Floriculture

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Photosynthesis and water use of vinca (*Catharanthus roseus*) during drought: the effect of different drying rates

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Index Words: annuals, automated irrigation, load cell

Significance to Industry: A large number of studies have explored plant responses to drought stress. However, the way the drought is imposed is often ignored and seldom controlled. We controlled how quickly the substrate dried out using an automated irrigation system, and investigated how vinca (*Catharanthus roseus*) responds to the different drying rates. The slow drying treatment allowed plants to acclimate to the drought stress. As a result, the plants exposed to the slow drying treatment had higher photosynthetic rates and higher water use efficiency at low substrate water content ($\theta < 0.2$ $m^3 \cdot m^{-3}$) than plants exposed to more rapid drought stress. These results indicate that vinca has a considerable ability to acclimate to drought stress conditions, but acclimates more if the drought stress is imposed gradually, rather than quickly.

Nature of Work: Plants may be exposed to drought stress during their production, but the consequences of such stress are not well understood. Although plants may suffer from drought stress, they can actively acclimate to drought using protective mechanisms. There is little information on how plants acclimate during the drying period and how the rate at which the drought stress develops affects the acclimation. The objective of this study was to investigate how different substrate drying rates affect vinca's acclimation to drought stress.

Seedlings of vinca (*Catharanthus roseus* 'Sun Devil Extreme Purple') in 288-plug trays were transplanted into 15 cm, round, plastic containers filled with a soilless substrate (Fafard 2P; 60% peat and 40% perlite; Fafard, Anderson, SC) with controlled-release fertilizer (Osmocote 14-14-14; Scotts, Marysville, OH) incorporated at a rate of 7.7 $kg \cdot m^{-3}$. Plants were grown in a greenhouse for a month (June 22 to July 21, 2009) until they reached a marketable size. At that time, eight plants of similar size were selected and placed individually on a load cells (LSP-2; Transducer Techniques, Temecula, CA). A soil moisture sensor (10HS; Decagon Devices, Pullman, WA) was placed in each pot. Load cells and soil moisture sensors were connected to a datalogger (CR10; Campbell Scientific, Logan, UT) to measure pot weights and substrate water contents (θ, $m^3 \cdot m^{-3}$) every ten minutes. When the weight of a particular pot dropped below a pot-specific set point, the datalogger opened a solenoid valve to irrigate that specific pot. Each pot received water for 10 s from a circular drip tube (dribble ring, Dramm, Manitowoc, WI) connected to pressure-compensated emitters (8 L/h, Netafim, Fresno, CA). The load cells with pots and sensors were placed inside whole-plant gas exchange chambers (van Iersel and Bugbee, 2000) inside growth chambers. Growth chamber conditions

were 14 h days/10 h nights with a PPF of 480 μmol·m^{-2}·s^{-1} at the canopy level, and a constant temperature of 25 °C.

All eight plants were maintained at a pot weight of 950 g for a 3-week acclimation period. After acclimation, plants were exposed to three different drying rates, with drying periods of 4 (fast), 8 (intermediate), and 12 days (slow) to reach a final pot weight of 500 g (θ ≈ 0.10 m^3·m^{-3}). To control the drying rate, the datalogger gradually decreased the weight at which the various plants were watered. The plants in the fast drying treatment were not irrigated after the initiation of the drying treatment until the pot weight reached the 500 g. The pot weight of control plants was maintained at 950 g throughout the experiment. The drying treatments were initiated at different times, so that all drought-stressed plants reached a target pot weight of 500 g at about the same time.

Whole-plant CO_2 exchange of each plant was measured every 10 minutes. Daily carbon gain (DCG, an indicator of growth rate) was calculated by integrating the CO_2 exchange rate over 24 h periods. Daily evapotranspiration (DET) was calculated from the pot weight decrease, and water use efficiency was calculated as DCG/DET.

The experimental design was a randomized complete block with four treatments and two replications. Data were analyzed using regression procedures using SAS (Cary, NC) and SigmaPlot (Systat Software, San Jose, CA).

Results and Discussion: The automated irrigation using a load cell system was successful in imposing the different drying rates. Pot weights and θ decreased gradually at different rates in the different treatments (Fig. 1). In spite of a constant pot weight of 950 g, θ of control pots decreased from 0.43 to 0.36 m^3·m^{-3} during the study due to a gradual increase plant weight.

All drying treatments reduced photosynthesis as pot weight and θ decreased (Fig. 2, 3). The slow and intermediate drying treatments reduced photosynthesis to 80% of the initial rate at seven and five days after drying initiation, whereas the fast drying treatments reduced photosynthesis to 80% of the initial rate after only one day (Fig. 2). The slow and intermediate drying treatments reduced photosynthesis to 80% of the pre-drought rate at θs of 0.17 and 0.20 m^3·m^{-3}, respectively. In contrast, the fast drying treatment reduced photosynthesis to 80% of the pre-drought rate at a θ of 0.25 m^3·m^{-3}. The fast drying treatment reached 50% of the pre-drought photosynthesis at a θ of 0.18 m^3·m^{-3}, at which θ the slow drying treatment still had a photosynthetic rate of more than 80% of the pre-drought rate. Throughout the experiment, the slow drying treatment maintained photosynthesis at more than 50% of initial photosynthesis, even at a θ of 0.06 m^3·m^{-3} (Fig. 2, 3). The much higher photosynthetic rate at low θ indicates that the slow drying rate allowed the plant to acclimate, enabling the plants to maintain relatively high photosynthetic rates, even under severe drought conditions.

Daily carbon gain (DCG) and daily evapotranspiration (DET) of control plants increased during the study because of increased plant size (Fig. 4). The slow drying treatment decreased DCG and DET gradually starting 5 days after the initiation of drying. The final DET and DCG were approximately 50% of the pre-drought level when the pots reached their final weight ($\theta \approx 0.09$ $m^3 \cdot m^{-3}$). The fast drying rate decreased DCG by 63% after one day and 76% at the end ($\theta \approx 0.14$ $m^3 \cdot m^{-3}$). DET of the fast drying treatment also decreased very quickly after the start of the drying treatment (Fig. 4B). The slow drying rate had a higher WUE than the other drought treatments at the end of the experiment, which further indicates acclimation to drought.

Overall, the slow drying treatment allowed plants to acclimate, resulting in higher photosynthetic rates and water use efficiency at low θ. Previous drought stress studies seldom considered the rate at which the drought stress was imposed. These results suggest that plants respond very differently to drought stress, based on how quickly it is imposed. This may have practical consequences: if growers carefully, and gradually, expose their plants to drought stress, they may be able to produce plants that may perform better under dry conditions.

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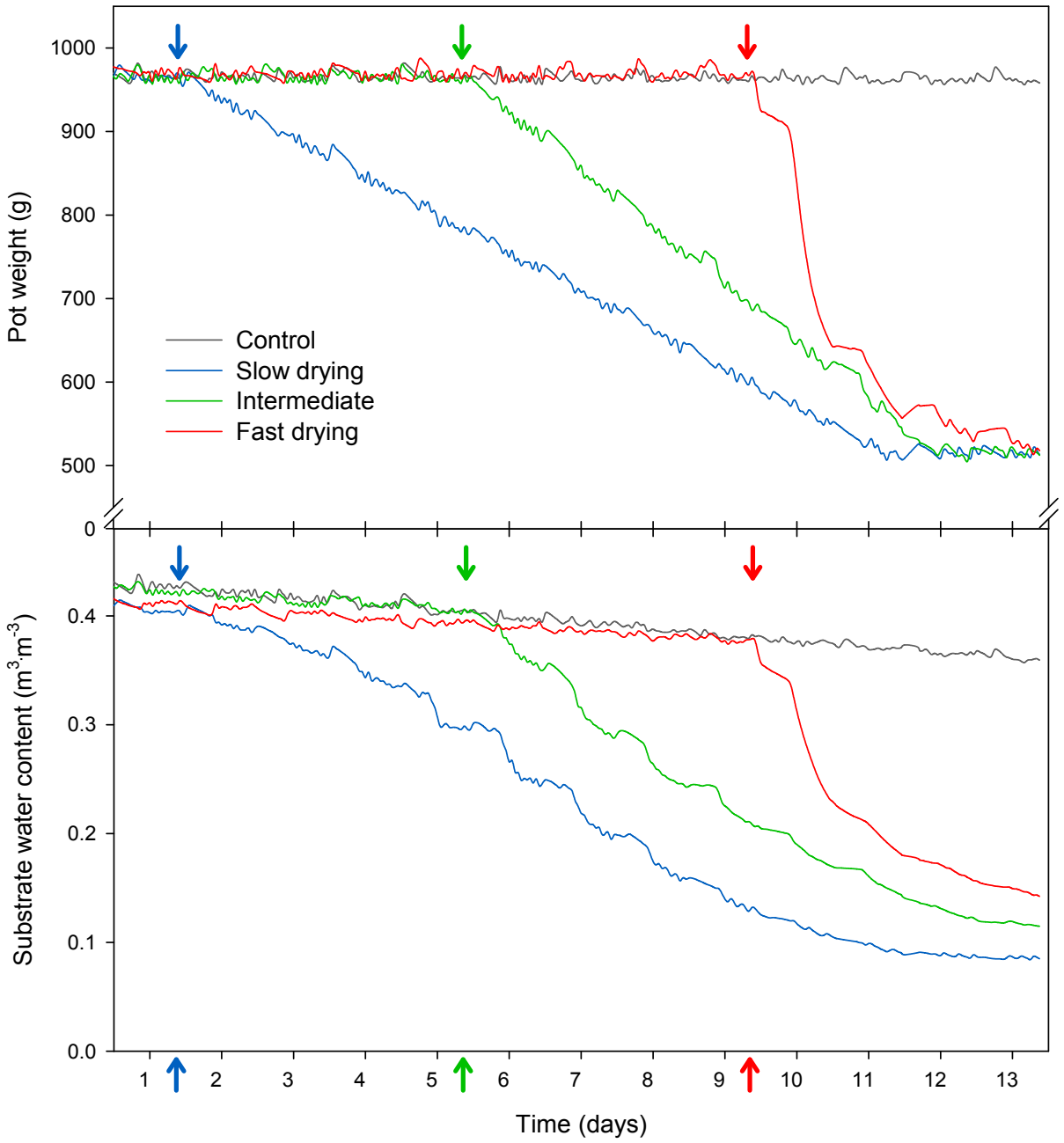

Fig. 1. Pot weight and substrate water content decreased gradually with different drying rates controlled by a load cell-based irrigation system. Arrows indicate the time when a particular drying treatment was initiated. Slow, intermediate, and fast drying treatments were set to reach the final weight (500 g) in 12, 8, 4 days, respectively. Substrate water content of control pots decreased gradually as plant weight increased.

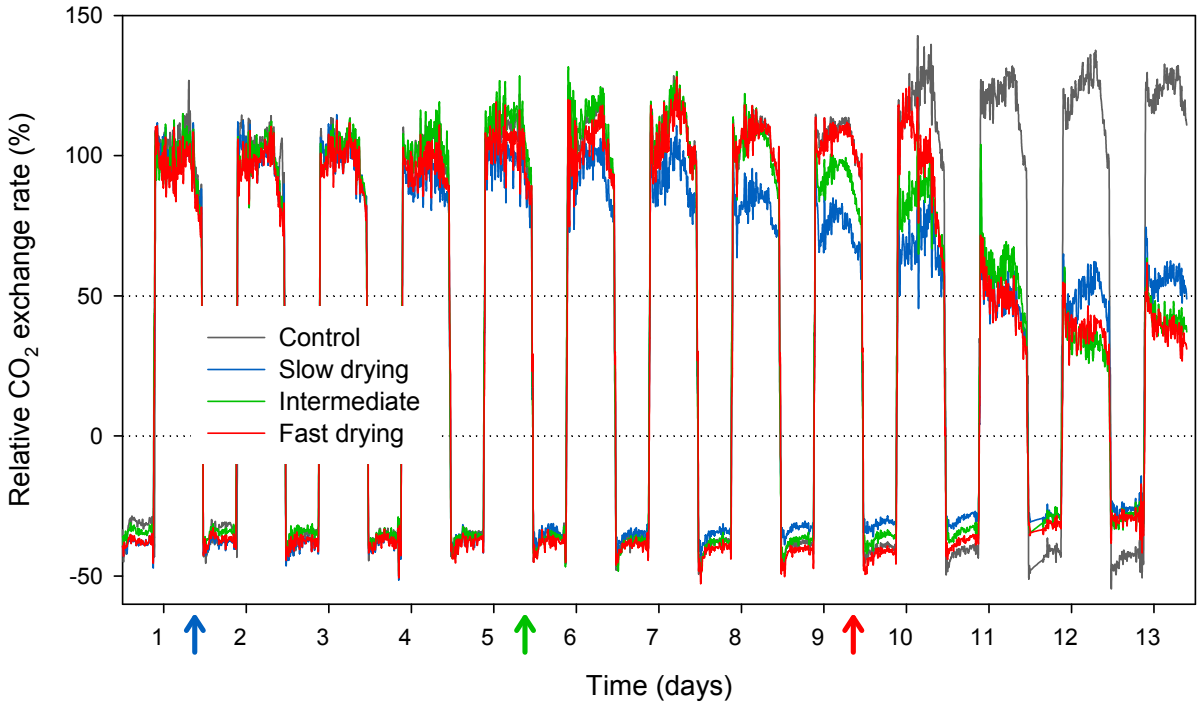

Fig. 2. Normalized photosynthesis and respiration rates of vinca plants exposed to different drying rates for 12 days. Arrows indicate the time when a particular drying treatment was initiated. Reductions in photosynthesis occurred after 6, 4, and 1 days after the start of the treatments of the slow, intermediate and fast drying treatments, respectively. Data were normalized using the average photosynthesis during the three days before the start of the study.

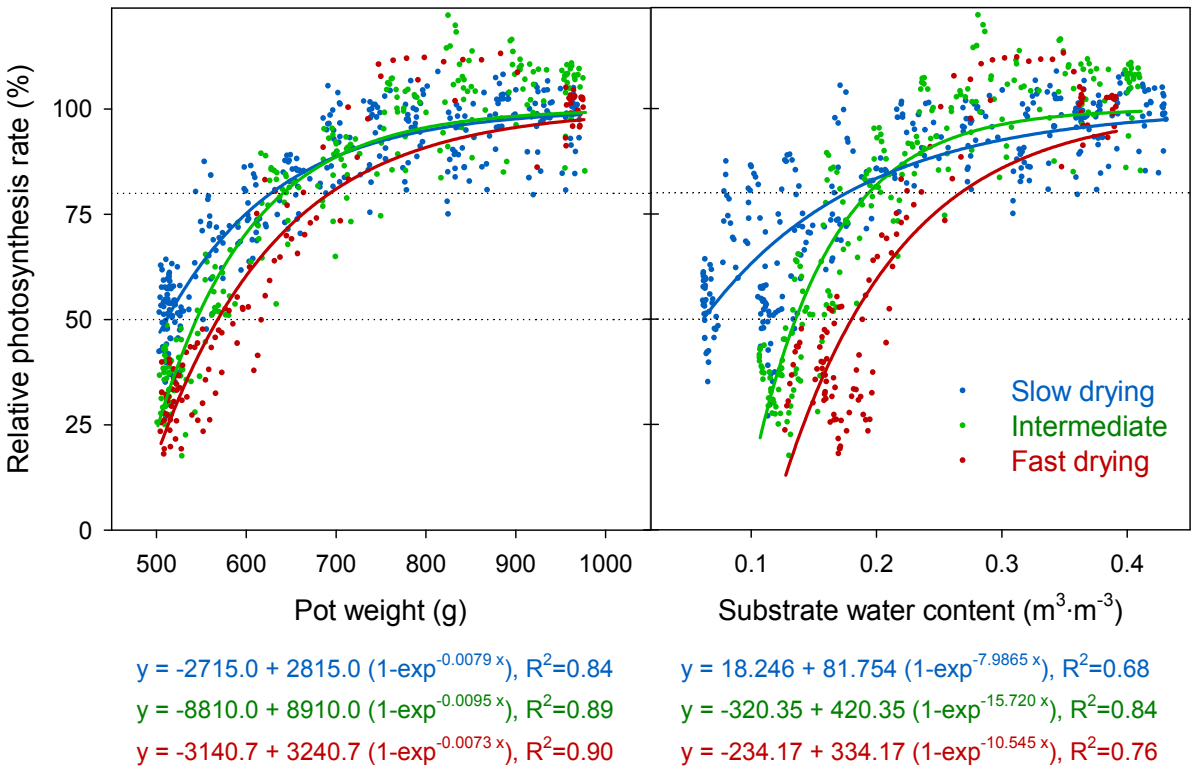

Fig. 3. Relative photosynthesis rate of vinca as a function of pot weight (left) and substrate water content (right). Plants in the slow drying treatment had higher photosynthetic rates when the pot weight reached the final target weight (500 g) and at low θ. Exposing plants to slow drying rates allowed them to acclimate and maintain higher photosynthetic rates in relatively dry substrates.

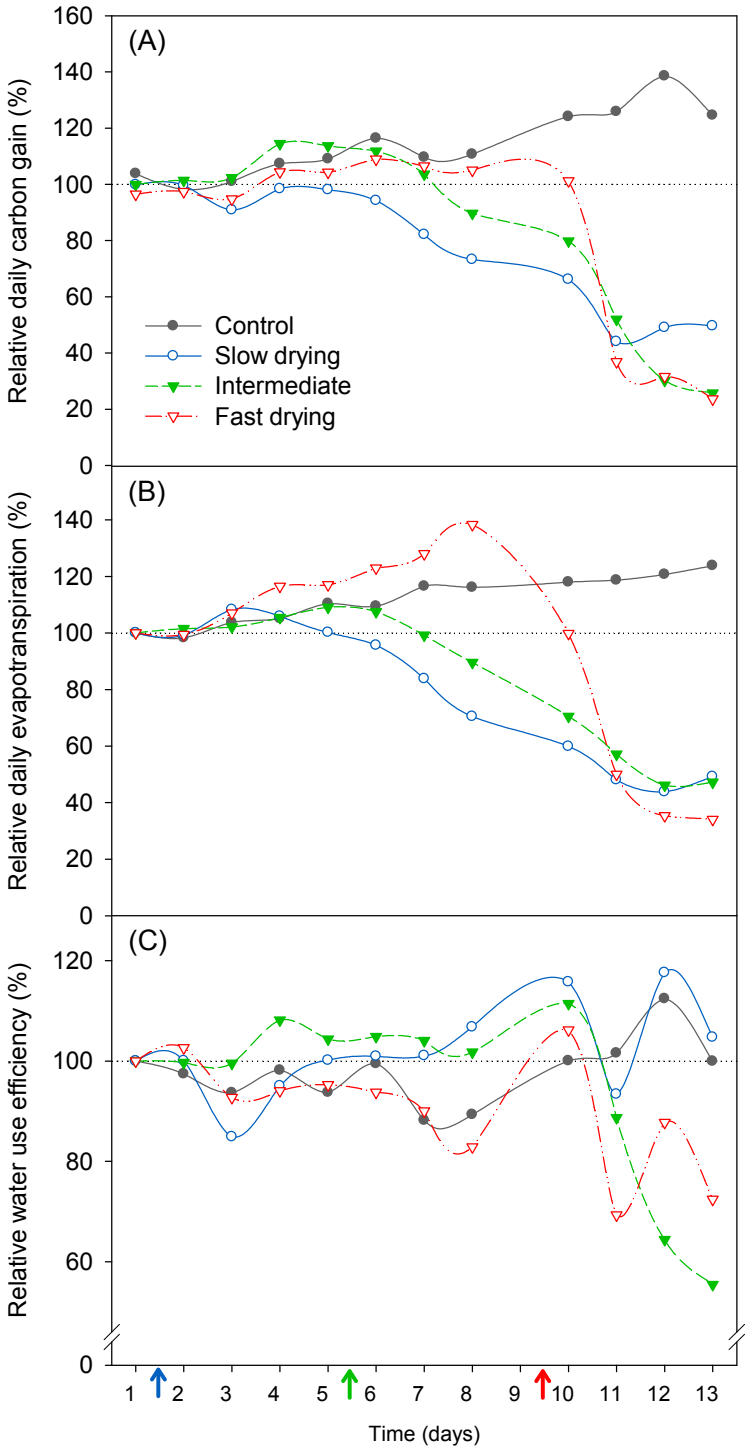

Fig. 4. Normalized (A) daily carbon gain (DCG), (B) daily evapotranspiration (DET), and (C) water use efficiency (WUE=DCG/DET) as affected by slow, intermediate, and fast imposition of drought stress. Arrows indicate the time when a particular drying treatment was initiated.

Characterizing seasonal and diurnal ion and water uptake patterns in greenhouse roses

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Index Words: hydroponics, nutrient solution, cyclic uptake, cut flowers

Significance to Industry: Greenhouse rose production for cut flowers is perhaps the one of the most intensive horticultural cropping systems, with astounding water and nutrient inputs. The overall objectives of this project are to characterize and confirm the seasonal, and more particularly the diurnal water and nutrient uptake patterns in hydroponically-grown roses. While water uptake followed leaf area development over the crop's phenology, we also confirmed a cyclical nutrient uptake pattern that showed minimum uptake rates when the flower shoots are developing at their fastest rate, and maximum uptake near the time when the shoots reach commercial (harvest) maturity. Diurnal (24-hour) fluctuations in water and nutrient absorption were also observed, with transpiration peaking at noontime hours, but nutrient uptake being displaced towards later times in the afternoon. These preliminary results suggest that water and nutrient use efficiency could be significantly enhanced by taking advantage of modern computerized fertigation systems that allow programming of multiple, uncoupled and precise fertigation applications within a day and over seasonal growth and flowering flushes.

Nature of Work: Greenhouse rose production has the distinction of being one of the most intensive agricultural cropping systems, receiving some of the highest water and fertilization inputs (Cabrera, 2003). Despite better knowledge and recent advances on the nutrition and physiology of roses, continuous unidirectional fertigation (i.e. nutrient solution is used once and drained, not recycled) is still the norm for most growing operations. Unfortunately, as nutrients are applied without much regard to actual requirements by the crop as a function of crop development and climatic conditions, heavy applications of fertigation solution cause salt build-up in the substrate's soil solution. This salt build-up affects water uptake (osmotic effect) and potentially some ion-specific toxicities, and thus irrigations with clear water (no fertilizer solution) are often required to keep the rootzone electrical conductivity (EC) at levels that do not affect flower productivity and quality (1, 4, 5).

The vicious cycle of heavy water and fertilizer use is due to both to the high requirements imposed by the growth of developing flower shoots and the relative sensitivity of roses to salinity (4,5). This points to the contrasting need for adequate levels of nutrients and water to meet plant uptake demand and the need to keep rootzone EC low enough to minimize osmotic and water stresses that lead to flower

yield losses. Instead of keeping a constant fertigation formulation and schedule, with in-between clear-water applications (1), a practical solution to this predicament would be to uncouple water and nutrient supply in such a way that they are applied only when needed and in the levels/amounts needed to meet plant demand (2, 3). The underlying premise would minimization of osmotic and water stress while maximizing the use efficiency of the applied water and nutrients. The objectives of this study were to evaluate the patterns of water and nutrient uptake by roses over hourly, daily and single flowering flushes cycles.

Rose plants of the cv. 'Happy Hour' grafted on the rootstocks 'Manetti' and 'Natal Briar', were transplanted into recirculating hydroponic units (2, 3). Briefly, these units consist of a 6-liter container (holding root system of a full-size rose plant) hooked to a 20-liter reservoir, and where nutrient solution is re-circulated by submersible pumps operated by timers. The solution is recirculated at a rate of 5.3 liters/minute in 1.5 minute cycles followed by 4.5 minutes of rest (pumps operating on 24h/7day basis). This recirculation rate and plumbing set-up is adequate enough to provide for the plants' oxygen needs without having to supplement with bubbled (compressed) air. A graduated hook gauge was used to calibrate and determine the volume in each individual unit (container, reservoir, connecting hoses and pump), allowing for an effortless and simple determination of water use (transpiration), whereas collection of small solution samples and determination of EC and/or specific ion concentrations allowed for determination of total or individual ion uptake by depletion (i.e., mass balance approach; 2, 3). The hydroponics units were located in a climate-controlled greenhouse (85°F day/ 65°F night). The base nutrient solution was a complete modified 0.25X Hoagland formulation that was supplemented with $CaCl_2$ or KCl at 4 meq L^{-1}, achieving a final solution EC of 1.9 dS m^{-1} (including EC of tap water). After an establishment period of 2 months, the plants were hard pinched to synchronize the flushes of growth and flowering, and periodic daily measurements of water and ion uptake (every 3 days on average) were made over a couple of flowering flushes, as well over specific diurnal (24-hour) cycles within those flushes.

Results and Discussion: The hot and sunny weather in the summer (July-August) accelerated the development of the rose crop, only 33 days from pinch to harvest, and also produced relatively short stems in both rootstocks (Fig. 1A). As in previous studies (2, 3), transpiration (Fig. 1B) pretty much followed the crop's leaf area development, with a rapid drop observed right after pinching (harvesting the flowers) from the previous cycle (day 0 in the graph). Bud break occurred at day 6 (after pinch) and the new leaf area produced by the developing shoots produced concomitant increases in the transpiration pattern. Despite changes in nutrient solution, the overall EC of resident solution in the hydroponic units increased steadily over time (Fig. 1C). The EC drops observed at days 6, 20 and 29 correspond to the days when about ½ of the resident solution in each hydroponic unit was replaced with fresh solution. This cumulative increase in overall solution EC in a recirculating hydroponic system is typical and expected when practicing zero drainage and there is only minimal or discreet addition of fresh water or new solution. The accumulation of both fertilizer and ballast (or

undesirable) ions or salts is due to the fact that the relative rate of water uptake by the plant is much faster than for the ions present in solution, and thus they tend to accumulate in solution (increasing EC). This attests to the differential or separate control of the plant over water and ion uptake (2, 3), and illustrates the need for a greenhouse manager to know what is the EC setpoint when fresh water needs to be added to keep the EC at desirable levels and eventually when and if the bulk of the solution in the system needs to be discarded/replaced (1).

As with water uptake, the uptake of ions (Fig. 1D), dropped after the hard pinch (harvest) of the previous flush of growth and reached its lowest point at the time when the shots were elongating at their fastest rate - SER (day 15). Once the SER began to decrease the ion uptake rates increased significantly and reached their maximum around harvest time. This pattern of total ion uptake mirrors the uptake of individual ions, like N, P, K, Ca and Mg previously reported by others (2, 6). Our results add the observation that while there may have been some minor differences in magnitude, the rootstocks ‘Manetti’ and ‘Natal Briar’ exhibited the same pattern of water and ion uptake. The overall data from all these studies support to the contention that source-sink relations in the rose plant control and/or govern, to a large extent, the distribution and competition within the plant for carbon and nutrients. During periods of rapid growth, shoots and leaves become major sinks for assimilates, diminishing their supply to the roots, thereby reducing root growth and ion uptake. The supply of ions from the soil solution and re-mobilization of reserves eventually cannot meet the demand of new shoots, resulting in the reduction/cessation of shoot growth. When shoot growth ceases or is significantly reduced, carbohydrates become available again for translocation to the roots, increasing ion absorption and root growth, and the cycle repeats itself. The timing of the oscillation in ion uptake rates is consistent with the shifts in assimilate (^{14}C) distribution previously reported in roses by Mor and Halevy (7).

Regardless of rootstock and sampling day during crop phenology, diurnal water uptake (transpiration) peaked at mid-day, between 12pm and 2pm (Fig. 2A, C), corresponding to the period of maximum evapotranspirative demand, and minimal during midnight hours. Plants on ‘Natal Briar’ tended to have slightly higher diurnal water uptake rates than those on ‘Manetti’, but these differences were not statistically significant. Hourly transpiration rates in plants on both rootstocks were higher during the day preceding flower harvest (Day 33), when biomass leaf area per plant was higher.

Regarding total ion (salt) uptake, it was readily apparent that its average hourly rates were significantly lower for the day when SER was at its lowest (Day 15) compared to day preceding harvest (Day 33). Furthermore, negative hourly uptake rates were observed on Day 15, mostly in night hours (~9pm to ~7am), but were hardly observed before flower harvest. Negative values in net ion uptake rates (i.e. net ion efflux) suggest the plants are not only not absorbing ions, but in fact excreting or losing ions from the plant into the surrounding soil solution. An integration of the hourly uptake rates (area under the curve) for Day 15 revels that barely, if any, net ion uptake occurred for that day. Conversely, on Day 33, near the point of flower shoot harvest, net

uptake rates were for the most part positive, and integration of the daily ion uptake rates shows the maximum whole plant daily values over the course of the flowering cycle. Maximum ion uptake rates, on both days, roughly corresponded with the maxim rates of water uptake, albeit the plants on the 'Manetti' rootstocks showed a peak pattern that was slightly displaced to later hours in the afternoon. A quick evaluation of the areas under the ion uptake curve for Day 33 (Fig. 2D) suggests that a larger fraction of total daily ion uptake occurs in the afternoon hours (from about 2pm to 8pm) compared to the morning hours (from about 8am to 2pm). This is very interesting as over a decade ago we observed that 'Royalty' roses growing on 'Manetti' showed maximum NO_3-N uptake rates in the afternoon to early evening hours (3). Although the literature does not report much more on these diurnal patterns of ion uptake in plants, it has been proposed that diurnal fluctuations in the rate of photoassimilate supply from shoots to roots may help explain this phenomenon (3).

Conclusions: The implications of these observations are very important and could help optimize both fertilizer and water use efficiency, as well as shoot elongation potential. According to the elegant work of Oki and Lieth (7), maximum SER in roses are observed during the early night hours (i.e. 6PM to 10PM), and they are adversely affected even by relatively small changes in rootzone EC. Putting together all this information, from a practical horticultural perspective, it would seem logical to sustain maximum fertilizer concentration application during daytime hours, up until the late afternoon, and then cut the fertilizer concentrations (but not eliminate them) as to minimize any undesirable osmotic (i.e. salinity) effects on shoot elongation rates, which tend to be maximum during the early night hours. This scenario would be, of course, only practically suitable and applicable to a hydroponic production system or an intensively managed (i.e. frequent fertigation) soilless system. It would be advisable to test this procedure in a commercial production system, using only a small section and under careful observation, until finding the fertilizer concentrations (i.e. nutrient solution EC's) more suitable to sustain flower productivity and quality (i.e. longer stems), while potentially maximizing fertilizer use efficiency (discharging less concentrated leachates or drainage volumes).

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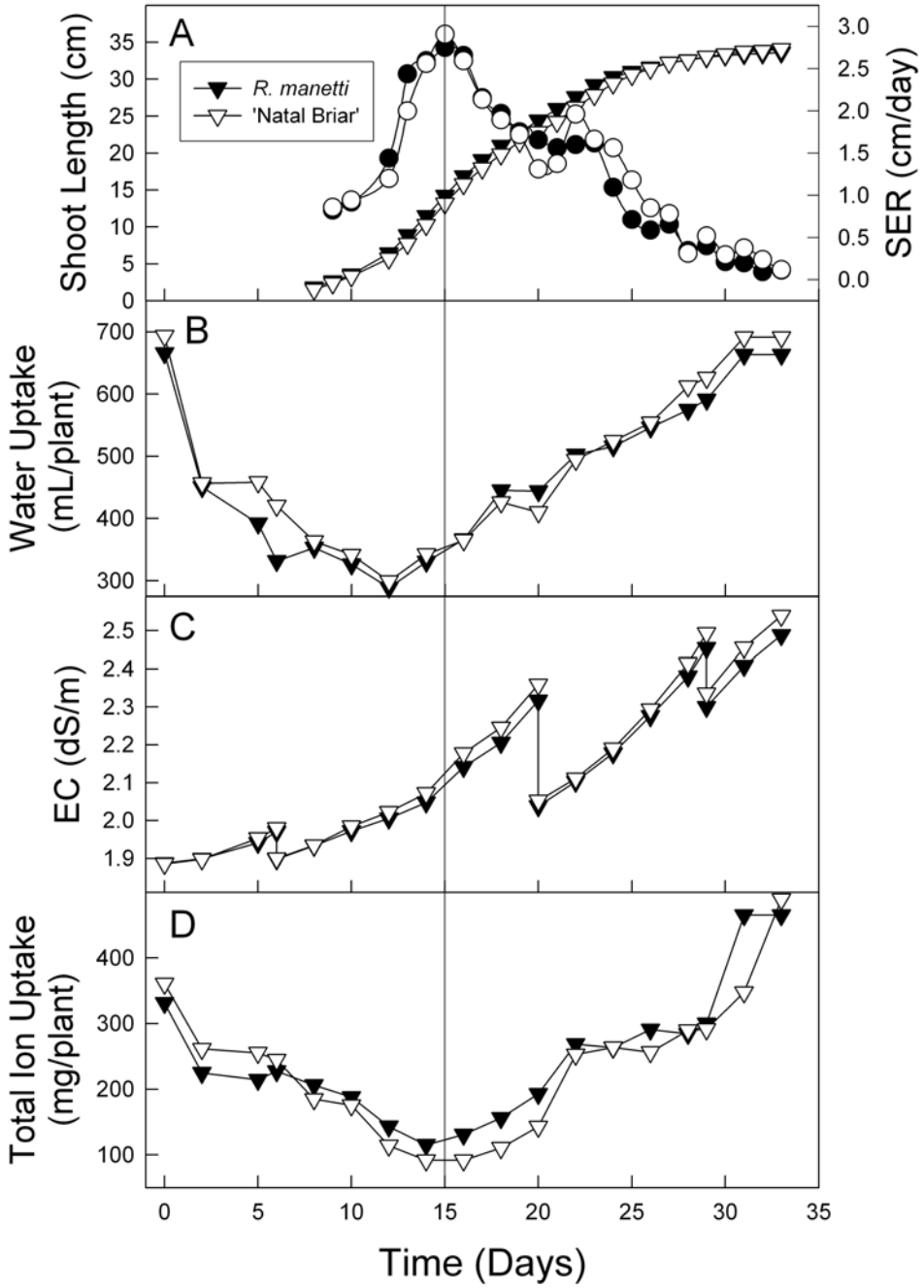

Fig. 1. Shoot length (triangles) and elongation rates (SER, circles) (A), water uptake (B), nutrient solution electrical conductivity, EC (C) and total ion uptake (D) in hydroponically-grown 'Happy Hour' roses grafted on the rootstocks 'Manetti' and 'Natal Briar'. Each data point is the mean of nine plants. The vertical line corresponds to the date when maximum SER was observed over this particular summer flush of growth and flowering.

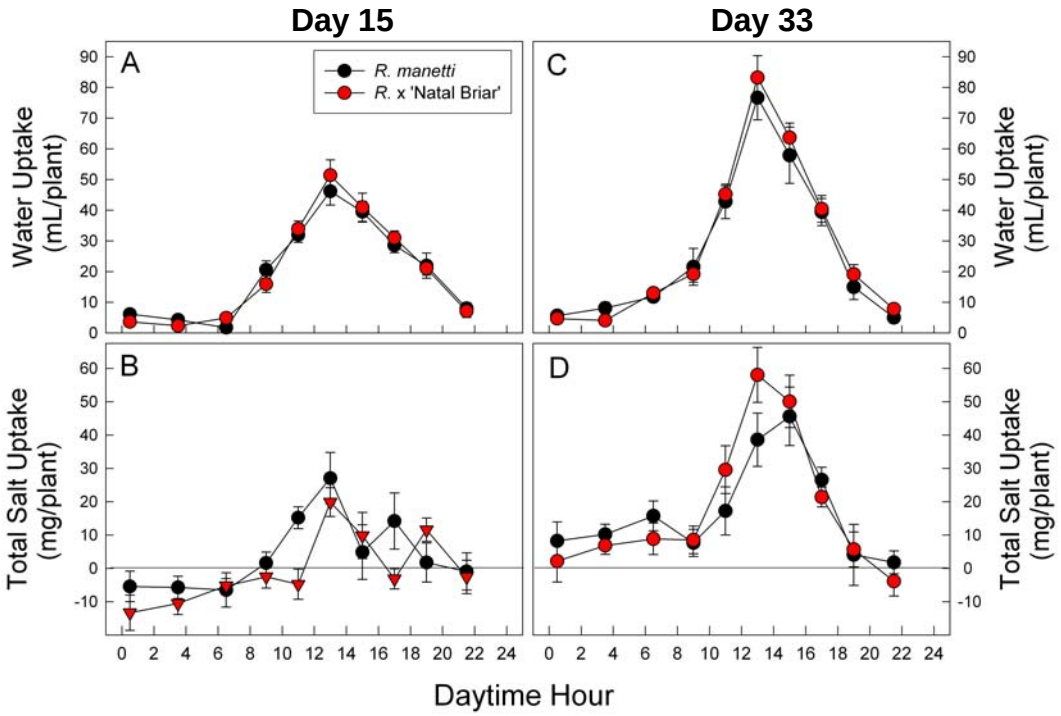

Figure 2. Hourly patterns of water (A, C) and total ion (salt) uptake (B, D), for two days (day 15 and 33) within a growth and flowering cycle in hydroponically-grown 'Happy Hour' roses grafted on the rootstocks 'Manetti' and 'Natal Briar'. Data points are means ± S.E. of nine plants.

Effect of vernalization and day length on flowering of *Michelia skinneriana*

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Index words: chilling, dormancy

Significance to Industry: Banana shrub (*Michelia skinneriana* Dunn.), an evergreen shrub native to Southern China, belongs to the Magnoliaceae and flowers from May to June (Liu et al., 2002). Potted plants targeting the holiday market play a substantial role in today's green industry. Based on the percentage of wholesale values and needs of floral product during holidays, the value of plants may be increased if flowering could be promoted or delayed to meet the holiday markets. Thus, the objective of this study was to investigate the effect of vernalization and day length on flowering of banana shrub. Results indicated that flowering in banana shrub requires a minimum of 8 weeks chilling to break flower bud dormancy in order to open flowers.

Nature of Work: A split-plot design was used with photoperiod (8, 10, 14, and16h) as the main plot factor and chilling (0, 6, 8, and 12 weeks) as the sub plot factor with three replicates. Entire experiment was repeated over time (block A and B). Two cuttings were planted into 6" azalea pots in Sunshine Mix1 (SunGro Hort., Bellevue, WA) on 20 Mar. 2008. Plants were grown in a greenhouse located at Starkville, MS (33° 27' 1" N / 88° 49' 5" W) and kept under full sun and natural daylength for three months before the treatment was started. Plants were fertilized at each watering with 200 ppm 20N−4P−6K (Peters® 20−10−20, Scotts Professional, Allentown, PA).

A total of 96 pots were randomly selected for the experiment and divided into Block A and B. Within each block, plants were randomly divided into 4 groups of 12 plants. One group of plants in Block A was randomly selected and moved to a cooler at Natchez Trace Greenhouses (Kosciusko, MS) for chilling treatment on 16 June 2008 for 12 weeks of chilling. Two other groups in Block A were moved to the cooler on 14 July and 28 July, respectively, for 8 or 6 weeks of chilling. The fourth group of plants in Block A remained in MSU greenhouse during the experiment. Plants in Block B were treated in a similar manner and 3 groups of plants were moved to Natchez Trace Greenhouses on 23 June, 21 July, and 4 Aug., respectively. Block A plants were all moved from the cooler to the greenhouse on 12 Sept. to receive photoperiod treatment and Block B on 19 Sept. 2008.

The cooler was set at 8 ºC (varying from 5.7 ºC to 11.3 ºC), 60% relative humidity (varying from 51.1% to 84.3%), and 12 h photoperiod. After plants were moved back to the greenhouse, three plants within each group were randomly assigned to one of four

photoperiod treatments (8, 10, 14, or 16 hr). The number of flowers and days to the first flower (DTF) after chilling were recorded until the experiment was terminated 80 days after the photoperiod initiation treatment. Statistical analyses were conducted using SAS System (V9.12) statistical packages (SAS Institute Inc., Cary, NC). Means were separated by LSD (p=0.1).

Results and Discussion: The percentage of flowering varied when plants were treated with different combination of chilling and photoperiod (Table 1). There were no significant interaction effects between chilling and photoperiod for DTF or the average number of flowers per pot (Table 2). Twelve weeks of chilling significantly delayed flowering compared to 8 weeks by about 10 days. Eight weeks of chilling produced 0.56 flowers per pot, which was more than 0.22 in 12 weeks of chilling treatment when comparing the average number of flowers per pot (Table 2). No significant differences were observed between photoperiod treatments with regard to DTF (Table 3) , which was 75.4 77.2, 74.4 days for plants under 10 h,14 h, and 16 h photopeoriod, respectively. The average number of flowers/pot was 0.5, 0.25, and 0.42 for plants treated with 10 h, 14 h, and 16 h photopeoriod, respectively. No flowers opened in plants treated with 8 h photoperiod (Table 3).

Specific temperature and duration of chilling to initiate flowers or to break flower bud dormancy varies between species (Moncur, 1992; Moncur and Hasan, 1994; Day et al., 1994; Sytsema and Ruesink, 1996). In this study, at least 8 weeks chilling was needed for banana shrub to break flower bud dormancy at 8ºC to produce flowers.

When applied at the right time, photoperiod may have an effect on both flower initiation and flower development. Twelve-hour or less photoperiod is necessary for poinsettia flower bud initiation (Joiner and Harrison, 1967). The results that all the post-chilling photoperiods except 8-h produced flowers suggests that post-chilling photoperiod influenced flower development in banana shrub.

Short day initiates flower buds in pōhutukawa (Henriod et al., 2000), azalea (Larson, 1993), and Japanese andromeda (*Pieris japonica* D.Don ex G.Don ‘Debutante’, Sytsema and Ruesink, 1996), which are all spring flowering plants. Banana shrub may have the same photoperiod requirement for flower initiation, thus, the small number of flowers/pot in banana shrub was probably due to SD being more productive for flower bud initiation in banana shrub than LD.

In conclusion, flowering in banana shrub requires a minimum of 8 weeks chilling to break flower bud dormancy in order to open flowers. Pre-chilling SD could be recommended for future study. Banana shrub has potential as a potted flowering plant due to its fragrance, charming flowers, and evergreen growth habit.

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Table 1. The percentage of banana shrub (*Michelia skinneriana* Dunn.) flowering after chilling treatments at 8 ºC and post-chilling photoperiod treatments. Six containers of plants were included in each treatment combination.

	Percentage of flowering plants			
Photoperiod	Chilling treatment duration			
	0-week	6-week	8-week	12-week
8 h	0	0	0	0
10 h	0	0	50%	0
14 h	0	0	33.3%	0
16 h	0	0	16.67%	33.3%

Table 2. Effect of chilling treatment on days to the first flower (DTF) and the number of open flowers after 96 pots of banana shrub were vernalized at 8 ºC for different durations. Entire experiment was repeated over time.

Chilling treatment duration (week)	DTF[z]	Number of flowers
0	No flower	0
6	No flower	0
8	36.7 b	0.56 NS[x]
12	46.5 a[y]	0.22 NS

z: Days between the completion of chilling treatments and the first flower.
y: Means followed by the same letter were not significantly different (LSD; p<0.1)
x: No significant difference was observed (LSD; p<0.1).

Table 3. Effect of post-chilling photoperiod on days to the first flower (DTF) and the number of open flowers on banana shrub. There were 96 pots in the experiment. Entire experiment was repeated over time.

Photoperiod (h)	Effect on flowering	
	DTF[z]	The number of flowers
8	No flower	No flower
10	75.4 NS[y]	0.50 NS
14	77.2 NS	0.25 NS
16	74.4 NS	0.42 NS

z: Days between the date of transferring to the greenhouse and the date to the first flower.
y: NS means there is no significant difference when means were separated by LSD (p=0.05).

Growth and Flowering of Intensia Phlox Affected by Irrigation and Growth Environments

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Index words: Irrigation amount, irrigation frequency, greenhouse, cold frame

Significance to Industry: This study evaluated the effects of irrigation (amount and frequency) and growth environments (heated greenhouse and cold frame) on growing liners of Intensia® phlox in 3 ½ inch pots to retail size. Results indicated that in general, plants grown in a cold frame were more compact and had higher or similar ratings on visual appearance than plants grown in the heated greenhouse, depending on cultivars, which indicates that growers can use cold frames to produce quality Intensia® phlox plants. Regardless of environment, more frequent, lighter irrigation tended to produce bigger plants with more flowers and higher overall quality ratings, however, less frequent, heavier irrigation tended to produce more compact plants, often a desirable trait, illustrating the choices and compromises growers have to make in selection of a production system.

Nature of Work: Plugs of three *Phlox hybrid* Intensia® cultivars: 'Cabernet', 'Lavender Glow', and 'Star Brite' were received from EuroAmerican Propagators in February 2007 at the Truck Crops Branch Experiment Station in Crystal Springs and the North Mississippi Research & Extension Center in Verona. Plugs were transplanted into 3 ½ inch pots (one plug per pot) in Fafard # 3 media (Conrad Fafard, Agawam, MA), and pinched at 3-4 nodes to promote branching. Plugs were kept in a heated greenhouse until 12 March when plugs were placed in two different environments, heated greenhouse and unheated cold frame, which were covered with standard greenhouse plastic. Four irrigation treatments were applied as following: 40 ml of water each day, zero day interval between irrigations (40/0); 60 ml of water every other day, 1 day interval between irrigations (60/1); 70 ml of water every third day, 2 days interval between irrigations (70/2); and 80 ml of water every fourth day, 3 days interval between irrigations (80/3). Fertilization at a rate of 200 $mg \cdot L^{-1}$ nitrogen from 20-10-20 Peters Peat Lite Special (20N-4.3P-16.7K; The Scotts Co., Marysville, OH) was applied every 12 days with 40 ml, 60 ml, 70 ml, or 80 ml water per pot for treatments 40/0, 60/1, 70/2, and 80/3, respectively. The experimental design was a split-split plot with environment (greenhouse or cold frame) being whole plots, irrigation treatments being subplot factors, and cultivars serving as the sub-subplot factors. There were four replications

consisting of four pots for each cultivar in each environment. Data from Crystal Springs and Verona were analyzed jointly using PROC MIXED program (SAS Institute Inc, Cary, NC).

Data collected at the termination of the study, 30 April 2007, were plant growth index (GI) [(height + widest width + perpendicular width) ÷ 3] and number of open flowers. Plant height was measured from substrate surface to the tallest plant part. A root rating was based on a rating of the four sides and bottom of the root ball. Each of these root ball surfaces was rated from 0-20 where a rating of 0 indicated that no roots grew out to the side of that surface and 20 indicated that the side of the root ball was 100% covered with roots. The root rating was calculated as the sum of the five surfaces of the root ball. A visual rating, 1-5, was assigned to indicate the overall growth and appearance of each plant with a rating of 1 indicating poor growth and appearance and 5 indicating a superior plant growth and appearance. Plants were cut from the substrate surface and above ground biomass were harvested to determine plant dry weight. The samples were placed into a 60°C forced-air oven to dry, and dry weights were recorded.

The gravimetric water content of fallow pots was determined. Fallow pots received the same irrigation treatments that pots with phlox plants received for 12 days which coincided with the water soluble fertilizer application schedule. After fertilizing the pots, a pre-irrigation soil sample was collected prior to an irrigation treatment and a post-irrigation treatment was collected 24 hours after the irrigation treatment was applied. Gravimetric water content (GW) was determined as follows; GW = (wet sample weight – dry sample weight)/dry sample weight.

The average maximum and minimum temperatures in the greenhouse during this trial were 82 and 69°F, while the maximum and minimum temperatures in the unheated cold frame were 85 and 51°F. The differences in maximum and minimum temperatures between the heated greenhouse and the unheated cold frame were 13 and 34°F, respectively. The cold frame was slightly warmer during the day compared to the greenhouse, but 18°F colder at night.

Results and Discussion: Regardless of the environment, plants receiving irrigation at higher frequencies with lower volume at each irrigation (40/0, 60/1) produced more or similar number of flowers, higher or similar GI, and rated higher or similar on both visual appearance and root ratings than plants receiving irrigation at lower frequencies with higher volume at each irrigation (70/2, 80/3), depending on cultivars (Tables 1 and 2). The 80/3 irrigation treatment produced plants with less dry weight compared to the 40/0 and 60/1 treatments for two of three Intensia® cultivars (Table 1). The substrate gravimetric water content was lowest in the 80/3 (Table 3). This is similar to results of gaura and vinca growth where plant dry weight was reduced by lower substrate water contents (1, 3). However, plants receiving irrigation at lower frequencies (70/2, 80/3) were more compact (lower GI), which is a desirable trait, than plants that received irrigation at higher frequencies (40/0, 60/1), depending on cultivars (Table 2). This agrees with the results of Burnett and van Iersel that reported decreased shoot length

with decreased substrate water content. Environment also has significant influence on plant growth and quality. Plants grown in the heated greenhouse produced more flowers than plants grown in the cold frame (Table 4). However, in general, plants grown in the cold frame were more compact and had higher or similar ratings on visual appearance than plants grown in the heated greenhouse, depending on cultivars (Tables 2 and 4).

In conclusion, results from this study indicate that growers can use cold frames to produce quality Intensia® phlox plants. More frequent, lighter irrigation resulted in higher substrate water contents which tended to produce bigger plants with more flowers and higher overall quality ratings. This has been seen in other bedding plant crops (1, 2, 3). However, less frequent irrigation tended to produce more compact plants. Growers must make production decisions based on the trade off among desirable plant traits and available production systems.

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Table 1. The effect of irrigation treatment on the number of flowers/plant, plant dry weight (g), and visual ratings of Intensia® phlox 'Cabernet', 'Lavender Glow' and 'Star Brite' at the end of the study.

Irrigation treatment	Number of flowers/plant			Plant dry weight (g)			Visual ratings [z]		
	Cabernet	Lavender Glow	Star Brite	Cabernet	Lavender Glow	Star Brite	Cabernet	Lavender Glow	Star Brite
40/0	37.81 a	45.17 a [y]	36 ab	1.99 ab	2.06 a	1.86 a	3.16 a	3.16 a	2.64 a
60/1	38.97 a	47.91 a	34.28 ab	2.13 a	1.95 a	1.5 b	3.28 a	3.01 ab	2.57 a
70/2	39.41 a	39.14 b	31.09 b	1.93 b	1.5 b	1.31 b	3.11 a	2.77 b	2.21 b
80/3	35.94 a	40.58 ab	39.66 a	1.68 c	1.4 b	1.55 ab	2.68 b	2.77 b	2.73 a

[z] Visual rating: 1= poor growth and appearance, 5 = superior growth and appearance
[y] Means compared by Fisher's Protected LSD at *P*=0.05. Columns within a series with the same letter do not differ at the 5% significance level.

Table 2. The effect of irrigation treatment on plant growth index (GI) and root rating of Intensia® phlox 'Cabernet', 'Lavender Glow' and 'Star Brite' at the end of the study.

Irrigation treatment	Plant growth index [z]				Root rating	
	Lavender Glow	Star Brite	Cabernet			
			Greenhouse	Cold frame	Greenhouse	Cold frame
40/0	18.39 a [y]	17.59 a	19.09 b	17.75 a	28.72 b	33.99 a
60/1	17.05 b	16.57 a	21.22 a	17.48 a	46.99 a	24.98 b
70/2	16.57 b	14.69 b	17.74 b	16.02 b	31.84 b	25.61 b
80/3	16.06 b	16.3 a	18.62 b	14.42 b	25.66 b	27.19 b

[z] GI = (height + width1 + width2)/3.
[y] Means compared by Fisher's Protected LSD at *P*=0.05. Columns within a series with the same letter do not differ at the 5% significance level.

Table 3. The effect of irrigation treatments on gravimetric water content (GW) of media in fallow pots measured before and after irrigation treatment.

Irrigation treatment	Gravimetric water content [z]	
	Pre-irrigation	Post-irrigation
40/0	4.52 ab [y]	5.43 a
60/1	4.79 a	5.21 a
70/2	4.16 b	5.47 a
80/3	3.41 c	4.63 b

[z] Gravimetric water content = (wet sample weight – dry sample weight)/dry sample weight

[y] Means compared by Fisher's Protected LSD at *P*=0.05. Columns within a series with the same letter do not differ at the 5% significance level.

Table 4. The effect of growing environment on the number of flowers/plant and visual ratings of Intensia® phlox 'Cabernet', 'Lavender Glow', and 'Star Brite at the end of the study.

	Number of flowers/plant			Visual ratings [z]		
	Cabernet	Lavender Glow	Star Brite	Cabernet	Lavender Glow	Star Brite
Greenhouse	43.93 a [y]	48.63 a	39.66 a	2.94 b	2.78 a	2.29 b
Cold frame	32.12 b	37.79 b	30.73 b	3.17 a	3.07 a	2.78 a

[z] Visual rating: 1= poor growth and appearance, 5 = superior growth and appearance

[y] Means compared by Fisher's Protected LSD at *P*=0.05. Columns within a series with the same letter do not differ at the 5% significance level.

Effects of Fertilizer Source and Rate on Zinnia Cut Flower Production in a High Tunnel

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Index Words: Compost, organic fertilizer, conventional fertilizer

Significance to Industry: High tunnels are unheated greenhouse-like structures with retractable ends and sides that provide a relatively low-cost modified environment for crop production. Growers use the tunnels to extend growing seasons, reduce environmental variability, increase yields, improve crop quality, and increase income (2). This study evaluated the effects of pre-plant compost incorporation and fertigation with different levels of conventional and organic fertilizers during the growing season on zinnia plant growth and number of cut flowers produced in a high tunnel. Results from this study shows that growers can have summer long production of zinnia cuts in a high tunnel in Mississippi. Results also indicated that similar levels of nitrogen (N) from either the conventional or organic fertilizer tested in this study can produce similar number of zinnia stems.

Nature of Work: Due to the relatively modest inputs required and the potential high profitability, high tunnels are rapidly emerging as a desirable system for many specialty crop producers. Among all the aspects related to high tunnel production, fertility management is one of the most important factors influencing plant growth, quality, and yield. It can also have potential impact on environment. While there has been extensive research on fertility management for field and greenhouses, fertility management in high tunnels have not been well researched, especially along the U.S. Gulf Coast. Around the country, farmers approach fertility management in high tunnels in a variety of ways, many of which are similar to their field practices (1). Pre-plant fertilizer incorporation and fertigation during the growing season are used for high tunnel production. Since most high tunnel growers produce their crops in the soil on which the tunnel rests, it is recommended that soil amendments including various composts be added to the soil to increase the organic matter content (1, 3). Adding organic matter to soils can improve soil structure. This in turn increases the soil's capacity to provide adequate oxygen, water, and nutrients to the crop. In addition, alteration in environmental factors such as temperature, water availability and soil amendments in high tunnels have the potential to alter soil microbial processes and organic matter cycling. The long-term sustainability and economic benefits of high tunnels can be best maximized if the system is managed not only to optimize plant growth but also to benefit heterotrophic microbial activity, growth, and the accrual of organic matter. The objective of this study is to investigate the effects of different types and amounts of composts, and organic and conventional

fertilizers on plant growth and yield in high tunnel.

The high tunnel was located at the Truck Crops Branch Experiment Station in Crystal Springs, MS, and placed in full sun and oriented north to south. The tunnel is 90 ft. long by 30 ft. wide. Benary's Giant Mix was selected for zinnia cut flower. This is a series that has good market acceptance, produces long stems, and has large flowers (4). Zinnia seedlings were transplanted to raise beds in the high tunnel on April 8, 2009. The soil was Loring silt loam. The beds were 1.5ft across the top and were spaced 4.5ft center to center. A single drip tape was placed in the center of the bed and buried 1 inch below the top of the bed. Irrigation was supplied as needed through the drip tape. The beds were covered with plastic mulch.

Three locally produced organic products were selected for initial soil amendment in the high tunnel: composted broiler litter (Currie Farms, Raleigh, MS), vermicompost (Church Hill Worm Farm, Church Hill, MS), and cotton gin compost (Bolton, MS). A liquid catfish processing byproduct MultiBloom (Hydrosylate Company of America, Isola, MS) was chosen for organic fertilizer. Peter's 20-10-20 water soluble fertilizer (20N-4.3P-16.7K; The Scotts Company, Marysville, OH) was chosen for conventional fertilizer. The study was arranged as a 4 × 5 factorial, with a split plot design. The main plot was one of four pre-plant compost applications: composted broiler litter, vemicompost, cotton gin compost, and control (no compost). The compost rate used was 4 tons/acre and the compost was incorporated into the bed before laying the plastic mulch. Under each compost treatment, there were five fertigation treatments: no fertilizer, organic low (100 ppm N from MultiBloom), organic high (200 ppm N from MultiBloom), conventional low (100 ppm N from Peter's 20-10-20), and conventional high (200 ppm N from Peter's 20-10-20). Each treatment combination included 10 zinnia plants which were planted half ft apart with two parallel rows on one bed. Each treatment combination was replicated 3 times. Starting April 20, 2009, each plant was supplied with 200 ml of solution from each treatment once a week for one month and then twice a week from late April through September.

On May 4, 2009, leaf greenness (chlorophyll content) was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ). For each plant, three recently fully expanded leaves were randomly chosen for SPAD measurement and the average of the three readings was recorded. On the same date, plant growth index [(height + widest width + perpendicular width) / 3] was recorded. Zinnia stems were harvested as soon as the blooms were completely opened, starting from mid-May through September. The number of stems longer than 12 inches was recorded.

Results and Discussion: There were significant main effects of compost ($P < 0.000001$) and fertigation ($P = 0.002405$) with no interaction between compost and fertigation ($P = 0.336721$) on SPAD readings. Regardless of fertigation, plants that received composted broiler litter had significantly higher SPAD reading than other treatments, and plants that did not receive any compost had the lowest SPAD readings (Table 1). Regardless of compost treatment, plants received high rates of both organic

and conventional fertilizer had higher SPAD readings than plants received conventional low or no fertilizer (Table 2). There was only significant main effect of compost ($P < 0.000001$) on plant growth index, and the trend was similar as SPAD reading with the composted broiler litter treatment produced the biggest size of plants (Table 1). Fertigation did not affect plant growth index. This could be due to the sampling date was only two weeks after the fertigation treatment began.

Even though the pre-plant compost had significant effect on SPAD reading and growth index during early stage of plant growth, it had no effect on the total number of stems produced ($P = 0.215583$). There was significant main effect of fertigation ($P = 0.000431$) with no interaction between compost and fertigation ($P = 0.765804$) on the number of stems. Plants that received high rate of organic fertilizers produced similar stems as plants treated with conventional high, but more stems than lower rates of either conventional or organic fertilizers (Table 2). Plants that did not receive any fertigation produced the lowest number of stems (Table 2). This study shows that growers can have summer long production of zinnia cuts in a high tunnel in Mississippi. The data also shows that similar levels of N from either the conventional or organic fertilizer tested in this study can produce similar number of zinnia stems.

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Table 1. Effects of pre-plant compost incorporation on SPAD value and plant growth index (GI) of Benary's Giant Mix Zinnia in a high tunnel. Data were taken 25 days after transplanting.

Compost treatment	SPAD value	GI[z] (cm)
None	31.4 c[y]	16.0 c
Cotton gin compost	32.3 bc	16.7 bc
Vemicompost	32.4 b	17.3 b
Composted broiler litter	34.3 a	19.2 a

[z]Plant growth index = [(height + widest width + perpendicular width) / 3].
[y]Means compared by Fisher's Protected LSD at *P* = 0.05. Means with the same-lower case letter in a column are not significantly different.

Table 2. Effects of fertigation with different levels of conventional and organic fertilizers during the growing season on SPAD value and number of cut flowers of Benary's Giant Mix Zinnia in a high tunnel.

Fertigation treatment	SPAD value	Number of stems/plant
No fertilizer	31.5 b[z]	16.6 c
Conventional low	32.0 b	23.7 b
Organic low	32.7 ab	23.1 b
Conventional high	33.4 a	26.0 ab
Organic high	33.4 a	27.1 a

[z]Means compared by Fisher's Protected LSD at *P* = 0.05. Means with the same-lower case letter in a column are not significantly different.