SUBSTRATE MOISTURE CONTENT EFFECTS ON GROWTH AND SHELF LIFE OF *ANGELONIA ANGUSTIFOLIA*

A Thesis

by

ALISON KARA BINGHAM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2012

Major Subject: Horticulture

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Approved by:

Chair of Committee,	Terri W. Starman
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ABSTRACT

Substrate Moisture Content Effects on Growth and Shelf Life of *Angelonia angustifolia*.

(May 2012)

Alison Kara Bingham, B.S, Texas A&M University

Chair of Advisory Committee: Dr. Terri W. Starman

Wilting during shelf life is a major cause of postharvest shrink for bedding plants shipped long distances from production greenhouses to retail outlets. The objective of this research was to determine if irrigation at lower, constant substrate moisture content (SMC) during greenhouse production would be a feasible way to acclimate plants for reduced shrinkage during shelf life, while potentially conserving irrigation water.

Rooted plugs of *Angelonia angustifolia* 'Angelface Blue' were grown in greenhouse production until a marketable stage in substrates irrigated at SMC levels of 10, 20, 30, and 40% using a controlled irrigation system. At the end of the greenhouse production stage, plants were irrigated to container capacity and subjected to a simulated shipping environment, in shipping boxes in the dark for two days. After shipping, plants were placed back in the greenhouse and watered minimally to simulate a retail environment. Data was taken at the end of each stage i.e. greenhouse production, simulated shipping, and simulated retail. Parameters measured at the end of the production stage were fresh and senesced flower number, stem number, pre-dawn and mid-day water potential, SPAD meter readings (Experiment 2), and plant height and

node number segmented into vegetative, flowering, and bud area. Plant quality was observed and rated. At the end of the simulated retail stage, the same data was taken, along with fresh and dry shoot and root weight.

Results indicated that as SMC decreased from 40 to 10%, plants were shorter in height, but had proportional flowering sections (Experiment 1) or more compact flowering sections (Experiment 2). The volume of water received by the 40% SMC plants was three times greater (Experiment 1) and 12 times greater (Experiment 2) than the 20% SMC plants during greenhouse production, and two times greater (Experiment 1) and nine time greater (Experiment 2) during simulated retail. Additionally, the 40% SMC plants used 15 liters (Experiment 1) and 38 liters (Experiment 2) of water during greenhouse production compared to the 20% SMC plants using only three liters in both experiments. During simulated retail the 40% SMC plants used six liters (Experiment 1) and nine liters (Experiment 2) of water while the 20% SMC plants used five liters (Experiment 1) and three liters (Experiment 2) of water. During production, mid-day water potentials decreased as the SMC levels decreased, but at the end of the simulated retail (Experiment 1), the mid-day water potentials were all the same, suggesting plants that were drought stressed during production area were acclimated to lower water levels experienced in retail settings.

Overall, the 20% SMC treatment produced the best postharvest quality plant due to reduced plant height without detrimental effects on flowering. The results demonstrate that while conserving water, controlled irrigation at a medium-low SMC can produce high quality plants that have equal shelf life to those that are irrigated at high levels.

DEDICATION

I would like to dedicate this thesis to my parents and my brother. Their constant support and love gave me strength and encouragement when times were rough. I love them more than words can say.

I would also like to dedicate this thesis to my Papaw who passed away while I was completing my Masters. His enduring strength, love, and values will always remind me of the person I should be.

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1. INTRODUCTION

Water conservation and proper water use are major concerns the greenhouse industry is facing due to populations and urbanization steadily increasing. Typically, greenhouse growers over-irrigate crops to ensure well-watered substrates throughout production but this can cause a decrease in plant quality and produce an overall unappealing product. Overwatering greenhouse crops leads to runoff and leaching of nutrients from the greenhouse into the environment which wastes good quality irrigation water. Recently, growers have been facing stricter runoff regulations from the government on agricultural water use and pollution from fertilizer runoff. Increasing water use efficiency is becoming important in greenhouse production and crop quality.

Horticulture crops are exposed to water deficits at the time of sale in retail environments, which can reduce quality and shelf life. During greenhouse production, plants are in an optimum environment receiving adequate water, light, fertilizer, and temperature. Although there is no typical retail setting in terms of light and temperature levels, irrigation is almost always limited, and plants wilt and decline. Toning a plant,

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This thesis follows the style of HortScience.

i.e., reducing irrigation and fertilization frequency and lowering temperatures during the final two to three weeks in production, has been shown to prepare plants for different environments they will face in retail settings. Reducing water and the amount of nutrients during the entire greenhouse production stage could serve to condition the plants to environmental stresses they receive after harvest.

Our objective was to acclimate or "condition" *Angelonia angustifolia* 'Angelface Blue' for improved shelf life by growing them at lower, constant soil moisture contents (SMC) during greenhouse production.

2. REVIEW OF LITERATURE

Proper watering is essential to quality crop production in floriculture greenhouses. Too little water causes stress to plants and wilting, while too much water and lack of oxygen to the roots favor fungal growth and root rot diseases (Silva et al, 1999). Both situations decrease plant quality and produce an overall unappealing commercial horticultural product. Container-grown plants in greenhouses require frequent irrigation because water drains readily from containers and limited substrate volumes restrict the amount of water and nutrients available to the plants (Warsaw et al., 2009). The limited water and nutrient reservoir of container-grown plants leads to more frequent irrigation and fertilizer need compared to those grown in the ground without restriction (Dole et al., 1994). Typically, greenhouse growers automate irrigation for most crops to ensure well-watered substrates throughout production. The automated systems are programmed to irrigate substrates to saturation with up to 60% drainage (Warsaw et al., 2009) regardless of plant water requirements, which result in high SMC and overwatered media (Nemali and van Iersel, 2006). Overwatering results in runoff and leaching of nutrients and contaminants from the greenhouse into the environment and wastes good quality irrigation water.

Decreasing water resources and limited water supplies caused by steadily increasing urban populations in the United States have increased pressure on the availability and usage of greenhouse irrigation water and have forced stricter governmental regulations of agricultural water use (Nemali and van Iersel, 2008).

Government concerns are about water usage and pollution from fertilizer runoff that contains high content of nitrates and phosphorus (Burnett and van Iersel, 2008). Nitrate-nitrogen concentrations ranging from 70 to 253 $mg \cdot L^{-1}$ are found in irrigation and fertilization runoff water at bedding and foliage plant nurseries (Sharma et al., 2009). While the runoff at some plant nurseries is captured and recycled for irrigation, at other operations, it is not (Sharma et al., 2009). Some state governments are considering laws and regulations to ensure that pollutants are assessed and regulated. For example, Maryland passed the Water Quality Improvement Act in 1998 stating that all nitrogen and phosphorus applications from both organic and inorganic sources will be regulated for all sectors of agriculture, and that greenhouses operations must document that they do not release large quantities of nutrient pollutants into the environment (Lea-Cox and Ross, 2001).

Water requirements for many floriculture crops still remain unknown, and much of the current information on ornamentals is anecdotal and not quantitative (Burnett and van Iersel, 2008). Starman and Lombardini (2006) found lantana [*Lantana camara* (L). 'New Gold'], lobelia [*Lobelia cardinalis* (L.)], mealy sage [*Savlia farinacea* (Benth.) 'Henry Duelberg'], and fan flower [*Scaevola aemula* (R. Br.) 'New Wonder'] irrigated at SMC levels as low as 13% container capacity had sufficient overall plant quality. When petunias [*Petunia*×*hybrida* (Vilm.) 'Lavender Mist'] were grown at SMC levels ranging from 5 to 40% for three weeks, 20% SMC was sufficient to grow quality plants. The 20% SMC was obtained by applying approximately 15 mL of irrigation water per day (Van Iersel et al., 2010). Research conducted on gaura [*Gaura lindheimeri* (Engelm and Gray) 'Siskiyou Pink'] (Burnett and van Iersel, 2008) grown under eight volumetric water contents, or theta (θ), ranging from 0.10 to 0.45 $m^3 \cdot m^{-3}$ showed 0.40 and 0.45 $m^3 \cdot m^{-3}$ levels normally used in greenhouse production had leaching and algae growth on the substrate surface whereas plants grown at 0.25 $m^3 \cdot m^{-3}$ or lower were large enough to be marketable. Water use efficiency (WUE) (shoot dry weight ÷ irrigation volume applied) was found to be lower as θ levels increased (Burnett and van Iersel, 2008).

Generally is it unknown how much water container plants utilize to maximize growth and aesthetic value (Burger et al., 1987). To establish coefficients for water use, Burger et al. (1987) used three commonly planted species in California, oleander [*Nerium oleander* (L.)], bottlebrush [*Callistemom citrinus* (R. Br.)], and sweet mock orange [*Pittosporum tobira* (Thumb.) W. T. Aiton] to determine how much water was used through evapotranspiration by weighing pots before and after watering. The difference in plant weight was used to determine water use of plants since 1 mL of water equals 1 g. Crop coefficients, determined from evapotranspiration rates, were used to determine when to irrigate and how much water to apply to a certain crop. Factors altering water use in container plants included cultivar, developmental stage of the plant, nutritional status, shading and spacing. Three water use coefficients were established: heavy water users (coefficients greater than 4.0), moderate water users (coefficients between 2.0 and 3.9), and light water users (coefficients less than 2.0). It was concluded that growers could easily determine a plant's crop coefficient to know when to irrigate by weighing plants to determine evapotranspiration rates and water use. Once growers know crop coefficients for their plants, they can group similar plants together based on water use and water all plants within a group at the same time.

Commercial greenhouses and nurseries use automated irrigation systems including microtube irrigation, ebb-and-flow benches, flood floors, and boom watering controlled by timers regulated by human judgment of the crop's water need rather than being based on SMC or plant species requirement (Burnett and van Iersel, 2008). Poinsettia [*Euphorbia pulcherrima* (Willd. Ex. Klotzsch) 'Gutbier V-14 Glory'] grown on ebb-and-flow bench irrigation systems used the least amount of water compared to hand-water, microtube, and capillary mat systems, and produced the least amount of runoff. Poinsettias grown on capillary mats used the greatest amount of water and produced the most runoff, while microtube and hand watered systems were intermediate in both water use and runoff (Dole et al., 1994). Additionally, the electrical conductivity (EC) of water leeched from capillary mats was higher than that of water leached from containers that received top irrigation. Plants from the capillary mats and ebb-and-flow benches were taller, higher quality, and had greater leaf, stem, and total dry weights compared to plants that were top watered. Overall, ebb-and-flow systems were found to be the most efficient water system for places with limited water supplies producing higher quality poinsettia plants with less water and fertilizer (Dole et al., 1994).

Recycling water and using cyclic irrigation, i.e., applying a daily quantity of water in several subvolumes throughout the day, are two ways growers are conserving water during production. Other ways to conserve water are grouping plants together in the same water zone by container size, plant species water needs, and substrate type

(Bilderback, 2002). In this way irrigation schedules are not dictated by species with higher water needs thus preventing over watering of species with less water need and conserving greenhouse water.

There are few sustainable options for wastewater disposal, and the unique chemical, physical, and biological properties of each waste produced make management practices and disposal difficult (Halliwell et al., 2001). To use water resources more efficiently, some growers are using sewage effluent or reusing wastewater they once would have discarded into the environment after use (Toze, 2005). Treating the wastewater by removing pathogens and salts from the water is effective with a reverse osmosis filtration system, but treatment is far too expensive to be economically viable for irrigation of crops and turf (Toze, 2005). Salts and other contaminants can be managed by effective water use such as alternating recycled water with low salinity water to leach and reduce salt levels.

Cyclic irrigation involves applying small quantities of water throughout the day to minimize stress, which otherwise could occur in the afternoon after a single morning irrigation (Beeson and Haydu, 1995). When growers irrigate once in the morning, plants can dry out and develop stress due to rising temperatures throughout the day. The higher the temperatures are, the faster the water loss and the more rapidly a plant can decline (Armitage, 1993). Multiple irrigation cycles throughout the day on live oaks [(*Quercus virginiana* (Mill.)], red maples [(*Acer rubrum* (L.)], crape myrtles [(*Lagerstroemia indica* (L.)] and winged elms [*Ulmus alata* (Michx.)] produced trees with significantly greater height, trunk diameter, and shoot dry weight compared to the same volume of water applied once per day (Beeson and Haydu, 1995). Cyclic irrigation substantially reduced water consumption by 25-50% compared to standard overhead practice of 12.7 mm applied daily. When growers apply irrigation to plants in several short cycles rather than one long cycle, nutrient leaching from containers is also reduced (Bilderback, 2002). In addition, water absorption rates by media are limited at high water volumes, so applying a smaller amount of water during each irrigation to resaturate the media is less wasteful (Warsaw et al., 2009).

There has been an increasing interest in the greenhouse industry to develop and improve methods and precision of irrigation for crop quality and water conservation and to deviate from irrigation decisions based on guesswork or intuition rather than on scientific data (Jones, 2008). Measurements of soil or substrate moisture with capacitance irrigation sensors provided precise information to schedule irrigation events in both soil and soilless substrates by sensing real-time water use to precisely schedule irrigation applications when plants need them (Lea-Cox, et al., 2008). Effective irrigation systems for greenhouse facilities are those that are sensitive to small changes in SMC, respond rapidly, adapt readily to different crops and growth stages, are reliable, user-friendly, and low cost (Jones, 2008). A good irrigation system will provide information to growers about their crops' water needs and serve as a prediction tool for automatic or manual decisions. These irrigation systems monitor soil moisture and accurately sense real-time plant water use, which help growers schedule irrigation and nutrient applications more precisely. Measuring SMC can also be achieved by using a soil probe to monitor moisture content of the media by either burying the probe in the substrate and leaving it long term, or taking a one time quick measurement each day. Monitoring soil moisture each day could help growers make more accurate decisions on when to irrigate their plants.

With irrigation controllers, constant θ was reliably maintained for impatiens [*Impatiens walleriana* (Hook.)], petunia, salvia [*Salvia splendens* Sellow (ex Roemer & J.A. Schultes)] and vinca [*Catharanthus roseus* (L.) G. Don.] for an extended period of time despite varying plant sizes with little to no runoff and wastage of water (Nemali and van Iersel, 2006). Irrigation controllers were used to irrigate a substrate to a set-point for constant θ, which was maintained close to that set-point throughout the growing season (Nemali and van Iersel, 2006). This new system used moisture sensors and solenoid valves interfaced to an irrigation controller. When θ dropped below the set point, the controller opened solenoid valves and the impatiens, petunias, salvia, and vinca were irrigated and substrate water content was returned to the set point. The irrigation controller system applied frequent, low volume application of irrigation water, which had the advantage of avoiding large swings in SMC between the excess irrigation applications and water deficits, maintaining SMC within a narrow range (Jones, 2008). By maintaining SMC, the irrigation system effectively replaced the water that was lost by evapotranspiration, creating a plant-driven system (Burnett and van Iersel, 2008).

Withholding irrigation has been used as a non-chemical height control method during greenhouse production of floriculture crops. Exposing plants to less irrigation can produce plants with smaller leaves, shorter internodes, and reductions in flower number, size, and quality (Álvarez et al., 2009). Reducing phosphorus and nitrogen have also been studied as methods for non-chemical growth regulation (Hansen et al., 2005). Drought stress reduced plant height of hibiscus [*Hibiscus rosa-sinensis* (L.) 'Cairo Red'] by 68% compared to 85% with reduced phosphorus, 43% with chemical growth regulators and 43% with drought stress and growth regulator application combined. Drought stress also reduced the number of chemical growth regulator applications needed (Hansen et al., 2005).

Moisture contents on a raised capillary mat used to irrigate marigolds [*Tagetes erecta* (L.) 'Queen Sophia'] varied due to elevation, i.e., as the elevation increased, the moisture content decreased (van Iersel and Nemali, 2004). Marigolds grown under drought conditions had reduced height, but were not more compact as measured by leaf area per unit plant height. Conversely for gaura, as the moisture level decreased, stem elongation decreased whereas leaf area also decreased (Burnett and van Iersel, 2008). Reduced leaf area due to drought means a decreased photosynthetic surface area, which provides the energy for growth and maintenance of the plant, which in turn could affect the plant's overall morphology. For gaura, decreasing soil moisture decreased the number of branches, making plants have less dense canopies and lower quality.

Strawberry plants [*Fragaria*×*ananassa* (Duch.) 'Salut'] water stressed at 50% of substrate water-holding-capacity had reduced growth of the above ground plant parts compared to controls at 90-100% substrate water-holding-capacity while still maintaining root system development (Klamkowski and Treder, 2006). Reduced fresh mass and leaf area in the canopy decreased transpirational surfaces, which reduced water loss during drought. Additionally, with a good root structure, plants had increased root depth and an increase in the amount of water uptake. Strawberry plants also had reduced stomatal density and size to minimize transpiration under drought conditions.

Potted miniature roses (*Rosa*×*hybrida* 'Charming' and 'Bianca Parade') were grown under four irrigation treatments based on evapotransportion as determined by gravimetric water loss: control, cyclic non-lethal water deficit in three cycles (five days of moderate stress then five days of recovery), moderate water deficit (75% of water availability), and severe water deficit (60% of water availability) (Williams et al., 1999). Plants grown under moderate or severe deficit conditions were more compact than both control and cyclic irrigated plants. Although all treatments reached flowering at the same time, all drought treatments reduced the number of buds per plant with control plants having 27 buds, cyclic irrigation having 17 buds, and the deficit treatments having 14 and 21 buds for moderate and severe, respectively. Although the severe deficit plants had more buds than the moderate treatment, the buds were smaller and less developed. Overall, all drought treatments reduced leaf area, with the severe deficit treatment having the most decreased leaf area and transpiration rate.

Two levels of deficit irrigation, moderate (70% of control) and severe (35% of control), reduced carnation [*Dianthus caryophyllus* (L.)] shoot and root dry weight, plant height and total leaf area proportionally to the imposed drought level (Álvarez et al., 2009). Carnation plants under moderate deficit irrigation produced the same number of shoots per plant and had similar foliage width as the control plants. Additionally, moderate deficit irrigated plants had similar flower numbers as the control treatments, as well as flower color parameters: hue angle, chroma, and lightness. It was concluded that the moderate deficit irrigation was the best treatment because it reduced dry mass and plant height while maintaining good overall quality. Moderate deficit irrigation reduced water consumption by 17 mL water per day and improved water use efficiency.

Moisture stress conditioning (MSC), i.e., exposing plants to non-lethal dry down cycles throughout production, has been shown to improve moisture stress tolerance during production through reductions in transpirational water loss (Eakes et al., 1991). Imposing MSC until visible wilt during production on salvia reduced water loss compared to controls, as indicated by lower transpiration rates due to lower leaf conductance and improved the tolerance of salvia to moisture stress. WUE measured as grams of carbon gained per liter of water lost from the growing medium was greater in MSC plants compared to the control plants (Eakes et al., 1991). Overall, MSC plants were able to acclimate to the lower moisture levels by stomatal changes and better regulation of transpiration compared to control plants. Plants underwent physiological acclimation to water deficit conditions during production by maintaining high stomatal conductance and gas carbon assimilation (Eakes et al., 1991).

MSC was applied to swamp mahogany [*Eucalyptus robusta* (Sm.)] and Sydney golden wattle [*Acacia longifolia* (Andrews) Willd. var. *longifolia*] in the greenhouse for 98 days using 16 drying cycles, each approximately six days long, until plants were visibly wilted. There was no difference in plant height, leaf area, and general plant appearance in the MSC plants compared to the controls. Moreover, water conditioning effectively reduced the water use during production given that control plants used 46% more water than MSC plants (Clemens and Jones, 1978).

Hardening off, or toning of a crop during the final phase of the production cycle, prepares the plants for a less than optimum environment during retail and results in increased shelf life (Jones, 2002). Reducing irrigation frequency, fertilizer rates, and temperatures in the greenhouse during the final weeks of production improved postproduction performances of salvia (Eakes et al, 1991), petunia [*Petunia hybrida* (Vilm.) 'Coral Sea') (Armitage and Kowalski, 1983), bracteantha [*Bracteantha bracteata* (Vent.) Anderb. & Heagi 'Dreamtime Copper'], nemesia (*Nemesia*×*hybrida* 'Vanilla Sachet'), and sutera (*Sutera hybrida* 'Bridal Showers') (Beach et al., 2009).

Nemali and van Iersel (2004) withheld irrigation from salvia and vinca until plants wilted for two consecutive drying cycles. Compared to the first drying cycle, both species had a higher WUE during the second drying cycle, indicating a physiological acclimation of the plants. In the second drying cycle, the plants were able to produce more dry matter with a given amount of water than in the first drying cycle.

Acclimating plants during production is a practice that has been shown to increase the shelf life of a variety of plants. Reducing fertilizer rates two weeks before harvest resulted in increased shelf life of several cultivars of vegetative annuals (Beach et al., 2009). Twenty-one cultivars were treated with 0%, 50%, or 100% of the typical production fertilizer rate of 300 $mg \cdot L^{-1}$ N starting two weeks prior to harvest and placement in a simulated retail environment for three weeks. Reduced end-of-production fertilizer resulted in higher quality ratings for bracteantha, nemesia, and sutera for an additional week during retail. In addition, two argyanthemum cultivars [*Argyranthemum* *frutescens* (L.) Sch. Bip 'Comet White' and 'Sunlight'] retained flowers for two additional weeks during simulated retail (Beach et al., 2009).

Two cultivars of potted miniature roses ('Charming' and 'Bianca Parade') subjected to reduced water availability during production were able to acclimate to inadequate watering during postproduction environments. Roses were grown during production with water availability equal to that of evapotranspiration (control), three 10-day water deficit cycles (cyclic water deficit), and two steady state water deficit treatments (60% and 75% of the control water availability). Following production, plants with 3-5 flowers were placed in a postproduction environment where half of the plants in a treatment were well watered, and the other half were allowed to wilt. Although control plants had slightly more buds than reduced water treatments at the beginning of the postproduction, throughout postproduction the control plants opened 15 flowers and the reduced water treatments opened between 10 and 13 flowers. Additionally, the cyclic water deficit plants had the lowest amount of damaged flowers due to water stress throughout postproduction. Based on their results, rose plants were able to adjust their water consumption to utilize water when it became available. Control plants had higher water contents, but tended to wilt sooner than plants grown with reduced water. Lower water consumption during production helped plants survive periods of inadequate water during postproduction without compromising the plant quality. Rose plants that are grown with reduced water during production were better acclimatized to harsh postproduction conditions such as water deficits and high light levels (Williams et al., 2000).

Petunias grown at three irrigation frequencies: low (media allowed to dry out completely and irrigated every three or four days), normal (surface media allowed to dry out between waterings and irrigated about once every two days) and high (media constantly wet and irrigated once or twice a day) during production were evaluated in three postproduction environments similar to retail settings: low (10 °C day/10 °C night), moderate temperature (20 °C day/20 °C night) or high (30 °C day/20 °C night). Plants irrigated with high frequency declined in quality (based on a visual rating scale) most rapidly and had the greatest number of senescenced flowers in the moderate and hot postproduction environments. Irrigation frequency was not significant for any measured parameters when the plants were placed in the cool postproduction environment. Lower frequency plants had slower flower development, but had less senescenced flowers, greater dry weight, and an overall better visual quality regardless of postproduction temperature than plants with the higher irrigation frequencies. It was concluded that the low irrigation frequency plants were already "toned" or preadapted to the postproduction environments (Armitage and Kowalski, 1983).

Abscisic acid (ABA) is a plant hormone that regulates stress in plants by inducing stomatal closure, and thereby allowing reduction of transpiration and plant water use (van Iersel et al, 2009), which can help extend the shelf life of retail plants. van Iersel et al. (2009) applied ABA drenches (125 to 1000 $mg \cdot L^{-1}$) to hydrangea [*Hydrangea macrophylla* (L.) 'Mini Penny'] and measured shelf life duration as time until plants wilted. Compared to control plants, those drenched with ABA had reduced transpiration and less water uptake. Control plants started to wilt after 12 days, but wilting was delayed in ABA plants for an additional 11 to 23 days, with number of days increasing as the ABA drench concentration increased. Although the higher concentrations delayed wilting and extended shelf life, there was some chlorosis of the older leaves in the 500 and 1000 mg·L^{-1} treatments. The results show that the use of ABA drenches can prolong shelf life of plants in poor retail environments longer than spray treatments.

ABA foliar sprays at rates of 125 or 250 mg·L^{-1} extended the marketability of vinca, New Guinea impatiens [*Impatiens hawkeri* (W. Bull) 'Harmony Grape'], geranium [*Pelargonium*×*hortorum* (L)], petunia, and verbena [*Verbena*×*hybrida* (L.) 'Superbena Purple'] by increasing drought tolerance and postharvest longevity by extending the days until plant material wilted, however it had no effect on bacopa [*Sutera cordata* (Aubl.) 'Cabana'] and impatiens (Blanchard et al., 2007).

Angelonia has been an important and new summer specialty annual in the greenhouse industry due to its long season color, good scent, long shelf life, and because it is an excellent cut flower (Greenhouse Product News, 2002). Angelonia is easy to grow and maintain in the greenhouse, needing bright space and warm (16-29 °C) temperatures during production. However, controlling growth is often a problem and a good plant growth regulator may be needed. Decreasing irrigation volumes could decrease plant height, save water and decrease plant growth regulator requirements. Limiting irrigation during production can reduce vegetative growth by decreased internode length and leaf size (Álvarez et al., 2009).

Angelonia [*Angelonia angustifolia* (Benth.)], or summer snapdragon, is a Scrophulariaceae and native to Mexico and Central America. It comes in a variety of flower colors including lavender, pink, purple, white and bi-color. Angelonia has an upright growth habit and grows 30 to 45 cm tall with an overall medium to fine texture and sparse branching. The leaves are narrowly lanceolate, 4 to 8 cm in length, and are medium to dark green in color. The flowers are single, 2 cm wide, and borne on 15 to 20 cm long terminal racemes. The upper petal on the flower has two lobes while the lower petal has three lobes. Angelonia needs full sun and regular irrigation to maintain dark green foliage and sustained flowering (Arnold, 2008).

3. MATERIALS AND METHODS

3.1 Plumbing the Irrigation System

Sixteen 16-L (28.1-cm wide, 45.7-cm long, 18.3-cm deep) plastic containers (Iris USA Inc., Pleasant Prairie, WI) were used to hold root substrate to grow the plants rather than commercial pots. These containers were necessary to accommodate the size of the Acclima Time Domain Transmissometry (TDT) sensors (5.4-cm wide, 20.3-cm long, 1.4-cm deep, with attached wire that was 304-cm in length) (Acclima, Inc., Meridian, ID). Six 0.64-cm holes (two rows of three holes 11-cm apart with 9-cm between the rows and 6-cm from the edge of the container) were drilled into each container to allow drainage. Three coats of Rust-Oleum Specialty Plastic Hammered Silver (Rust-Oleum Corporation, Vernon Hills, IL) spray paint were applied to the outside of each container to restrict light penetration and algae growth within the containers. Containers were arranged on two 3×1 m greenhouse benches with 51-cm between containers and the narrow width of the container at the edge of the bench (Fig. 1 and 2).

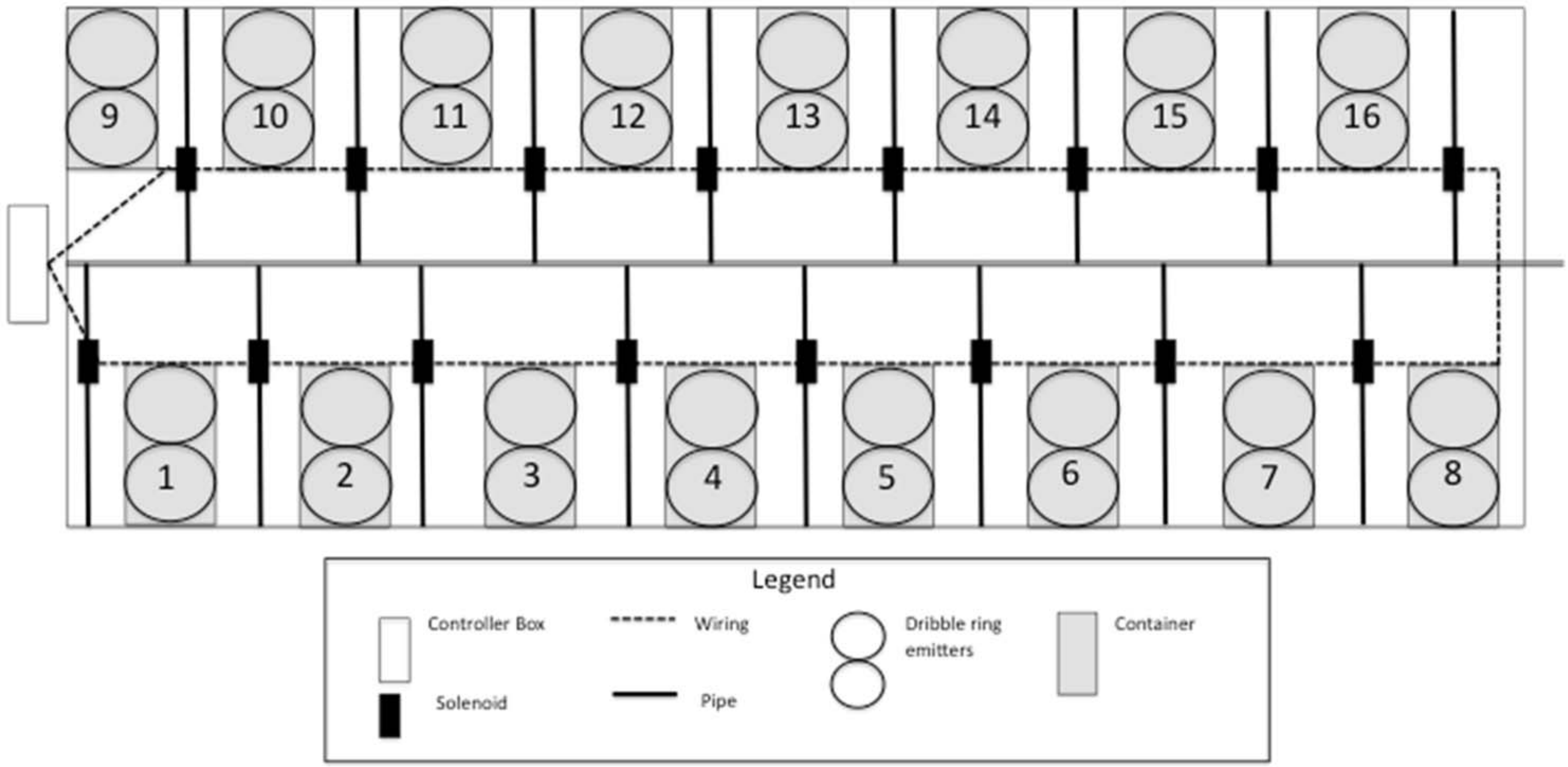


Fig. 1. Diagram of the greenhouse bench for Experiments 1 and 2. Containers were spaced 51-cm apart. Wires ran from the controller box to all the solenoid valves and back to the controller box in a closed loop. A header pipe was placed down the middle of the bench to deliver water to pipes branching from the header pipe to each container with two dribble ring emitters placed in each container.

Fig. 2. Photograph of the greenhouse bench set-up used for both experiments. Containers were spaced 51-cm apart. Wires ran from the controller box mounted on the greenhouse column to all the solenoid valves and back to the controller box in a closed loop. A header pipe was placed down the middle of the bench to deliver water to pipes branching off the header pipe to each container with two dribble ring emitters placed in each container.

The irrigation system consisted of a polyethylene header pipe running the entire length in the center of the bench. Polyethylene pipe (Silver-line Plastics, Asheville, NC) was cut to fit between the header and each container and attached to the header with a tee fitting (Lasco Fittings Inc., Brownsville, TN). There were 15 tees (T-shaped fitting), one at each of the 15 containers and one ell fitting (L-shaped fitting) used to cap off the header pipe at the end of the bench to the last container (Lasco Fittings Inc.)

A 10-cm section of pipe was attached to each tee with a PVC threaded male adapter (Lasco Fittings Inc.) and Teflon tape (LG Sourcing Inc., North Wilkesboro, NC) that was attached to the solenoid valve (N-100F-H; Weathermatic, Dallas, TX). From the solenoid valve another male adapter was attached with a 25-cm section of polyethylene pipe closed off with a 2.5 cm plug (Lasco Fittings Inc.). All polyethylene pipe and fitting connections were secured using #20 hose clamps (King Seal Fastener Technology, Hunt Valley, MD). To deliver water to the plants, two dribble ring emitters (61-cm lead, 15-cm diameter) (Dramm Corporation, Manitowoc, WI) were evenly spaced and connected to the 25-cm polyethylene pipe by a microtube. All the tees were connected to the header pipe with the appropriate amount of pipe to maintain container spacing. At the water source end of the bench, an ell piece of pipe was attached to another pipe and a garden hose adapter (Lasco Fittings Inc.). The garden hose was used to connect the system to a pressure regulator (25 PSI; Mister Landscaper, Dundee, FL) at the greenhouse water main faucet. The piping was secured to the bench with 20-cm cable ties (Commercial Electric, distributed by Home Depot, Atlanta GA).

3.2 Wiring the Irrigation System

All sensors were prepared for wiring by installing insulated disconnect pairs (Ideal Industries Inc., Sycamore, IL) for ease in disconnecting from the system as needed for simulated shipping treatment. Sensors were placed and an extension cord (Chicago Electrical Power Tools, distributed by Harbor Freight Tools, Camarillo, CA) was cut into 86-cm pieces to connect each sensor and to be used as a power supply cable. The system was wired in a 2-wire full loop design as recommended by the Acclima manual (http://acclima.com/wd/acclimadocs/CS3500/CS3500%20User%20Manual.pdf) because it "allows the system to function properly even if some wires are severed." Therefore, each sensor/solenoid combination was connected to the next in one large loop running around the bench.

All wire connections were secured with a #22 to #14 yellow wire nut (Storehouse, distributed by Harbor Freight Tools, Camarillo, CA) and electrical tape (Duck Brand, distributed by SHURTECH Brands LLC, Avon, OH). Two power supply cables were connected to the controller, and power was connected to the controller by an electrician according to the Acclima Manual's directions.

3.3 Calibrating the Irrigation System

The Acclima sensors required calibration since they generally read too low (M. W. van Iersel, personal communication). Three 1-L beakers were filled to a known volume with root substrate (Sunshine LC1 mix; SunGro Horticulture, Bellevue, WA) to be used in the experiments. Water was applied to the beakers in varying amounts to obtain a continuum of dry to wet media. An Acclima sensor was used to take readings in each beaker followed by weighing each beaker. The substrate from each beaker was then spread evenly over autoclavable trays and put into a drying oven (214330; Hotpack Corp., Philadelphia, PA) at 80 °C for 48 h. Once dry, the substrate was weighed gravimetrically with a Mettler balance (PM 16; Mettler Industries Corp., Hightstown, NJ), and the amount of water in the beaker was calculated by subtracting the weight of the dry media from the weight of the wet media. This number was divided by the beaker volume. All data were entered into the computer and then graphed using Microsoft Excel (Excel:mac 2008; Microsoft Corp., Redmond, WA) to make a calibration graph (Fig. 3). When 40, 30, 20, 10% SMC treatments were entered into the calibration equation determined from the data, the actual SMC levels were calculated to use as the upper and lower thresholds. From the graph the Acclima readings were converted to SMC using the graphical relationships.

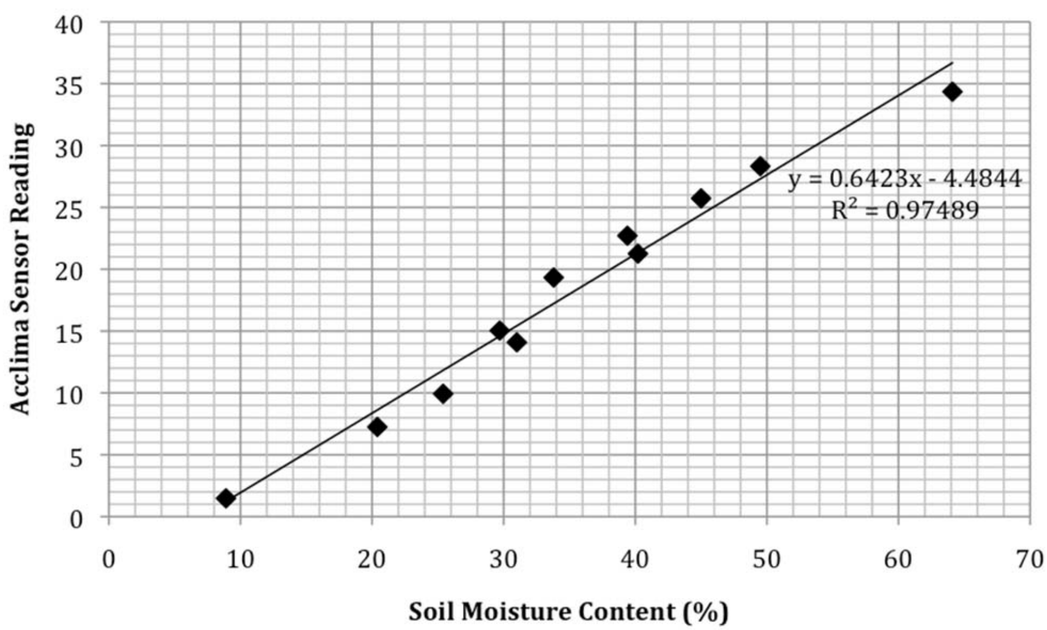


Fig. 3. Calibration graph of Acclima soil moisture sensor readings for the LC1 media used in both experiments. Sixteen Acclima sensors were used to take readings of various soil moisture contents (SMC) and these readings were from a range of 10-60% SMC.

The dribble ring emitters were tested to determine the flow rate by opening one valve and placing the two dribble rings into a bucket to catch the water. By opening the dribble rings, the amount of water emitted in one second was determined by measuring the weight of the water and dividing it by the time (in seconds) the dribble rings were on. Next, to make sure the flow rate was the same with multiple valves opened, two valves were opened and both rings were placed from one valve into a bucket to catch the water. The flow rate of a dribble ring was determined to be 5.3 mL per second. Plants were irrigated with reverse osmosis (RO) water due to unsuitable tap water.

3.4 Programming the Irrigation System

Initially, sensor serial numbers were recorded, and each sensor was assigned to a container (numbered one through 16). The Acclima System was controlled through the Acclima computer software (Irrigation Manager 1.4.5), which was downloaded from Acclima's website (http://acclima.com/wd/index.php/downloads). A laptop computer was connected to the irrigation controller box by a universal serial bus (USB) wire. The new system was named, the computer's time was verified, and then the computer time was synced with the controller's time. Adjustments were made to allow 16 zones and to take readings every 10 minutes.

To install the sensors, the serial numbers were entered when prompted into the "Install System Devices" part of the program. After all sensors were installed, the solenoid valves (zone switches) were installed by adding the serial numbers +1 from the sensors (adding one number to the serial number). Zones were created with one zone controlling each container. When a zone was added, the type of zone (dependent, sensor, or timed) was selected for the sensor associated with it, and the zones were given treatment names to correspond to experiment treatments of 10, 20, 30, and 40% SMC. When a sensor needed to be replaced, the “replace sensor” radio button was depressed, a new serial number was added, and the new sensor was replaced and rewired.

Once all sensors were installed, the soak cycle was determined to be a watering duration of 30 s with an interval length between watering of 4 min. Finally, the “configure devices” radio button was ready to be used to set an upper and a lower threshold for each SMC (Table 1). After the calibration of the Acclima sensors, the four SMC levels that were chosen were put into the calibration equation to determine which level they equated to in the Acclima system. This number was used to set the upper and lower thresholds in the Acclima system. The 40% SMC treatment was put into the equation and equaled to an Acclima reading of 20.47, so for this treatment the Acclima thresholds were set as 20.47 for the lower threshold and 20.57 for the upper threshold. Once the soil moisture dropped below 20.47, the solenoids would open and stay open until the soil moisture read 20.57. This was done for all treatments to find the threshold for the Acclima system.

Table 1. Upper and lower thresholds for the Acclima system from four soil moisture contents (SMC) treatments in both experiments. Thresholds were determined using a calibration graph (Fig. 3) to determine the actual SMC of the substrate, which was set as the lower threshold. When the SMC dropped below the lower threshold the water would turn on and irrigate until the SMC reached the upper threshold.

	Acclima Reading	
SMC %	Lower threshold (%)	Upper threshold (%)
40	20.47	20.57
30	14.43	14.53
20	8.40	8.50
10	2.36	2.46

3.5 Troubleshooting the Irrigation System

When a sensor needed to be replaced, the "Replace Sensor" part of the program was used and a new serial number was added, then the sensor was replaced and rewired. When a sensor failed, that container was made dependent on another zone to make sure it still watered while waiting for a new sensor to be delivered by mail from Acclima.

3.6 Containers and Media

A line was marked on each of the 16 containers, 3.8-cm down from the top of the container to designate the level to fill the container with media (media line). Another line was drawn 6.3 cm down from the media line to demarcate the level of sensor placement within the container (sensor line). This was necessary because the sensors should be no more than 7.6 cm below the media line (Acclima Manual, Acclima, Inc., Meridian, ID). Containers were filled with root substrate and evenly compacted to the media line. The root substrate was then removed from one container at a time and placed onto a clean, polyethylene sheet on the greenhouse bench and 54 grams of 15N-3.9P-9.9K Osmocote (Peters Professional, Scotts-Sierra, Marysville, OH) slow release fertilizer was incorporated evenly throughout the root substrate. The root substrate was placed back into the container up to the sensor line. Then the sensor was placed in the center of the container, lying flat, with the cord coming out one end. The remainder of root substrate was used to cover the sensor up to the media line.

The sensors were wired to their corresponding solenoid and to the neighboring sensor. Lastly, two dribble ring emitters were placed on top of the root substrate and around the plants and secured with greening pins (Fig. 4).

Fig. 4. Photograph of a dribble ring placed around angelonia plants and secured with greening pins.

3.7 Plant Material, Stages, and Treatments

Rooted cuttings of *Angelonia angustifolia* 'Angelface Blue' were obtained from a commercial grower (Proven Winners North America, Campbell, CA), and were graded to select plants that were uniform in height and that had been previously pinched to promote branching.

Each experiment consisted of three stages: (1) greenhouse production with four soil moisture content (SMC) levels; (2) simulated shipping in the dark for 48 h; and, (3) simulated retail.

The four SMC treatment levels were 40, 30, 20 and 10% with four reps (containers) with eight plants planted in two rows of four per container for a total of 128 plants. The 40% SMC treatment corresponded to conventional irrigation (well-watered plant) and the 10% SMC treatment corresponded to drought stress. Prior to initiation of treatments, the root substrate in the containers was irrigated to container capacity and drenched evenly with Banrot (Peters Professional, Scotts-Sierra, Marysville, OH) until runoff to prevent root rot.

The greenhouse production stage utilized an irrigation system like the one recently developed at University of Georgia (Nemali and van Iersel, 2005) that measures SMC in multiple containers and irrigates them based on container-specific SMC thresholds. Twice a day a laptop computer was connected to the irrigation system to monitor and observe SMC levels and plants, and to check for problems. Plants were grown in the greenhouse production stage until plants were flowering and deemed marketable, i.e., full foliage and evenly covered in flowers. Plants were grown in a glass-wall and polycarbonate roof greenhouse. Day and night air temperature and light converted into daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$) were measured every hour and averaged into daily measurements at plant canopy level using data loggers (WatchDog, Spectrum Technologies, Plainfield, IL). Temperature set points for the greenhouse were 24 °C day/18 °C night. Average temperature in the greenhouse for Experiment 1 was 26 °C day/23 °C night for the greenhouse production stage (Fig. 5) and 25 °C day/22 °C night during the simulated retail environment (Fig. 6). Average light levels were 14 $mol \cdot m^{-2} \cdot d^{-1}$ for the greenhouse production stage, and 5 $mol \cdot m^{-2} \cdot d^{-1}$ for the simulated retail stage.

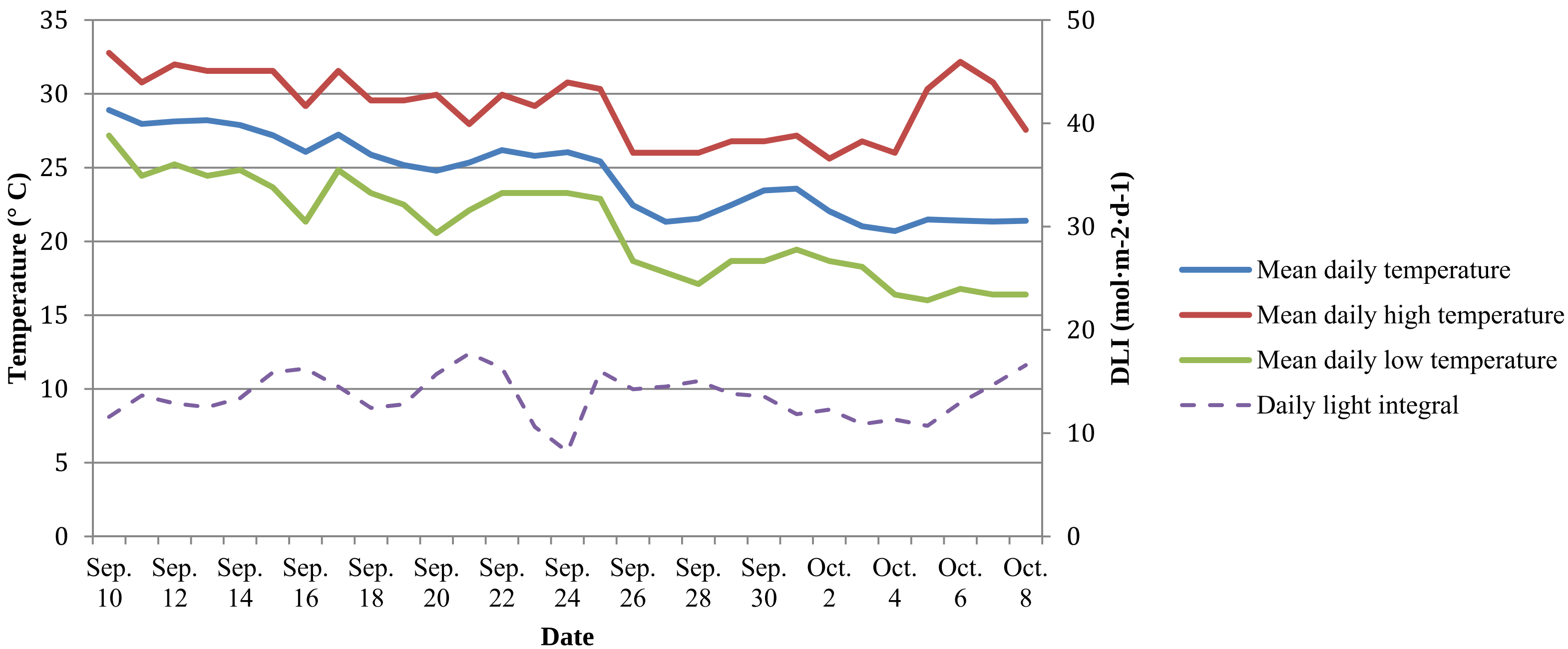


Fig 5. Temperature (°C) and daily light integral (mol·m^{-2}·d^{-1}) during the five week greenhouse production stage in Experiment 1. Day and night air temperature and light in the greenhouse was measured every hour and averaged into daily measurements at plant canopy level.

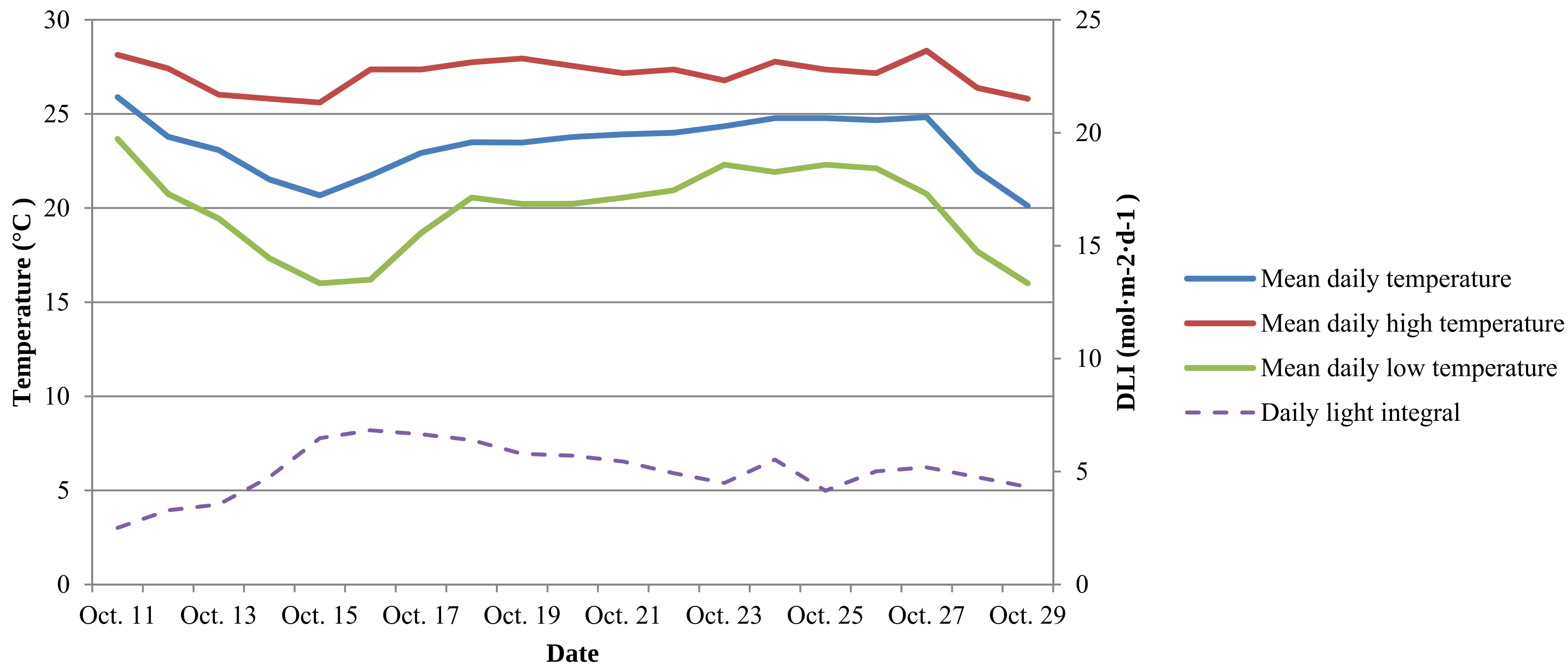


Fig. 6. Temperature (°C) and daily light integral (mol·m^{-2}·d^{-1}) during the three week simulated retail stage in Experiment 1. Day and night air temperature and light in the greenhouse was measured every hour and averaged into daily measurements at plant canopy level.

Average temperature in the greenhouse for Experiment 2 was 23 °C day/21 °C night for the greenhouse production stage (Fig. 7) and 24 °C day/22 °C night during the simulated retail stage (Fig. 8). Average light levels were 7 $mol \cdot m^{-2} \cdot d^{-1}$ for the greenhouse production stage, and 12 $mol \cdot m^{-2} \cdot d^{-1}$ for the simulated retail stage.

At the end of the greenhouse production stage, plants were subjected to simulated shipping. Each container was watered until runoff, and then placed into a 38 cm wide × 61 cm long × 64 cm deep cardboard shipping box. The boxes were sealed with plastic packaging tape and randomly stacked with air channels between them in the simulated shipping area and held in the dark at 20 ± 2 °C for 48 h. After 48 h of simulated shipping, the plants were removed from the boxes and placed back into the greenhouse to simulate a retail environment.

Data taken at the end of greenhouse production and simulated retail stages were fresh and senesced flower number, total and flowering stem number, pre-dawn and mid-day water potential, plant quality, and plant height and node number partitioned into vegetative, flowering, and bud areas.

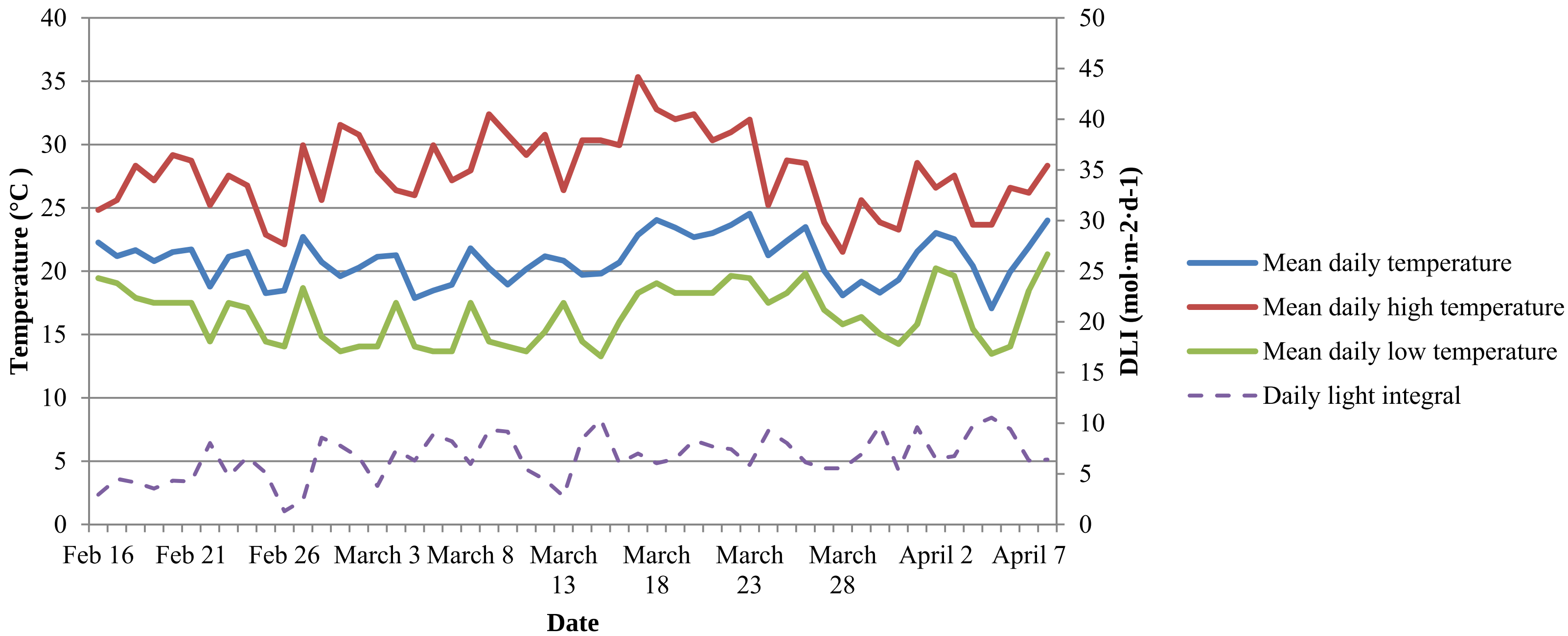


Fig 7. Temperature (°C) and daily light integral ($mol{\cdot}m^{-2}{\cdot}d^{-1}$) during the eight week greenhouse production stage in Experiment 2. Day and night air temperature and light in the greenhouse was measured every hour and averaged into daily measurements at plant canopy level.

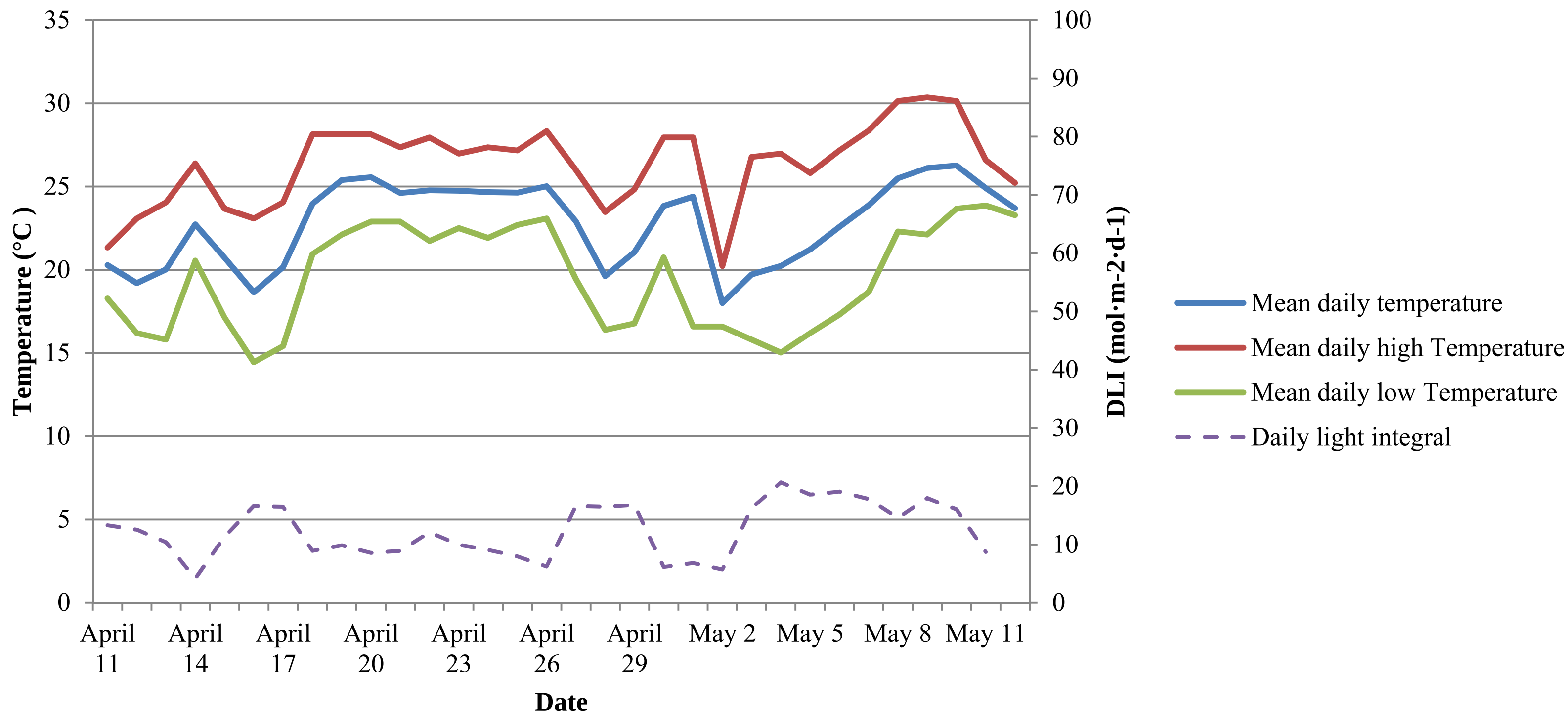


Fig. 8. Temperature (°C) and daily light integral (mol·m^{-2}·d^{-1}) during the four week simulated retail stage in Experiment 2. Day and night air temperature and light in the greenhouse was measured every hour and averaged into daily measurements at plant canopy level.

Fresh flower, bud, and senesced flower numbers, and stem numbers were taken on every stem on every plant in a treatment. Fresh flowers were those with the reproductive flower parts visible, and senesced flowers were those with three or more petals wilting and still attached to the plant. Plant quality was determined by giving each plant a quality rating from 0 to 5 using the quality assessment table modified for angelonia using guidelines outlined in Starman et al. (2007) measured at the end of the greenhouse production and simulated retail stages. In this rating system, 0 indicates a completely senesced plant and 5 indicates a healthy plant showing no symptoms of postproduction decline (Table 2).

Node number and plant height for the vegetative, flowering, and bud sections were taken on the tallest stem on each plant in a container. Vegetative height was determined by measuring the stem from the base to the basal fresh flower, flowering height from the basal fresh flower to the apical fresh flower, and bud height from the apical fresh flower to the apex of the stem. Node numbers for each section were counted and internode length was determined by dividing the section height by the node number in that section.

Table 2. Quality rating scale and corresponding postharvest decline symptoms for *Angelonia angustifolia*

Quality rating	Postharvest decline symptoms
5	plant is healthy with no visible decline symptoms
4	<25% flower abscission with visible change in flower color <10% wilting <10% chlorotic lower leaves <10% lodging stems
3	<50% flower abscission <25% wilting <25% chlorotic lower leaves <25% lodging stems
2	<75% flower abscission <50% wilting <50% chlorotic lower leaves >25% lodging stems
1	90% flowers abscission >50% wilting >50% chlorotic lower leaves >50% lodging stems
0	total plant senescence

Mid-day and pre-dawn water potentials were taken in a pressure chamber (3005 series; Soil Moisture Equipment Corp., Santa Barbara, CA) by cutting a stem off the same plant in the same location in each container. Pre-dawn water potentials were taken early in the morning before sunrise and mid-day water potentials were taken at noon.

Total abscised flower numbers was the sum of those counted in the shipping boxes and growing container after simulated shipping. Abscised flower percentage was calculated by dividing the total number of abscised flowers after shipping by the total fresh and senesced flowers attached to the plant prior to shipping and multiplying by 100.

Fresh and dry root and shoot weights was measured gravimetrically with a scale (N1B110; Ohaus Corp, Parsippany, NJ) at the end of the simulated retail stage. Shoot weights were taken by cutting a plant at the media line and placing it in a brown paper bag. Paper bags were placed in a drying oven for 48 h at 80 °C until stems were dry. Roots of each container were gently washed and separated, weighed and placed in a brown paper bag. Paper bags were placed in a drying oven for 48 h at 80 °C and then reweighed. Shoot to root ratios was calculated by dividing stem dry weight by the root dry weight of all plants in a container.

Photographs of plants of the same container from each treatment were taken at the end of greenhouse production and again after the simulated retail stages. Photographs of roots were taken at the termination of the experiment by turning over each container and photographing the root system from the bottom of the container.

Electrical conductivity (EC) was measured once a day by the Acclima soil moisture sensors and recorded in the sensor log. Number and duration of irrigations were taken from the Acclima water data logs and multiplied to get the total irrigation duration. Total volume of water applied was calculated by multiplying the total irrigation duration (in seconds) by the dribble rings flow rate of 5.3 mL/s, which was the amount of water emitted from the dribble rings in one second. Water use efficiency (WUE) was calculated by dividing the stem dry weight of all plants in a container divided by the amount of water used by a container during the greenhouse production and simulated retail stages of each experiment.

The treatments in each experiment were completely randomized and data were analyzed using SAS 9.2 statistical software (SAS Institute, Cary, NC).

3.8 Experiment 1

On 3 Sept. 2010, Experiment 1 was initiated (Fig. 9) by planting angelonia plants in the containers and drenching the root substrate with Banrot. Then, the containers were allowed to dry down to their respective SMC treatment levels. On 22 Sept, 19 d after planting, the 40% SMC treatment received its first irrigation treatment. One day later the 30% SMC treatment received its first irrigation event, followed by one more day for the 20% SMC treatment. Five additional days past before the 10% SMC treatment was watered for the first time on 29 Sept. On 9 Oct. (i.e., five weeks after the start of the experiment) all treatments were ready to “ship”. At this time, all treatments were disconnected from the irrigation system, watered by hand to prevent wilting during shipping, and allowed to drain. Plants were placed into simulated shipping for 48 h and then back into the greenhouse on 11 Oct. to simulate a retail environment. It took 5 d in simulated retail until wilting was observed on the 40% SMC treatments and at that time, all treatments were set to water at 20% SMC for the duration of simulated retail. Simulated retail lasted for three weeks at which time the experiment was terminated on 29 Oct.

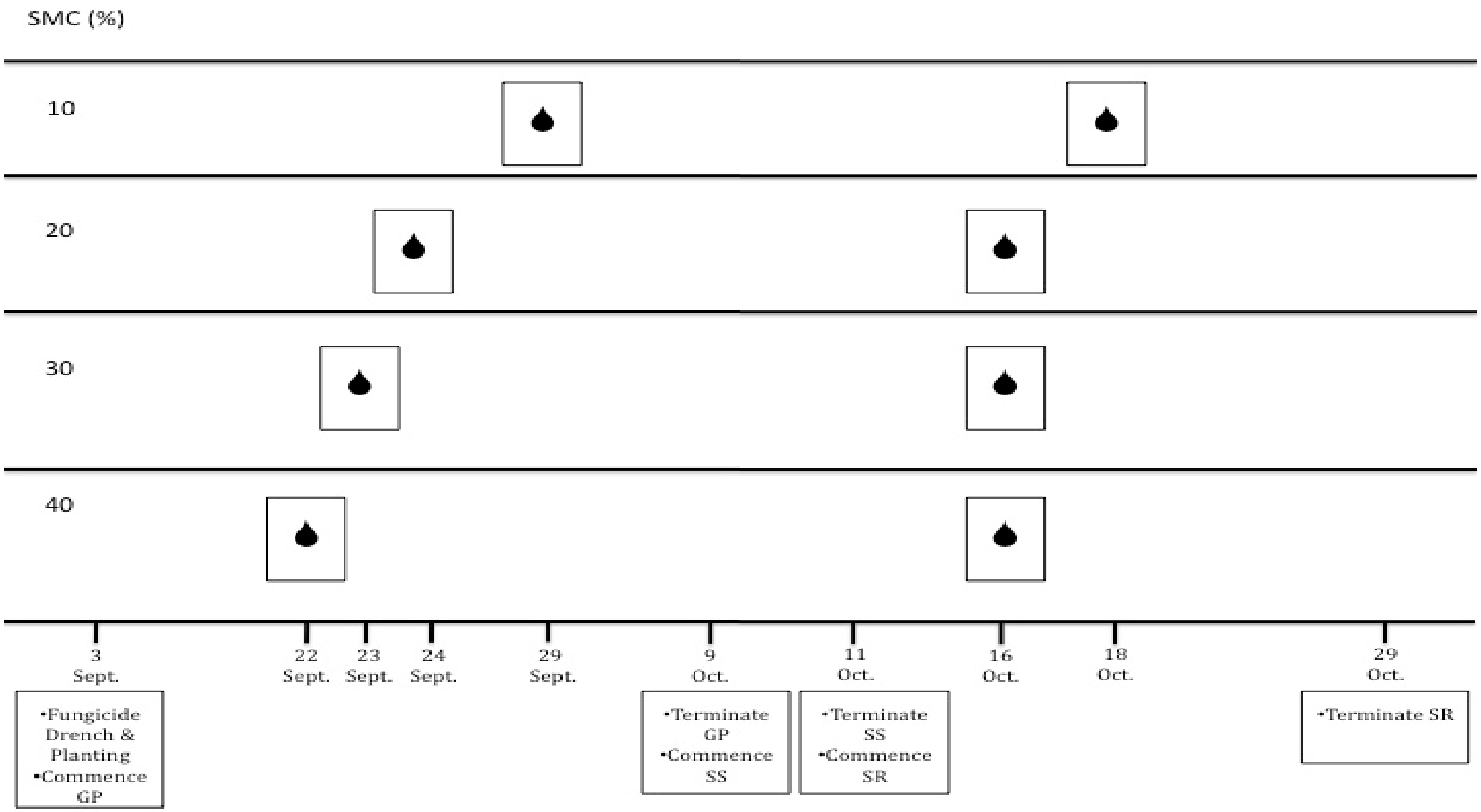


Fig. 9. Timeline of Experiment 1 from fungicide drench, planting and commencement of greenhouse production (GP), through simulated shipping (SS), to simulated retail (SR). First irrigation event (♦) was the first day *Angelonia angustifolia* 'Angelface Blue' was automatically irrigated during GP and SR for each soil moisture content (SMC) level. All SMC treatments were automatically irrigated at 20% SMC during SR. Total duration of GP was 5 weeks, SS was 2 days, and SR was 3 weeks.

3.9 Experiment 2

Four additional hand-watered containers, each with eight plants for a total of 32 plants, were included in this experiment as controls and placed on an adjacent bench in the same greenhouse. Hand-watered plants were watered until runoff when a typical greenhouse crop would be watered, i.e., when the surface of the media was dry, and the container was light in weight. Soil moisture ($m^3 \cdot m^{-3}$) was measured with a soil moisture probe (type HH2; Delta-T Devices, Cambridge, U.K.), set on the organic soil setting, before and after hand watering by inserting the probe into the root substrate until the entire sensor probe was fully covered by the substrate (Fig 10). Readings from the soil moisture probe were put into a calibration equation to determine the actual SMC for the root substrate in the experiment (Fig. 11).

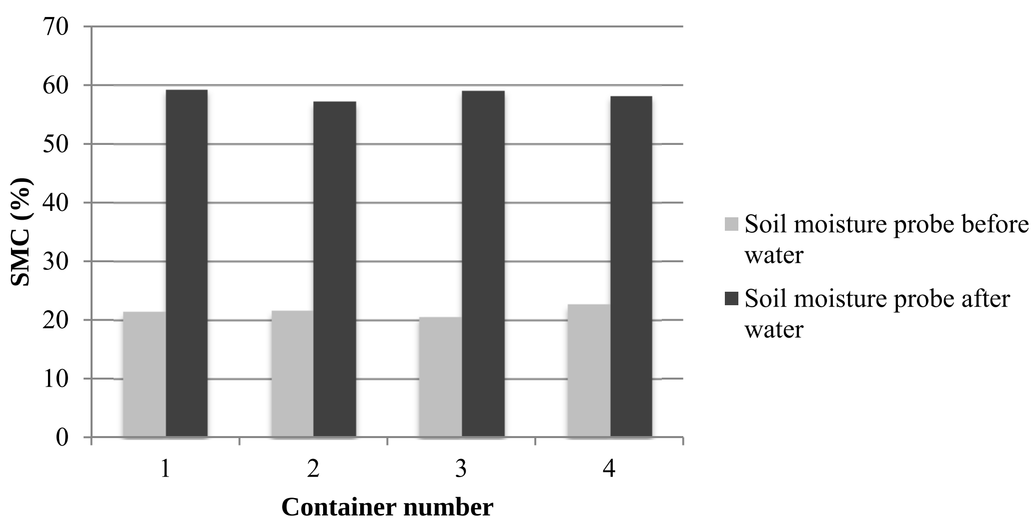


Fig. 10. Average soil moisture probe readings before and after irrigating for the four hand-watered containers in Experiment 2. Soil moisture probe readings were put into a calibration graph to determine the actual soil moisture content (SMC).

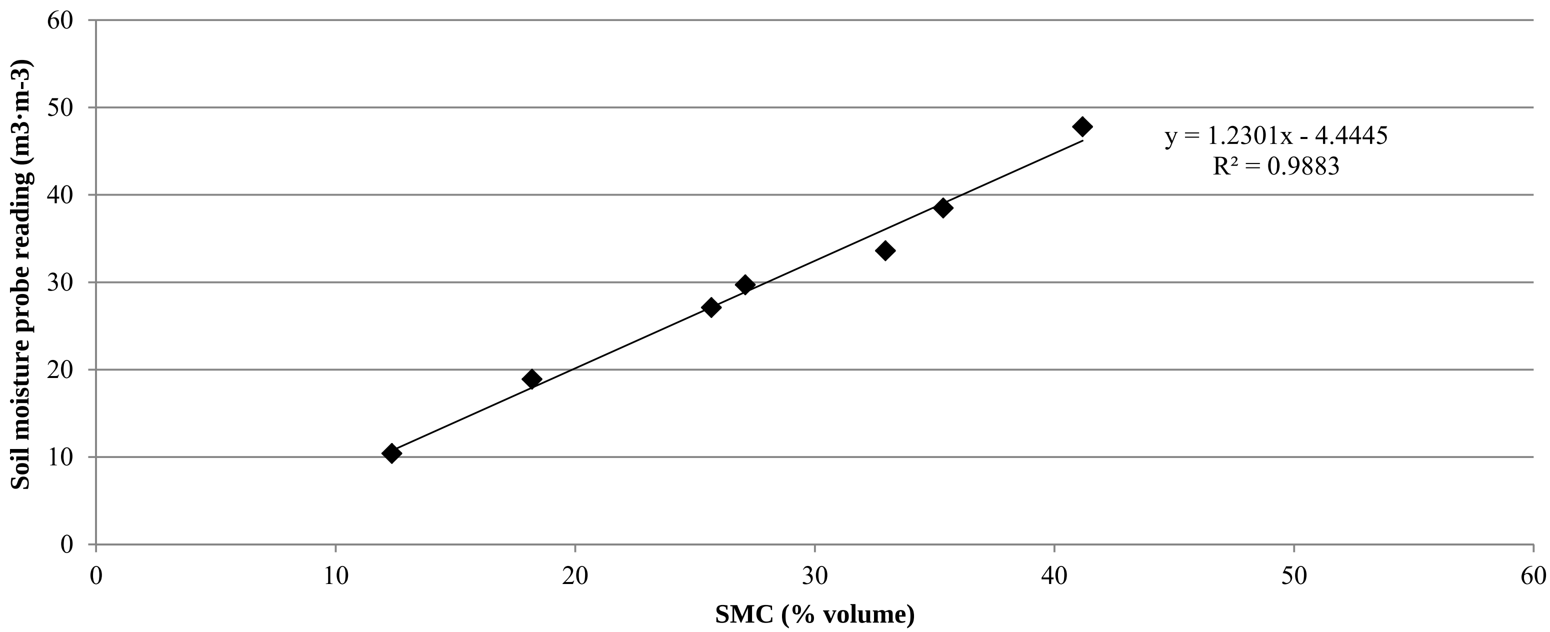


Fig. 11. Calibration graph of soil moisture probe readings and soil moisture contents (SMC) for the LC1 media used for the hand-watered treatments in Experiment 2. The soil moisture probe was used before and after each hand watering to take readings at various soil moisture contents (SMC) ranging from 10-40%. Soil moisture probe readings were put into the calibration equation to calculate the actual SMC.

Because it took 26 d in the first experiment for the root substrate of the 10% SMC treatment to dry down, and the crop was ready to ship 10 d later, two modifications were made in Experiment 2. The first modification was to not plant the containers until the root substrate had dried down after drenching with Banrot and was therefore closer to the desired SMC. On 25 Jan., the root substrate was watered evenly with Banrot (Fig. 12). Two weeks later on 8 Feb., all containers had dried to 30% SMC and angelonia was planted. The 40% SMC treatment was held at 40% continuously. On 9 March after 4 weeks of holding at 30% SMC for root establishment the greenhouse production stage commenced with the first irrigation event of the 30% SMC treatment. The 20% SMC treatments received its first irrigation 10 d later. It took 11 more days for the 10% SMC treatments to dry down enough to be irrigated for the first time. On 8 Apr., all plants were marketable and were placed in simulated shipping for 48 h then placed in a simulated retail environment for four weeks.

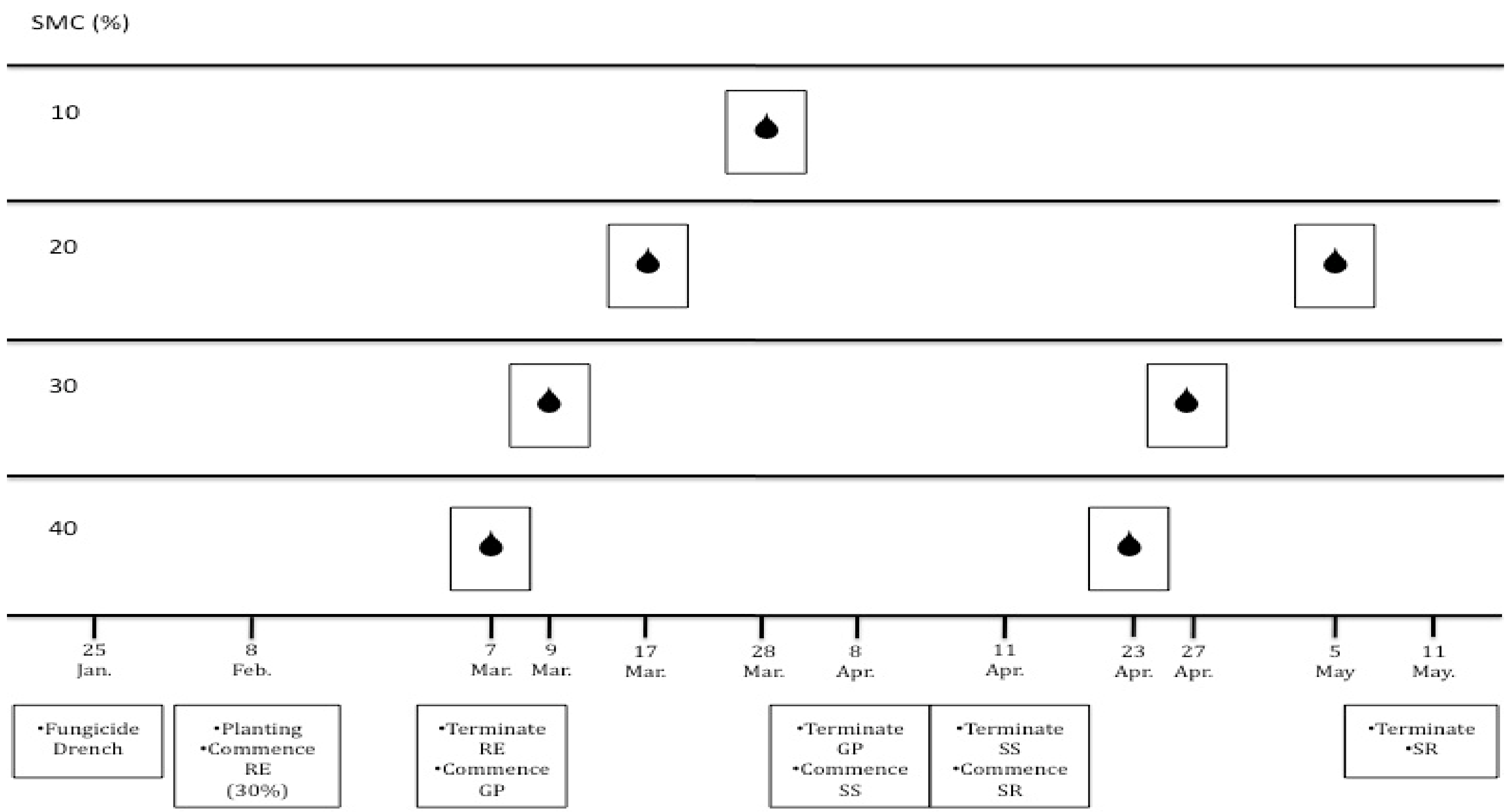


Fig. 12. Timeline of Experiment 2 from fungicide drench through root establishment (RE), greenhouse production (GP), simulated shipping (SS), and simulated retail (SR). First irrigation event (♦) was the first day *Angelonia angustifolia* 'Angelface Blue' was automatically irrigated during GP and SR for each SMC level. The 40% soil moisture content (SMC) treatment was held at 40% during RE while all other treatments were held at 30% SMC. All SMC treatments were automatically irrigated during SR when a plant from a treatment wilted and held slightly above that SMC to prevent wilting for the remainder of SR. The SMC levels during SR were held at 26% SMC (40% treatment), at 11% SMC (30% treatment) and at 7% SMC (20% treatment). The 10% SMC treatment never wilted during SR and therefore was never irrigated. Total duration of RE was 4 weeks, GP was 4 weeks, SS was 2 days, and SR was 4 weeks.

Another deviation from Experiment 1 was during the simulated retail stage. Rather than holding all treatments at 20% SMC, each treatment was observed for wilting. Once wilting was observed in the 40% treatment, the SMC level was noted and the 40% treatment was held constant slightly above that SMC for the remainder of the experiment to prevent wilting. All SMC treatments were automatically irrigated during simulated retail when a plant from a treatment wilted and held slightly above that SMC to prevent wilting for the remainder of simulated retail. The SMC levels during simulated retail were 26% SMC (40% treatment), 11% SMC (30% treatment) and 7% SMC (20% treatment). The 10% SMC treatment never wilted during simulated retail and therefore was never irrigated. (Table 3). It took the 40 % SMC treatments 12 d, the 30% SMC 16 d, and the 20% SMC treatment 21 d to wilt and be held at their respective simulated retail treatments.

When hand-watered plants began to wilt after approximately 22 d, the SMC was 13% (14% actual SMC) measured with a soil moisture probe and this was assigned as the wilting point to water this treatment for the remainder of the experiment (Fig. 13). On 11 May the experiment was terminated.

Table 3. Simulated retail environment soil moisture content (SMC) levels for the 40, 30, 20, and 10% treatments in Experiment 2.

SMC %	Days to dry down	Acclima reading (%)	Actual soil moisture content (%)
40	12	12	26
30	16	11	24
20	21	7	18
10	n/a	n/a	n/a
Hand-watered	22	13[z]	14

[z]Hand-watered plants were read with a soil moisture probe
n/a = 10% SMC plants never wilted and therefore were not watered during the simulated retail

In addition to the parameters measured in Experiment 1, leaf chlorophyll content was measured with a SPAD meter (SPAD-502, Konica Minolta Sensing Inc., Osaka, Japan) during the greenhouse production stage and the simulated retail stage. SPAD readings were taken on two leaves each of three plants in each container: a new leaf that was 5-6 nodes down from the stem tip; and a mature leaf below the basal fresh flower.

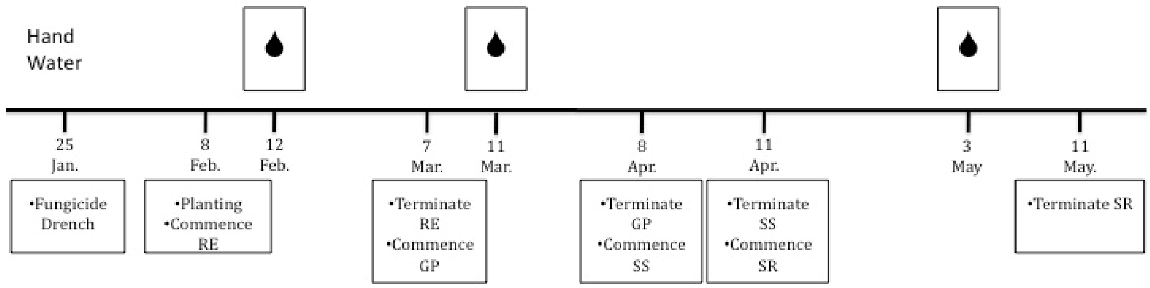


Fig. 13. Timeline of hand-watered plants in Experiment 2 from the fungicide drench through root establishment (RE), greenhouse production (GP), simulated shipping (SS), and simulated retail (SR). First irrigation event (♠) is the first day *Angelonia angustifolia* 'Angelface Blue' was hand-watered during the RE, GP and SR. Hand-watered plants were watered when the media was light in color and the pot was light in weight. During SR, when plants began to wilt a soil moisture probe was used to determine wilting point (14%) and all plants were watered when soil moisture content (SMC) was slightly above 14% to prevent wilting. During SR hand watered plants were watered once. Total duration of RE was 4 weeks, GP was 4 weeks, SS was 2 days, and SR was 4 weeks.

4. RESULTS

4.1 Experiment 1

At the end of the greenhouse production stage and prior to simulated shipping, plants in all SMC treatments had three stems per plant, and SMC did not affect the internode length and number of days to first flower (Table 4). Plants in all treatments flowered at the same time, opening several flowers simultaneously, and took approximately 15 days from planting to first flower. The 40% SMC resulted in the tallest plants. The 40 and 30% SMC plants had a greater number of nodes and more fresh flowers than the 10% SMC plants and more buds than the 20 and 10% SMC treated plants. The 10 and 20% SMC plants had the most senesced flowers and the 30 and 40% SMC plants had the least number of senesced flowers. The 10% SMC treatment resulted in less plant height, least amount of nodes, fresh flowers, and buds, and the most number of senesced flowers. The 30% SMC plants had the least amount of senesced flowers, and the 20 and 40% SMC plants were intermediate and similar. As SMC decreased from 40 to 10%, plant size and flowering parameters were reduced proportionally and all treatments produced aesthetically pleasing plants.

Table 4. Number of stems per plant, plant height, node number, internode length, days to first flower, fresh flower, bud, and senesced flower numbers for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' during the five week greenhouse production stage in Experiment 1. Plant height, node number, and internode length were measured on the tallest stem on every plant in a container. Stem number, fresh flower, bud, and senesced flower numbers were measured on every stem on each plant in each container. Parameters were averaged for all plants in a container, and then all containers in a treatment averaged.

SMC %	Stems/plant (no.)	Plant height (cm)	Node (no.)	Internode length (cm)	Days to first flower	Fresh flower (no.)	Bud (no.)	Senesced flower (no.)
40	3.1 (1.30)	50.5 (5.35) a[z]	50 (6.32) a	1.0 (0.05)	15 (0)	36 (11.26) a	32 (4.46) a	3 (5.61) bc
30	3.1 (1.20)	45.0 (4.93) b	47 (6.34) ab	1.0 (0.03)	15 (0)	31 (16.73) ab	34 (3.86) a	2 (3.70) c
20	2.9 (1.15)	38.1 (4.91) b	43 (5.33) b	1.0 (0.16)	15 (0)	28 (10.20) b	24 (4.12) b	6 (8.89) ab
10	2.8 (0.98)	35.0 (4.04) c	35 (4.04) c	0.9 (0.09)	15 (0)	17 (7.34) c	14 (3.11) c	9 (9.99) a
Significance	NS	***	***	NS	NS	***	***	**

Mean (standard deviation)

[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.

[NS,**, ***]Nonsignificant or significant at $P=0.01$, or 0.001, respectively.

Because angelonia is an indeterminate flowering plant, we measured the portion of the inflorescence that was in full flower and the portion that was in bud to determine if SMC affected flowering potential. The 10% SMC plants had reduced height and node number in the flower portions of the inflorescence compared to 30 and 40% SMC, and reduced bud height and node number compared to all other SMC treatments (Table 5). Regardless of SMC, flowers were spaced the same distance apart on the raceme; however, bud internode length increased as SMC decreased.

Table 5. Flowering and bud height, flowering and bud node number, and flowering and bud internode length within the inflorescence of *Angelonia angustifolia* ‘Angelface Blue’ for four soil moisture content (SMC) treatments during the greenhouse production stage in Experiment 1. Parameters were measured on the tallest stem on each plant in a container, averaged throughout all plants in a container, and then treatments were averaged.

SMC %	Flowering height (cm)	Bud height (cm)	Flowering node (no.)	Bud node (no.)	Flowering internode length (cm)	Bud internode length (cm)
40	19.8 (5.61) a[z]	11.0 (2.37) a	20 (5.84) a	16 (2.23) a	1.0 (0.09)	0.4 (0.08) d
30	16.8 (7.57) ab	10.0 (1.62) a	18 (7.19) a	17 (1.93) a	1.0 (0.11)	0.5 (0.08) c
20	14.7 (6.04) bc	5.5 (1.56) a	16 (6.35) ab	12 (2.06) b	0.9 (0.27)	0.6 (0.06) b
10	9.8 (3.97) c	2.6 (0.97) c	12 (4.09) b	7 (1.56) b	0.8 (0.23)	0.7 (0.08) a
Significance	**	*	*	***	NS	***

Mean (standard deviation)
[z]Mean separation in columns by Duncan’s multiple range test at P≤0.05.
[NS, *, **,***]Nonsignificant or significant at P=0.05, 0.01 or 0.001, respectively.

Table 6. Total volume of water applied during all irrigation events, number of irrigation events, total irrigation duration, and electrical conductivity (EC) of the root substrate for four soil moisture content (SMC) treatments on *Angelonia angustifolia* ‘Angelface Blue’ during the greenhouse production stage in Experiment 1. Total volume of water applied, number of irrigation events, and total irrigation duration was obtained from the Acclima water logs and treatments were averaged. EC was obtained from the Acclima sensor logs and treatments were averaged.

SMC %	Total volume (L)	Number of irrigation events	Total irrigation duration (s)	EC (dS/m)
40	14.7	38	2744	2.3 (0.28) a[z]
30	7.1	31	1340	1.7 (0.06) b
20	2.9	15	549	1.4 (0.11) b
10	1.9	11	349	1.3 (0.31) b
Significance	---	---	---	**

Mean (standard deviation)
[z]Mean separation in columns by Duncan’s multiple range test at P≤0.05.
**Significant at P=0.01

Total volume of water applied with the 40% SMC treatment was 87% greater than was applied with the 10% SMC treatment, and 40% SMC plants were watered 27 more times than the 10% SMC plants (Table 6). The irrigation duration throughout production was highest in the 40% SMC plants, and was 87% longer than the 10% SMC treatment. The 40% plants were taller and thus required more water, therefore they were watered more frequently and the total duration of watering throughout production was longer for these plants. The EC were higher in the 40% SMC plants than the other treatments (Table 6). This could be due to the fact that the 40% SMC plants received more water and therefore more salts leached from the fertilizer into the root substrate. The 10% SMC treatment resulted in more negative pre-dawn and mid-day water potential compared to the other SMC treatments. During mid-day, water potential measurements for 20% SMC also resulted in more negative water potential than 30% (Fig. 14). The 20% plants were stressed at mid-day, but not at pre-dawn, and the 10% plants were always stressed and never recovered overnight. Near the end of the greenhouse production stage the 10% plants were wilted throughout the day, which took away from their visual quality (Fig. 15).

The visual quality for the 10 and 40% SMC plants was judged a rating of 3.0 (Table 2) due to the 10% SMC plants being wilted at the end of production and the 40% SMC plants being tall with lodging stems (Fig. 15). The quality rating for the 20 and 30% SMC plants was judged a 4.0 due to higher aesthetic appeal. Overall, the 20 and 30% SMC plants were the most visually appealing due to their compact size, proportional flowering stem sections, giving a colorful overall appearance, and turgid, dark green leaves.

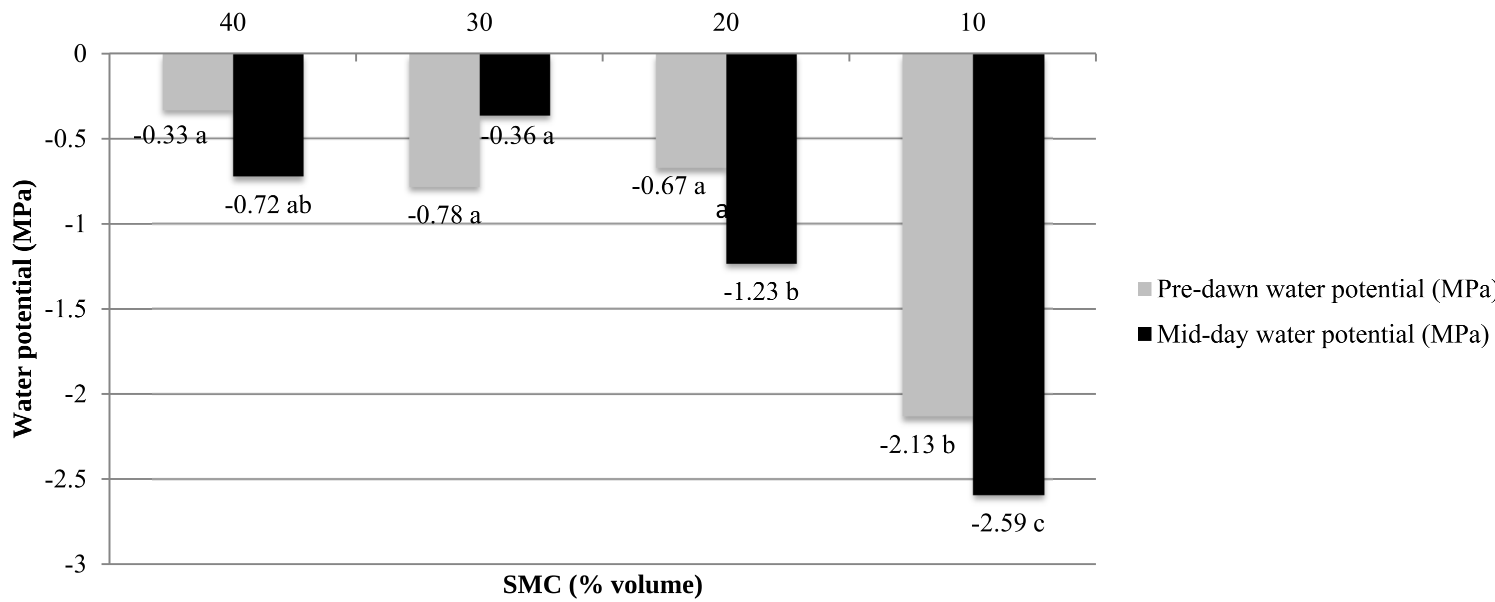


Fig. 14. Pre-dawn and Mid-day water potentials for four soil moisture content (SMC) treatments on *Angelonia angustifolia* ‘Angelface Blue’ during the greenhouse production stage in Experiment 1. Water potentials were taken on one stem from each container and then containers were averaged. Mean separation by Duncan’s multiple range test at time of measurement (pre-dawn vs. mid-day) at $P \leq 0.05$. Mean totals with a common letter are not different.

SMC

10% 20% 30% 40%

Fig. 15. Photographs of 10, 20, 30 and 40% soil moisture content (SMC) treatments of *Angelonia angustifolia* ‘Angelface Blue’ after the termination of the five week greenhouse production stage and immediately before the start of the 48 h simulated shipping stage in Experiment 1. One container from each treatment was photographed as a representative. Angelonia in the 10% treatments began to wilt throughout the day near the end of the greenhouse production stage, and 40% plant stems began to lodge.

The 40% SMC plants abscised 20 flowers during simulated shipping while the 10% SMC plants abscised seven flowers. However, the percentage of abscised flowers among treatments was not different because the 40% SMC plants went into shipping with more flowers compared to the 10% SMC plants, and they lost a proportional amount of flowers (Table 7).

Table 7. Total number of abscised flowers and abscised flower percentage of total flowers and buds at beginning of simulated shipping for the four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' after the 48 h simulated shipping in Experiment 1. Flowers were counted in each shipping box and treatments were averaged.

SMC %	Total abscised flower (no.)	Total abscised flower (%)
40	20 (5.32) a[z]	7 (1.55)
30	14 (3.59) ab	5 (1.71)
20	12 (8.81) ab	4 (2.22)
10	7 (3.86) b	3 (2.06)
Significance	*	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[NS, *]Nonsignificant or significant at $P = 0.05$.

From the end of production through simulated retail, the 40% SMC treated plants developed two more stems, 20 and 30% SMC treated plants developed one new stem, whereas the 10% SMC plants did not develop any new stems (Table 8). Total plant height decreased with decreasing SMC, but there was no difference in node number or internode length after simulated retail. The 40% SMC plants had more fresh flowers than the other treatments, which were similar, and the 10% SMC plants had the least amount of senesced flowers compared to other treatments. The 10% SMC plants were the only treatment to continue to develop new buds from the greenhouse production through the simulated retail stage.

During simulated retail, the 10% SMC treated plants had increased bud height and bud node numbers (Table 9). However, the flowering height, flowering node number, and flowering and bud internode lengths within the inflorescence were similar for all SMC treatments. These results indicate that although the 10 and 20% SMC plants had less total plant height, they had the same length of flowering sections on the inflorescence as the 30 and 40% SMC plants, therefore they were as floriferous and colorful.

Table 8. Number of stems per plant, plant height, node number, internode length, fresh flower, bud, and senesced flower numbers for four soil moisture content (SMC) treatments on *Angelonia angustifolia* ‘Angelface Blue’ during the three week simulated retail stage in Experiment 1. Plant height, node number, and internode length was measured on the tallest stem on every plant in a container. Stem number, fresh flower, bud, and senesced flower numbers were measured on every stem on each plant in each container. Parameters were averaged for all plants in a container, and then all containers in a treatment were averaged.

SMC %	Stems/plant (no.)	Plant height (cm)	Node (no.)	Internode length (cm)	Fresh flower (no.)	Bud (no.)	Senesced flower (no.)
40	5 (1.52) a[z]	55.2 (6.24) a	59 (7.88)	1.0 (.22)	34 (17.66) a	16 (3.60) b	76 (22.66) ab
30	4 (1.30) ab	51.5 (6.66) ab	55 (6.29)	0.9 (0.05)	22 (11.40) b	16 (3.98) b	81 (23.71) a
20	4 (1.47) a	48.0 (5.76) bc	58 (6.89)	0.9 (0.04)	25 (11.05) b	18 (4.66) b	67 (16.34) b
10	3 (0.93) c	45.6 (10.02) c	50 (12.40)	0.8 (0.05)	19 (9.6) b	22 (3.81) a	48 (12.70) c
Significance	***	**	NS	NS	***	***	***

Mean (standard deviation)
[z]Mean separation in columns by Duncan’s multiple range test at $P \leq 0.05$.
[NS, **, ***]Nonsignificant or significant at $P=0.01$, or 0.001, respectively.

Table 9. Flowering and bud height, flowering and bud node number, and flowering and bud internode length within the inflorescence of *Angelonia angustifolia* ‘Angelface Blue’ for four soil moisture content (SMC) treatments during the simulated retail stage in Experiment 1. Parameters were measured on the tallest stem on each plant in a container, averaged throughout all plants in a container, and then treatments were averaged.

SMC %	Flowering height (cm)	Bud height (cm)	Flowering node (no.)	Bud node (no.)	Flowering internode length (cm)	Bud internode length (cm)
40	9.3 (8.43)	3.5 (1.28) b[z]	15 (7.08)	8 (1.99) b	0.6 (0.10)	0.4 (0.74)
30	7.0 (4.95)	3.4 (1.25) b	12 (5.01)	8 (1.80) b	0.6 (0.12)	0.4 (0.12)
20	7.8 (3.59)	4.0 (1.84) b	14 (4.44)	9 (2.33) b	0.5 (0.29)	0.5 (0.12)
10	7.0 (3.49)	5.4 (1.28) a	10 (7.26)	11 (1.91) a	0.7 (0.48)	0.5 (0.07)
Significance	NS	*	NS	**	NS	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan’s multiple range test at P≤0.05.
[NS, *, **]Nonsignificant or significant at P=0.05, or 0.01, respectively.

Table 10. Total volume of water applied during all irrigation events, number of irrigation events, total irrigation duration, electrical conductivity (EC) of the root substrate, and water use efficiency (WUE) for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' during the simulated retail stage in Experiment 1. Total volume of water applied, number of irrigation events, and total irrigation duration was obtained from the Acclima water logs and then treatments were averaged. EC was obtained from the Acclima sensor logs and then treatments were averaged. WUE was calculated by dividing the stem dry weight of all plants in a container divided by the amount of water used by a container during the greenhouse production and simulated retail stages in Experiment 1.

SMC (%)	Total volume (L)	Number of irrigation events	Total irrigation duration (s)	EC (dS/m)	WUE
40	6.0	35	1127	1.7 (0.40)	0.23 (0.22) c[z]
30	4.7	28	887	1.6 (0.09)	0.50 (0.18) bc
20	5.1	31	968	1.6 (0.18)	0.88 (0.20) b
10	2.4	14	452	1.5 (0.07)	1.37 (0.50) a
Significance	---	---	---	NS	**

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[NS,**]Nonsignificant or significant at $P=0.01$

Total volume of water applied to the 40% SMC was 60% greater than the 10% SMC, and 40% plants were watered 21 more times than the 10% plants during simulated retail (Table 10). Just as during greenhouse production, the 40% plants were taller and required more water, therefore they were watered more frequently and the duration of watering was longer for these plants. Towards the end of simulated retail the 40% SMC plants began to wilt in the afternoons. The 20% SMC plants were watered three more times than the 30% SMC plants, and received 7% more water. The 20 and 30% SMC plants were very similar in size and growth, and this could be why they were watered so similarly. There was no difference in EC during simulated retail among treatments. Water potentials for pre-day and mid-day during simulated retail were not different among treatments (Fig 16). This could be due to all treatments being watered at 20% SMC during retail production. The WUE for the 10 and 20% SMC plants was higher than the 40% plants (Table 10).

The visual quality for the 30 and 40% SMC plants was rated a 3.0 (Table 2) due to being the tallest plants with lodging stems (Fig. 17). The visual quality for the 10 and 20% SMC plants was rated a 4.0 because of their reduced height with comparably long flowering sections. Although the 10% SMC plants wilted during the greenhouse production stage, during the simulated retail stage, they never wilted. However, the 40% SMC plants did wilt during this time.

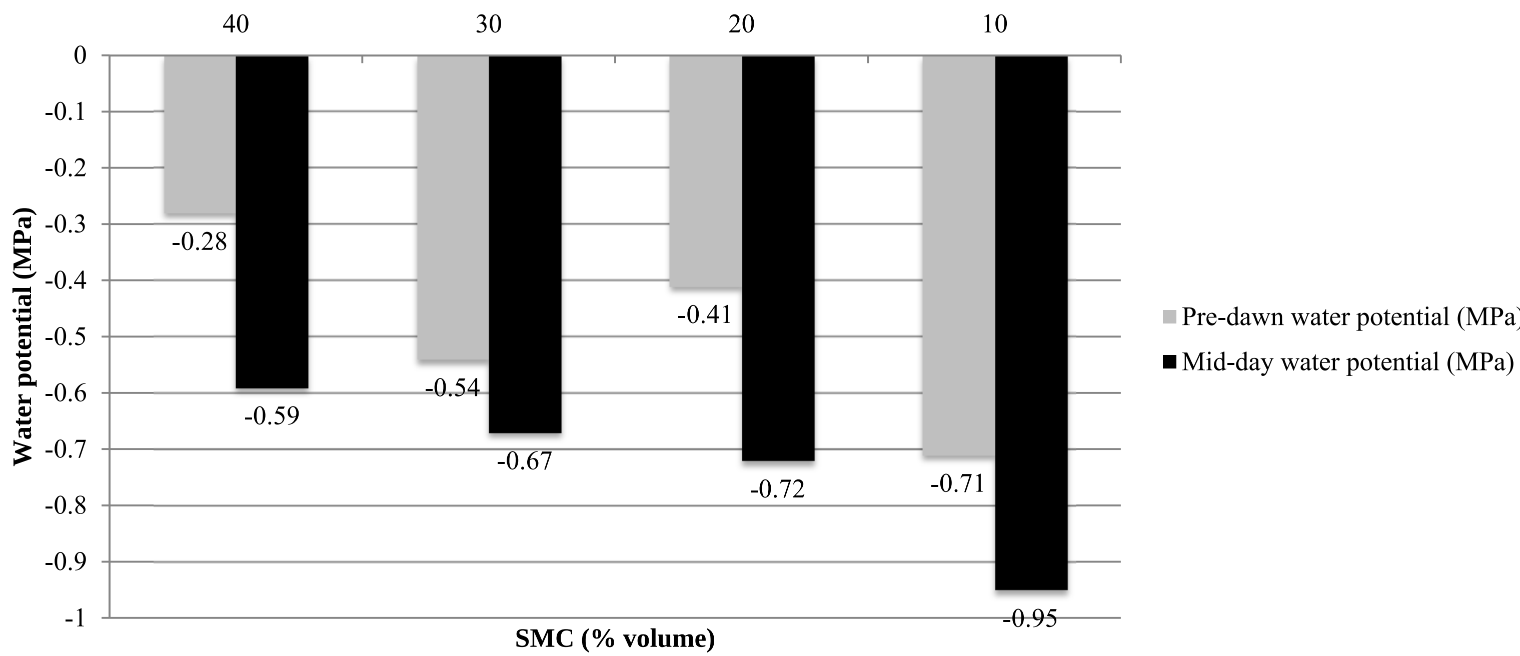


Fig. 16. Pre-dawn and Mid-day water potentials for four soil moisture content (SMC) treatments on *Angelonia angustifolia* ‘Angelface Blue’ during the simulated retail stage in Experiment 1. Water potentials were taken on one stem from each container and then containers were averaged. There was no difference between treatments for pre-dawn and mid-day water potentials.

SMC

10% 20% 30% 40%

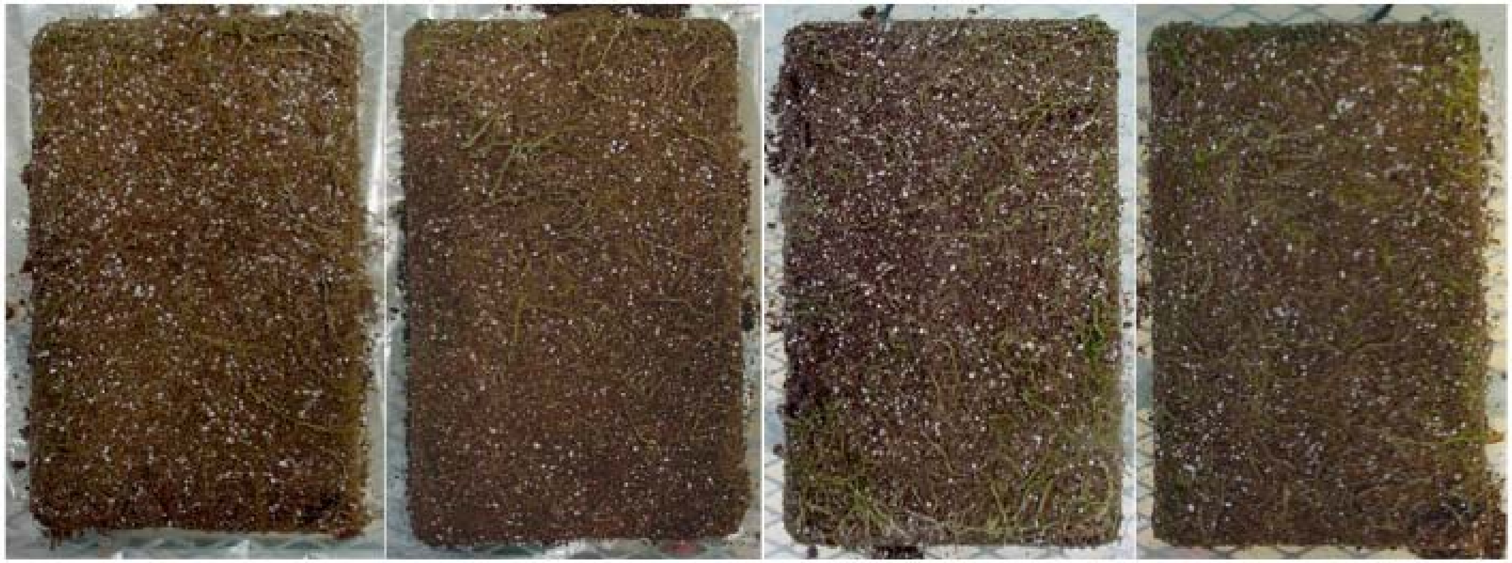
Fig. 17. Photograph of the 10, 20, 30 and 40% soil moisture content (SMC) treatments of *Angelonia angustifolia* ‘Angelface Blue’ after the termination of the three week simulated retail stage in Experiment 1. The same container photographed during greenhouse production was photographed at the termination of simulated retail. The 30 and 40% SMC plants were the tallest plants and had lodged stems, and the 40% plants began to wilt in the afternoons at the end of the simulated retail. The 10 and 20% plants were similar in size and visual quality and had no lodging of stems or wilting.

At termination of the experiment, stem fresh and dry weight decreased with SMC levels. As SMC levels decreased from 40 to 20%, root fresh and dry weight decreased but there was no further decrease from 20 to 10% SMC (Table 11). There was no difference in shoot : root ratios among treatments. Visually, the 10% roots had the least amount of visible roots at the bottom of the container, while the 40% treatments had the longest and most visible roots (Fig. 18).

Table 11. Stem and root fresh and dry weight, and shoot to root ratios for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' at termination of Experiment 1. Stem and root measurements were taken on each plant, averaged for each container, and then all containers in a treatment were averaged. Shoot to root ratios was calculated by dividing stem dry weight by the root dry weight of all plants in a container.

SMC %	Stem fresh weight (g)	Stem dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot : root ratio
40	47.7 (11.18) a[z]	7.4 (1.93) a	21.6 (6.88) a	1.9 (0.79) a	4.98 (3.28)
30	38.1 (8.79) b	6.3 (1.77) b	15.1 (3.41) b	1.3 (0.40) b	5.42 (2.34)
20	37.1 (9.02) b	5.0 (1.92) c	11.8 (3.00) c	1.0 (0.49) c	7.23 (6.25)
10	28.6 (5.99) c	3.8 (1.30) d	11.9 (3.67) c	1.0 (0.47) c	5.68 (4.74)
Significance	***	***	***	***	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[NS,***]Nonsignificant or significant at $P = 0.001$.



SMC

10% 20% 30% 40%

Fig. 18. Photograph of *Angelonia angustifolia* 'Angelface Blue' root system for the four soil moisture content (SMC) treatments viewed from the bottom of the container at termination of Experiment 1. Visually, the 10% roots had the least amount of visible roots at the bottom of the container, while the 40% treatments had the longest and most visible roots.

4.2 Experiment 2

At the end of the greenhouse production stage and prior to simulated shipping the 20, 30 and 40% SMC plants had three stems per plant, and the 10% SMC plants had two stems (Table 12). The 40% SMC resulted in the tallest plants with the longest internodes and greatest number of buds. The 30 and 40% SMC plants had a greater number of nodes and fresh flowers than the 10 and 20% SMC plants. The 10% SMC treatment resulted in the least plant height, node number, and fresh flower number. The 10% SMC plants were very stunted in height, which took away from their visual quality. SMC did not affect days to first flower, and there was no difference in senesced flower number between treatments.

Because angelonia is an indeterminate flowering plant, we measured the portion of the inflorescence that was in full flower, and the portion that was in bud to determine if SMC affected flowering potential. In addition, we measured the vegetative section of the stem. The 10% SMC reduced the height, node number, and internode length of the flowering section compared to the other SMC treatments (Table 13). The 10 and 20% SMC plants had reduced height, node numbers, and internode length in the vegetative and bud sections on the stem. The 40% SMC plants had the longest inflorescences, which were less compact than the other SMC treatments.

Table 12. Number of stems per plant, plant height, node number, internode length, days to first flower, fresh flower, bud, and senesced flower numbers for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' during the four week greenhouse production stage in Experiment 2. Plant height, node number, and internode length was measured on the tallest stem on every plant in a container. Stem number, fresh flower, bud, and senesced flower numbers were measured on every stem on each plant in each container. Parameters were averaged for all plants in a container, and then all containers in a treatment were averaged.

SMC %	Stems/plant (no.)	Plant height (cm)	Node (no.)	Internode length (cm)	Days to first flower	Fresh flower (no.)	Bud (no.)	Senesced flower (no.)
40	3.0 (0.88) a[z]	41.4 (4.12) a	43 (4.21) a	1.0 (0.05) a	35 (0)	32 (12.94) a	33 (3.33) a	0.5 (0.84)
30	3.0 (1.09) a	34.0 (5.54) b	42 (5.54) a	0.9 (0.06) b	35 (0)	28 (13.06) a	28 (4.65) b	1.0 (1.37)
20	2.5 (1.02) b	21.5 (4.20) c	31 (4.17) b	0.7 (0.05) b	35 (0)	17 (9.69) b	20 (3.66) c	1.0 (1.35)
10	2.3 (1.12) b	16.2 (3.03) d	23 (3.76) c	0.7 (0.05) b	35 (0)	5 (4.49) c	19 (4.85) c	1.4 (1.99)
Significance	**	***	***	***	NS	***	***	NS

Mean (standard deviation)

[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.

[NS,**, ***]Nonsignificant or significant at P=0.01, or 0.001, respectively.

Table 13. Vegetative, flowering and bud height, vegetative, flowering and bud node number, and vegetative, flowering and bud internode length within the inflorescence of *Angelonia angustifolia* 'Angelface Blue' for four soil moisture content (SMC) treatments during the greenhouse production stage in Experiment 2. Parameters were measured on the tallest stem on each plant in a container, averaged throughout all plants in a container, and then averaged among treatments

SMC %	Vegetative height (cm)	Flowering height (cm)	Bud height (cm)	Vegetative node (no.)	Flowering node (no.)	Bud node (no.)	Vegetative internode length (cm)	Flowering internode length (cm)	Bud internode length (cm)
40	11.2 (1.77) a[z]	20.4 (3.59) a	9.8 (1.79) a	8 (1.32)	19 (4.11) a	16 (1.67) a	1.4 (0.25) a	1.2 (0.62) a	0.6 (0.08) a
30	10.2 (2.86) ab	15.8 (3.31) b	8.1 (1.76) b	11 (18.13)	17 (3.37) b	14 (2.33) a	1.3 (0.40) a	1.0 (0.12) b	0.6 (0.6) a
20	9.2 (2.49) b	8.4 (3.01) c	4.0 (1.16) c	9 (2.49)	12 (3.25) c	10 (1.83) a	1.1 (0.21) b	0.7 (0.69) c	0.4 (0.08) b
10	9.9 (2.46) b	2.4 (2.05) d	4.0 (1.46) c	10 (2.68)	4 (2.93) d	9 (2.42) b	1.0 (0.23) b	0.4 (0.31) d	0.4 (0.11) b
Significance	*	***	***	NS	***	***	***	***	***

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[NS, *, ***]Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 14. Total volume of water applied during all irrigation events, number of irrigation events, total irrigation duration, and electrical conductivity (EC) of the root substrate for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' during the greenhouse production stage in Experiment 2. Total volume of water applied, number of irrigation events, and total irrigation duration was obtained from the Acclima water logs and then treatments were averaged. EC was obtained from the Acclima sensor logs and then treatments were averaged.

SMC %	Total volume (L)	Number of irrigation events	Total irrigation duration (s)	EC (dS/m)
40	38.0	226	7286	1.5 (0.35) a[z]
30	13.6	81	2454	1.2 (0.10) ab
20	3.1	19	594	1.0 (0.22) b
10	1.0	6	352	1.0 (0.03) b
Significance	---	---	---	*

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[*]Significant at $P=0.05$

Total volume of water applied to the 40% SMC treatment was 97% more than was applied to the 10% treatment, and 40% SMC plants were watered 220 more times than the 10% SMC plants (Table 14). The duration of time that the irrigation was on throughout production was highest in the 40% SMC plants, and was on 95% longer than the 10% SMC plants. The 40% SMC plants were the tallest ones compared to other treatments and thus required more water, were watered more frequently, and the total irrigation duration was longer throughout production. The EC was the highest in the 40% SMC plants, closely followed by the 30% SMC plants (Table 14). Just as in Experiment 1, the 40% SMC plants received more water and therefore more salts could have leached from the fertilizer in the root substrate.

The 10% SMC treatment resulted in more negative pre-dawn and mid-day water potential compared to the other SMC treatments on all days water potential was measured (Fig. 19). During mid-day on day 56, the end of greenhouse production, the 20% SMC also resulted in a more negative water potential than the 30 and 40% SMC. The 20% SMC plants were stressed mid-day at the end of greenhouse production, but not pre-dawn, and the 10% SMC plants were always stressed and never recovered from pre-dawn to mid-day. Near the end of the greenhouse production stage, the 10% SMC plants wilted throughout the day, which took away from their visual quality, and stunted in height (Fig. 20).

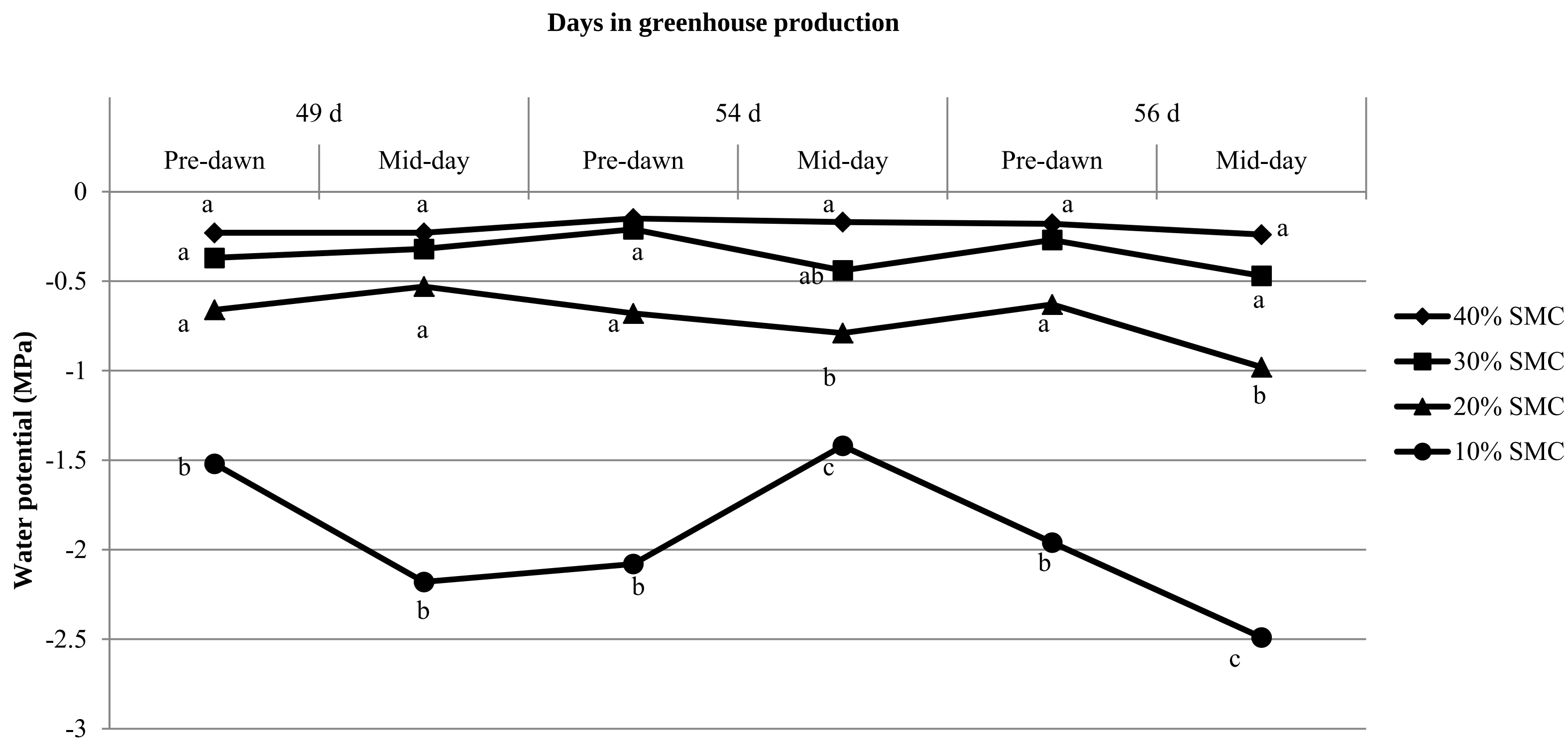


Fig. 19. Pre-dawn and Mid-day water potentials for four soil moisture content (SMC) treatments on *Angelonia angustifolia* ‘Angelface Blue’ 49 d, 54 d, and 56 d after the beginning of he greenhouse production stage in Experiment 2. Water potentials were taken on one stem from each container and then treatments were averaged. Mean separation by Duncan’s multiple range test within day and time of measurement at P≤0.05. Mean totals with a common letter are not different.

SMC

10% 20% 30% 40%

Fig. 20. Photographs of 10, 20, 30 and 40% soil moisture content (SMC) on *Angelonia angustifolia* ‘Angelface Blue’ after the termination of the eight week greenhouse production stage and immediately before the start of the 48 h simulated shipping stage in Experiment 2. One container from each treatment was photographed as a representative and was the picture plant. The 40% SMC plant stems began to lodge and the 10% SMC plants were very short in height compared to the other treatments, and leaves were darker in color. The 10% SMC plants began to wilt throughout production near the termination of that stage.

Table 15. Leaf chlorophyll index (SPAD values) for the four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' on three separate days during greenhouse production in Experiment 2. SPAD readings were taken on two leaves each of three plants in each container then averaged for a container, and than treatments were averaged.

	Leaf chlorophyll index (SPAD values)		
SMC %	3-29-11	4-4-11	4-6-11
40	50.6 (4.43) d[z]	53.8 (5.30) b	52.0 (4.55) b
30	54.8 (4.64) c	56.2 (10.12) b	54.9 (5.18) a
20	62.9 (4.24) b	64.9 (6.87) a	61.8 (8.11) a
10	67.9 (5.93) a	64.9 (8.34) a	65.2 (6.30) a
Significance	***	***	***

Mean (standard deviation)

[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.

***Significant at $P = 0.001$

Seven weeks into greenhouse production it was observed that the 10% SMC plants had darker green leaves compared to the other SMC treatments, and this was confirmed by SPAD meter readings (Table 15). However, as greenhouse production continued, the 20 and 30% SMC plant leaves were also darker in color, resulting in the 40% SMC plant leaves being the lightest in color by the end of the greenhouse production stage.

The visual quality rating for 10, 20 and 40% SMC plants was rated a 3.0 (Table 2) due to the 10% SMC plants being wilted and stunted throughout production, the 20% SMC plants small in height, and the 40% SMC plants being tall with lodging stems (Fig. 21). The visual quality for the 30% SMC plants was rated a 4.0 due to higher aesthetic appeal. Overall, the 30% SMC plants were the most visually appealing due to their compact size and turgid, dark green leaves (Fig. 21).

The 40% SMC plants abscised 39 flowers during simulated shipping while the 10% SMC plants abscised eight flowers. Although the 40% SMC plants abscised four times as many flowers on average during simulated shipping as the 10% SMC plants, there was no significant difference of percent of abscised flowers found among treatments because the 40% SMC plants went into shipping with more flowers compared to the 10% SMC plants, and they lost a proportional amount of flowers (Table 16).

SMC

10% 20% 30% 40%

Fig. 21. Photographs of 10, 20, 30 and 40% soil moisture content (SMC) on *Angelonia angustifolia* 'Angelface Blue' during the four week simulated retail stage in Experiment 2. The same plant from each treatment used for greenhouse production pictures was selected again. The 40% SMC plants were very tall and branched, and stems were lodging. The 10% SMC plants were stunted and had small flowering parameters. The 30% SMC plants were had the highest quality due to their height and flowering parameters. Visually the 20% SMC plants were also high quality, but because they were shorter, not as appealing at the 30% SMC plants.

Table 16. Total number of abscised flowers and abscised flower percentage for the four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' after the 48 h simulated shipping in Experiment 2. Flowers were counted in each shipping box and numbers were averaged among treatments.

SMC %	Total abscised flower (no.)	Abscised flower (%)
40	39 (9.68) a[z]	35 (40.53)
30	34 (11.87) a	56 (14.79)
20	15 (7.26) b	48 (23.23)
10	8 (5.68) b	28 (40.53)
Significance	***	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[NS, ***]Nonsignificant or significant at $P=0.001$.

From the end of production through simulated retail, no plants developed new stems (Table 17). Plant height and node number decreased with decreasing SMC, with the 30 and 40% SMC plants having the longest internode lengths, and the 10 and 20% SMC plants having the smallest. The 40% SMC plants had the most number of fresh flowers while the 10% SMC plants had the least number. SMC had no affect on bud or senesced flower numbers between treatments, but at the termination of simulated retail, all treatments had senesced a majority of their flowers, which took away from the visual appeal.

Table 17. Number of stems per plant, plant height, node number, internode length, fresh flower, bud, and senesced flower numbers for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' during the four week simulated retail stage in Experiment 2. Plant height, node number, and internode length was measured on the tallest stem on every plant in a container. Stem number, fresh flower, bud, and senesced flower numbers were measured on every stem on each plant in each container. Parameters were averaged for all plants in a container, and then all containers in a treatment were averaged.

SMC %	Stems/plant (no.)	Plant height (cm)	Node (no.)	Internode length (cm)	Fresh flower (no.)	Bud (no.)	Senesced flower (no.)
40	3.0 (0.98) a[z]	46.1 (6.22) a	56 (9.13) a	0.8 (0.03)	9 (7.50) a	1 (4.12)	6 (4.23)
30	2.8 (1.73) a	42.0 (6.15) b	49 (9.11) b	0.8 (0.06)	3 (3.11) b	0.5 (2.83)	5 (3.55)
20	2.5 (0.96) ab	29.1 (7.02) c	42 (8.45) c	0.8 (0.22)	3 (3.41) b	0 (0)	5 (4.61)
10	2.1 (0.96) b	23.5 (6.46) d	38 (7.68) d	0.6 (0.10)	0.3 (0.92) c	1 (3.94)	4 (4.01)
Significance	*	***	***	NS	***	NS	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at P≤0.05.
[NS, *, ***]Nonsignificant or significant at P=0.05, or 0.001, respectively.

Table 18. Vegetative, flowering and bud height, vegetative, flowering and bud node number, and vegetative, flowering and bud internode length numbers in the inflorescence of *Angelonia angustifolia* ‘Angelface Blue’ for four soil moisture content (SMC) treatments during the simulated retail stage in Experiment 2. Parameters were measured on the tallest stem on each plant in a container, averaged throughout all plants in a container, and then averaged among treatments

SMC %	Vegetative height (cm)	Flowering height (cm)	Bud height (cm)	Vegetative node (no.)	Flowering node (no.)	Bud node (no.)	Vegetative internode length (cm)	Flowering internode length (cm)	Bud internode length (cm)
40	45.6 (6.45) a[z]	0.2 (0.69)	0.2 (0.75)	55 (10.06) a	0.5 (1.69)	0.6 (1.06)	0.8 (1.04) a	0.04 (0.13)	0.07 (0.12)
30	42.0 (6.17) b	0 (0)	0.1 (0.44)	48 (9.17) b	0.1 (0.35)	0.3 (1.41)	0.9 (0.19) a	0 (0)	0.01 (0.06)
20	29.1 (7.02) c	0 (0)	0 (0)	42 (8.45) c	0 (0)	0 (0)	0.7 (0.13) b	0 (0)	0 (0)
10	23.2 (6.43) d	0.1 (0.37)	0.2 (0.81)	37 (7.20) d	0.3 (1.28)	0.5 (2.00)	0.6 (0.14) b	0.01 (0.06)	0.03 (0.10)
Significance	***	NS	NS	***	NS	NS	***	NS	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan’s multiple range test at $P \leq 0.05$.
[NS, ***]Nonsignificant or significant at $P=0.001$.

During simulated retail there was no difference among treatments of flowering and bud height, node number, and internode length (Table 18). Again, this could be due to the fact that all plants had lost a majority of their flowers when these parameters were measured. Vegetative height and node number decreased with decreasing SMC, and the 30 and 40% SMC plants had the longest vegetative internodes.

Total volume of water applied to the 40% SMC was 100% more than the 10% SMC because the 10% SMC plants were never watered during simulated retail. The 40% SMC was watered 67% more than the 20% SMC plants, and 40% plants were watered 48 more times than the 20% plants (Table 19). Just as in greenhouse production, the 40% SMC plants were taller and required more water, therefore they were watered more frequently and the duration of irrigation was longer for these plants. There was no difference in EC during simulated retail among treatments. Right after simulated shipping the 10% SMC resulted in more negative pre-dawn water potential, but during mid-day there was no difference among treatments (Fig. 22). At termination of simulated retail, the10% plants were the most stressed during pre-dawn, and the 10 and 20% SMC plants were the most stressed during mid-day. There was no difference in WUE between treatments (Table 19).

Table 19. Total volume of water applied during all irrigation events, number of irrigation events, total irrigation duration, electrical conductivity (EC) of the root substrate, and water use efficiency (WUE), for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' during the simulated retail stage in Experiment 2. Total volume of water applied, number of irrigation events, and total irrigation duration was obtained from the Acclima water logs and average among treatments. EC was obtained from the Acclima sensor logs and averaged among treatments. WUE was calculated by dividing the stem dry weight of all plants in a container divided by the amount of water used by a container during the greenhouse production and simulated retail stages in Experiment 2.

SMC %	Total volume (L)	Number of irrigation events	Total irrigation duration (s)	EC (dS/m)	WUE
40	9.0	54	1685	2.1 (0.43)	0.14 (0.14)
30	5.5	33	1029	1.9 (0.33)	0.24 (0.24)
20	3.0	6	185	1.9 (0.16)	0.81 (0.66)
10	0.0	0	0	1.8 (0.32)	0.90 (0.68)
Significance	---	---	---	NS	NS

Mean (standard deviation)
Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
^{NS}Nonsignificant

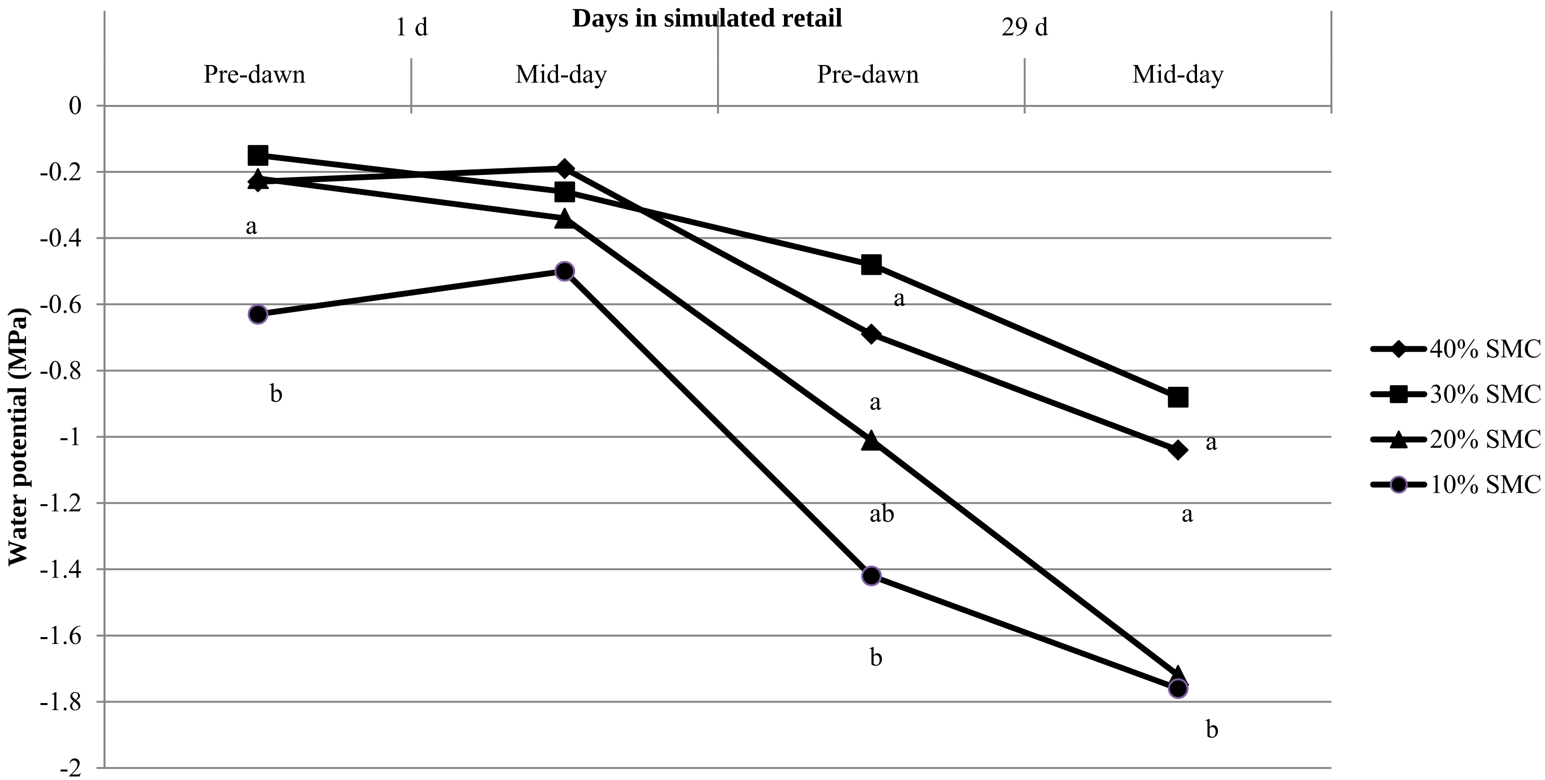


Fig. 22. Pre-dawn and Mid-day water potentials for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' 1 d and 29 d after the beginning of the simulated retail stage in Experiment 2. Water potentials were taken on one stem from each container and then treatments were averaged. Mean separation by Duncan's multiple range test within day and time of measurement. at P≤0.05. Mean totals with a common letter are not different. 1 day after shipping there was no mid-day water potential difference among treatments.

Table 20. Leaf chlorophyll index (SPAD values) for the four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' from two separate days during simulated retail in Experiment 2. SPAD readings were taken on two leaves each of three plants in each container then averaged for a container, and than treatments were averaged.

	Leaf chlorophyll index (SPAD values)	
SMC %	4-12-11	5-10-11
40	50.3 (5.21)	53.7 (7.21)
30	53.3 (5.94)	50.9 (7.03)
20	55.0 (10.98)	53.4 (5.86)
10	54.1 (6.87)	54.3 (6.49)
Significance	NS	NS

Mean (standard deviation)
Mean separation in columns by Duncan's multiple range test at P≤0.05.
[NS]Nonsignificant

Throughout simulated retail there was no difference in darkness of leaf color among treatments (Table 20). The quality ratings for all the treatments at the termination of simulated retail were low due to so many of their flowers already having senesced. In retrospect, the quality rating should have been made a week earlier. The 10, 30 and 40% SMC plants were rated of 2.0 (Table 2) because the 30 and 40% SMC plants were tall and branched, with lodged stems, while the 10% SMC plants were very stunted. Although the 10% SMC plants wilted during the greenhouse production stage, during the simulated retail stage, they never wilted and therefore were never watered during this time. The 20% SMC plant quality was rated the highest at 3.0 because of their compact height.

At termination of the experiment 40% SMC plants had the most stem and root fresh and dry weight (Table 21). The 10 and 20% SMC treatments had the lowest stem and root fresh weight, and root dry weight. The 10% SMC plant had the lowest stem dry weight, while the 20 and 30% SMC plants were intermediate and similar. There was no difference in shoot : root ratios between treatments. Visually the 10% SMC plants had the least amount of visible roots at the bottom of the container, while the 40% SMC treatment had the longest and most visible roots (Fig. 23).

Table 21. Stem and root fresh and dry weight, and shoot to root ratios for four soil moisture content (SMC) treatments on *Angelonia angustifolia* 'Angelface Blue' at termination of Experiment 2. Stem and root measurements were taken on each plant, averaged for each container, and then all containers in a treatment were averaged. Shoot to root ratios was calculated by dividing stem dry weight by the root dry weight of all plants in a container.

SMC %	Stem fresh weight (g)	Stem dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot : root ratio
40	37.7 (18.28) a[z]	6.4 (3.57) a	22.0 (9.06) a	2.9 (1.25) a	2.30 (1.01)
30	23.6 (9.97) b	3.6 (1.96) b	15.0 (5.47) b	1.9 (0.67) b	2.06 (1.20)
20	11.7 (6.04) c	2.6 (3.45) bc	8.0 (4.12) c	1.1 (0.59) c	3.43 (8.60)
10	8.2 (3.30) c	1.3 (0.72) c	5.4 (2.33) c	1.0 (0.43) c	1.36 (0.71)
Significance	***	***	***	***	NS

Mean (standard deviation)
[z]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[NS,***]Nonsignificant or significant at $P = 0.001$.

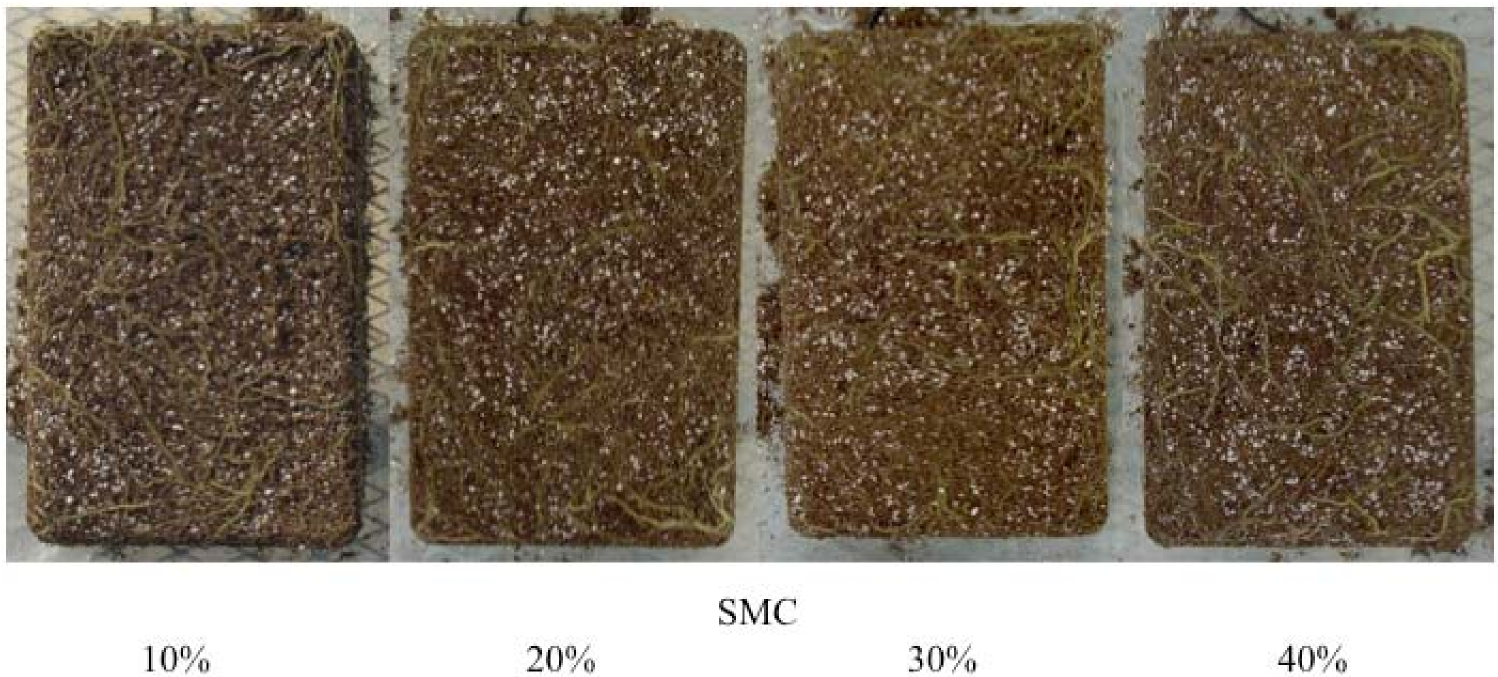


Fig. 23. Photograph of *Angelonia angustifolia* ‘Angelface Blue’ root system for the four soil moisture content (SMC) treatments viewed from the bottom of the container at termination of Experiment 2. Visually, the 10% roots had the least amount of visible roots at the bottom of the container, while the 40% treatments had the longest and most visible roots.

Measurements for the hand-watered treatments were similar to the 20 and 30% SMC treatments for most measurements, but more similar to the 30%. The hand-watered treatment were similar to the 30% plants during greenhouse production in height, internode length, SPAD readings, fresh flower number, and bud number, but more similar to the 20% treatment in node number measured after greenhouse production. Flowering and bud stem sections were also similar to the 30% treatment throughout the greenhouse production and simulated retail. During the simulated retail stage, the hand-watered treatments were similar to the 30% treatment in stem number, fresh flower number, SPAD readings, fresh and dry stem and root weights, water potentials, and number of abscised flowers after shipping, but more similar to the 20% in internode length. Overall, the hand-watered plants received about the same volume of water that the 30% treatments did, but were watered four times less during greenhouse production, and six times less during simulated retail. The hand-watered and 30% SMC treatments were similar in size and appearance, and were high in quality (Fig. 24).

Fig. 24. Photographs of the hand-watered *Angelonia angustifolia* 'Angelface Blue' after the termination of the four week greenhouse production stage (left) and during of the four week simulated retail stage (right) stage in Experiment 2. One container from the hand-watered treatments was used as a representative and was the picture plant. During simulated retail hand-watered plants were similar to the 30% SMC treatment and of high quality due to reduced height and flowering parameters

5. DISCUSSION

Plant height decreased with decreasing SMC throughout the experiment. Inhibition of growth is among the earliest responses of plants to drought (Klamkowski and Treder, 2006). Other floricultural crops such as gaura (Burnett and van Iersel, 2008), salvia (Eakes et al., 1991), marigolds (van Iersel and Nemali, 2004), carnations (Álvarez et al., 2009), hibiscus (Hansen et al., 2005), and petunia (Armitage and Kowalski, 1983) had reduced growth when they were drought stressed. Conversely, drought stress had no effect on plant height of swamp mahogany and Sydney golden wattle (Clemens and Jones, 1978). Using moisture sensors, such as TDT sensors used in these experiments, growers would be able to control the level of SMC and therefore the level of drought stress to reduce plant height without damage to plant quality. Smaller plants caused by drought stress could be appealing to growers because of a decrease in the need for plant growth regulators while conserving water.

In Experiment 1, although the 10 and 20% SMC plants were shorter in height, their ratio of flowers to foliage and flowers to plant height was still proportional like the 30 and 40% SMC plants. However, during Experiment 2 the plants grown at 10 and 20% SMC were shorter in height and more compact compared to plants grown at 30 and 40% SMC conditions. Gaura (Burnett and van Iersel, 2008), miniature roses (Williams et al., 1999), and salvia (Burnett et al., 2005) were more compact when drought stressed compared to controls. Depending on drought stress time, reducing water can reduce the height of angelonia while still producing a proportional plant (Experiment 1), or compact plant (Experiment 2) that is still visually appealing with no effect on flower time or production time in the greenhouse. Growing plants with lower SMC levels that are still marketable at the same time as higher SMC plants could be advantageous to growers. Turnover of crops is vital to greenhouse production profitability therefore growers would not be as inclined to conserve water during production if it extended production time.

Although the 10 and 20% plants had less fresh flowers during the simulated retail stage in Experiment 1 compared to the 30 and 40% plants, the lower SMC plants had more buds than the higher SMC plants, which indicated more fresh flowers would open later. The 10% SMC was the only treatment in which plants continued to develop buds during retail, and had the least amount of senesced flowers, which could indicate acclimation to lower water levels. In Experiment 2 the 30 and 40% plants had more fresh flowers throughout the experiment, but because postproduction data was taken late and the majority of flowers had senesced, we cannot verify this conclusion for this experiment.

Throughout Experiment 1 the flowering section on all treatments was similar and flowers were spaced at the same distance apart on the raceme. Lower SMC treatments were smaller in height, but still had proportional flowering stem sections; therefore they were as floriferous and colorful. During Experiment 2 lower SMC plants were smaller in height and had more compact flowering sections on the stem. During Experiment 2 the plants were given a four week root establishment phase where they were held at 30% SMC (except the 40% SMC plants which were held at 40% SMC). During this time, our intention was to give plants more time for assimilates to be transported to roots rather than shoots before SMC treatments were imposed, but either roots never got established, or growth was reduced because of drought stress. Bedding plants such as angelonia are only marketable if they are in flower therefore it is important that lowering SMC does not reduce the flowering potential of angelonia.

During Experiment 1 greenhouse production stage, the 40% SMC received over seven times more water than the 10% SMC, and over five times more water than the 20% SMC. The 40% SMC plants in Experiment 2 received over 12 times more water than the 20% SMC plants. This is similar to impatiens, petunia, salvia, and vinca (Nemali and van Iersel, 2006) where the highest SMC treatment (32% SMC) received 92% more water than the lowest treatment (9% SMC). Additionally, gaura (Burnett and van Iersel, 2008) grown at the highest SMC treatment (45% SMC) received 93% more water than the lowest treatment (10% SMC). During simulated retail in Experiment 1 the 40% plants used one more liter of water than the 20% plants, and in Experiment 2, three more liters. The 40% SMC plants used more water in Experiment 2, and this could be because the greenhouse production stage was three weeks longer, and the simulated retail was one week longer than in Experiment 1. Regardless, this much saving of water without loss in plant quality is substantial.

The 30% SMC plants were similar to the 20% in most parameters measured in Experiment 1 during greenhouse production and simulated retail, however the 30% SMC plants used over two times more water during greenhouse production. Although the 20% SMC plants used more water than the 30% SMC plants during the simulated retail stage, it was not a substantial amount. During Experiment 2 the 30% SMC plants were more similar to the 40% SMC plants. Growing angelonia at 20% SMC will produce a similar crop as the 30% SMC with less water. Additionally, the visual quality for the 20% SMC plants was deemed higher than the 30% SMC because of reduced height, no lodged stems, and comparably long flowering sections.

In Experiment 1 the 40% SMC plants had higher EC readings than other SMC treatments, which could be due to these plants receiving more water, and therefore more salts leached from the slow release fertilizer capsules into the root substrate. Leachate volume correlates positively with irrigation volume, which means that more water would pass through a slow release fertilizer capsule and more nutrients would leach out (Burnett and van Iersel, 2008). This could also explain why the 40% plants were so tall and toppled over. More nitrogen and phosphorus can make plants taller in height (Harris, 1992). This contradicts results found with gaura (Burnett and van Iersel, 2008), in which EC was higher in treatments irrigated at a lower SMC using an irrigation controller and a continuous liquid feed fertilizer.

The 10% SMC plants in Experiment 1 had a more negative pre-dawn and mid-day water potential reading during greenhouse production but not during simulated retail, probably due to all treatments being watered at 20% SMC during retail. It is possible the 10% SMC plants became acclimated to drought stress. The 40% SMC plants wilted in the afternoons, but had a similar water potential as lower SMC treatments. During Experiment 2 the 10% SMC plants had a more negative pre-dawn and mid-day water potential during greenhouse production. However, after the simulated shipping the 10% SMC had the most negative pre-dawn water potential, but there was no difference in the mid-day water potential. At termination of simulated retail the 10 and 20% SMC plants had the most negative mid-day water potential. The 10% SMC plants were always stressed, which is why they were probably stunted. All plants having a similar water potential reading coming out of simulated shipping could be due to all plants being well watered before shipping. Lower water potentials for drought stressed plants compared to controls is a common occurrence and was also found in strawberries (Klamkowski and Treder, 2006) and in carnations (Álvarez et al., 2009).

In Experiment 2 there was no difference in WUE, but in Experiment 1 the 10 and 20% SMC treatments had a higher WUE than the 40% SMC treatment. Increase in WUE has been shown to be a frequent response of plants in drought conditions, and is considered a mechanism for drought resistance (Starman and Lombardini, 2006)

After shipping, the number of abscised flowers found in the shipping box was much higher for the 40% plants, with the 20 and 30% being more than 10% SMC (Experiment 1) and highest in number for 30 and 40% SMC plants (Experiment 2). Overwatering in production can cause abscission of leaves and flowers (Nell, 1993). The lower SMC plants may have been more acclimated to the stressful conditions such as temperature fluctuations, low light intensities, and high ethylene levels in shipping. Plants in the Scrophulariaceae family are sensitive to ethylene and flower abscission can be high during shipping (van Doorn, 2002). Although the higher SMC plants abscised more flowers, there was no difference in percent of abscised flowers from shipping.

Lower SMC plants in both experiments had less fresh and dry shoot weights compared to plants grown with higher levels of SMC, which is similar to gaura (Burnett and van Iersel, 2008), impatiens, petunia, salvia, and vinca (Nemali and van Iersel, 2006), miniature roses (Williams et al., 1999) (Williams et al., 2000), carnations (Álvarez et al., 2009), hibiscus (Hansen et al., 2005), marigolds (van Iersel and Nemali, 2004), salvia (Eakes et al., 1991), and petunia (Armitage and Kowalski, 1983). Additionally, the root systems were smallest in the 10 and 20% SMC treatments, and highest in the 40% SMC plants similar to carnations (Álvarez et al., 2009). On the other hand, strawberries (Klamkowski and Treder, 2006) grown under drought stress had similar root weights as controls. Plant species respond differently morphologically to drought stress by producing smaller roots, longer roots, or no difference in root length. On the other hand, some plant species increase an investment of roots to enhance root depth to provide a greater water uptake during drought (Klamkowski and Treder, 2006).

Hand-watered plants were most similar to the 30% SMC treatment in the Acclima system, and received a similar amount of water during production. However, the 20% SMC plants were of higher quality and were shorter in height than the hand-watered plants, and used 14 L less water during production.

The environmental conditions changed between the two experiments and this is because each experiment was carried out in a different season. Experiment 1 was performed during the fall, and weather and temperatures was fairly constant (Fig. 5 and 6), while Experiment 2 was performed during the spring when the weather and temperatures fluctuated (Fig. 7 and 8). Additionally, the simulated retail environments were different for each experiment. In Experiment 1 the treatments were set to water at 20% SMC because it is a low water level without harming the plants, and it would be similar to a typical retail setting. In Experiment 2 the simulated retail was altered by setting SMC levels to allow plant wilting before watering. Both situations are similar to how plants would be watered in a retail setting. In fact there is no conventional retail environment, but wilting is a common occurrence where plants are displayed on a hot sidewalk in bright light, or inside the store with low light levels.

It is estimated the 40% SMC treatment would use 4 L or 12 L of water in a 10 or 15 cm standard pot, respectively. The 20% SMC treatment would require 0.4 L or 1.4 L in 10 and 15 cm standard pots. This is approximately nine to ten times more water need by the 40% SMC treatment compared to the 20% SMC treatment, which is quite substantial for a greenhouse production.

6. CONCLUSIONS

- SMC from 10-40% during greenhouse production had no affect on shelf life quality or longevity of *Angelonia angustifolia* 'Angelface Blue'.
- As SMC levels decreased from 40 to 10% during production *Angelonia angustifolia* 'Angelface Blue' plant growth decreased but flowering mode and timing were similar at all SMC levels.
- The 20% SMC plants were visually appealing and of higher quality because of reduced height, proportional flower sections of the stems and they never wilted or lodged stems.
- The 20% SMC plants used 12 liters (Experiment 1) and 35 liters (Experiment 2) less water compared to the 40% SMC during production, and 1 liter (Experiment 1) and 3 liters (Experiment 2) less during simulated retail.
- The 10 and 20% SMC plants could maintain quality at the lower water conditions in simulated retail.

7. RECOMMENDATIONS

- Less irrigation frequency and volume is recommended to conserve water and reduce chemical plant growth regulator use while producing proportional, compact *Angelonia angustifolia* 'Angelface Blue' plants that have less stem bending, breakage, and flower abscission during shipping.
- Overwatering *Angelonia angustifolia* 'Angelface Blue' should be prevented to reduce stem lodging and flower abscission during shipping and retail.

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