A COMPARATIVE ANALYSIS OF ROOTTRAPPER®-IN-POT INSERT'S ABILITY TO CONTROL ROOT ESCAPE AND CIRCLING FOR POT-IN-POT PRODUCTION

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A COMPARATIVE ANALYSIS OF ROOTTRAPPER®-IN-POT INSERT'S ABILITY TO CONTROL ROOT ESCAPE AND CIRCLING FOR POT-IN-POT PRODUCTION

A Thesis

Presented to

the Faculty of the Hutson School of Agriculture

Murray State University

Murray, Kentucky

In Partial Fulfillment

of the Requirements for the Degree

of Master of Science in Agriculture

by

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December 2012

ABSTRACT

The RootTrapper®-in-Pot Insert was compared to the Nursery Supplies GL 6900 plastic container as a research project conducted from March of 2010 to October of 2011 at the University of Kentucky Research and Education Center in Princeton, Kentucky. A total of 76 Shumard oak (*Quercus shumardii*) were planted in an aged pine bark media, half in the RootTrapper®-in-Pot Insert and half in the Nursery Supplies GL 6900 plastic container. The objectives of this study were to determine whether the RootTrapper®-in-Pot Insert significantly reduced the number of escaping and circling roots, and significantly increase growth rates over the Nursery Supplies GL 6900 plastic container.

The results of this study suggested that the RootTrapper®-in-Pot Insert significantly reduced the number of escaping roots, with a T-test showing $p \leq 0.015$. The overall rootball quality was also suggested to be higher with the RootTrapper®-in-Pot Insert with a Chi-Square showing $p \leq 0.001$. Finally, caliper increase was observed to be greater with the RootTrapper®-in-Pot Insert with a T-test showing $p \leq 0.023$. These findings indicate that the RootTrapper®-in-Pot Insert significantly reduced the number of escaping roots, increased rootball quality, and increased the rate at which the plant increased in caliper when compared to the Nursery Supplies GL 6900 plastic container.

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CHAPTER I

INTRODUCTION

Traditionally, nursery plant production primarily relied on field production. Over the past 60 years, however, an increasing portion of the nursery production of shade and ornamental trees has moved into container production. The capital investment required to begin field tree production is the lowest when compared to above ground container production and pot-in-pot container production (McNiel et al., 2001). Plants grown in field production operations tend to be the most resilient, requiring less irrigation and fertilization. The major hindrance of field production comes at the time of harvest when large pieces of machinery are required to remove the product from the ground. Field grown trees can weigh several hundred pounds due to the large amount of field soil removed along with the tree. This makes transporting the plant more expensive and more difficult to maneuver at the time of planting. Field grown plants have a shorter life span between harvest and planting due to their tendency to dry out.

These issues make a field-grown tree less accessible for the average homeowner planting a tree by hand. Transporting these large plants requires heavy machinery to which the average non-professional does not have access. Comparative weights with the bark media used in container production produces a lighter product. Containerized trees and shrubs are easily moved by hand with minimal labor required and have a longer shelf life. Provided they are properly irrigated and allowed adequate growing room, containerized plants can be held almost indefinitely. Capital costs required for this method of production are generally higher due to costs of the materials required. The bark media used in this production method is shipped in, generally by the semi-truck load. Media is an ever increasing expense with the rise in fuel costs. Using this bark media makes proper irrigation more important. Media is designed to drain more than field soils to help promote proper root formation and combat soil-borne pathogens (Whitcomb, 2001). Fertilization is important with bark media as there is little to no available nutrients present. Irrigation and fertilization, especially fertigation, is often inefficient with this production method as broadcast emitters are used to cover the entire production area, including the area between containers. Another issue is container blow over where the plant canopy acts as a sail that can tip the container over. This can lead to fertilizer spill when growers top dress with granular fertilizer.

Pot-in-pot production was first researched in the 1970s with the intention of addressing the issues present with above ground container production (Whitcomb, 2001). Pot-in-pot production refers to the act of placing a socket pot in a hole dug into the ground. A liner pot, the saleable unit, is placed into this socket pot. This provides added stability to the plant as well as temperature protection for both hot and cold temperatures. In this system, spray stakes are generally placed in each container. Less water is used and less runoff is produced. To ensure that the containers are properly drained, drainage tiles are generally run beneath each row of socket pots. This can help with installation in areas where the soil is poorly drained. All of these requirements associated with pot-in-pot make it the most expensive in terms of required capital (McNiel et al., 2001).

In the spring of 2010, the Horticulture Department at the University of Kentucky Research and Education Center in Princeton Kentucky began research on a new container developed by the RootMaker® Company. Called the RootTrapper®-in-Pot Insert, this fabric container was designed to address the two major issues found in pot-in-pot production: root escape and root circling. Root escape refers to a condition in the pot-in-pot production system where roots grow out of the liner pot and into the surrounding socket pot. This becomes an issue when these roots further escape from the socket pot into the surrounding soil. Root circling refers to a condition inherent to container production where roots reach the container wall and are deflected along its perimeter. This leaves the plant less apt to survive after being transplanted.

The University of Kentucky Research and Education Center houses the UKREC Pot-in-Pot Research and demonstration plot. This pot-in-pot setup contains 77 15-gallon socket pots used to test issues with this method of nursery plant production. Shumard oak (*Quercus shumardii*) were grown in the RootTrapper®-in-Pot Insert as well as a #15 Nursery Supplies GL 6900 plastic container.

Statement of the Problem

Given the effect that root circling has in the landscape, it becomes an issue for growers who are trying to produce a plant that will perform well in the landscape. Root circling adversely affects a plants ability to establish in the landscape. It can also lead to eventual girdling roots and the death of the plant. This makes root circling an issue to nursery crop producers. Pot-in-pot production also has the issue of root escape, where roots grow through the drainage holes and into the surrounding soil. When these roots enlarge, they make removal of the plant from the pot-in-pot difficult or impossible. This forces the grower to spend money on labor and repair work to the pot-in-pot production system.

Purpose of the Study

This study's purpose was to evaluate the effectiveness of the RootTrapper®-in-Pot Insert in controlling root escape and root circling in pot-in-pot production of Shumard oak (*Quercus shumardii*). These fabric containers made by the Rootmaker® company were compared to a standard smooth walled GL 6900 Nursery Supplies 15-gallon plastic nursery container. This smooth-walled plastic container is representative of the containers that are commonly used in pot-in-pot production. The hypothesis for this experiment was RootTrapper®-in-Pot Inserts will significantly reduce both the number of roots escaped and the quality of the rootball. Rootball quality refers to the amount of circling or deflected roots in a container produced rootball. This study focused specifically on counting the number of roots escaping, evaluating root circling., and measuring increase in caliper

Research Objectives

This study was intended to answer three major questions about the performance of the RootTrapper®-in-Pot Insert and its ability to affect root escape and root circling:

1. Does the RootTrapper®-in-Pot Insert significantly reduce the number of escaped roots in pot-in-pot production compared to the Nursery Supplies GL 6900 plastic container under equal conditions?
2. Does the RootTrapper®-in-pot Insert significantly improve rootball quality by reducing the amount of circling and deflected roots compared to the Nursery Supplies GL 6900 plastic container under equal conditions?

3. Does the RootTrapper®-in-Pot Insert significantly increase the rate at which the plant increases in caliper compared to the Nursery Supplies GL 6900 plastic container under equal conditions?

Theoretical Framework

There were two guiding principles behind this study. The first was that root circling, due to the change in the morphological state of the root system, is detrimental to the quality of the end product. The second was that root escape for pot-in-pot production can lead to the expenditure of time and money in the effort to remove the liner container from the socket container when the problem is bad enough.

Assumptions

This study assumed that root circling reflects a lower quality crop. Smaller, more juvenile roots are the site of water and nutrient uptake. With root circling, roots are often larger and circle the container perimeter. This means that the plant will have more difficulty establishing in the ground and could eventually die due to girdling roots. It is also assumed that root escape costs money for the grower in labor and repair expenses.

Definition of Terms

The following terms are important to this study and will be used throughout. This section will define these terms.

1. Caliper - The diameter of a trunk at six inches above the soil, measured in inches. (ANLA, 2004)
2. Container production - The production of plants in a container using a soilless substrate, primarily composed of pine bark (Whitcomb, 2001).

3. Deflected roots - Roots that have reached the side of the container and had their direction altered (Whitcomb, 2001).
4. Fabric containers - Production containers made from fabric that are designed to girdle root tips and/or prune them by drying in the surrounding air (Whitcomb, 2001).
5. Fertigation - The act of applying a liquid fertilizer through irrigation water.
6. Field Production - The production of nursery plants in the ground. These trees are harvested using heavy machinery (Whitcomb, 2001).
7. Girdle - Refers to a condition where roots grow around the trunk or rootball and restrict the potential growth of a plant (Hudler and Beale, 1981).
8. Nursery Supplies GL 6900 - A standard plastic container. This is a 15-gallon container made with smooth walls and drain holes at the bottom. This container is commonly used in pot-in-pot production.
9. Pot-in-Pot - This container production system places a container into a hole dug in the ground to provide stability. A plant is grown in a liner pot that is recessed into the in-ground socket pot (Whitcomb, 2001).
10. PourThru - A procedure where water is collected from the bottom of a container plant and measured for its fertilizer content and pH (Bilderback, 2001).
11. Root Circling - In container production, where roots reach the sidewall of the container and are deflected away to continue growing around the perimeter of the container (Hudler and Beale, 1981).

12. Root Escape - When roots in pot-in-pot production grow out of their liner container. This can lead to the roots growing through the socket pot and into the surrounding soil (Whitcomb and Whitcomb, 2004).
13. RootTrapper®-in-Pot Insert - A fabric container made by the RootMaker® company. This container is designed to replace the liner pot in pot-in-pot production and is advertised as having the ability to reduce root escape and root circling (Whitcomb and Whitcomb, 2004).

Delimitations

This study focused on the number of roots escaping the containers, the quality of the rootball, and increase in caliper. These were the issues said to be controlled by the RootTrapper®-in-Pot Insert and were specifically being addressed. Canopy density, chlorophyll content, and landscape establishment were not addressed in this study. Canopy density and chlorophyll content were less specific to the root issues being addressed in this study.

Limitations

This study's generalization will be limited by a couple of factors. There was no replication of species in this trial, making it very specific to Shumard oak. These liners were also grown from seed which increases genetic variation and growth patterns. It was also limited by the fact that only one plastic container is being used. Other plastic containers may perform differently. This again makes this study reflective of a very specific production system and a very specific crop. This study did not take into account canopy density and chlorophyll content due to the limited amount of labor available to carry it out.

Significance of the Study

This study was important as it has the potential to address an issue that costs nursery growers a significant amount of time and money. The collapse of the housing market has severely affected the nursery industry. Those businesses that did survive were forced to downsize their labor and cut as many costs as possible. This makes production activities that require labor even more detrimental. The reduction of labor means fewer employees whose time became more valuable. The reduction of new home construction meant a reduced market to move product. This increased competition making a higher quality product more competitive. Root circling in container production can reduce product quality by stressing a plant during establishment. The RootTrapper®-in-Pot Insert has the potential to increase the end product's quality without increasing the amount of labor needed.

CHAPTER II

LITERATURE REVIEW

Pot-in-Pot Production

Pot-in-pot production presents a unique problem. When roots escape through the drain holes in the liner pot, they have the potential to escape again through the drain holes in the socket pot and into the surrounding soil. When these roots enlarge, removal of the liner pot is nearly impossible without damage to the growing area. When this occurs, growers are forced to spend extensive time digging out the socket pot and repairing the damage (Whitcomb and Whitcomb, 2004).

Another major issue with pot-in-pot production inherent to all container production is root circling. When roots reach the wall of a plastic container, they are deflected away. This can affect the plant's ability to establish in the landscape and remain stable after doing so (Gilman, 2001). Once these roots have been deflected, they begin to grow around the periphery of the container, thus forming circling roots. In the long term, these roots have the potential to girdle the tree. As the trunk increases in caliper, it fills out the original rootball circumference and the original circling roots begin to press in on the tree. This lead to the xylem becoming malformed and the eventual decline of the tree as a whole (Hudler and Beale, 1981). To combat this circling, copper was traditionally used to line the container. Cupric hydroxide copper was generally applied as spray to the interior of the containers. When the root tips came in contact with the copper, they were pruned chemically and encouraged to branch laterally (Arnold, 1996). Root morphology is highly important to plant establishment in the landscape. Smaller, juvenile roots are the site of water and nutrient uptake while more mature roots are often hardened off (Taiz and Zeiger, 2006). This makes plant production methods that discourage larger roots in favor of a more fibrous root system desirable for growers who wish to produce a product that will establish well in the landscape.

Similar to the development of container culture to address the issues with field production, fabric containers were designed to address the issues with container production. The term *grow bags* refer to the practice of growing plants in fabric containers that were designed to prune root tips to prevent circling (Whitcomb, 2001). There are several different forms of grow bags as well as several different manufacturers. Like the other forms of nursery crop production, bag production has above ground and in-ground forms. With the in-ground method, bags are typically a single layer mesh designed to allow roots to escape into the surrounding soil, while girdling the roots to prevent them from becoming too large. These in-ground bags are typically backfilled with the same soil removed when digging the hole they are placed in. When it comes time for harvest, the smaller roots escaping the container are usually cut with a spade to allow the container to be removed from the ground.

Above ground fabric containers also come in several different forms. Above ground bags are sometimes single layered, though they typically consist of more than one layer. The inner layer was designed to allow root penetration while the outer layer was more impervious (Whitcomb, 2001). When the root tips enter this fabric material, they quickly become girdled. This forces the root to stop growing in that direction and branch laterally. This branching produced a more fibrous root system with smaller roots than those typically produced by solid-walled plastic containers. These smaller roots were typically where most root hairs grew, which were the site of water and nutrient uptake

(Taiz and Zeiger, 2006). These smaller roots were also more adept at new root generation (Marler and Willis, 1996) which can aid the plant when establishing in the landscape.

Nutrient Monitoring in Container Production

Container production has been studied by many different research teams who focused on a variety of production practices. Proper fertilization along with nutrient and pH monitoring has been addressed in great detail by North Carolina State University where several publications have been produced. Warren, Bilderback, and Kraus of the Department of Horticulture Science at NCSU published Method of fertilizer application affects nutrient loses of controlled-release fertilizer (2001), where nutrient levels of Cotoneaster (*Cotoneaster dammeri* 'Skagholm') were monitored using the PourThru technique. Two other publications on the PourThru include Bilderback's Using the PourThru Procedure for Checking EC and pH for Nursery Crops (2001), and Bilderback, Warren, and Daniels Managing Irrigation by Electrical Conductivity (1999). These publications demonstrate the PourThru procedure where containers were irrigated, allowed to drain, sat in collection trays, doused with a set amount of irrigation water, and the resulting leached water collected and measured by use of a pH/EC meter. This procedure allows a nursery producer to see exactly where their nutrient levels were during the growing season. This procedure is useful for growers, yet this study was more concerned with root behavior in container production.

The Use of Copper to Control Root Circling

Addressing the issues of root escape and root circling has been the focus of many research projects over the years. Developed from this research was the use of copper in root pruning. In 2000, Maynard, Brothers, and Johnson published Control of Root Circling with Copper in Co-Extruded Nursery Containers. In this study, China Doll (*Radermachera sinica*) was grown in copper-containing polymer containers with various amounts of copper and varying wall thicknesses. Specifically used was Migratrol™ (cuprous chloride) applied at various concentrations. This study found the copper treated containers to be highly effective in controlling root circling compared to untreated containers. This provided a baseline establishment that copper was effective in controlling root circling.

R. C. Beeson and R. Newton (1992) of the University of Florida Central Florida Research and Education Center conducted another study titled Shoot and Root Responses of Eighteen Southeastern Woody Landscape Species Grown in Cupric Hydroxide-treated Containers, where the effects of copper treatments on the plant's health was observed in eighteen commonly grown woody landscape plants in the south east: red maple (*Acer rubrum*), calamondin citrus (*Citris mitus*), bald cypress (*Taxodium distichum*), Dahoon holly (*Ilex cassine*), Savannah holly (*Ilex* x *attenuate* 'Savannah'), East Palatka holly (*Ilex* x *attenuate* 'East Palatka'), crape myrtle (*Lagerstroemia indica*), wax privet (*Ligustrum japonicum* 'Texanum'), sweet gum (*Liquidambar styraciflua*), mahogany (*Swietenia mahagoni*), laurel oak (*Quercus laurifolia*), live oak (*Quercus virginiana*), Jerusalem thorn (*Parkinsonia aculeate*), slash pine (*Pinus elliotii*), loblolly pine (*Pinus taeda*), weeping willow (*Salix babylonica*), Tabebuia (*Tabebuia alba*), and windmill palm (*Trachycarpus fortune*). This study found no signs of copper toxicity in any of the species studied and also found effective control of root circling in all species except for bald cypress and laurel oak though circling was found to be reduced. This study established the fact that using copper treatments can be done safely for the plants being produced.

In a similar study, Michael Arnold of the Department of Horticultural Sciences at Texas A&M University published Mechanical Correction and Chemical Avoidance of Circling Roots Differentially Affect Post-transplant Regeneration and Field Establishment of Container-grown Shumard oak (1996). In this experiment, *Quercus shumardii* seedlings were grown in 2.3-liter plastic containers that were either treated or not treated with cuprous chloride for 3 or 7 months. After this growth period the seedlings were transplanted alongside non-copper treated seedlings that were either mechanically root pruned or not pruned at all. This study observed there was a greater regeneration of roots in seedlings grown with a copper treatment. This suggests that this root pruning changes the morphological state of the roots at the time of transplant. Smaller roots are the site of water uptake, and this change in root size to a smaller root diameter helps to reduce stress at the time of transplant. This study also observed greater growth in those seedlings treated with copper over those mechanically pruned in the first two growth seasons after transplant (Arnold, 1996).

Another researcher studied the effect of copper treatment on plant establishment. In 1993, Daniel Struve of The Ohio State University Department of Horticulture published Effect of Copper-Treated Containers on Transplant Survival and Regrowth of Four Tree Species. In this study, northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), sweetgum (*Liquidambar styraciflua*) , and ‘Autumn Flame’ red maple (*Acer rubrum* ‘Autumn Flame’) liners were grown in containers that were either treated or untreated with copper. The liners were then transplanted into the ground, half of the nontreated liners mechanically root pruned and half not. This study found no significant difference in the survivability between all treatments and species. There was a greater amount of growth observed with scarlet and red oak grown in copper treated containers. This study suggests that mechanically pruned and chemically pruned liners have roughly the same survival rates. This would support the use of a container that mechanically prunes roots as it uses no chemicals and is more sustainable (Struve, 1993).

The Effect of Container Type on Root Morphology and Plant Establishment

Fabric container technology has been around for roughly 30 years and has been evaluated over this timeframe by many different research teams. Marler and Willis of the University of Guam College of Agriculture and Life Sciences published a study in 1996 titled Chemical or Air-Pruning Containers Improve Carambola, Longan, and Mango Seedling Root Morphology and Initial Root Growth after Transplanting. In this study, Carambola (*Averrhoa carambola* L.), longan (*Dimocarpus longan* Lour.), and mango (*Mangifera indica* L.) were grown in copper-treated, air-root-pruning, or untreated conventional plastic containers. This study found that there was no influence on root growth from the copper treatments on carambola or mango, but it was observed that there was more root growth while the plants were still in the containers and after transplant for longan. In the air-root-pruning containers, there was an increased proportion of root growth in the upper part of the rootball as well as increased root regeneration after transplant for both carambola and mango. This study suggested that some species may respond better to air-root-pruning than copper treatments. An increase in root growth in the upper part of the rootball would help a plant establish in the landscape as would root generation after transplant. The RootTrapper®-in-Pot Insert was an example of an air-root-pruning container.

In 2004, Hoyt March and Bonnie L. Appleton of the Virginia Tech Hampton Roads Agricultural Research and Extension Center published Use of Air-Root-Pruning Containers in Pot-in-Pot Systems. In this study, willow oak (*Quercus phellos*) and red oak (*Quercus rubra*) were planted in seven different types of 3-gallon containers including: Nursery Supplies GL 2000, RootMaker® (plastic), Accelerator (plastic), RootTrapper® (fabric), Root Control Smart Pot (fabric), Terra-Cell ARPACC (plastic), and Texel Tex-R Agroliner (fabric). All treatments were placed in a pot-in-pot system with a drip irrigation system. The experimental results found no difference in shoot or root biomass with red oak between any of the containers used in the study. Using willow oak, the RootTrapper® container was found to produce higher root and shoot dry biomass. The authors suggest that this was due to the design of this particular container. The RootTrapper® container has no drain holes and water only drains through the seams where the container is sewn together. It was suggested that media in these containers held more water resulting in the higher root and shoot biomass. The RootTrapper® container was essentially the same container that was used in this trial.

When it comes to a plant's ability to establish itself in the landscape, there have been several studies aimed at identifying the effect of production method on plant performance. In 1996, Gilman and Beeson published Production Method Affects Tree Establishment in the Landscape where 2 inch caliper laurel oak (*Quercus laurifolia*) and East Palatka holly (*Ilex* x *attenuata* Ashe. 'East Palatka') were transplanted from above-ground plastic containers, in-ground fabric containers, and field ball and burlap production. Growth rates seven months after transplant were found to be equal among all production methods. Field ball and burlap trees were found to have greater shoot growth one year after transplant and roots on trees transplanted from plastic containers were found to be less substantial than those from field or fabric production. Irrigation was reduced 14 weeks after transplant and trees transplanted from plastic containers were found to be more stressed than fabric or field grown trees. This study implied that trees grown in fabric containers have an easier time establishing in the landscape than those grown using the traditional plastic containers.

Another study in 2001 by Gilman of the University of Florida was Effect of Nursery Production Method, Irrigation, and Inoculation with Mycorrhizae-Forming Fungi on Establishment of *Quercus virginiana* researches this question of comparing the establishment rate differences between the different nursery crop production methods. This experiment took 2.5 inch caliper live oak (*Quercus virginiana*) from different container and field production systems and transplanted them into a landscape either with or without mycorrhizae-forming spore inoculations. Two different irrigation strategies were used. Gilman observed that, while in the nursery, all trees from all different production methods grew at the same rate. After transplanting, however, it was observed that trees grown in the field and were root pruned had the best ability to survive in the landscape after planting. Container grown trees were also observed to have the most need for staking in the landscape to prevent blowing over. Air-root-pruned trees were observed to have the greatest trunk diameter. This study again implied there was greater performance of trees grown using air-root-pruning containers over those grown in Nursery Supplies GL 6900 plastic containers.

Though many of these studies used members of the oak genus, a couple have studied the effect of container type on red maple (*Acer rubrum*). In 1998, Marshall and Gilman published Effects of Nursery Container Type on Root Growth and Landscape Establishment of *Acer rubrum* L. where red maples were grown in seven different types of containers to a mean caliper of 1.5 inches. The trees were then transplanted into landscapes under either a frequent or intermittent irrigation schedule. This study observed no affect from container type on red maple root mass, trunk caliper or height while in the nursery. This study also observed that deflected root length, or the length roots grew after changing directions at the container sidewall, was longest in the standard black plastic container. This suggested that root circling would be reduced in containers that incorporate root pruning. Trees irrigated frequently after landscape planting were observed to have the greatest increase in root mass, trunk caliper, and height. This study established root pruning containers have potential to reduce levels of root circling found in container production (Marshall and Gilman, 1998).

In another study in 2010 on red maple, Gilman, Harchick, and Paz of the University of Florida wrote Effect of Container Type on Root Form and Growth of Red Maple, which studied the affect of container wall type on roots. The types of containers used in this study were: standard smooth sided containers, Air-Pot™ Fanntum pot, Florida Cool Ring™, Jackpot™, RootBuilder®, RootMaker®, and Smart Pot®. It was observed that there was no difference in trunk caliper between standard black plastic containers and other types of container materials. It was also observed that only the smooth-walled containers had roots circling around the entire top of the container. This study established a rating scale of rootball quality of 1 to 5 which states 5 = highest quality with few roots growing along periphery of rootball, 1 = lowest quality with many deflected roots down, up, or around the periphery of rootball. According to this scale, smooth-walled containers were found to have a lower rootball quality over other types of root-pruning containers. Researchers noted that, while the root mass was not measured, there was no observed difference in fine root generation between the different container types. This study reaffirmed the ability of root-pruning container to help reduce root circling in container production.

The long-term effect of root circling was examined in 1981 by Hudler and Beale in their study <u>Anatomical Features of Girdling Root Injury</u>. This study examined a Norway maple that displayed girdling root damage. The tree's roots were excavated and examined using cross-sectional microscopy of the xylem. The xylem was observed to be 1 mm in compressed areas where uncompressed areas were 25 mm. It was concluded that the girdling roots led to the eventual decline of the tree as a whole due to a reduction of stem conductivity. Circling roots in container production can lead to eventual girdling root damage and the long-term decline of the plant. This establishes the importance of preventing root circling in container production.

In this research review, several key points were established. While some studies suggested that field-grown root-pruned trees perform best, it was also established that root-pruning containers exhibited better performance than standard smooth-walled plastic containers. Root pruned containers displayed a reduction in root circling and better landscape establishment. Also established was the effect of cupric hydroxide on container production. Copper treated containers were proven effective in the control of circling by several studies and were not found to have any detrimental effects on plant health and eventual performance in the landscape. The long-term effect of circling roots was also discussed and was found to have the potential to lead to the eventual decline of trees due to compression of the xylem from girdling roots.

CHAPTER III

MATERIALS AND METHODS

Research Hypothesis

The hypothesis for this trial was the RootTrapper®-in-Pot Insert will provide a significant reduction in root escape and provide a significant increase in rootball quality and caliper.

Context of Study

This study was conducted at the University of Kentucky Research and Education Center Department of Horticulture Pot-in-Pot Research Plot in Princeton, KY. This plot used the same set-up as common nursery operations. The plot contained 76 15-gallon sockets with 10-gallon per hour spray stake irrigation running for 12 minutes at 10:00 am and 2:00 pm daily for eight months.

Data Source

In this study, 76 Shumard oak (*Quercus shumardii*) were transplanted from 3-gallon RootTrapper® bag containers (Figure 1). The Shumard oak was chosen as it represented a commonly grown shade tree in the Kentucky nursery industry. This species also worked well for this study as it has been used before in similar research projects. A disadvantage to these particular liners, however, was that they were produced from seed. This does open results to more variation than might be found in clonally propagated plants. The standard deviation in caliper with this batch of liners was observed to be 0.06 inches, suggesting a uniform crop size (Table 1).

Figure 1. Shumard oak (*Quercus shumardii*) grown in 3-gallon RootTrapper® liners.

Table 1. Mean starting calipers of 76 Shumard oak (*Quercus shumardii*) liners.

Mean Starting Caliper (Inches)	Standard Deviation (Inches)
0.78	0.06

Half of these liners were potted in Nursery Supplies GL 6900 #15 smooth-walled plastic containers (Figure 2). The other 38 liners were potted in the 15-gallon RootTrapper®-in-Pot Insert (Figure 3). This product was specifically made to fit the socket pot being used. In this case, the liners were made to fit the Nursery Supplies GL 6900. The media used was pure, aged pine bark. Containers were top-dressed with 135 grams of Osmocote® 15-9-12 slow release fertilizer. Weed control was obtained using Snapshot® 2.5 TG that was broadcasted over the containers at a rate of 158.8 grams per 100 sq. ft. All chemical applications were applied equally to both container types and were repeated at the beginning of the second growing season.

Figure 2. A Shumard oak planted in a Nursery Supplies GL 6900 #15 smooth-walled plastic container.

Figure 3. The open-sided 15-gallon RootTrapper®-in-Pot Insert.

The University of Kentucky Research and Education Center Department of Horticulture Pot-in-Pot Research plot is divided into three blocks, 2 blocks of 28 sockets and one block of 21 sockets. Containers were randomized within these blocks to help control for environmental factors (Table 2).

Table 2. Plot Randomization. The UKREC Pot-in-Pot is divided into three beds. Spaces marked with C represent the Nursery Supplies GL 6900 plastic containers, while those marked with B represent the RootTrapper®-in-Pot Insert bag container.

C1	**B5**	**C7**	**C10**
C2	**B6**	**B9**	**B13**
C3	**C4**	**B10**	**B14**
B1	**C5**	**B11**	**C11**
B2	**C6**	**C8**	**B15**
B3	**B7**	**C9**	**C12**
B4	**B8**	**B12**	**C13**

C14	**C19**	**B22**	**C26**
B16	**B18**	**B23**	**B25**
C15	**C20**	**C22**	**B26**
C16	**B19**	**C23**	**C27**
C17	**B20**	**B24**	**B27**
C18	**C21**	**C24**	**B28**
B17	**B21**	**C25**	**C28**

C29	**C31**	**C35**
B29	**B33**	**C36**
B30	**C32**	**C37**
B31	**C33**	**C38**
	B34	**B36**
B32	**C34**	**B37**
C30	**B35**	**B38**

<u>Data Collection Methods</u>

Evaluation for this study began after two seasons of growth when the mean trunk caliper at 6 inches above the soil line for all 76 trees approached 2 inches. The American Nursery and Landscape Association American Standard for Nursery Stock lists 2-inches as the largest size recommended for a 15-gallon container (ANLA, 2004). Trunk calipers were measured using a digital caliper reading three decimal places. On September 10, 2011, after reaching an overall mean caliper of 2 inches, the containers were evaluated on the number of escaping roots found at the outside container wall. Only roots above the root hair level were counted to make this measurement possible. After counting escaping roots, the rootballs were removed from their containers. They were evaluated on the same scale established by Gilman, Harchick, and Paz in <u>Effect of Container Type on Root Form and Growth of Red Maple</u> (2010). Using this scale, a rootball rated at 1 rating displayed large circling roots covering most of its surface. A 2 rating had half large circling roots and half small circling roots. A 3 rating had mostly small circling roots covering the entire rootball. A 4 rating had few circling roots, and a 5 rating had no root circling. Initial caliper and ending calipers were compared using a digital caliper to evaluate any differences observed between the type container types.

Data Analysis

After data collection, the rootballs were compared statistically to see if there were any significant differences in the levels of root escape, root circling, and caliper increase observed.

Validity

Several measures were taken to ensure results of this study were valid. Randomization of the containers in the plots helped to control for environmental factors such as proximity to surrounding trees, shading due to location in the plot, and wind exposure. Treatments were also replicated to 38 plants per container type. All factors between treatments were equal. Both container types contained the same amount of media, received equal amounts of fertilizer and weed control. Also, all containers were irrigated equally. Not only does this assure that observed results were due to the container type only, but it also helped show this container works in actual nursery crop production.

CHAPTER IV

RESULTS

This study addressed three objectives. The first objective asked if the RootTrapper®-in-Pot Insert significantly reduced the number of escaped roots in pot-in-pot production compared to a Nursery Supplies GL 6900 plastic container under equal conditions. The second objective asked if the RootTrapper®-in-Pot Insert significantly improved rootball quality by reducing the amount of circling and deflected roots compared to the Nursery Supplies GL 6900 plastic containers under equal conditions. The final objective asked if the RootTrapper®-in-Pot Insert significantly increased the rate at which a tree increases in caliper compared to a Nursery Supplies GL 6900 plastic container under equal conditions.

Objective 1: Root Escape

The first research objective was to determine if the RootTrapper®-in-Pot Insert significantly reduced the number of escaped roots during pot-in-pot production compared to a Nursery Supplies GL 6900 plastic container under equal conditions. Roots escaping the containers were counted at the container wall. This location was chosen as roots branched after leaving the container which helped assure that a uniform method of data collection was used across all treatments. The mean number of escaping roots for the 38 trees grown in Nursery Supplies GL 6900 plastic containers was observed to be 9.342. The 38 Shumard oak (*Quercus shumardii*) grown in the RootTrapper® containers were observed to have a mean of 6.763 escaping roots at the container wall (Table 3).

Table 3: The mean number of escaping roots of *Quercus shumardii* counted at the outside container wall in the Nursery Supplies GL 6900 and the RootMaker® #15 RootTrapper®-in-Pot Insert.

Container Type	Mean Number of Escaping Roots	*p*-value
Nursery Supplies GL 6900	9.342	0.015
RootTrapper®-In-Pot Insert	6.763	

The mean number of escaping roots was observed to be significantly fewer with the RootTrapper®-in-Pot Insert than what was observed with the Nursery Supplies GL 6900 plastic container (Figure 4). The T-test showed a p-value of 0.015 revealing a significant reduction of escaping roots with the RootTrapper®-in-Pot Insert.

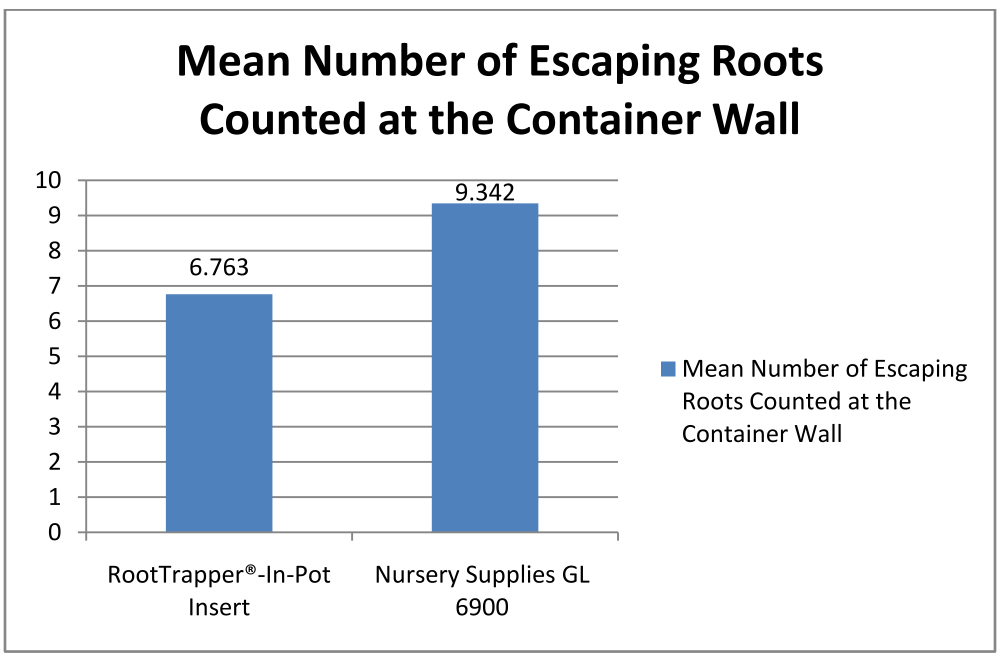

Figure 4. Mean number of escaping roots compared by container type.

Objective 2: Root Circling

The rootball quality was measured using an established scale created by Gilman et al. (2010). Using this scale, a rootball rated at 1 displayed large circling roots covering most of its surface. A 2 rating had half large circling roots and half small circling roots. A 3 rating had mostly small circling roots covering the entire rootball. A 4 rating had few circling roots, and a 5 rating had no root circling (Figure 5). Using this scale, the 38 trees grown in the Nursery Supplies GL 6900 plastic container were found to have a mean rootball rating of 2.658. The 38 trees grown in the RootTrapper®-in-Pot Insert were found to have a mean rating of 3.676.

Figure 5: Rootball Rating Scale. A rootball rating of 1 is a less desirable nursery tree and sales quality improves up to the rating of 5.

The mean rootball quality rating was observed to be significantly higher in trees grown in the RootTrapper®-in-Pot Insert. Trees grown in the Nursery Supplies GL 6900 plastic container had a mean rootball rating of 2.568 (Figure 6). The 38 trees grown in the RootTrapper®-in-Pot Insert had a mean rootball rating of 3.676. Using a Chi-Square to compare the observed frequencies of scores to the expected frequencies, a p-value of $\leq$ 0.001 was observed.

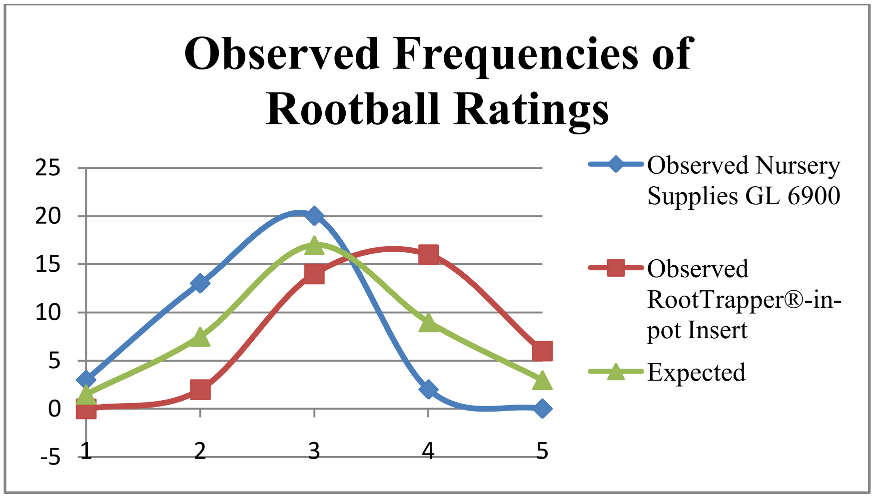

Figure 6. Observed rootball rating frequencies of 76 Shumard oak (*Quercus shumardii*) grown in the Nursery Supplies GL 6900 15-gallon nursery container and the #15 RootTrapper®-in-Pot Insert.

Objective 3: Trunk Caliper

The thickness of the trunk, known as trunk caliper, was measured at six inches above the soil line at time of potting and at harvest using a digital caliper. At the time of planting, the mean starting caliper for both container types was 0.782 inches. At harvest the 38 trees grown in the Nursery Supplies GL 6900 containers had a mean caliper of 1.855 inches with a mean increase of 1.069 inches. The 38 trees grown in the RootTrapper®-in-Pot Inserts had a mean caliper of 1.959 inches with a mean increase of 1.175 inches (Figure 7). Compared statistically using a T-test, these were statistically different with a p-value ≤ 0.023 (Table 4).

Table 4: Mean trunk caliper at six inches above the soil by container type.

Caliper Date	Nursery Supplies GL 6900	RootTrapper®-In-Pot Insert	*p*-value
Mean Starting Caliper	0.782	0.782	0.023
Mean Harvest Caliper	1.855	1.959	

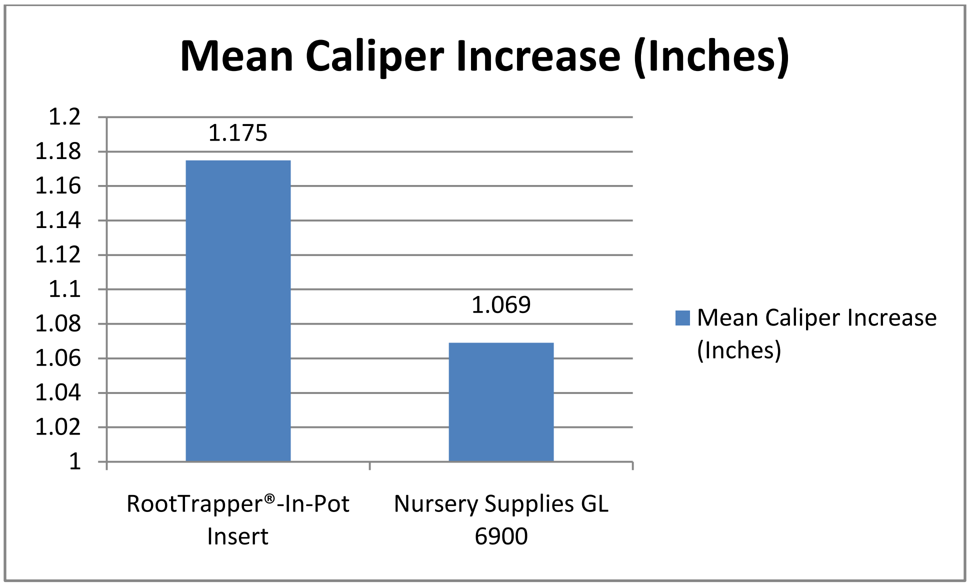

Figure 7. A comparison of the increase in caliper (inches) over 19 months between container types.

<u>Comparisons</u>

Root escape was found to be reduced with the RootTrapper®-in-Pot Insert over the Nursery Supplies GL 6900. This supported the findings of Whitcomb and Whitcomb, who observed fewer escaping roots with the RootTrapper®-in-Pot Insert over a conventional nursery container (Whitcomb and Whitcomb, 2004). The results of this study also support those observed by Gilman, Harchick, and Paz (2010). The trees grown in the smooth-walled Nursery Supplies GL 6900 were observed to have a lower mean rating than those found with the RootTrapper®-in-Pot Insert. However, this study observed an increase in the mean caliper of the trees grown in the RootTrapper®-in-Pot Insert over those grown in the Nursery Supplies GL 6900 smooth-walled container where other studies did not. Marshall and Gilman (1998) reported no change in trunk caliper at the end of production between container types.

CHAPTER V

SUMMARY AND CONCLUSIONS

In Chapter IV, the raw data were presented and analyzed. The RootTrapper®-in-Pot Insert was observed to have significantly fewer escaping roots than the Nursery Supplies GL 6900 plastic container. The RootTrapper® container was also observed to have a higher mean rootball quality using the rating scale established by Gilman, Harchick, and Paz (2010). Starting with equivalent sized calipers, the 38 trees grown in the RootTrapper® container were observed to increase in caliper more quickly than the 38 grown in the Nursery Supplies GL 6900 plastic container.

Objective 1: Root Escape

The escaping roots found in the plastic containers were with few exceptions, observed to escape through the drain holes in the container bottom of the (Figure 8). With the RootTrapper® container, escaping roots were found forcing their way through the sewn seams and open overlapping sides (Figure 8). The RootTrapper® container provided less opportunity for roots to escape from the liner container into the surrounding socket container. Those roots that escaped through the seams of the RootTrapper® container were observed to mostly be smaller roots that were constricted. Apical root dominance was lost when this occurred which encouraged root branching (March and Appleton, 2004). With few exceptions, these roots did not enlarge to prevent removal of the liner pot from the socket pot. Roots escaping from the drainage holes in the Nursery Supplies GL 6900 plastic container were able to enlarge more readily due to the larger holes through which the roots grew.

Figure 8. Roots escaping from the drainage holes in the Nursery Supplies GL 6900 plastic container and the overlapping sides and seams of the RootTrapper®-in-Pot Insert.

Root escape in pot-in-pot nursery plant production can be a costly problem for nursery growers (McNiel et al., 2001). Time must be spent on labor, replacement sockets, and sometimes, diesel to run a backhoe. This means that any product that reduces root escape can prove to be a money saver for growers who continually face this issue. Prevention of root escape can also allow the grower to hold the tree in the nursery a longer period of time without fear of damaging their infrastructure.

Objective 2: Root Circling

The observed rootball quality was significantly influenced by the container type in which the trees were grown. Roots deflected by the container wall of the Nursery Supplies GL 6900 plastic container continued to grow and enlarge. These roots eventually circled the entire container and enlarged, thus reducing the assigned rating of the rootball (Figure 9). With the RootTrapper®-In-Pot Insert, roots reaching the container wall were girdled as they grew into the fabric container. While some root circling was observed, most roots branched laterally with this container.

Figure 9. Comparison of root growth. Left: An extreme case (1 Rating) of large circling roots from a tree grown in the Nursery Supplies GL 6900 plastic container. Right: Fine roots (5 Rating) with little to no root circling on tree grown in the RootTrapper®-in-Pot Insert. This shows one of the best observed rootballs in this study.

A reduction in root circling can help growers in a number of ways. Circling roots are a sign of a lower quality plant (Hudler and Beale, 1981), and any product that can help reduce root circling will create a higher quality product. These trees are more than apt at survival in the landscape. This benefits growers who may use their own trees in any landscaping jobs they take on. A nursery's reputation can also be helped by becoming known as a source of higher quality product. This reduction of circling also adds to the duration for which the grower can hold the plant on site in the original container (Hudler and Beale, 1981).

Objective 3: Trunk Caliper

At the beginning of this experiment, liners were randomly divided between the two container types. This initial group of liners had a mean caliper of 0.782 inches at six inches above the soil. This location was used to measure the liners as it is the nursery industry standard. At the time of harvest, the trees grown in the Nursery Supplies GL 6900 plastic container had a mean caliper of 1.855 inches, thus gaining a mean of 1.069 inches. The trees grown in the RootTrapper® containers gained a mean of 1.175 inches with an ending caliper of 1.959 inches. The RootTrapper®-in-Pot Insert significantly increased the caliper of the tree more quickly than was observed with the Nursery Supplies GL 6900 plastic container.

The RootTrapper®-in-Pot Insert

Removal of the fabric from the rootball was found to be more difficult and time consuming than with the Nursery Supplies GL 6900 plastic container. As the RootTrapper® container was designed to have the root tips grow into the inner fabric, there was a greater amount of resistance when pulling the fabric from the rootball. The quickest method of removal was to tear the container at the sewn seams. This method was only possible due to the overlapping sides that were designed to aid in fabric removal. Thus, while this feature did create the potential for additional escaping roots, it did fill its purpose. This method prevented reuse of the container. This can be cost ineffective for growers who use their own plants in their landscaping services. At the time of this trial, the #15 RootTrapper®-in-Pot Insert cost $4.95, while the Nursery Supplies GL 6900 cost $8.64. The greater cost of the Nursery Supplies GL 6900 could potentially be compensated for with its reuse. In three cases, damage was done to the rootball during this fabric removal process. This issue could potentially be addressed by an earlier harvest when the roots have not yet grown into the fabric container wall as much.

The RootTrapper®-in-Pot Insert was also not a plantable container. This container does not degrade when planted in the ground like the RootPouch® container, nor does it allow roots to grow into the surrounding soil like the RootMaker® Knit fabric container. Growers using this product would need to educate their customers on how to properly use this product.

It was also important to note that with the 38 open-sided RootTrapper®-in-Pot Inserts, the containers could not be removed from the socket pot until the trees were rooted in to the media. As two sides of this container were simply overlapping fabric, the rootball would fall apart when removed from the socket pot requiring the tree to be repotted. This issue would be addressed by using the closed sided version of the RootTrapper®-in-Pot Insert.

Observations and Suggested Improvements

Root escape with the RootTrapper®-in-Pot Insert would likely be considerably reduced by using the closed sided version as opposed to the overlapping open-sided version used in this study. When the RootTrapper® containers were slid into the socket pot, there was a chance of the fabric sliding too far down and creating an opening in the overlapping sides. When this occurred, large roots were able to escape and enlarge. This led to several cases where the tree was stuck in the socket pot (Figure 10).

Using this project as a starting point, a similar study using the RootPouch® plantable fabric container was begun in the spring of 2012 at the University of Kentucky Research and Education Center in Princeton, KY. This container, made from shredded recycled plastic, was designed to degrade after planting based upon the time frame of the production system in which it was used. Custom blends of plastic can be ordered to change how quickly the containers degrade. This study also used two different varieties of trees, Autumn Flame Red Maple (*Acer rubrum* 'Autumn Flame') and Eastern Hophornbeam (*Ostrya virginiana*), to test how different trees behave in this production system.

Figure 10. A large root which had to be cut before removal of the RootTrapper®-in-Pot Insert from the socket pot.

Conclusions

This study set out to assess the ability of the RootTrapper®-in-Pot Insert's ability to control the major issues faced by pot-in-pot nursery plant production. When compared to a Nursery Supplies GL 6900 plastic nursery container, the RootTrapper® container was found to significantly reduce the number of roots escaping from the liner container into the surrounding socket container. While escaping roots were still found with the

RootTrapper® container, they were mostly smaller roots forcing their way through the container's seams. What few large roots were observed were found to be growing through the overlapping bag sides.

The overall rootball quality was observed to be higher in the 38 RootTrapper® containers as well. Fewer circling roots were observed with those trees grown in the RootTrapper® container than in the Nursery Supplies GL 6900 plastic container. When roots grew into the fabric container wall, they were constricted. Following this constriction, the roots branched laterally as opposed to being deflected and circling as was observed in the Nursery Supplies GL 6900 plastic containers.

During the time frame of this study, trees grown in the RootTrapper® container were observed to increase in caliper at a statistically significant faster rate than those grown in the Nursery Supplies GL 6900 plastic containers. This has the potential to help increase the production speed of a crop. Growers using this product would have to factor this increase in growth into their production cycle.

While several issues were observed with the RootTrapper®-in-Pot Insert, it did have benefits over the Nursery Supplies GL 6900 plastic container. Growers who are continually plagued by the problems of root escape and root circling could potentially adapt this product to their growing system as a method of control. While further testing could help to further prove this products value, these initial results indicate that the RootTrapper® container has the potential to aid growers with two of container productions biggest issues.

LITERATURE CITED

American Nursery and Landscape Association. 2004. American Standard For Nursery Stock. *Amer. Nursery and Landscape Assn., Washington, DC*.

Arnold, M. A. 1996. Mechanical correction and chemical avoidance of circling roots differentially affect post-transplant root regeneration and field establishment of container-grown Shumard oak. J. Amer. Soc. Hort. Sci. 121(2):258-263.

Beeson, R. C. and R. Newton. 1992. Shoot and root responses of eighteen southeastern woody landscape species grown in cupric hydroxide-treated containers. J. Environ. Hort. 10(4):214-217.

Bilderback, T. 2001. Using the PourThru procedure for checking EC and pH for nursery crops. North Carolina State University publication HIL 401.

Bilderback, T. E., S. L. Warren and J. H. Daniels. 1999. Managing Irrigation by Electrical Conductivity. Acta Hort. 481, ISHS.

Gilman, E. F. 2001. Effect of nursery production method, irrigation, and inoculation with mycorrhizae-forming fungi on establishment of *Quercus virginiana*. Journal of Arboriculture 27(1): January 2001.

Gilman, E. F. and R. C. Beeson, Jr. 1996. Production method affects tree establishment in the landscape. J. Environ. Hort. 14(2):81-87.

Gilman, E. F., C. Harchick, and M. Paz. 2010. Effect of container type on root form and growth of red maple. J. Environ. Hort. 28(1):1-7.

Hudler, G. W. and M. A. Beale. 1981. Anatomical features of girdling root injury. Journal of Arboriculture 7(2): February 1981.

March, H. W. and B. Appleton. 2004. Use of air-root-pruning container in pot-in-pot systems. SNA Research Conference – Vol. 49.

Marler, T. E. and D. Willis. 1996. Chemical or air root-pruning containers improve Carambola, Longan, and Mango seedling root morphology and initial root growth after transplanting. J. Environ. Hort. 14(2):47-49.

Marshall, M. D. and E. F. Gilman. 1998. Effects of nursery container type on root growth and landscape establishment of *Acer rubrum* L. J. Environ. Hort. 16(1):55-59.

Maynard, B. K., C. T. Brothers, and W. A. Johnson. 2000. Control of root circling with copper in co-extruded nursery containers. SNA Research Conference Vol. 45 – 2000.

McNiel, R., B. Behe, and C. C. Montgomery. 2001. Physical and economic requirements for pot-in-pot nursery production. *Nursery and Landscape Program*, 11.

Struve, D. K. 1993. Effect of copper-treated containers on transplant survival and regrowth of four tree species. J. Environ. Hort. 11(4):196-199.

Taiz, L. and E. Zeiger. 2006. Plant Physiology, 4th Edition. Sinauer Associates, Inc., Publishers. Sunerland, MA.

Warren, S. L.,T. E. Bilderback, and H. H. Kraus. 2001. Method of fertilizer application affects nutrient losses of controlled-release fertilizer. Acta Hort. 548, ISHS.

Whitcomb, C. E. 2001. Production of landscape plants II (in the field). Lacebark Inc., Stillwater, OK.

Whitcomb, C. E., and A. C. Whitcomb. 2004. Solutions for pot-in-pot root escape, root circling and heat shock at harvest. In *The International Plant Propagators Society Proceedings* (Vol. 54).

ADDENDUM A

Figure 11. Shumard oak (*Quercus shumardii*) liner transplanted into a 15-gallon RootTrapper®-in-Pot Insert.

Figure 12. A side by side comparison of the RootTrapper®-in-Pot Insert to the Nursery Supplies GL 6900 plastic container.

Figure 13. Fabric removal using the overlapping sides of the RootTrapper®-in-Pot Insert.