INFLUENCE OF A MODIFIED POT-IN-POT STRATEGY ON ROOT TEMPERATURE AND GROWTH OF *RHODODENDRON* x 'MRS. G.G. GERBING' IN FULL SUN

By

Brennan Whitehead, Bachelor of Science in Agriculture

Presented to the Faculty of the Graduate School of

Stephen F. Austin State University

In Partial Fulfillment

Of the Requirements

For the Degree of

Master of Science in Agriculture

Stephen F. Austin State University

December, 2008

Abstract

Rhododendron ‘Mrs. G.G. Gerbing’ liners were planted to test the influence of a pot-in-pot (PIP) full-sun strategy on root temperatures and growth when compared to a full sun above ground area (FS) and a 50% shade house (SH). The treatments for the (PIP) area included black weed barrier with and without middle line irrigation; and white weed barrier with and without middle line irrigation. The growth and root temperature data from the (PIP) system was compared to data from (FS) and (SH). Soil temperature readings were taken in the three areas at the hottest time of day during August. When statistically analyzed the four different treatments in the (PIP) study had no effect on plant growth. At the conclusion of the studies, (PIP) azaleas rated superior, while (FS) plants were small and (SH) plants were spindly and less dense.

ACKNOWLEDGMENTS

The author would like to thank Dr. David Lee Creech for his help and guidance throughout this study. Thanks go to Drs. J. L. Young and J. Yeiser for serving on the author’s graduate committee. The author also would like to express his appreciation to Dawn Stover for the training and job experience while employed at the SFA Mast Arboretum.

The author wishes to express a special thanks to his parents and family for their encouragement and support.

Table of Contents

List of Figures

List of Tables

INTRODUCTION

Over the past few decades the growth and economic impact of the nursery industry in the United States has been dramatic (Hall et al. 2005). From 1987 to 2003 the nursery and greenhouse industry in the US grew from $10.7 billon to $14.7 billion in sales. Growers are constantly challenged with new plant materials, products and production techniques.

A relatively new production technique called pot-in-pot (PIP) combines the advantages of both above-ground container grown and in-field production systems (Adrian et al. 1998; Bilderback, 1999; Fain et al. 2000; Ruter, 1997). PIP is also considered to be more environmentally sound than standard above-ground containers and field grown production. These systems direct and retain runoff water that can contain fertilizers and pesticides (Fare et al. 1991). In most cases, the pot-in-pot system uses micro-irrigation which reduces the amount of runoff.

The objectives of this study were to:

1. Evaluate the influence of weed barrier color (white and black) on container soil temperature and plant growth.

2. Evaluate the influence of a middle-line irrigation line on container soil temperature (drip irrigation line was placed between the socket pots to “cool” the soil around the pots).

3. Compare root temperatures and growth of full sun pot-in-pot azaleas with above-ground azaleas placed in full sun and in a 50% shade house.

LITERATURE REVIEW

Environmental Impact

The concern over sustainable production practices in agriculture is an increasingly important topic. Efficient and environmentally sound methods to manage irrigation are a key interest for plant nurseries. Nurserymen face increasing demands on water supply and the consequences of runoff into surface and ground water sources.

The availability of water has been an issue for growers for many years (Irmak et al., 2003). A recent example of the need for efficient use of a limited water source is the drought that affected the southeastern part of the United States in 2007, and continued in 2008. Many of the region’s surface water sources were depleted because of lack of rain and ground water sources were also challenged. This issue remains an increasingly important worldwide concern in the future (Postel, 2000).

Excessive amounts of water used during irrigation becomes runoff and can have a negative effect on surface and ground water. The runoff water may contain herbicides and pesticides as well as fertilizers. Many nurseries are considered a water pollution point source (Fare et al., 1991). The enrichment of a water source with chemical nutrients can lead to eutrophication (Smith et al., 1999). The adding of nutrients such as nitrogen and phosphorus can promote growth of plants within the water ecosystem. The added nutrients often cause the growth of algae, which can compete with other biota for oxygen causing a die-off of fish (Mallin, 2000).

Irrigation Techniques

New resource management practices have been developed over the years to combat water issues. From collection ponds to cyclic irrigation, there are many ways a grower can control the runoff that might affect the surrounding ecosystem. The irrigation method by which water is delivered to the plant has a dramatic effect on the amount of runoff produced.

Most nurseries use overhead irrigation which is considered to be highly inefficient (Beeson and Knox, 1991). Sprinkler irrigation systems can have water losses of up to 80% due to missing the target, evaporation and runoff (Fare et al., 1991). Overhead irrigation has an efficiency of only about 25% in one gallon pots and 10% with larger three gallon containers (Garber et al., 2002). Managers may apply more that 40,000 gallons of water per acre daily (Tilt, 1990; Fare et al., 1991). Another concern for nurserymen is the non-uniform wetting pattern of water overhead sprinklers provide. Many factors can affect the efficiency of overhead irrigation systems including wind, improper sprinkler heads that are paired with plants that are not spaced correctly, or too much or too little water pressure (Smajstria and Pitts, 1996).

Micro-irrigation is a more efficient form of irrigation. Each container plant has a drip or sprayer type nozzle which provides an individual plant with water (Mathers et al., 2005). Very little water is wasted using this irrigation system because only the container is being watered and not the entire container yard (Bilderback, 2002). Containers larger than a gallon can have an efficiency of about 90% (Haman and Yeager, 1997). Higher efficiency can be achieved by using irrigation timers and rain sensors (McGuff et al., 1975). While this form of irrigation does not completely eliminate water loss by evaporation it can drastically reduce the amount of runoff water. However, there are drawbacks to this system. There is a need for a filtration system, because drip and spitter nozzles have a tendency to clog over time. Another disadvantage for nurseries that use smaller containers is the resulting complication of more plumbing and drip emitters in a container yard. Larger containers (5-7 gallons and larger) are best suited to micro-irrigation.

Pot-In-Pot

A production technique developed around 1990 called pot-in-pot (PIP) has the benefits of both container and field production systems (Fain et al., 2000). This unique system uses a ‘socket pot’ that is placed in the ground with the lip of the pot exposed above ground about three to six inches (Bilderback, 1999). The insert pot is then placed into the socket pot (Parkenson, 1990). The socket pot is considered to be a permanent structure in this system, while the insert pot is changed whenever the plant is sold (Bilderback, 1999). Because this production strategy uses containers that are below ground it is often important to place a drainage line underneath the socket pots unless the container area is in a very well drained soil. If containers are flooded by heavy rains the pots can wash out of the ground or the plant can be waterlogged. Drain lines below a row of socket pots can carry water away from the pot-in-pot yard and into a water retention area. The four advantages to this system are (1) roots are not exposed to excessive heat so plants have a higher root quality, (2) blow-over problems are reduced, (3) the plants in the system can be over-wintered on-site, and 4) reduced cost of harvesting the plant (Bilderback, 1999; Ruter, 1997).

Temperature

Container-grown plants in a conventional system are susceptible to high root temperatures. Black pots absorb the sun's rays causing excessively high root ball temperatures. Containers can experience root zone temperatures above 140° F in full sun (Bilderback, 1999; Greene, 2001). In one study, the recommended maximum temperature for container tree roots was 107.6° F (Martin, et al. 1997). High temperatures can be damaging and in some cases lethal to the plant. High root zone temperatures are also linked with poor shoot and root dry weights (Greene, 2001). The heat is speculated to cause a decrease in the uptake of water and nutrients and to slow down or completely stop photosynthesis (Martin, et al. 1997). It is believed that brief exposures to very high temperatures result in a loss of membrane integrity (Larcher, 1995). For this reason, many nurserymen recognize the importance of reducing root zone temperature (Greene, 2001). Since container heat is such a problem for nurserymen there have been several different types of container systems developed over the years to deal with the problem. In one study, mycorrhizal fungal inoculum compensated for the loss of nutrients due to root zone heat (Greene, 2001). Another system, RootTrappers®, uses a spun black fabric that has been laminated with a white coating to reduce container temperatures (Whitcomb, 2008). The fabric is cut to length to fit the size of the plants root system. However, the fabric only lasts a couple of seasons. The PIP system places the roots below ground thereby avoiding direct sunlight on the containers and sensitive roots along the edge of the container are spared the impact of excessive temperatures (Bilderback, 1999). Since the system protects the plants from extreme heat, the PIP technique produces more desirable plants faster than any conventional technique (Martin et al., 1999; Ruter, 1998). In fact, one study with *Acer rubrum* (red maple) found that trees grown with reduced root zone temperatures had a greater shoot water potential than the trees that had higher root zone temperatures even though all trees were well irrigated (Graves et al., 1989).

The system's ease of use cannot be overlooked. In many tree farming facilities large plants require the labor of many workers and mechanical equipment to lift and prepare the tree for market. Often, at a time when the grower has limited time for harvest, some plants can only be harvested when the plant is dormant. In the PIP system the tree can be moved and taken anywhere the grower needs it at any time of the year (Halcomb and Fare, 1995). Since the plants are in a stable socket pot they cannot be blown over by wind. This saves the grower money and time because of the amount of labor required to upright plants and the possibility of damage due to overturned plants (Skillman, 2002). PIP produced plants can be harvested and sold at any time of year which increases the potential for profit (Halcomb and Fare, 1995; Skillman, 2002). The system also requires fewer workers to tend and harvest plants, thereby saving the grower money (Adrian et al. 1998).

In order to maximize efficiency and profit, the pot-in-pot system lends itself to modifications by the nursery. One example would be the Gro-Eco™ system designed and patented by Jay Fraliegh in Madison County, Florida (http://www.gro-eco.com/index.html). Fraliegh believes that the cost of construction as well as the time spent on construction is less when compared to other systems (Albanesi, 2007). The cost of installing Fraleigh's modified pot in pot system can be as much as 50 percent less than other conventional nursery systems as reported by Albanesi. According to Fraliegh, this strategy can take used farm land and convert it to a Gro-Eco nursery in less than 60 days. The Gro-Eco system is unique in that, along with micro-irrigation, drip tubing is placed below the bed between the buried socket pots in order to cool the soil around the socket pots during the hot summer. According to Fraliegh, around five acres of a Gro-Eco system can be managed by one person, five times the acreage one person could manage with a conventional system (Albanesi, 2007).

Economics

The economics of the pot-in-pot system are, of course, a concern for any grower. The initial investment is greater when compared to field grown systems or container yards because of the cost of the socket pots and the expense of installing the system (Haydu, 1997). One grower has stated that the construction of his nursery's pot-in-pot system cost him $30 per pot (Crowder, R. 2008. Personal contact with the owner of Hawk-Ridge Nursery in Hickory, North Carolina.). But, it has been shown that after a few years of use the cost per plant is less than that of field or container grown plants (Adrian et al., 1998; Ruter, 1997). In fact, in one study of the three methods of plant production (in-field, above-ground container and pot-in-pot systems) results indicated that labor and equipment cost were $1.39 for in-field grown, $.77 for above-ground container, and $.67 for pot-in-pot system per harvested plant (Adrian et al. 1998). This study compared the three production techniques by a cost per harvested plant over a three year production cycle. *Lagerstromeia indica* (Crapemyrtle) trees were used in all three study areas (Adrian et al. 1998). Pot-in-pot and above-ground area plant material was finished in #10 containers. Six to seven feet tall ball and burlap trees were the finished product for the in-field growing area. The in-field tree liners were planted in rows 5ft apart with an in-row spacing of 3ft, resulting in 19.5ft² per plant. After the third year 18,990 plants were harvested in the in-field production area. For the above-ground container area the final year allocated 16ft² for 8.4 acres. A total of 23,338 plants were harvested in the pot-in-pot area (0.4 acres). The in-field production cost $23.73; the above-ground container system cost was $23.71, the pot-in-pot system had the lowest cost at $21.52.

When microirrigation is used with a pot-in-pot system the need for fertilizer is less because the system reduces nutrient leaching. Since the socket pots are permanent and at a fixed location, a micro-irrigation system would be ideal choice to use with the pot-in-pot system. An important factor to consider when using microirrigation is to ensure that water is uniformly distributed over the container substrate surface (Bilderback, 1999). An even distribution of water creates a uniform root system in the container. Most nurseries use nozzles that are turned upside down and spray water 360 degrees. It is important to monitor plant water needs during the growing season.

Cyclic-irrigation is a more efficient technique in a pot-in-pot production strategy (Fain et al., 1997). Cyclic- irrigation simply allows time for a predetermined amount of water to move through the media. The amount of water needed by the plant is divided in intervals throughout the day. In one study, water efficiency had been improved by 38% when compared to one time irrigation applications (Fain et al., 1997). By applying low volumes of water several times per day, the plant can take up nitrogen efficiently and reduce the loss of nutrients due to leaching (Karam and Niemiera, 1994). Using cyclic irrigation has been shown to reduce the amount of nitrogen leached by at least 89% when compared to single irrigation applications (Fain et al., 2000). Because cyclic irrigation allows the water to move more slowly throughout the media, plants have been shown to have greater dry shoot weight (Fain et al., 2000). Growers attempt to reduce leached volumes to only that amount needed to prevent salt build up.

Management Techniques

Growers that monitor evaportranspiration can determine plant water needs during the growing season to fine-tune irrigation volumes and frequencies to meet that need (Fain et al., 1997). By monitoring water requirements a more efficient irrigation program can be developed and applied throughout the season (Tyler et al., 1996). However, many nurserymen grow a diverse selection of species that have different water and nutrient needs. Management can be complicated. In fact, the interactions between nutrients, water requirements and growing conditions for a specific species may not be known (Zhu et al., 2005 (A)).

Monitoring the water that is leached in a pot-in-pot system is not an easy task. The pots are below ground and the amount of water drainage is difficult to observe (Zhu et al., 2005 (B)). Zhu concluded that, with proper monitoring techniques, a grower can alter the frequency of irrigation taking into account any volumes of water supplied by rainfall. If rainfall is high then more fertilization may be required to compensate for losses due to leaching of nutrients.

Pot-in-pot Problems

Overall, the pot-in-pot method has few problems. In some cases there are problems with plants “rooting out” (Tatum et al., 1999). “Rooting out” is a term used to describe the tendency for roots to grow out of their containers. If rooting out does occur, it can be very damaging to the system. The socket pot and in some instances the insert pot can be destroyed, which can be costly for the grower to replace if large containers are being used. Roots can become too large outside of the container and then the insert pot cannot be removed from the socket pot. The plant could be deemed unharvestable. A study conducted by Mississippi State University investigated this problem. This study looked into modifying the containers being used. Using chemically treated socket pots to deter root growth when the roots touch the wall of the socket pot is a possible means of preventing this problem (Tatum et al., 1999).

MATERIALS AND METHODS

Pot-In-Pot, Full Sun Above-ground, 50% Shade Study, 2006

Plant material

Rhododendron x 'Mrs. G.G. Gerbing' liners provided by Greenleaf Nursery, El Campo, Texas were used in this study. Two liners were planted in each 7800ml (2.06 gallon) plastic nursery container. The substrate used was a mixture of 50% Pro-mix™ potting soil (45%-50% peat moss and 45% bark) and 50% double ground pine bark. The selection of plants to the three growing systems was random. Most of the containers were placed in a pot-in-pot study area at the Stephen F. Austin State University (SFASU) Mast Arboretum, Nacogdoches, Texas. For comparative purposes, thirty plants were placed in a full sun container yard at the Piney Woods Native Plant Center, SFASU, Nacogdoches, Texas, and forty plants were placed in a 50% shade house at the SFASU Mast Arboretum, Nacogdoches, Texas.

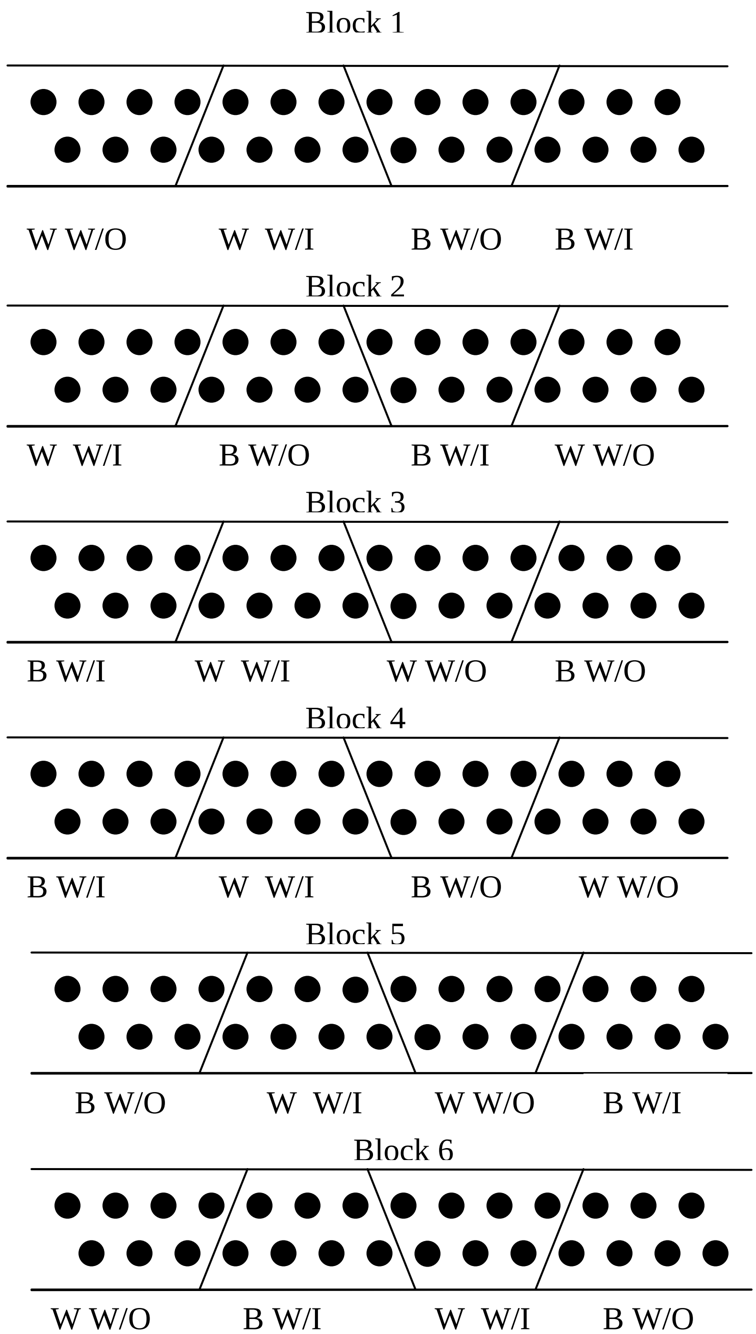
The experimental design

In the pot-in-pot study area, treatments included 1) color of weed barrier (white or black) and 2) middle line irrigation placed between the socket pots. A randomized block design was utilized with six blocks, with six replications of each treatment. Each of the six blocks in the study contained four treatments. Each treatment contained seven plants, 28 plants per block. A total of 168 plants were used planted in the pot-in-pot experiment. Only the three interior plants in each treatment were analyzed in order to prevent an edge effect (Figure 1).

Experimental procedures

The azalea liners were planted on March 9, 2006 and harvested on October 10, 2006. Measurements for the pot-in-pot experiment began on April 7, 2006 and concluded October 10, 2006. The four treatments in the pot-in-pot experiment included the following:

1. Black weed barrier with no middle line irrigation.
2. Black weed barrier with middle line irrigation.
3. White weed barrier with no middle line irrigation.
4. White weed barrier with middle line irrigation.



<u>Abbreviation Key</u>

● - Azalea Plant

B- Black Weed Barrier

W- White Weed Barrier

W/O- Without Middle Line Irrigation

W/I- With Middle Line Irrigation

Figure 1. Block design of the pot-in-pot area. In the field, blocks were positioned end to end and numbered consecutively one through six. The positions of the six individual rows are for illustration purposes only.

Pot-in-pot field construction

A 200’ x 6’ container bed was constructed in a full sun location at the SFASU Mast Arboretum. A total of 120 cubic yards of sand was used to build the container bed. Weed barrier was placed on top of the sand bed and holes for the socket pot were placed in a triangular design (24” x 20”), 3.45 square feet per container (Figure 2).

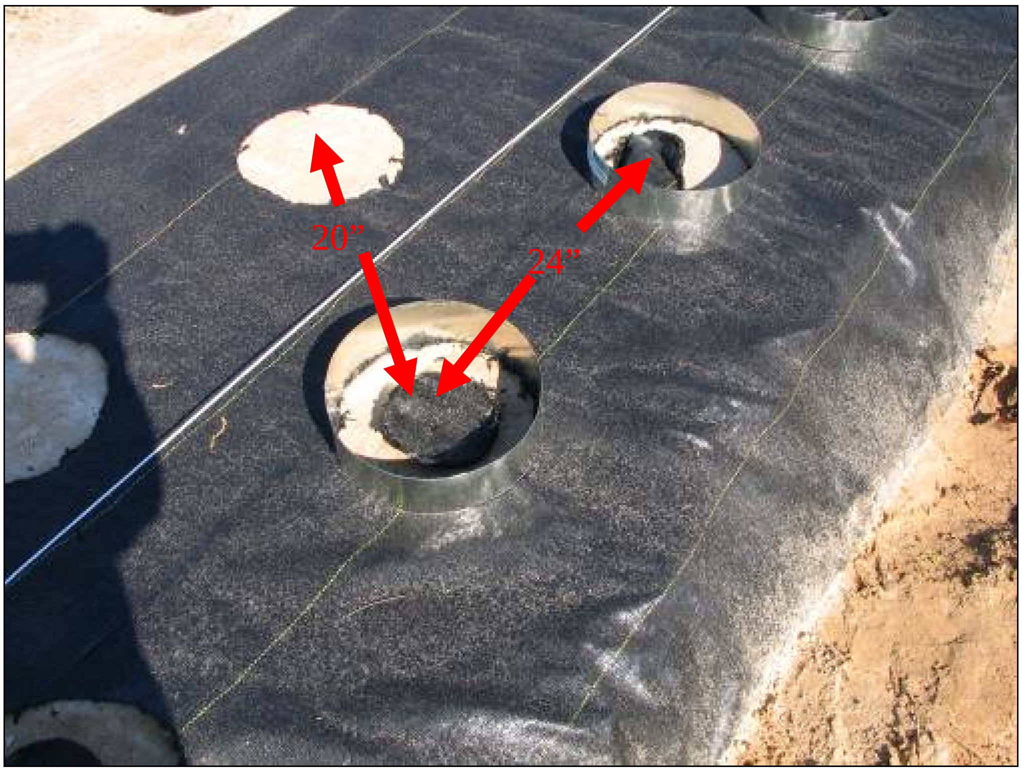


Figure 2. Triangular design of socket pots in pot-in-pot bed.

Figure 3. Socket pot hole placement down the length of pot-in-pot bed.

An irrigation system was installed with Agrifim drip emitters that supplied 1 gallon of water per hour. A DiG model 540 battery operated timer system was used to automatically irrigate the plants at a selected time of day and for a set duration every day during the study.

A Netafim irrigation line, Rain Typhoon, was used to irrigate the sand between the randomly selected socket pots of the two lines. The in-line nozzles of the Netafim were spaced at 12 inches apart and supplied 1 gallon of water per hour. This middle line irrigation was controlled by the battery irrigation timer. The timer was programmed to turn on four times every day for a selected length of irrigation time.

Full sun container yard and 50% shade house

Thirty plants were placed in the full sun container yard and 40 plants in the 50% shade house structure. Containers in both areas were spaced with the same spacing as the pot-in-pot structure. These two areas were irrigated by overhead irrigation as needed throughout the study. To prevent an edge effect only 18 plants from the full sun container yard and the 50% shade house were used to collect data. The 18 plants were randomly selected within each of the two growing areas.

Irrigation and fertilization

Daily drip line irrigation of the pot-in-pot azaleas began in April, 2006 and ended on September 9, 2006. Prior to the daily irrigation schedule, plants were watered by hand as needed. The rate, timing, and water volume of the irrigation was adjusted throughout the trial and accurate records kept. Plants were initially fertilized with 30mls of Osmocote® 18-6-12 (Ammonical Nitrogen 10%, Nitrate Nitrogen 8%). Leachate was gathered by a pour-through technique to monitor electrical conductivity. When the average electrical conductivity of 6 plants fell below 0.3 mhos/cm, 10mls of Osmocote® 18-6-12 (Ammonical Nitrogen 10%, Nitrate Nitrogen 8%) were applied to azaleas in the three study areas. All plants in the three study areas were fertilized five times based on electrical-conductivity readings (Table 1).

Table 1. Leachate conductivity values via a pour-throught technique (dsms/cm).

Date	Average Reading
April 26	0.33
June 22	0.18
July 19	0.42
Aug 8	0.22
Aug 15	0.45

Temperature analysis

Temperature data was collected by using a digital thermometer. Soil temperature readings were taken at the top center of the container, top of the container next to the side of the container and bottom of the center of the container. Temperature readings were taken during the hottest months (August through September). Six azaleas where randomly selected from the pot-in-pot study for temperature analysis. Data from the same six plants was collected weekly during the temperature study. Data from six plants were also randomly selected from the full sun container yard and the 50% shade house. The same six plants from the full sun container yard and the 50% shade were used throughout the temperature study.

Height and dry weight analysis

Above-ground dry weight and plant height data was gathered at the end of the experiment in all three study locations. Azaleas were cut at a half inch above soil level and placed in a paper bag to be dried in an oven prior to weighing.

Visual analysis

Thirty plants (ten from each growing area) were also visually scored 1 through 5 on over all growth and appearance. The scoring system designed as follows:

(1) no growth at all, plant is dead.

(2) very little growth, plant is not able to be sold.

(3) poor performance, plant is able to be sold but it is not a desirable plant.

(4) average marketable plant.

(5) very good plant.

Data analysis

A randomized block ANOVA test was performed on both plant height and dry weight. Temperature data from the four treatments in the pot-in-pot study was subject to analysis of variance (ANOVA) using General Linear Models (GLM) procedure of Statistical Analysis System (SAS) was used to compare the effect of the treatments by temperature location (top center, top edge and center bottom). A Tukey Studentized Ranged Test (α= .05) was used to identify groups. A repeated measures ANOVA test was performed on the temperature data from the four treatments. A Tukey Studentized Ranged Test (α= .05) was used to identify groups.

While not statistically valid an ANOVA was performed using the GLM procedure to test for any differences in weight, height, temperature, and visual ranking between the three test areas. A Duncan's Multiple Range Test (α= .05) was performed to identify groups.

Pot-In-Pot, Full Sun Above-ground, 50% Shade Study, 2007

<u>Plant Material</u>

Rhododendron x 'Encore' azalea liners were used in this study and were provided by PDSI, Loxley, Alabama. Two liners were planted in 7800ml (2.06 gallons) containers. Most azaleas liners were placed in the pot-in-pot area in the Mast Arboretum at SFASU, Nacogdoches, Texas. The azalea liners were planted in 100% double ground composted pine bark. Containers were then placed into either the pot-in-pot area, full sun above-ground container yard, or a 50% shade house.

<u>Pot-in-pot area</u>

The same pot-in-pot area used in the study in 2006 was used in the 2007 study. There were 168 plants placed in the pot-in-pot study area. The middle line irrigation was not used during this study. The same irrigation pipes and drip emitters that were used in the 2006 study were used in the 2007 study. Ten azaleas were selected randomly at the end of the study for data analysis.

<u>Full sun container yard and 50% shade house</u>

Thirty plants were placed in the full sun container yard and 30 plants in the 50% shade house structure. Containers in both areas were spaced apart with the same spacing as the pot-in-pot area. The full-sun container yard and 50% shade house were irrigated by overhead irrigation as needed throughout the study. Ten azaleas from each of the full sun yard and the 50% shade house were randomly selected for data analysis and the end of the study.

Irrigation and fertilization

Drip line irrigation of the pot-in-pot azaleas began in May 2007 and ended in February 2008. Plants were initially fertilized with 30mls of Osmocote® 18-6-12 (Ammonical Nitrogen 10%, Nitrate Nitrogen 8%). Repeated applications of 10mls of Osmocote® were made twice during the course of the study.

Height and dry weight analysis

Above-ground dry weight and plant height data was gathered at the end of the experiment in all three study locations. Ten azaleas from each study area were cut at a half inch above soil level and placed in a paper bag and dried in an oven. After oven-drying, the weight of each plant was measured in grams.

Visual analysis

Thirty plants (ten from each growing area) were also visually scored 1 through 5 on over all growth and appearance. The scoring system designed as follows:

(1) no growth at all, plant is dead.

(2) very little growth, plant is not able to be sold.

(3) poor performance, plant is able to be sold but it is not a desirable plant.

(4) average marketable plant.

(5) very good plant.

Data analysis

The height, dry weight and visual ranking of the azaleas from each study area were averaged and compared against each other. An ANOVA was performed using the GLM procedure to test for any differences in weight, height and visual ranking between the three test areas. A Duncan's multiple range test was performed to identify groups.

RESULTS AND DISCUSSION

2006 Study

Root Temperatures at Center, Bottom and Edge of Containers in the Pot-in-pot area

Six azaleas in each treatment were randomly selected, one from each block, for temperature measurements in the pot-in-pot area. The same six plants were used throughout the temperature study. Temperature measurements of the four treatments in the study were white weed barrier with and without middle line irrigation and black weed barrier with and without middle line irrigation. Temperature treatment means for each measurement date in August and September 2006 are presented in Tables 2, 3 and 4 for the top center, top edge and bottom center of the containers, respectively. Our assumption in the experimental design was that the black ground cover would have been warmer than the white and that the irrigated treatments would have been cooler. The treatments means do not bear this out. Differences between treatment means for the four treatments at each measurement date were compared within each temperature measurement location using analysis of variance (ANOVA), Table 5. Temperatures were statistically different due to treatment at the center, edge and bottom locations. Comparison of mean temperature for each of the measurement locations at each measurement date were accomplished using Tukey's

Studentized Range Test in Tables 2, 3 and 4 for the center, edge and bottom of the containers.

Temperature data from the four treatments areas was subjected to ANOVA using the GLM procedure in SAS (Table 5). A Tukey's Studentized Range Test was performed showing any statistically significant differences in the treatments by location (top center, top edge and center bottom) (Table 2, 3, 4). Temperatures in the white weed barrier with middle line irrigation treatment showed a significantly higher temperature in the edge of the container when compared to the other three treatments (Table 3). It is believed that the white-wash paint used to color the black weed barrier prevented the water emitted by the middle line irrigation from wetting the soil underneath the weed barrier.

Table 2. Center of container temperature means for the four treatments on each measurement date, 2006.

Date	White With Irrigation*	Black With Irrigation*	White Without Irrigation*	Black Without Irrigation*
Aug-9	92 AB	90 B	93 A	94 A
Aug-15	93 A	91 BC	92 AB	90 C
Aug-24	93 A	91 BC	92 AB	90 C
Aug-31	92 B	90 BC	89 C	93 A
Sep-7	90 A	85 BC	87 B	82 C
Sep-14	90 A	85 B	89 A	82 C

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Tukey's Studentized Range Test.

Table 3. Edge of container temperature means for the four treatments on each measurement date, 2006.

Date	White With Irrigation*	Black With Irrigation*	White Without Irrigation*	Black Without Irrigation*
Aug-9	92 AB	90 B	93 A	94 A
Aug-15	104 A	101 B	99 C	101 B
Aug-24	101 A	97 B	97 B	98 B
Aug-31	99 A	97 B	98 AB	97 B
Sep-7	96 A	94 B	95 AB	90 C
Sep-14	99 A	95 B	93 C	96 B

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Tukey's Studentized Range Test.

Table 4. Bottom of container temperature means for the four treatments on each measurement date, 2006.

Date	White With Irrigation*	Black With Irrigation*	White Without Irrigation*	Black Without Irrigation*
Aug-9	90	89	90	90
Aug-15	89 A	88 AB	89 A	87 B
Aug-24	87	87	87	88
Aug-31	82 A	80 B	80 B	81 AB
Sep-7	81 AB	80 B	80 B	82 A
Sep-14	82 A	80 B	80 B	81 AB

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Tukey's Studentized Range Test. Means without a letter were not significantly different according to ANOVA.

Table 5. ANOVA table using a GLM procedure on temperature data from the four treatments in the pot-in-pot area, 2006.

		Means Square					
Source	D. F.	Aug 9	Aug 15	Aug 24	Aug 31	Sep 7	Sep 14
Center Temp.	3	17.5**	8.7***	38.0****	17.5***	50.0****	65.5****
Center Temp. Error	20	2.8	0.9	0.9	0.9	3.1	0.7
Edge Temp.	3	17.5**	25.9****	20.0****	5.1****	54.8****	41.4****
Edge Temp. Error	20	2.8	0.8	0.5	0.9	0.6	0.7
Bottom Temp.	3	1.4 ns	3.7**	1.4 ns	4.3***	4.4***	7.5**
Bottom Temp. Error	20	0.6	0.7	0.8	0.6	0.6	1.2

ns Not Significant level of probability.
* Significant at the 0.1 level of probability.
** Significant at the 0.01 level of probability.
*** Significant at the 0.001 level of probability.
**** Significant at the 0.0001 level of probability.

Averaging the temperatures from the three temperature locations (the top center, bottom center and top edge of the containers) in the four treatments in the pot-in-pot area were subjected to ANOVA using a repeated measures design in SAS (Table 8). The four treatments had significantly different means (Table 6). Tukey's Studentized Range Test showed differences in the treatments, averaging the temperature locations, during the six week study (Table 6). The temperature averages in the white with middle line irrigation treatment were significantly higher during the six week study (Table 6). It is believed that the white wash paint used to color the weed barrier sealed the weed barrier which caused the water to roll off the weed barrier instead of evaporating off its surface.

As might be expected when the temperatures from the four treatments were averaged, the location (top center, bottom center and top edge) from which the temperature was taken showed significant differences when subjected to ANOVA using a repeated measures design in SAS (Table 8). Tukey's Studentized Range test showed differences in the temperature location during the six week study (Table 7).

Table 6. Means from the four treatment types averaging temperatures from the three temperature locations in the pot-in-pot area, 2006.

Date	White With Irrigation*	Black With Irrigation*	White Without Irrigation*	Black Without Irrigation*
Aug-9	93 A	91 B	93 A	94 A
Aug-15	95 A	93 B	93 B	93 B
Aug-24	94 A	92 B	91 C	93 B
Aug-31	91 A	89 B	89 B	90 A
Sep-7	89 A	85 B	88 C	86 D
Sep-14	90 A	87 B	87 B	87 B

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Tukey's Studentized Range Test.

Table 7. Means from the three temperature locations on container averaging temperatures from the four treatment areas in the pot-in-pot area, 2006.

Date	Center*	Bottom*	Edge*
Aug-9	92 A	90 B	96 C
Aug-15	91 A	88 B	101 C
Aug-24	92 A	88 B	98 C
Aug-31	91 A	81 B	98 C
Sep-7	86 A	81 B	94 C
Sep-14	87 A	81 B	95 C

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Tukey's Studentized Range Test.

Table 8. ANOVA using a repeated measures design data on temperatures in the four treatments and in the three measurement locations in the pot-in-pot study, 2006.

		Means Square					
Source	D. F.	Aug 9	Aug 15	Aug 24	Aug 31	Sep 7	Sep 14
Treatment	3	23.02****	22.9****	35.93****	13.27****	36.01****	52.16****
Treatment Error	15	1.5	1.5	0.8	1.0	0.8	1.8
Temp. Location	2	1109****	1110****	763****	1755****	764****	1258****
Temp. Location Error	46	1.6	1.6	2.1	1.6	2.1	9.0

**** Significant at the 0.0001 level of probability.

<u>Height and Dry Weight Evaluation</u>

Height data and dry matter weight data were collected in an effort to measure growth differences in the four treatments (Table 9). The range in height of azaleas in the four treatments was less than one inch (Table 9). An ANOVA test on height data showed that there were no statistical differences among the four treatments (Table 10). The range in dry matter weight among the four treatments was less than 11 grams (Table 9). No statistical significant differences in the dry weight of the azaleas were found among the four treatments (Table 10).

Figure 4. Pot-in-pot project area, 2006

Table 9. Influence of weed barrier color (white or black) and middle line irrigation (with or without) on growth (height in inches, dry weight in grams) on azaleas in pot-in-pot study, 2006.

Treatment Area*	Height (inches) ^{ns}	Dry Weight (grams) ^{ns}
W W/I	18.3	138.4
B W/I	18.8	140.1
W W/O	18.0	130.2
B W/O	18.3	129.5

* W- White weed barrier, B- Black weed barrier, W/I- with middle line irrigation, W/O- without middle line irrigation.

^{ns} Means without a letter were not significantly different according to ANOVA.

Table 10. ANOVA data on azalea height and dry matter weight in the pot-in-pot area, 2006.

Source	DF	Height	Dry Matter
Block	5	1.95^{ns}	597.7^{ns}
Treatment	3	0.75	181.33
Error	15	2.68	294.60
Total	23	-	-
CV		8.92	12.80

^{ns} Not Significant level of probability.

Comparison of the Three Growing Methods, 2006

<u>Temperature Comparison</u>

When plants from each of the three different growing areas (pot-in-pot, full sun above-ground yard and 50% shade house) were compared with each other, several trends emerged. Temperature means are presented in tables 11, 12 and 13 for the top center, top edge and bottom center of the containers. Since the three growing areas were at different locations, statistical comparisons of the three growing systems are not strictly valid. However, using individual plants as replications the data from the three growing systems was subject to ANOVA using GLM procedure in SAS for comparative purposes (Table 12, 14, 16) for the temperature location. A Duncan's Multiple Range Test was performed for each temperature location (top center, top edge and center bottom) to find significant differences between the three growing areas (Table 11, 13, 15). The plants from the full sun container yard had significantly higher temperatures during the six week study when compared to the shade house and pot-in-pot areas (Table 11, 13, 15). Temperature was numerically highest on the edge of the container in the three growing techniques. The highest recorded temperature, 120°F, was recorded in the full sun container yard on the edge of the container (Table 13).

This recorded temperature is well above the recommended maximum temperature of 107.6°F for trees (Martin, et al. 1997).

Table 11. Center of container means for the three growing areas on each measurement date, 2006.

	Growing Areas		
Date	Shade House*	Full Sun*	Pot-in-pot*
Aug-9	91 A	109 B	92 A
Aug-15	91 A	105 B	91 A
Aug-24	89 A	98 B	92 C
Aug-31	89 A	98 B	91 C
Sep-7	81 A	98 B	86 C
Sep-14	82 A	99 B	87 C

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Duncan's Multiple Range Test.

Table 12. ANOVA of the center temperature comparisons of the three study areas, 2006.

		Date					
Source	D. F.	Aug 9	Aug 15	Aug 24	Aug 31	Sep 7	Sep 14
Study Area	2	684.4 ****	456.8****	135.6****	142.8****	458.9****	497.0****
Error	33	3.8	3.3	4.6	2.4	6.7	6.6
CV		2.1	1.9	2.3	1.7	2.9	2.9

**** Significant at the 0.0001 level of probability.

Table 13. Edge of container means for the three growing areas on each measurement date, 2006.

	Growing Areas		
Date	Shade House*	Full Sun*	Pot-in-pot*
Aug-9	96 A	116 B	96 A
Aug-15	100 A	120 B	101 A
Aug-24	99 A	117 B	98 A
Aug-31	97 A	117 B	98 A
Sep-7	98 A	119 B	98 C
Sep-14	98 A	119 B	96 C

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Duncan's Multiple Range Test.

Table 14. ANOVA of the edge temperature comparisons of the three growing areas, 2006.

		Means Square					
Source	D. F.	Aug 9	Aug 15	Aug 24	Aug 31	Sep 7	Sep 14
Growing Area	2	1061.5****	888.4****	857.3****	966.5****	1503.4****	1299.4****
Error	33	4.8	4.2	5.4	2.8	7.4	5.1
CV		2.2	2.0	2.3	1.6	2.7	2.2

**** Significant at the 0.0001 level of probability.

Table 15. Bottom of container means for the three growing areas on each measurement date, 2006.

	Growing Areas		
Date	Shade House*	Full Sun*	Pot-in-pot*
Aug-9	89 A	99 B	90 A
Aug-15	90 A	105 B	88 A
Aug-24	90 A	96 B	87 C
Aug-31	85 A	96 B	81 C
Sep-7	81 A	88 B	81 A
Sep-14	81 A	89 B	81 A

* Means within the same row or date followed by the same letter are not significantly different (α = 0.05) using Duncan's Multiple Range Test.

Table 16. ANOVA of bottom temperature comparisons of the three study areas, 2006.

Source	D. F.	Date					
		Aug 9	Aug 15	Aug 24	Aug 31	Sep 7	Sep 14
Study Areas	2	233.8****	692.1****	199.5****	525.4****	120.2****	158.7****
Error	33	0.9	4.0	5.3	1.0	1.4	1.9
CV		1.1	2.2	2.6	1.9	1.4	1.7

**** Significant at the 0.0001 level of probability.

Height Comparison

When plants from each of the three different growing areas (pot-in-pot, full sun above-ground yard and 50% shade house) were compared with each other, several trends emerged. Since the three growing areas were at different locations, statistical comparisons of the three growing systems are not strictly valid. However, using individual plants as replications height data from the three growing systems was subject to ANOVA using GLM procedure in SAS was performed for comparative purposes (Table 18). At the termination of the experiment, the tallest group of azaleas was produced in the 50% shade house (Table 17) with an average height of 23.8 inches. However, it should be noted that these azaleas were not uniform in growth and had stems that were tall and spindly (Figure 5). The pot-in-pot azaleas yielded plants that were much more uniform and marketable.

Table 17. Comparison of azalea heights among the three growing strategies at the end of the experiment in inches, 2006.

Growing Area	Number of Plants	Average Height (inches) Means square*
Pot-in-pot	72	18.4 B
50% shade house	18	23.8 A
Full sun above-ground	18	18.0 B
Total	108	

* Means using Duncan's Multiple Range Test. Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 18. ANOVA of the azalea heights in the three growing areas, 2006.

Source	DF	Mean Square	F Value	Pr > F
Treatment	2	228.08	49.14	< 0.0001
Error	105	4.64	-	
Total	107	-	-	
CV	11.2	-	-	

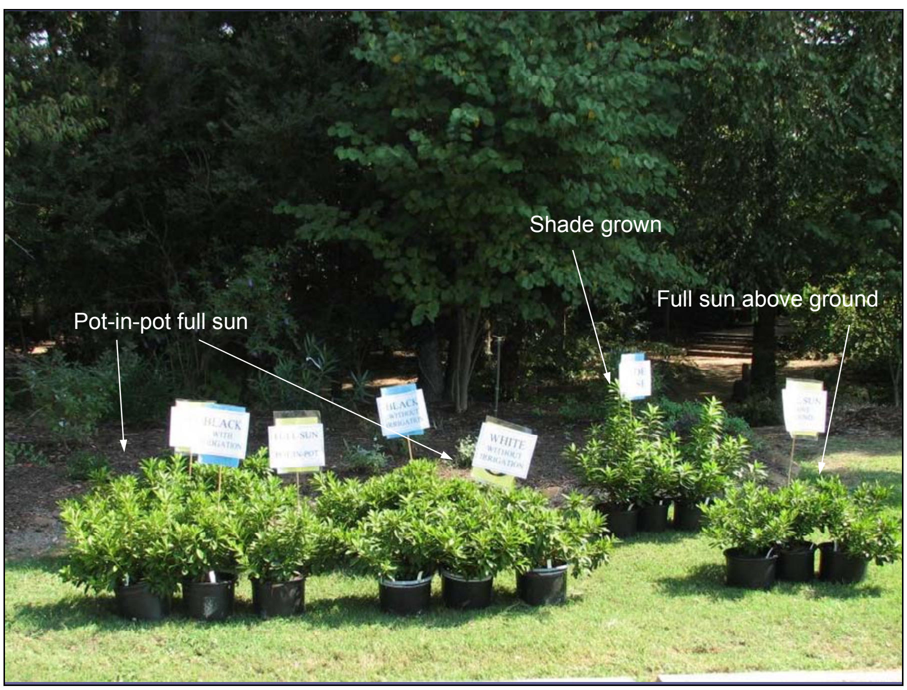


Figure 5. Visual comparison of azalea heights from three experimental locations, 2006.

Dry Weight Comparison

Noticeable differences in dry weights were observed between the three growing systems. For comparative purposes individual plants as replications data for the three growing areas was subject to ANOVA using the GLM procedure in SAS (Table 20). Statistical comparisons of the three growth systems are not strictly valid because of location differences. The pot-in-pot azaleas had the highest dry weight (Table 19), averaging 134.6 grams.

Table 19. Comparison of azalea dry matter weight among the three growing strategies at the conclusion of experiment, 2006.

Growing Area	Number of Plants	Average Weight (grams)
Pot-in-pot	72	134.6 A
50% shade house	18	93.9 B
Full sun above-ground	18	106.4 B
Total	108	

* Means using Duncan's Multiple Range Test. Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 20. ANOVA of the azalea weights from the three growing areas, 2006.

Source	DF	Mean Square	F Value	Pr > F
Treatment	2	14907.8	17.18	< 0.0001
Error	105	867.5	-	
Total	107	-	-	
CV	23.9	-	-	

Visual Root Comparison

At the end of the experiment azaleas were pulled from their containers to visually evaluate root growth. Azaleas grown in the full sun container yard had very poor root growth (Figure 6). The azaleas in the pot-in-pot area had very vigorous white roots that filled the container (Figure 6). The azaleas were ranked as follows:

(1) no growth at all, plant is dead.

(2) very little growth, plant is not able to be sold.

(3) poor performance, plant is able to be sold but it is not a desirable plant.

(4) average marketable plant.

(5) very good plant.

While not strictly valid, differences were found in data from the three growing areas when subjected to ANOVA using a GLM procedure (Table 22). Also, the ranking system produces discrete data and the ANOVA used assumes continuous data. This also reduces the validity of this statistical comparison. The azaleas grown in a 50% shade house had root systems that ranked between the pot-in-pot azaleas and the full sun grown azaleas (Table 21). It should be noted that the roots of full sun above-ground azaleas were exposed to very high temperatures. The poor performance of the full sun above-ground azaleas confirms the study performed by Martin et al. (1997) stating that container tree roots should not be exposed to temperatures greater than 107.6°F. Greene (2001) stated that high root zone temperatures are linked to with poor shoot dry weights.

Table 21. Visual comparison of azaleas among the three growing strategies at the end of experiment ranked 1 to 5 (2006).

Growing Area	Number of Plants	Ranking (1 to 5)
Pot-in-pot	10	4.7 A
50% shade house	10	3.2 B
Full sun above-ground	10	2.8 C

* Means using Duncan's Multiple Range Test. Means with the same letter are not significantly different (α = 0.05).

Table 22. ANOVA of visual ranking comparisons of the three growing areas 1 through 5, 2006.

Source	DF	Mean Square	F Value	Pr > F
Treatment	2	9.14	19.94	< 0.0001
Error	26	0.46	-	
Total	28	-	-	
CV	18.35	-	-	

Figure 6. Visual comparison of root growth between the full sun yard and the pot-in-pot area.

2006 Pot-in-Pot Water Requirements of the Three Areas

Pot-in-Pot Plant Water Use

The pot-in-pot study area was irrigated for a total of 182 days. Each plant received a total of 45.36 gallons (8.8 inches per acre) through the growing season (Table 23). The greatest amount of irrigation used was between August 11 and August 16 at 55 minutes twice a day (Table 23). The irrigation system was programmed during August to run twice a day in order to keep the plants cooler. The azaleas were showing signs of heat stress during the afternoon in August. Five drip irrigation emitters were randomly selected to gather data for an average water output.

Table 23. Irrigation usage throughout the 2006 growing season.

Irrigation Date	Length of Irrigation (mins/day)	Irrigation Amt (mls/day/pot)	Days of Irrigation/pot	Total Amt/pot (Liters)	
April 7 - July 6	30	800	92	73.6	
July 7 – Aug 7	40	900	31	27.9	
Aug 8 – Aug 10	55	1150	2	2.3	
Aug 11 – Aug 16	55 twice daily	2300	5	11.5	
Aug 17 – Sep 5	45 twice daily	1900	20	38	
Sep 6 – Oct 7	40	900	32	28.8	
Total Amount/Season					182.1 L/pot (45.36 gallons/pot)

<u>Influence of Middle Line Irrigation</u>

Throughout the study the middle irrigation line was cycled four times a day at differing durations. The purpose of the middle line was to cool the soil between and around the socket pots. For the 88 days of middle line irrigation each cycle was turned on at 11am, 1pm, 3pm and 5pm every day. The total season long volume of water used by the middle line irrigation system averaged 44.5 gallons per pot (8.7 inches per acre) (7560 gallon per 100’ row) (Table 24). Five nozzles were randomly selected to gather data for determining an average water output.

Table 24. Middle line irrigation usage throughout the season (2006).

	June 13-Aug10	Aug 11- Sep 5	Total Amount of Irrigation/season/opening
Duration of Irrigation (min)	10	15	
Irrigation Amount (ml/opening)	700	1000	
Days of Irrigation	59	26	
Total Amount of Irrigation/opening (L)	41.3	26	
			269.2 Liters 44.5 gallons

Comparison of the Three Growing Methods, 2007

Due to a severe *Chrysopa spp.* (lacewing) infestation overall plant quality and size was low when compared to the 2006 study.

Height Evaluation

Plants from each of the three growing areas were measured and data collected at the end of the study. Azaleas grown in the 50% shade house were taller, while the full sun container yard and the pot-in-pot area were very similar in height. Since the three growing areas were at different locations, statistical comparisons of the three growing systems are not strictly valid. However, using individual plants as replications the data from the three growing systems was subject to ANOVA using GLM procedure in SAS was performed for comparative purposes (Table 26). The average height in the 50% shade house area was 19.1

inches, while the average heights in the full sun container yard and the pot-in-pot area were 13.7 and 14.2 inches, respectively (Table 25).

Table 25. Comparison of average azalea height (inches) among the three growing strategies at the end of the experiment (2007).

Growing Area	Number of Plants	Height (inches) *
Pot-in-pot	10	14.20 B
50% Shade house	10	19.10 A
Full sun above-ground	10	13.70 B
Total	30	

* Means using Duncan's Multiple Range Test. Means with the same letter are not significantly different (α = 0.05).

Table 26. ANOVA of azalea heights from the three growing areas, 2007.

Source	DF	Mean Square	F Value	Pr > F
Treatment	2	93.10	17.04	< 0.0001
Error	27	5.46	-	
Total	29	-	-	
CV	14.98	-	-	

Dry Weight Comparisons

The Encore azaleas from the pot-in-pot area had the highest average dry weight, while the lowest average dry weight was from the full sun above-ground container area. Valid statistics could not be performed because of location differences in the three areas. However, a GLM procedure test was performed in SAS for comparative purposes (Table 28). The average weight for the pot-in-pot area was 49.8 grams; the average weight for the 50% shade house area full sun above-ground container yard was 20.5 and 33.4 grams respectively (Table 27).

Table 27. Comparison of average azalea weight (grams) among the three growing strategies at the end of experiment (2007).

Growing Area	Number of Plants	Average Weight (grams) *
Pot-in-pot	10	49.80 A
50% shade house	10	20.50 C
Full sun above-ground	10	33.40 B
Total	30	

* Means using Duncan's Multiple Range Test. Means with the same letter are not significantly different (α = 0.05).

Table 28. ANOVA of azalea weights from the three growing areas, 2007.

Source	DF	Mean Square	F Value	Pr > F
Treatment	2	2164.45	28.61	< 0.0001
Error	27	75.64	-	
Total	29	-	-	
CV	25.14	-	-	

<u>Visual Comparison</u>

The azaleas were ranked as follows:

(1) no growth at all, plant is dead.

(2) very little growth, plant is not able to be sold.

(3) poor performance, plant is able to be sold but it is not a desirable plant.

(4) average marketable plant.

(5) very good plant.

While not strictly valid, data from the visual rankings of the three growing areas was subjected to ANOVA using the GLM procedure (Table 30). Also, the ranking system produces discrete data and the ANOVA used assumes continuous data. This also reduces the validity of this statistical comparison. The highest ranked azalea came from the pot-in-pot growing system with a ranking average of 2.5 (Table 29). The lowest ranked azalea came from the 50% shade house area, average ranking of 1.8 (Table 29).

Table 29. Visual comparison of azaleas among the three growing strategies at the end of experiment ranked 1 through 5 (2007).

Growing Area	Number of Plants	Ranking (1 to 5)
Pot-in-pot	10	2.5
50% shade house	10	1.8
Full sun above-ground	10	2.2

Table 30. ANOVA of the azalea visual rankings of the three growing areas 1 through 5, (2007).

Source	DF	Mean Square	F Value	Pr > F
Treatment	2	1.23	2.85	0.07
Error	27	0.43	-	
Total	29	-	-	
CV	30.38	-	-	

Discussion of 2006 and 2007 Studies

In this pot-in-pot study, the color of the weed barrier and the use of middle line irrigation had no significant effect on the growth of azaleas, even though there were statistically significant temperature differences between the four treatments. It is believed that the design of the middle line irrigation system was improper; it was placed on top of the weed barrier. When the irrigation cycle began the water released from the nozzle openings was hot. Also, the weed barrier did not allow all the water to soak through to the underlying sand. Instead, the water tended to roll off the weed barrier. We concluded too late that the middle line irrigation system should be placed underneath the weed barrier to prevent the sun from heating the line. The white weed barrier with irrigation treatment had a statistically higher temperature when compared to the other three treatments. It is believed that the white wash paint used to color the weed barrier sealed the weed barrier which caused the water to roll off the weed barrier instead of evaporating from its surface.

The expense involved in the setup of the pot-in-pot area was greater when compared to the other two growing systems used in this study (Table 31). The total cost of materials per pot in this study was $4.18. The pot-in-pot system has shown, in this study, to produce higher quality more marketable plants than the other two growing techniques. While it is difficult to determine the exact amount of time for one person to construct a pot-in-pot area an estimate of 50 hours is believed to be close to the amount of time it took to complete the study area at SFASU. Larger plots and improved mechanization would have reduced the amount of labor per pot

Table 31. Pot-in-pot construction costs, excluding labor.

Item	Quantity for study area	Cost for study area	Quantity for 1 acre* (210’ row with 198 pots)	Cost/ acre
Weed Barrier	(6’ X 200’) 1200sqft	$129.80	34,020sqft	$3,742.2
Socket Pots	196	$194.73	5,346	$5,308.58
Insert Pots	196	$195.10	5,346	$5,292.54
Drip Emitters	196	$92.12	5,346	$2,512.62
Clock	1	$82.50	1	$82.50
Solenoid	3	$124.95	1 (2” valve)	$51.00
Total Cost		$819.2		$16,989.44

* Beds are 6’ wide with 2 rows of pots per bed arranged similarly to the study area, 3.45sqft per container. Beds had an aisle width 18” resulting in a distribution of 7.6’ from center of one row to the next. There are 27 rows in this acre.

In central and northern East Texas, azaleas are considered difficult to grow in full sun. Growers often report bleached plants and poor plant performance. PIP appears to offer nurserymen an opportunity to produce azaleas in full sun. PIP influences container root temperatures dramatically and the system has promise for other crops.

CONCLUSION

When statistically analyzed the four different treatments in the pot-in-pot study had no effect on the growth of the azaleas in the pot-in-pot area. The pot-in-pot azaleas were obviously superior when compared to the full sun above ground area and the 50% shade house. The pot-in-pot azaleas were more uniform and dense while the full sun above-ground plants were small and the 50% shade grown plants were tall, spindly and less dense. Pot-in-pot produced the benefits of a shade house structure (cooler root temperatures) with benefits of a full sun container area (uniform compact growth). The pot-in-pot area kept the root temperatures similar to those in the 50% shade house area, while producing plants that were uniform.

Like the previous year's study the pot-in-pot azaleas in the 2007 study were superior. However, due to an infestation of lacewings plant quality and size was much lower than the plant produced in the 2006 study. The pot-in-pot azaleas in the 2007 were more uniform and dense while the full sun above-ground plants were small and the 50% shade grown plants were tall, spindly and less dense.

A potential grower can take advantage of the pot-in-pot system's ability to produce high quality azaleas in full sun. When used in conjunction with a micro-irrigation technique this system can conserve water and reduce the amount of runoff. The pot-in-pot system also reduces the amount of labor. The risk of plants blowing over is no longer a concern because insert containers are placed into a socket pot in the ground.

LITERATURE CITED

Adrian, J.L., Montgomery, C.C., Behe, B.K., Duffy, P.A., Tilt, K.M. 1998. Cost comparisons for infield, above-ground container and pot-in-pot systems. Journal of Environmental Horticulture 16:65-68.

Albanesi, Ed. 2007. “Gro-Eco method saves water and reduces runoff.” *FloridAgriculture* April 2007: 5-6.

Beeson, R.C. and Jr, Knox, G.W., 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848-850.

Bilderback, T.E. 1999. Pot-in-pot. http://www.ces.ncsu.edu/depts/hort/nursery/cultural_docs/container/PnP.pdf.

Bilderback, T.E. 2002. Water management is key in reducing nutrient runoff from container nurseries. HortTechnology 12.4:541-544.

Fain, G.B., Tilt, K.M, Gilliam, C.H., Ponder, H.G., Sibley, J.L. 1997. Effects of cyclic micro-irrigation and media on irrigation application efficiency and growth of *Quercus acutissima* in pot-in-pot production. SNA Research Conference 42: 23-27.

Fain, G.B., Tilt, K., Sibley, J., 2000. Irrigation study shows cyclical irrigation reduces water loss and nitrogen leaching in container-grown trees. Highlights of Agricultural Research 47: 1-8.

Fare, D.C., Gilliam, C.H., Keever, G.J., Olive, J., Stephenson, J.C., 1991. Nitrogen levels in irrigation effluent from container nurseries. Proceedings SNA Research Conference 36: 81-83.

Garber, M.P. 2002. Survey of container nursery irrigation practices in Georgia. HortTechnology 12.4: 727-731.

Graves, W.R., Dana, M.N., Joly, R.J. 1989. Root-zone temperature affects water status and growth of red maple. Journal American Soc. Horticulture Science 114: 406-410.

Greene, V. Appleton, B., Rudiger, E.L., Eaton, G., 2001. Reducing root zone temperature of container-grown plants. SNA Research Conference 46: 108-112.

Hall, C.R., Hodges, A.W., Haydu, J.J. 2005. Economic Impacts of the Green Industry in the United States http://prohort.ifas.ufl.edu/pubs/Economic%20Impacts%20of%20the%20US%20Green%20Industry.pdf.

Halcomb, M.A. and Fare, D.C. 1995. A survey of the pot-in-pot growers in middle Tennessee. Proceedings Southern Nursery Association Res. Conference 40:147-148.

Haman, D. and Yeager, T.H. 1997. Irrigation system selection for container nurseries. University of Florida IFAS Extension AE263: 1-2.

Haydu, J.J. 1997. To bag or pot? American Nurseryman 185:40-42.

Irmak, S., D.Z. Harman, A. Irmak, J.W. Jones, K.L. Campbell, and T.H. Yeager. 2003. New irrigation-plant production system for water conservation in ornamental nurseries; quantification and evaluation of irrigation, runoff, plant biomass, and irrigation efficiencies. Applied Engineering in Agriculture 19:651-665.

Karam, N.S. and Niemiera, A.X. 1994. Cyclic sprinkler irrigation and pre-irrigation substrate water content affect water and N leaching from containers. Journal of Environmental Horticulture 12:198-202.

Larcher, W. 1995. Physiological plant ecology. Springer- Verlag, Berlin. 3rd ed.

Mallin, M.A., Burkholder, J.M., Cahoon, L.B., Posey, M.H., 2000. The North and South Carolina coasts. Marine Pollution Bulletin 56-75.

Martin, C.A., Igram, D.L., Nell, T.A., 1997. Supraoptimal root-zone temperature alters growth and photosynthesis of holly and elm. Journal of Arboriculture 15:272-276.

Martin, C.A., McDowell, L.B., Bhattacharya, S. 1999. Below ground pot-in-pot effects on growth of two southwest landscape trees was related to root membrane thermostability. Journal of Environmental Horticulture 17: 636-638.

Mathers, H.M., Case, L.T., Yeager, T.H. 2005. Improving irrigation water use in container nurseries. HortTechnology 15:8-12.

McGuff, J., Saunders, P., Cook, F. 1975. Automation of greenhouse and nursery irrigation systems. Annual technical conference proceedings, p.33-35.

Parkenson, C.H., 1990. P & P: A new field-type nursery operation. Proceedings International Plant Prop. Society 40:417-419.

Postel, S. 2000. Redesigning irrigation agriculture. National Irrigation Symposium, Proceedings of the 4th Decennial Symposium. American Society Agriculture Engineers, St. Joseph, MI 49085. pp. 1-12.

Ruter, J.M., 1997. The practicality of pot-in-pot. Amer. Nurseryman 185(1):32-37.

Ruter, J.M. 1998. Fertilizer rate and pot-in-pot production increase growth of Heritage river birch. Journal of Environmental Horticulture 16: 135-138.

Skillman, L. 2002. Pot-in-pot nursery production may provide new crop opportunity. http://www.ca.uky.edu/agc/news/2002/Jul/potf.htm.

Smajstria , A.G. and Pitts, D.J., 1996. Efficiencies of irrigation systems used in Florida nurseries. University of Florida IFAS Extension BUL312: 1-8.

Smith, V.H., Tilman, G.D., Nekola, J.C. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine and terrestrial ecosystems. Environmental Pollution, 179-196.

Tatum, D., Matta, F., Johnson, K. 1999. Rooting –out control in pot-in-pot production. SNA Research Conference 44: 29-33.

Tilt, K.M., 1990. Saving nursery irrigation runoff offers conservation and production advantages. Highlights of Agriculture Research 37:11-12.

Tyler, H.H., Warren, S.L., Bilderback, T.E. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. Journal of Environmental Horticulture 14:199-204.

Whitcomb, C. Accessed on July 9, 2008. The Original Root Branching System. The Whitcomb™ System. http://www.rootmaker.com/whitsys.php.

Zhu, H., Krause, C.R., Zondag, R.H., Brazee, R.D., Derksen, R.C., Reding, M.E., Fausey, N.R., 2005 (A). A new system to monitor water and nutrient use efficiency in pot-in-pot nursery production systems. Journal of Environmental Horticulture 23(1): 47-53.

Zhu, H., Krause, C.R., Zondag, R.H., 2005 (B). Monitoring water use, nutrient management, drainage and leachate in pot-in-pot nursery container production. Proceedings of the 9th International Congress on Mechanization and Energy in Agriculture & 27th International Conference of CIGR Section IV: The Efficient Use of Electricity and Renewable Energy Sources in Agriculture.

VITA

Brennan Whitehead entered Stephen F. Austin State University at Nacogdoches, Texas in the Fall of 2002 and graduated with a Bachelor of Science in Agriculture in May of 2006. In June of 2006 he entered the Graduate School of Stephen F. Austin State University. In May of 2007 he entered a horticulture internship program at the Biltmore Estate in Asheville, North Carolina. Brennan returned to Stephen F. Austin State University in January of 2008 to finish his degree. In December of 2008 he received the degree of Master of Science.

Permanent Address: 2521 County Road 721
Buna, TX 77621

The American Society of Horticultural Science format was used in this thesis.

This thesis was typed by Brennan Whitehead.

INFLUENCE OF A MODIFIED POT-IN-POT STRATEGY ON ROOT TEMPERATURE AND GROWTH OF *RHODODENDRON* x 'MRS. G.G. GERBING' IN FULL SUN

By

Brennan Whitehead, Bachelor of Science in Agriculture

APPROVED:

____
Dr. David L. Creech, Thesis Director

____
Dr. Leon Young, Committee Member

____
Dr. Jimmie Yeiser, Committee Member

____
Dr. Tom Wheeler
Associate Vice President for
Graduate Studies and Research