identical to trial 1. Treatment factors were identical to trial 1, apart from pot size- trials 2 and 3 utilized a smaller 1.47 L container. Experimental design was a randomized complete block design with ten blocks. Decagon 5TE and sensors and EM50 data loggers (Decagon Devices Inc., Pullman, WA) were used to measure and record RZT (°C), EC (mS/cm Saturation Extract) and volumetric water content (VWC; $m^3 \cdot m^{-3}$) every 30 minutes during both studies. Sensors were positioned vertically approximately 4 cm from the container sidewall and inserted into media to the full depth of the probe. Trial 2 GIs (height + width at widest point + perpendicular width) / 3) were measured at installation, 47 DAP and 76 DAP. Trial 3 GIs were reported at 14, 28, 46, 60, 69 DAP. Flower percent coverage was documented using a visual rating using the same scale reported in trial 1 at 63, 69 and 85 DAP. Fresh and dry weights of the canopy of trials 2 and 3 were collected at termination of each project, 76 and 75 DAP, respectively. Roots of plants were evaluated by carefully removing plants from their container, using a visual rating scale identical to trial 1.

All data was analyzed using a mixed model analysis of variance. The model included container color and spacing as main effects and their interaction (JMP Pro software ver. 14 SAS Institute, Cary, NC). When an interaction was significant post hoc means comparisons were conducted using Tukey's honest significance test (HSD)($P \leq 0.05$) In cases were no interaction was detected, Student's T test was utilized for means comparisons of main effects ($P \leq 0.05$).

Results

Trial 1

Temperature was recorded on four random sunny days 23, 41, 50, and 72 DAP. Temperatures were only observed over 38°C on day 23 where black pots had approximately 60% more time over 38°C than white. All other days resulted in zero time units over 38° C, likely due to shading provided by canopies (data not shown).

No interaction was detected between fertilizer type and container color (Table 2.1). The main effect, fertilizer longevity, did influence GI with the 8 to 9 month treatment being 4% and 9% larger than the 5 to 6 month and 3 to 4 month treatments, respectively (Table 2.1). Growth index increased with increasing duration of fertilizer releases rates. Container color did not influence GI but did impact fresh weight.

An interaction was observed between time and fertilizer type in relation to canopy diameter. Differences between treatment was not observed until 71 DAP where the 8 to 9 month release rate resulted in a larger plant canopy (Figure 2.1). Differences were detected in 8 to 9 month treatment and 3 to 4 month treatments at 71, 79 and 85 DAP. Significant differences were detected at 79 DAP between 8 to 9 month and 5 to 6 month treatments. Generally, 3 to 4 month and 5 to 6 month treatments followed the same trend of fertilizer release rate and time after planting effect growth.

Electrical conductivity levels were impacted by container color over time (Figure 2.2). White container ECs were statistically lower through day 69 in all fertilizer treatments. However, all treatments, color and fertilizer, seemed to exhaust all nutrients when based on EC readings after 69 DAP. More research is needed to determine if irrigation or precipitation influenced release rates over a short time interval.

At termination (106 DAP), significance in color and fertilizer type were detected in fresh weight measurements. Plants grown in white containers (1127 g) were 5% larger than plants grown in black containers (1063.2 g). Fertilizer type was a significant main effect for fresh weight and dry weights, with 5 to 6 and 8 to 9 month treatments weighing 8% more than 3 to 4 month treatments in fresh weights and 5 to 9 month dry weights being 8% heavier. However, a 5 to 6 month treatment (1,129.9 g) was slightly larger, less than 1%, than the 8 to 9 month fertilizer treatment (1,122.7 g). No interactions of main effects were observed in root coverage rating (Table 2.1). Container color had a significant effect on root ratings, with white containers (2.5) exhibiting 33% greater root ratings than black containers (1.7). Fertilizer type did not significantly affect root ratings.

Flower coverage (Table 2.2) was not influenced by an interaction between container color and fertilizer type across all three sampling dates (86, 92 and 106 DAP). Container color had a significant effect at 86 DAP for flower coverage where white containers had 31% more flower coverage than black. Color was not significant beyond 86 DAP. Fertilizer type had significant effects across all three sample dates. Generally, the 8-9 month release rate treatments were slower in flowering than the shorter release rates. At 86 DAP, the 3 to 4 and 5 to 6 month release rates had approximately 44% and 26% more flower coverage than 8 to 9 month treatments, respectively. At 92 DAP the 3 to 4 and 5 to 6 month were still 30 to 40% ahead of the 8 to 9 month, however all had increased coverage. By 106 DAP the 8 to 9 month had nearly caught up with only a 3 to 5% difference in flower coverage and all treatments were >90% covered in flowers. These observations are consistent with previous studies reporting that higher fertilizer rates reduce bloom rates. Fertilizer rate effects were similar for both 3 to 4 month and 5 to 6 month treatments.

Trial 2: Auburn Location

Growth index (Table 2.3) was influenced by an interaction between fertilizer type and container color at 35 DAP; however, none was observed at 75 DAP. This potentially was a result of smaller plant canopies and increased solar radiation exposure to pots and growing substrate. At 35 DAP, plants grown in black pots with 3 to 4 month fertilizer were smaller than all other treatments but were similar in size to the black 5 to 6 month and the white 8 to 9 month. At 75 DAP, color was a significant factor in growth index, white containers (26.4) were 10% larger than those in black containers (23.8). Fertilizer type was also a significant effect at 75 DAP on GI. Fertilizer types 5 to 6 month (25.4) and 8 to 9 month (26.7) treatments were 10% larger than plants grown with 3 to 4 month (23.3) treatments.

Table 2.3 shows that both main effects, container color and fertilizer longevity, had significant effects on both fresh and dry weights. No interactions between the main effects were detected on biomass. Fresh weights from black containers (212.4 g) were 21% smaller than those collected from white containers (296.0 g). Dry weights followed the same trend with shoots from white containers weighing an average of 24% more than those in black containers. Fertilizer longevity also had a significant effect on biomass. Fresh weights from treatments with 3 to 4 month release rates weighed the least (204.8 g) with 25% less than 8 to 9 month treatments (276.4 g) and 13 % less than 5 to 6 month treatments (241.0 g). Dry weights followed the same trend with 3 to 4 month treatments (21.6 g) weighing 28% less than 8 to 9 month treatments (30.3 g) and 17% less than 5 to 6 month treatments (26.1 g).

Significant interaction was detected between container color and fertilizer type in root ratings (Table 2.3). All white container and fertilizer type combinations were the same and had the greatest root ratings. Black containers with 5 to 6 and 8 to 9 month treatments were the same and were reported to have 18% lower root rating than treatments including white containers.

Black containers with 3 to 4 month (2.36) treatments had the lowest rating, and were 18 to 41 % lower in root rating when compared to 5 to 6 and 8 to 9, respectively.

Temperature data, or time over 38°C, is not shown or reported due to malfunctioning data loggers. However, trends of trial 2 were consistent with those of trial 1 and trial 3 with white containers generally experiencing significantly less time units over 38°C than black containers.

Trial 3: Mobile Location

Table 2.4 represents time over 38°C in containers in plants grown at the Ornamental Horticulture Research Station (OHRC) in Mobile, AL. This data was collected over the course of 52 days of the total 85 growing days. Container color influenced RZT significantly, increasing time over 38°C by 82% in black containers (124.0) when compared to white containers, (22.7). This is equivalent to 62 hours over the course of the observation interval with black containers experiencing supraoptimal temperatures and white experiencing 11 hours of supraoptimal temperatures.

Table 2.5 shows growth data and significance of effects. No effect was detected in fertilizer treatments and no interaction was observed between the main effects, container color and fertilizer longevity.

No interaction between container color was observed in growth index or fresh and dry weight. No significance was observed in the main effect fertilizer longevity on growth index at 34 or 75 DAP; however, container color had a significant effect on both sampling dates. White containers were 19% larger than black containers at 34 DAP and 13% larger at 75 DAP (Table 2.5).

Container color had a significant effect on fresh weights and both main effects, container color and fertilizer longevity impacted dry weights. White containers (206.7 g) were 27%

heavier than black containers (150.1 g). Dry weights followed a similar trend with plants grown in white containers (27.5 g) weighing 36% more than plant shoots collected from black containers (17.6 g). Significance was detected in fertilizer longevity in dry weights with 8 to 9 month treatments (23.5 g) weighing more than 5 to 6 and 3 to 4 month treatments (23.2 g, 20.9 g).

Both container color and fertilizer type had significant effects on root ratings however, no interaction was detected. White containers (3.85) scored 55% higher than those in black containers (1.71). Plants grown with 3 to 4 month (2.9) and 5 to 6 month (2.9) fertilizer types were rated 17% greater than 8 to 9 month treatments. No interaction between the two main effects was detected.

Container color impacted fertilizer release rates as seen in Figure 2.3. Generally, trends indicate that white containers had lower EC levels over time than black containers. Spikes in container EC were observed in black containers at 28 DAP but not in white containers. Water vapor and temperature have a direct relationship on nutrient release rates. Lower RZTs in white containers may have buffered release rates, thus reducing sporadic nutrient diffusion in all three treatments.

No interaction was observed between container color and fertilizer type on flower coverage. Container had no effect on flower coverage (Table 2.6). Fertilizer type affected percent flower coverage at 63, 69 and 85 DAP and followed a similar trend as the Auburn trial with the 3 to 4-month release rate reaching a greater percentage of flower coverage sooner than the other types at 63 DAP. At 69 and 85 DAP the 3 to 4 remained ahead of the 8 to 9 month. The 5 to 6 month treatments were similar to the other fertilizer types at 69 and 85 DAP.

Discussion

Growth index was impacted across all trials in both locations. Color had an effect on trials 2 and 3 but not on trial 1. Previous studies have reported a decrease in temperature variations in larger containers (Martin and Ingram, 1993). Differences between factor response in all three trials suggest that larger, 11.3 L containers were impacted less by solar radiation than 1.47 L containers by as much as 22%. Martin and Ingram (1993) reported that container size would slow and ultimately reduce temperatures in substrate due larger dimension containers having greater temperature buffering capacities (Martin and Ingram, 1993).

In all three trials, both container size, 1.47 L and 11.3 L containers, were significantly impacted by fertilizer type. Generally, the longer the fertilizer release rate, the larger the plant would be. This indicated that lower longevity fertilizers most likely expended their nutrient load sooner. Osmocote® is tested at temperatures ranging 0 to 100°C, with 21°C reported as the optimal temperature for labeled release rates (Lamont et al., 1987). Our containers average 12 to 20°C higher than the optimal rate, increasing release rates, as suggested by Lamont et al. (1987) and Kochba et al. (1990) indicating that resin coated nutrient prills were more likely to have reduced efficacy in temperatures over 21°C.

Fresh and dry weights were generally impacted by both main effects, container color and fertilizer longevity treatments. Previous studies have reported that container color can reduce RZTs by as much as 10-20 %. Our study suggests that white containers were exposed to temperatures above 38°C 82% less time than black containers. Witcher et al., (2020) reported that white containers were exposed to supraoptimal temperatures over 80% less than those in black containers. Witcher et al., (2020) also reported that increased root mass, in their study 7% more root mass in traditional containers versus air pruning pots, increased growth rate and growth index by as much as 13% percent. Furthermore, additional research has correlated increased root mass with increased shoot mass and growth (Markam et al., 2011; Martin and Ingram, 1993). This is consistent with previous studies indicating the white containers can reduce RZTs, reducing time over the critical temperature of 38°C.

Root ratings followed trends suggested by previous studies, indicating that white containers scored higher than those of black containers (Ingram and Johnson, 1981; Schneck et al., 2021). Root ratings were generally impacted by color across all trials. White containers scored approximately 37% larger than those in black containers. This was decreased to 33% in 11.3L containers, validating data from previous studies that indicated that containers with larger dimensions had increased temperature buffering abilities (Martin and Ingram, 1993). In trial 3, a significant interaction was detected between container color and fertilizer longevity on root rating (Table 2.3). Generally, this trend applied to all combinations of fertilizer in white containers, outperforming those same treatments in black containers.

Figure 2.2 shows an interaction between container color and fertilizer treatments. Fertilizer had a greater effect on plant growth in trial 2 (Paterson Greenhouse Complex, Auburn, AL) when compared to trials 1 and 3 (OHRC, Mobile AL). While evaluating volumetric water content data, differences were detected in substrate water content between locations (data not shown). These differences can be attributed to watering practices varying from one location to another. The OHRC staff waters plants based on plant needs, often running more dry than other research locations. The Auburn study was subjected to timed irrigation, being watered three times per day for thirty minutes, regardless of moisture in containers. This increased moisture in containers impacted the rate of fertilizer release. Water vapor is the limiting factor in prill release rates with temperature increasing the rate when water vapor is available (Kochba et al., 1990).

Increased moisture, combined with increased RZT, shortened efficacy rates of fertilizers resulting in earlier flowering and smaller plants (Husby et al., 2003; Lamont et al., 1987).

Generally, lower fertilizer longevity increased flowering in all observations. Mali et al., (2016), reported data from three nitrogen fertilizer rates influence on mum flowering, where higher fertilizer rates delayed or reduced flower and units with lower fertilizer rates saw earlier flower bud break (Mail et al., 2016). This, when combined with plant growth data, may indicated that 5 to 6 month or 8 to 9 month treatments could lead to larger plants with slightly delay flowering, perhaps extending the bloom cycle after the plant has left the producer and is purchased.

Conclusion

This study indicates that root zone temperatures in black containers are significantly hotter than white containers. This increased time above the critical temperature of 38°C has a deleterious effect on root development, shoot development, plant efficiencies and nutrient uptake. Furthermore, our studies indicate that container buffering capacity increases with increased volume. While this buffering ability reduces the impact of container color on root development, there is still a significant impact on overall plant growth. Our study also indicates that growers that chose to utilize controlled release fertilizers to achieve nutrient requirements of garden mums may be able to delay or speed up flowering by utilizing a fertilizer with decreased or increased longevity ratings. However, all resin coated fertilizers have the tendency to release their nutrient loads far quicker than the label indicates, especially when temperatures are well above the manufacturers' recommended optimal temperature. Our data also indicates that irrigation can also play a role in the release of fertilizer times and reduce the longevity of prills.

With substrate moisture, specifically water vapor, being the limiting factor in nutrient release, increased irrigation may lead to faster release rates of CRFs. With water vapor and temperature having a direct relationship on nutrient release and with diurnal temperature fluctuations that are commonly experienced in nursery conditions, growers should account for a reduced efficacy of CRFs when utilizing irrigation that is applied with a time system versus a “by need” system. Lastly, growers should consider that all combinations of fertilizer longevity were more effective in producing larger plants with healthier roots when in white containers when compared to black containers. All white container combinations outcompeted any fertilizer treatment in black containers. Growers could utilize white containers with the appropriate fertilizer treatment for their operation to increase the growth rate and size of plants while reducing grow out times.

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Tables and Figures

Table 2.1. Treatment[z] data of 'Beverly Gold' *Chrysanthemum* trial conducted at the Auburn Ornamental Horticulture Research Station, Mobile, AL.

Least square mean for main effect: container color					
Color		Growth Index[Y]	Fresh Weight	Dry Weight	Root Coverage Rating
Black		58.3	1063.2 B	193.9	1.7 B
White		58.4	1127.1 A	196.4	2.5 A
Significance		0.8267	0.0345	0.5415	<0.0001
Least square mean for main effect: fertilizer longevity[X]					
Fertilizer		Growth Index	Fresh Weight	Dry Weight	Root Coverage Rating
3-4 month		55.3 C	1032.8 B	184.4 C	2.1
5-6 month		58.3 B	1129.9 A	198.7 B	2.1
8-9 month		60.9 A	1122.7 A	202.4 A	2.1
Significance		0.0001	0.0159	0.0015	0.8855
Interaction least square means for container color × fertilizer longevity[W]					
Color	Fertilizer	Growth Index	Fresh Weight	Dry Weight	Root Coverage Rating
Black	3-4 month	55.8	1010.0	185.2	1.7
Black	5-6 month	57.9	1123.8	200.2	1.6
Black	8-9 month	61.2	1055.8	196.4	1.7
White	3-4 month	55.9	1055.6	183.6	2.5
White	5-6 month	58.7	1136.0	197.2	2.6
White	8-9 month	60.8	1189.6	208.4	2.4
Significance		0.8282	0.2267	0.2515	0.4326

[Z]2 x 3 Factorial. Container color= black and white containers. 3 Fertilizer longevity treatments; 3-4 month, 5-6 month, 8-9 month.

[Y]Growth index = (height + width at widest point + perpendicular width) / 3.

[X] Fertilizer longevity. Fertilizer used was Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio) in 3-4 month, 5-6 month and 8-9 month treatments.

[W]When interaction terms (Spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Table 2.2. Flower coverage comparison[Z] data of 'Beverly Gold' *Chrysanthemum* trial conducted at the Auburn Ornamental Horticulture Research Station, Mobile, AL.

Least square mean for main effect: container color				
Color		Flower Coverage 86 DAP	Flower Coverage 92 DAP	Flower Coverage 106 DAP
Black		23.7 B	50.7	95.3
White		34.3 A	56.0	96.8
Significance		0.01185	0.2130	0.3070
Least square mean for main effect: fertilizer longevity[Y]				
Fertilizer		Flower Coverage 86 DAP[x]	Flower Coverage 92 DAP	Flower Coverage 106 DAP
3-4 month		37.5 A	64.5 A	96.5 AB
5-6 month		28.5 AB	56.5 A	98.3 A
8-9 month		21.0B	39.0 B	93.5 B
Significance		0.00727	<0.0001	0.0339
Least square means for container color × fertilizer longevity[X]				
Color	Fertilizer	Flower Coverage 86 DAP	Flower Coverage 92 DAP	Flower Coverage 106 DAP
Black	3-4 month	34.0	67.0	96.5
Black	5-6 month	20.0	51.0	98.5
Black	8-9 month	17.0	34.0	91.0
White	3-4 month	41.0	62.0	96.5
White	5-6 month	37.0	62.0	98.0
White	8-9 month	25.0	44.0	96.0
Significance		0.54695	0.2336	0.2422

[Z]2 x 3 Factorial.

[Y]Fertilizer longevity. Fertilizer used was Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio) in 3-4 month, 5-6 month and 8-9 month treatments.

[X]When interaction terms (fertilizer by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Table 2.3. Fresh and dry weights, growth indices and root ratings across two sample dates for 'Katie White' mums grown in Auburn, Alabama.

Least square means for container color						
		Fresh Weight (g)	Dry Weight (g)	GI[Z] 35 DAP[Y]	GI 75 Dap	Root Rating
Black		212.4 B	22.3 B	17.2	23.9 B	2.7
White		269.0 A	29.7 A	19.4	26.4 A	3.9
Significance		<0.0001	<0.0001	0.0045	<0.0001	<0.0001
Least square means for fertilizer longevity[X]						
		Fresh Weight (g)	Dry Weight (g)	GI 35 DAP	GI 75 Dap	Root Rating
3-4 Month		204.8 C	21.6C	16.8	23.3 B	3.2
5-6 Month		241.0 B	26.1 B	19.4	25.4 A	3.4
8-9 Month		276.4 A	30.3 A	18.7	26.8 A	3.4
Significance		<0.0001	<0.0001	0.0215	<0.001	0.0544
Least square means for container color × fertilizer longevity[W]						
		Fresh Weight (g)	Dry Weight (g)	GI 35 DAP	GI 75 Dap	Root Rating
Black	3-4 Month	174.6	16.7	14.3 B	21.5	2.36 C
Black	5-6 Month	212.9	23.1	17.8 AB	24.5	2.9 B
Black	8-9 Month	249.5	27	19.5 A	25.5	2.9 B
White	3-4 Month	234.8	26.4	19.4 A	25	4.0 A
White	5-6 Month	269	29	21.0 A	26.3	4.0.A
White	8-9 Month	303.3	33.6	17.9 AB	27.9	4.0 A
Significance		0.957	0.2371	0.0023	0.3101	0.0500

[Z]Growth index = (height + width at widest point + perpendicular width) / 3.

[Y]Days after planting.

[X]Main effects include container color, black and white and fertilizer longevity. Fertilizer used was Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio) in 3-4 month, 5-6 month and 8-9 month treatments.

[W]When interaction terms (spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Table 2.4. Comparisons of time[Z] over 38°C associated with container color in root zone of 'Katie White' garden mums grown in Mobile, AL.

Least square mean for main effect: container color	
Black	124.0 A
White	22.7 B
Significance	0.0068
Least square mean for main effect: fertilizer longevity[Y]	
3-4 month	87.7
5-6 month	62.0
8-9 month	26.6
Significance	0.7783
Interaction least square mean: fertilizer × longevity[W]	
Black 3-4 month	144.3
Black 5-6 month	108.3
Black 8-9 month	119.3
White 3-4 month	31.0
White 5-6 month	15.7
White 8-9 month	21.3
Significance	0.9576

[Z] Time units were recorded over 52 days (08/3/2021 to 9/23/2021). Data Was collected in Mobile, AL

[Y]Fertilizer used was Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio) in 3-4 month, 5-6 month and 8-9 month treatments.

[W]When interaction terms (spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Table 2.5. Growth comparisons of 'Katie White' *Chrysanthemum* trial conducted at The Ornamental Horticulture Research Station in Mobile, AL.

Least Square means for Main Effect: Container color[z]						
Color		Growth Index[Y] 34 DAP[x]	Growth Index 85 DAP	Fresh Weight	Dry Weight	Root Coverage Rating
Black		17.7 B	23.8 B	1063.2 B	193.9	1.667 B
White		21.9 A	27.3 A	1127.1 A	196.4	2.50 A
Significance		<0.0001	< 0.0001	<0.0001	<0.0001	<0.0001
Least Square Mean for Main Effect: Fertilizer longevity[W]						
Fertilizer		Growth Index 34 DAP	Growth Index 85 DAP	Fresh Weight	Dry Weight	Root Coverage Rating
3-4 month		20.4	24.9	1032.8 B	184.4 C	2.10
5-6 month		19.2	25.8	1129.9 A	198.7 B	2.10
8-9 month		19.9	25.9	1122.7 A	202.4 A	2.05
Significance		0.5883	0.09419	0.1012	0.0599	0.3851
Least square means for container color × fertilizer longevity[V]						
Color	Fertilizer	Growth Index 34 DAP	Growth Index 85 DAP	Fresh Weight	Dry Weight	Root Coverage Rating
Black	3-4 month	18.0	23.8	150.6	17.4	2.0
Black	5-6 month	17.8	23.7	144.5	17.1	1.9
Black	8-9 month	19.3	23.9	155.4	1718.2	1.3
White	3-4 month	22.8	26.0	181.4	24.4	4.0
White	5-6 month	20.6	28.0	214.9	29.4	3.9
White	8-9 month	22.5	27.8	223.9	28.8	3.9
Significance		0.5865	0.0822	0.1012	0.0599	0.3851

[Z]Two container colors, black and white.

[Y]Growth index = (height + width at widest point + perpendicular width) / 3.

[X]DAP = Days after planting with a planting date of 5/11/2021.

[W] Fertilizer longevity. Fertilizer used was Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio) in 3-4 month, 5-6 month and 8-9 month treatments.

[V]When interaction terms (Spacing by color) were not significant (α = 0.05) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test (α = 0.05). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons (α = 0.05).

Table 2.6. Flower coverage comparison[Z] data of 'Katie White' *Chrysanthemum* trial conducted at the Auburn Ornamental Horticulture Research Station, Mobile, AL.

Least square mean for main effect: container color				
Color		Flower Coverage 63 DAP[Y]	Flower Coverage 69 DAP	Flower Coverage 85 DAP
Black		40.3	69.1	86.7
White		35.0	63.0	83.2
Significance		0.2085	0.1130	0.1430
Least square mean for main effect: fertilizer longevity[X]				
Fertilizer		Flower Coverage 63 DAP	Flower Coverage 69 DAP	Flower Coverage 85 DAP
3-4 month		50.3 A	76.4 A	89.0A
5-6 month		31.0 B	64.4 AB	85.2 AB
8-9 month		31.3 B	60.3	80.6 B
Significance		0.0003	0.0174	0.0199
Least square means for container color × fertilizer longevity[W]				
Color	Fertilizer	Flower Coverage 63 DAP	Flower Coverage 92 DAP	Flower Coverage 106 DAP
Black	3-4 month	54.8	77.0	90.6
Black	5-6 month	30.8	67.9	85.7
Black	8-9 month	35.3	62.4	83.9
White	3-4 month	45.8	70.9	87.5
White	5-6 month	31.9	60.9	84.7
White	8-9 month	27.4	58.2	77.4
Significance		0.5505	0.9429	0.6339

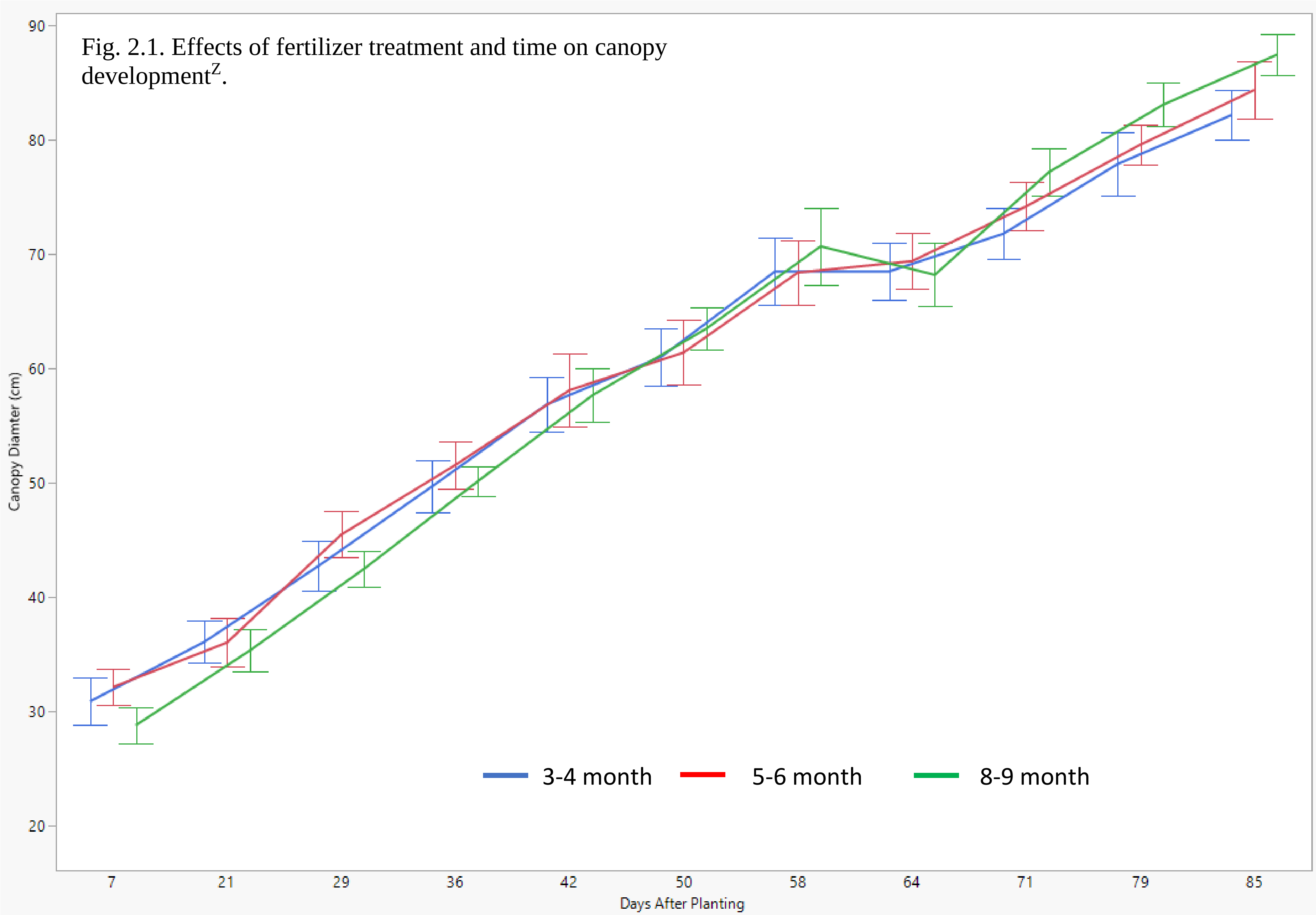
[Z]Ratings represent a scale of 0 to 4 on percent of canopy covered in open flowers coverage (0 = none; 1 = 1 to 25%; 2 = 26 to 50%; 3 = 51 to 75%; 4 = 76 to 100%).

[Y]Days after planting

[X]Fertilizer longevity. Fertilizer used was Osmocote® Plus 15N-9P-2K (ICL Specialty Fertilizers, Dublin Ohio) in 3-4 month, 5-6 month and 8-9 month treatments.

[W]When interaction terms (Spacing by color) were not significant ($\alpha = 0.05$) means were separated for each main effect. Means followed by the same level are not significantly different using Student T's test ($\alpha = 0.05$). When the interaction term was significant, means were separated using the Tukey method for multiple comparisons ($\alpha = 0.05$).

Fig. 2.1. Effects of fertilizer treatment and time on canopy development[z].



[z]Canopy measured at 7, 21, 29, 36, 42, 50, 58, 64, 71, 79, 85 and 95 days after planting (DAP)

Figure 2.2. Trial 1. Interaction plot of container color X fertilizer release rate x date on electrical conductivity (α=0.05)

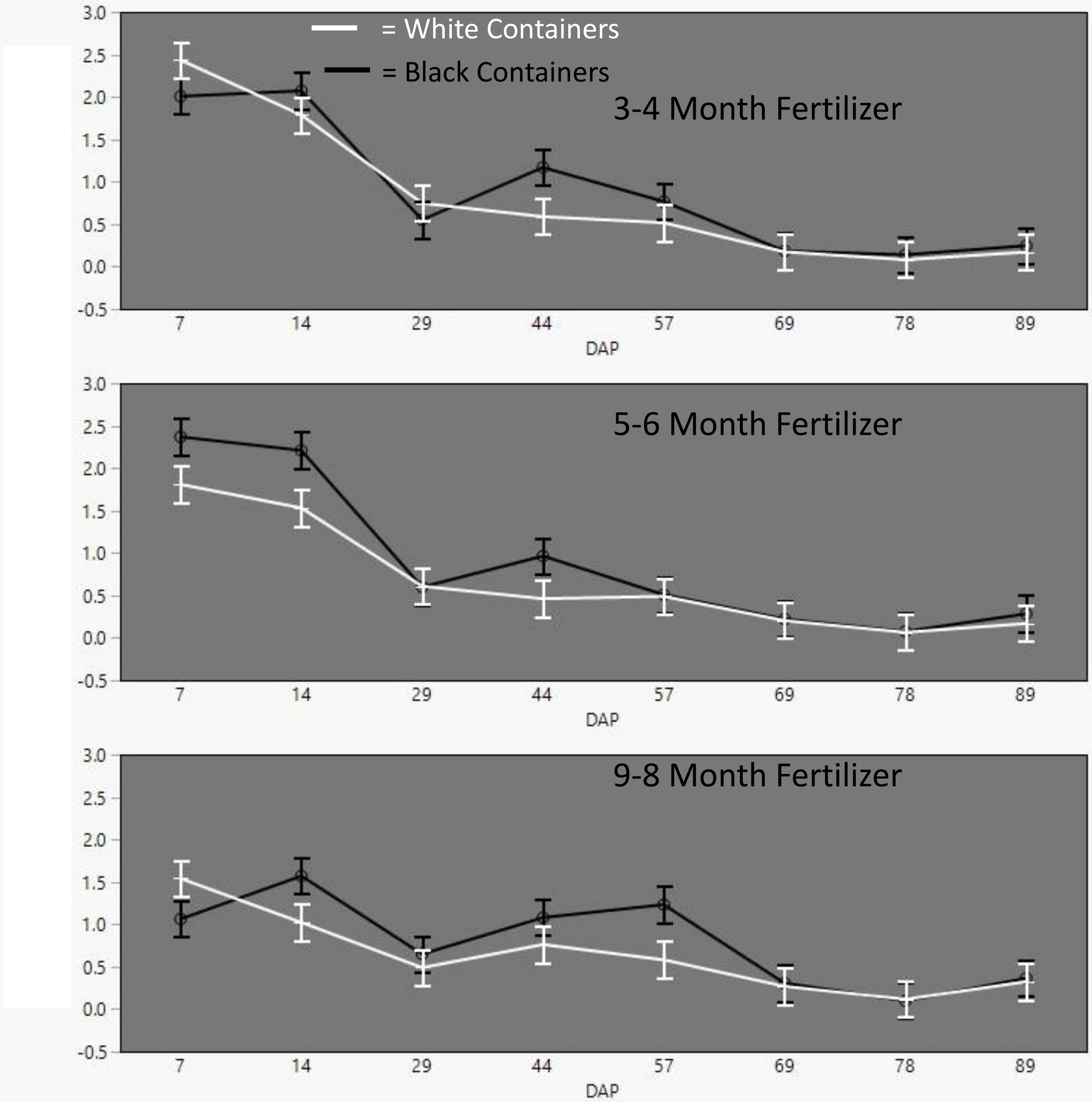


Figure 2.3. Trial 3. Interaction plot container color X fertilizer release rate x date on electrical conductivity (α=0.05).