Effects of Root Pruning Containers and Traditional Containers on Growth of Roots and Shoots of Selected Landscape Plants

by

Rucha Chandrashekhar Shevade

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Approved by

Kenneth M. Tilt, Co-chair, Professor of Horticulture
Floyd M. Woods, Co-chair, Associate Professor of Horticulture
Amy Noelle Wright, Associate Professor of Horticulture
Elina Coneva, Associate Professor of Horticulture

Abstract

Objectives of this research were to compare the effects of container root pruning technology, RootMaker® containers, traditional containers, and a combination of both production systems on plant growth using a diverse range of plant species (from liners to saleable plants). *Catalpa speciosa*, *Quercus coccinea*, *Quercus rubra*, *Quercus alba*, *Hydrangea macrophylla* 'Penny Mac', *Ilex cornuta* 'Ponderi' and *Ilex* x 'Nellie R. Stevens' were transplanted through a combination of container sizes and the two root pruning systems to reach a prescribed saleable plant size. Only hydrangea's showed differences in height and growth indices when plants grown in RootMaker® containers, traditional containers and a combination of both were compared. Root growth showed differences depending on species, container shifting sequence and method of root measurement. No differences were observed among pure traditional and RootMaker® systems when the roots were scanned and analyzed using WinRHIZO software, but some differences were seen among the hybrid (combination of both systems) systems. Work continues to determine reliable root measurement technique as a predictor for transplant and establishment success and if either system provides any growth advantages.

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Table of Contents

List of Tables

List of Figures

Chapter 1

Literature Review

1.1 Introduction

Wholesale production of woody nursery crops in the United States contributes $26 billion to the economy with more than 50% of that production produced in containers (Hall et al., 2005). Generally consumers prefer containers as they are clean, neat and easy to handle but they can have some inherent problems (Whitcomb, 2003). When plants are grown in containers, the basic physiological principals involved in the production of any crop are not altered, neither are the plant genetics altered but, some conditions are unique in the container production system when compared to any other plant production system. (Whitcomb, 2003).

Metal food cans with vertical sidewalls were the first containers that were used to produce plants outside of greenhouses. Plastic containers followed, but, initially they were brittle. Technology improved and they became more durable and lasted through several crops. But, confining roots with smooth walls led to root deformities (Whitcomb, 2003).

Container produced plants have shown increased establishment success after transplanting, or resulted in greater transplanting quality over field produced plants (Mathers et al., 2007). In container grown plants roots are packaged and transplant stress is minimized compared to the field grown stock. In the field grown nursery stock many fine roots are damaged during harvest with about 30% of root area left in the soil, lost or damaged during digging and handling of bareroot plants (Thomas, 2000). Fine roots help in the uptake of nutrients and water. Due to damaged or lost roots, plants face stress (Harris and Gilman, 1993). Transplanting success is increased with container produced plants due to preservation of intact root systems when handled and transplanted (Mathers et al., 2007).

Ideally, container transplanting should be done as soon as the root development has progressed to hold the soil mix together but before root-bound stress occurs. As plants become root-bound, growth rate starts declining due to root intermingling, congestion and decrease in oxygen and space available for further development of roots (Whitcomb, 2003). Container transplanting is used for establishing vegetable crops, but is also used for some field crops including cotton, oilseed rape and tobacco (Thomas, 1993 ; Hu et al., 1996 ; Frantz et al., 1998). When seedlings are harvested from a field seedling nursery, transplanting causes root damage to seedlings. However, degrees of root injury vary from minimal to substantial. Plant growth can be retarded by transplanting shock even when there is no specific root injury. Plant root damage and subsequent growth reduction can induce nutritional problems that are not found in direct sown crops in the same soil. The ability of plants to absorb nutrients from the soil at least until root function has recovered will be limited due to the loss of roots at transplanting. There is less growth after transplanting due to combination of factors which have lasting effects on crop growth and nutrition. Yield potential during the remaining growing season is limited due to the lag period for root recovery, compared to the direct sown plants (Mulyati et al., 2009).

1.2 History of Container production

Much attention has been given to the physical structure of roots within the green industry over the past 5 years. Trees with well developed, balanced, and highly branched root system are preferred by most people in the green industry. A fibrous root system with perfect radial symmetry is generally considered to grow and establish more readily than a more coarse root system, but in reality, more than the physical structure, the physiological growth potential of a root system is probably more important. Some major physical abnormalities like girdling roots, circling roots and misdirected roots are common in container production and should be discouraged (Altland, 2007).

Roots that grow across the root ball and in close proximity to the tree stem or root collar are called girdling roots. The root collar is the region where the tree stem transitions to the root system. Roots that grow and conform to the round container shape are called circling roots. Roots that grow in seemingly the opposite direction to what they should have grown are called misdirected roots (Altland , 2007).

1.3 Root pruning

These three problems i.e. circling, girdling, and misdirected roots can be corrected by pruning roots of the plants. Root pruning is the act of cutting the roots of shrubs or trees to force more vigorous root growth or to prepare plants for transplanting (Landscape Ontario Horticultural Trade Association, Appendix F, 2004). Root pruning is done by using three different methods: manual pruning, chemical pruning and air pruning.

Varied responses on root growth and morphology have been seen as a result of the effect of manual pruning of container grown plants (Gilman et al., 2009).

Different types of manual pruning include:

Butterfly pruning : Two cuts are made perpendicular across the basal roots of the root ball severing circling roots.

Manual cutting : Roots at the bottom and sides are cut manually with a knife in a linear manner.

Disturbing : Roots at the bottom of the root ball are disturbed by vigorously hand-rubbing the root ball. This disturbs the roots with the purpose to free the roots from their circling path and expose broken and freed roots to the surrounding soil (Arnold, 1996).

In a recent study researchers found that the amount of roots growing into substrate outside the original root ball was enhanced as a result of light cutting of circling roots of shrubs (Blanusa et al., 2007). In contrast Gilman et al. (1996) showed redistribution of cut roots of Burford holly (*Ilex cornuta* 'Burfordii') roots at planting, but no increase in roots were found when compared with non-pruned controls. Harris et. al. (2001) observed total root length after planting to be unaffected by root pruning treatments up to 15 cm below the soil surface though the primary seedling radical developed more main lateral roots (>2 mm in diameter) after the treatments on Pin Oak (*Quercus palustris* Munchh.) liners. Krasowski and Owens (2000) found greater root growth was produced in the root system of mechanically pruned *Picea glauca* (Moench) Voss than control or chemically root pruned treatments despite a smaller root ball at planting.

One of the most essential attributes of high quality seedlings in nursery production are well developed and well structured root systems with numerous lateral roots (Aldhus, 1994). Moreover, the form of root development of seedlings largely affects the plantation performance (Sutton, 1980). In vigorous plant species grown in containers, or in plants held too long in a given size container, densely matted, kinked and downward deflected surface roots are common. Container grown stock results in poor establishment and reduced shoot growth after transplanting root balls with undesirable root forms (Arnold et al., 1993).

Copper has been used to modify root growth of tree seedlings from the earliest development and use of container production technology. Root configuration can be improved by copper treated containers. Cell division at the root apex and root elongation at the root/container-wall interface are inhibited by a copper coating on container cavity walls (Barnett and McGilvary, 2001). Lateral roots are allowed to turn downwards by most container types, resulting in the accumulation of most of the active growing tips at the base of the plug or container. Copper treated containers effectively prune roots at the walls preventing the lateral roots from turning downward. This results in a root system with many short, branched roots (Barnett and McGilvary, 2001). Lateral root egress from the upper part of the plug increases access of the plants to the nutrients upon transplanting nearer the soil surface. Short lateral branching roots promotes seedling stability and increased survival and growth (Burdett et al., 1983 ; Wenny et al., 1988). Root tips resume growth and produce a more branched root system after transplanting (Barnett and McGilvary, 2001).

Romero et al., (1986) analyzed root development of Caribbean pine grown in copper carbonate treated containers and found seedlings with more lateral roots, as well as significantly larger stem diameters than untreated seedlings. They also noted a change in root morphology. Seedlings from treated containers showed finer, more fibrous root systems and were easier to extract from containers. However, the major benefits of chemical root pruning occurred after transplanting (Barnett and McGilvary, 2001).

Pinus halepensis seedling quality was improved by coating containers with basic cupric carbonate without causing visible phytotoxicity symptoms. Chemical root pruned seedlings survived no better than non treated seedlings two years after field planting, but exhibited higher stem volume and annual growth (Tsakaldimi and Ganatsas, 2006).

Root morphology can be changed for the better by container dimensions, size and container surface porosity (Arnold, 1996 ; Marshall and Gilman, 1998 ; Struve, 1993). Less packed roots, less spiraling roots, and fewer L–shaped roots were seen in *Pinus radiata* D. Don seedlings planted in the air pruning 5 cm diameter containers (Ortega et al., 2006). Authors noted that less root defects were produced in tree seedlings in air pruning containers than those grown in solid walled containers, but also had slower canopy and root growth due to the lateral air pruning (Ortega et al., 2006).

1.4 Air root pruning

Air root pruning is the technique wherein root tip exposure to air movement desiccates and kills the root tip in a suitable container. As roots get pruned, the area behind the root tip is stimulated to produce branches providing many more secondary roots. As more secondary roots develop, it increases nutrient absorption enabling the plant to grow more rapidly. Air root pruning utilizes containers that have holes or slots in its walls along with a system of ribs or other devices to direct root tips to grow out of the holes/slots being exposed to drying air currents.

Marshall and Gilman (1998) reported that Accelerator® air root pruning containers caused an increase in number of descending roots compared to smooth sided containers probably due to the corrugated sides.

Tap root growth was stopped by placing the tap root into a small plastic cone and the tip exposed to air. The tap root was pruned instead of being blocked. The existing lateral roots positioned close to the soil surface were invigorated and grew faster. When new roots were generated at the cut end of the tap root, lateral roots grew only slightly faster than non-pruned controls (Thaler and Pages, 1997). This has been attributed in young seedlings to carbon moving to the cut end of the tap root when no lateral roots were present, or to the lateral roots when lateral roots were present. An immediate increase was seen in the radioactive carbon accumulation in the upper lateral roots when the tap root tip of more mature seedlings (with existing lateral roots in the upper section of the root zone) was removed (Atzmon, 1994).

It was shown by Gilman et al. (2002) that the caliper of Live Oak (*Quercus viginiana* Mill) was not affected by root pruning, but slight impact on the height of the plant was seen. The number of roots seemed to increase when root pruning was done with a hand spade or when it was done using root pruning fabric that was placed under the liner at planting. Gilman et al. (2002) also showed that small diameter (< 5 mm) root weight : shoot ratio was reduced when root pruning was carried out with fabric in combination with a spade. Authors concluded that trees that were root pruned had better survival rate in summer and winter digging seasons than the trees that were not pruned.

Cathedral Oak® Live Oak trees regularly root pruned throughout the production period grew at a slower rate than the trees which were not pruned. However, in the last year of production root pruning did not affect trunk and canopy growth. Number of small diameter (< 3 mm) roots increased and number of large diameter roots decreased when hand spade was used for root pruning throughout the production period (Gilman and Anderson, 2006).

A different type of container, the RootMaker® was originated from a study which was designed for a different purpose, but ended up showing that trees having lots of root branching at the stem-root junction outgrew the trees having fewer large roots at this location (Whitcomb, 2003).

Root pruning was efficiently carried out using the RootMaker® container which was introduced by Dr. Carl E. Whitcomb. Root constriction pruning grew from a chance observation in 1967. He performed air-root pruning in 1968 using milk cartons with bottoms removed. This eventually led to the development and introduction of RootMaker®. According to Whitcomb, fibrous, non circling root systems grow horizontally and vertically by using RootMakers® to develop plants roots for transplanting success. A fibrous root system means a greater root tip surface area and translates into a greater efficiency in the absorption of water and nutrients; an increase in growth rate, establishment, and vigor; a higher transplant survivability, and ultimately, superior performance for the customers. RootMaker® containers are designed to direct roots into openings in the container. (Whitcomb, 2003 www.rootmaker.com).

Usually, the tap root is the first root to reach and become exposed to air at the openings in root pruning containers. The tip dehydrates and stops growing. When this occurs, secondary roots form immediately behind the root tip that are more horizontal in growth habit. These secondary roots soon reach side openings causing dehydration of the root tips, resulting in additional branching. Timing is very important when the RootMaker® root pruning container is used. Monitoring root growth and plant progress is essential. Horsley (1971) showed that new roots are generated primarily near the cut end of a root and grew more or less in line with the orientation of the cut root. A rule of thumb proposed by Carl Whitcomb was “the 4-inch (10 cm) Rule”. Similar to pruning trees or shrubs where the greatest production of shoots is immediately behind the cut stem, when roots are pruned, root branching occurs at the tip of the root to about four inches back. As a result, RootMaker® propagation containers are four inches (10 cm) deep. (Whitcomb, 2003 www.rootmaker.com). The “4-inch rule” helps to maximize root branching in containers. If the 4-inch rule is not used plants grown in containers can extend aimlessly through the porous container substrate with less resistance resulting in less natural branching. Use of the 4-inch rule could bring about optimum root branching of maximum growth and utilization of container volume (Whitcomb, 2003).

Previous studies showed air root pruning containers, containers with copper hydroxide treated walls, and shallow wide containers reduce root circling. Even with the abundance of container types designed to reduce circling roots, no containers appeared to eliminate root defects (Marshall and Gilman, 1998). As descending, ascending and circling roots appear to be common and can become a serious root defect contributing to instability and poor health, root pruning container grown trees need much more attention (Gilman et al., 2009).

March and Appleton (2004) found no differences in shoot and root dry weights for *Quercus rubra* (Red Oak) when using different container types. Containers used were RootMaker® (plastic), Accelerator® (plastic), RootTrapper® (fabric), Root control smart pot (fabric), Terra-cell ARPACC (plastic) and Texel Tex-R Agroliner (fabric). RootTrapper® grown trees showed statistically significant higher root and shoot dry weights than the ARPACC containers.

The capability of roots to explore the soil for water and nutrients and to grow is an extremely important factor in determining the plant's growth rate. As roots elongate through soil, they experience mechanical impedance and reduced growth rates because of the force required to displace soil particles. Strong soil can restrict the entry of the roots to water and nutrients, hence it can be a serious issue of concern in agriculture and can reduce the crop yield (Clark et al., 2003). Clark et al., (2003) also reported that the possibility of wider roots to deflect or buckle against the strong soil layer is less. It was demonstrated by Materechera et. al. (1992) that root size had a significant influence on its capability to penetrate a strong soil layer. He discussed three mechanisms by which thicker roots could enter a strong soil layer. They were as follows: thicker roots have better resistance to bending and other root properties, thick roots exert high axial pressure and if roots are thick, stress relief results at the root tip. Results obtained showed that the diameter of the root can have an important influence on the entry of roots into the strong soil layer.

Root tips of plants grown in soil with a compacted layer had larger diameter than those from uncompacted soil. Bigger diameters and relative root diameter were seen in tap rooted species than fibrous rooted species. Large proportion of thicker roots penetrated the strong layer at the interface when compared to the thinner roots. Roots had larger relative root diameter also had higher penetration percentage (Materechera et. al., 1992).

Many different techniques have been developed in order to evaluate roots. Weight has been used as the means of assessing the amount of roots by most quantitative studies, but it is generally accepted that the capability of the root system to take up water and salts is usually more closely related to surface area or total length than to its weight (Newman, 1966). Newman (1966) stated that line intersection method which is counting the number of intersections between the roots and random straight line when the roots are laid out on a flat surface achieved higher precision than weighing in a given time and it was much quicker than the given measurements. Total root length is measured by $\pi NA/2H$ where N is the number of intersections, A is the area within which the roots lie, and H the total length of the straight lines. It was shown by Bouma (2000) that WinRHIZO and Delta -T Scan software packages give accurate measurements of root-diameter and root length distribution. According to the author, the WinRHIZO had an advantage over the Delta – T scan due to some features.

Two other methods used for root evaluation are the soil trench method and the core-break method. Soil trench method involves digging a soil trench, fixing a grid on the trench wall and counting the number of roots exiting the wall in each grid section. And the core-break method consists of extracting a core from soil using a tube, washing the sample and later measuring the root length or biomass (Lopez-Zamora et al., 2002). Lopez-Zamora (2002) stated that the soil trench method is less laborious and acts faster than the soil core break method. Wright and Wright (2004) stated that measuring roots by Horhizotrons is a simple and non destructive method. Roots can be measured by this method under different ranges of rhizosphere conditions. The Horhizotron is made up of 4-wedge shaped glass quadrants. These quadrants allow measurement of roots as they grow and extend away from the original root ball. To evaluate the effect of substrate, or root environment on root growth, the substrate in each quadrant can be changed accordingly. Five longest roots on each side of the quadrant can be measured or first 5 root tips hitting the glass of each quadrant can be monitored.

The main objective of this research was to compare container root pruning technology using the RootMaker® container vs traditional container production systems and a diverse range of plant species (from seed / cuttings to saleable plant) on :

- Plant growth – to compare the growth of roots and shoots of plants grown in traditional as well as RootMaker® container systems.
- Transplant establishment – potential effects of root pruning on establishment success of a plant is when roots leave the original root ball and exploit the surrounding soil and environment and no longer depend on the original

container environment. Hypothesis is that increased root growth rate and density of roots equals greater comparative establishment success.

- Combinations of technologies i.e. possible effects of hybrid systems – using combinations of both RootMaker® containers as well as the traditional containers and subsequent effects on growth and transplant success.

This research evaluates the effect of RootMaker® production system, and the traditional container system on the growth and quality of the plants. The study focused to assess if the RootMaker® container production system facilitate a root pruned system that translates into any advantages for transplant success and growth of transplanted plants to the landscape or other containers?

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Chapter 2

Effects of Root Pruning Containers and Traditional Containers on Growth of Roots and Shoots of Selected Landscape Plants

Index Words: Root pruning, transplantation, air root-pruning containers

2.1 Abstract:

Objectives of this research were to compare the effects of container root pruning technology, RootMaker® containers, traditional containers, and a combination of both production systems on plant growth using a diverse range of plant species (from liners to saleable plants). *Catalpa speciosa*, *Quercus coccinea* (scarlet oak), *Quercus rubra* (red oak), *Quercus alba* (white oak), *Hydrangea macrophylla* 'Penny Mac', *Ilex cornuta* 'Ponderi' (ponder holly) and *Ilex* x 'Nellie R. Stevens' (Nellie R. Stevens holly) were transplanted through a combination of container sizes and the two root pruning systems to reach a prescribed saleable plant size. Only hydrangea's showed differences in height and growth indices when plants grown in RootMaker® containers, traditional containers and a combination of both were compared. Root growth showed differences depending on species, container shifting sequence and method of root measurement. No differences were observed among pure traditional and RootMaker® systems when the roots were scanned and analyzed using WinRHIZO software, but some differences were seen among the hybrid (combination of both systems) systems. Work continues to determine reliable root measurement technique

as a predictor for transplant and establishment success and if either system provides any growth advantages.

2.2 Significance to the Nursery Industry

In 2002, container nursery crop production represented 60% of a 13.8 billion dollar industry (Yeager et al., 2007). Circling roots and girdling roots are observed to be the most common root deformities in all container produced plants and can affect the growth and establishment of plants. Research evaluated effects of air root pruning containers, RootMaker® System, on growth of Catalpa's, Scarlet oaks and Hydrangea's and compared results with plants grown in traditional containers and subsequent growth potential after transplant. A combination of both systems were also used to assess the potential advantages of hybrid systems. We hypothesized that increased root growth and density of roots will result in a greater comparative container and landscape transplant establishment success. The height and the growth index of hydrangea's were affected by the container type. Different root measurement techniques were used for root evaluation, and no consistent results were obtained. Limited top growth advantages were seen for hydrangea when grown in the RootMaker® System, but for other species tested there was no clear advantage to either production system for top growth. Evaluation of root deflection or root wrapping were not directly measured since all transplants were shifted prior to root wrapping but number of surface root tips of catalpa trees from 26.5 l containers were greater in RootMaker® container-grown trees. Other root evaluation parameters did not show differences between container systems. There is limited data for species tested to indicate enhanced root systems for transplanting to support top growth advantages with the two systems.

2.3 Introduction

When plants are grown in containers, basic physiological principals involved in the production of any crop are not altered, neither are plant genetics altered (Whitcomb, 2003). Container produced plants have shown increased establishment success after transplanting, or resulted in greater transplanting quality over field produced plants (Mathers et al., 2007). In container grown plants roots are packaged and transplant stress is minimized as compared to the field grown stock. In field grown stock many fine roots are damaged and 30% of root area are left in the soil, lost or damaged during digging and handling of bareroot plants (Thomas, 2000). Ideally, transplanting should be done as soon as the root development has progressed to hold the soil mix together but before root-bound stress occurs. As plants become root-bound, growth rate of the plants starts declining due to root intermingling, congestion and decrease in oxygen and space available for further development of roots (Whitcomb, 2003). Transplant establishment success of a plant is determined by the ability of the plant roots to leave original root ball and exploit surrounding soil environment and no longer depend on the original container environment resources.

Roots that grow across the root ball and in close proximity to the tree stem or root collar are called girdling roots. The root collar is the region where the tree stem transitions to the root system. Roots that grow and conform to the round container shape are called circling roots. Roots that grow in seemingly the opposite direction to what they should have grown are called as misdirected roots (Altland , 2007). These three problems can be corrected by pruning roots of the plants. Root pruning is the act of cutting the roots of shrubs or trees to force more vigorous growth, or to prepare plants for transplanting (Landscape Ontario Horticultural Trade Association, Appendix F, 2004). Root pruning is done by using three different methods: manual pruning, chemical pruning and air pruning.

Root pruning was efficiently carried out using the RootMaker® container which was introduced by Dr. Carl E. Whitcomb. Root constriction pruning grew from a chance observation in 1967. He performed air root pruning in 1968 using milk cartons with bottoms removed. This eventually led to the development and introduction of RootMaker® (Whitcomb, 2003 www.rootmaker.com). RootMaker® containers are designed with holes in the sides and bottom and include interior ridges that direct roots to root pruning openings to reduce circling roots and to create a fibrous root system where as traditional containers have smooth sides and holes at the base of the container for drainage purposes. A rule of thumb proposed by Carl Whitcomb was "the 4-inch (10 cm) Rule". Similar to pruning trees or shrubs where the greatest production of shoots is immediately behind the cut stem, when roots are pruned, root branching occurs at the tip to about four inches back. As a result, RootMaker® propagation containers are four inches (10 cm) deep. (Whitcomb, 2003 www.rootmaker.com). The "4-inch rule" helps to maximize root branching in containers. If the 4-inch rule is not used plants grown in containers can extend aimlessly through the porous container substrate with less resistance resulting in less natural branching. Use of the 4-inch rule could bring about optimum root branching of maximum growth and utilization of container volume (Whitcomb, 2003).

Air root pruning is the technique wherein root tip exposure to air movement desiccates and kills the root tip in a suitable container. As roots get pruned, the area behind the root tip is stimulated to produce branches providing many more secondary roots. As more secondary roots develop, it increases nutrient absorption enabling the plant to grow more rapidly. Air root pruning works by the containers have holes or slots in its walls along with a system of ribs or other devices to direct root tips to grow out of the holes/slots and be exposed to drying air currents. Marshall and Gilman (1998) reported that Accelerator® air root pruning containers caused an increase in number of descending roots compared to smooth sided containers probably due to the corrugated sides. March and Appleton (2004) found no differences in shoot and root dry weights for *Quercus rubra* (red oak) when different air root pruning container types were used. It was shown by Gilman et. al. (2002) that the caliper of Live Oak (*Quercus viginiana* Mill) was not affected by root pruning, but slight impact on the height was seen. It was seen that the tree height was reduced but only at P = 0.06 level, hence it was not considered statistically significant. The number of roots seemed to increase when root pruning was done with a hand spade or when it was done using root pruning fabric that was placed under the liner at planting.

Many different techniques have been developed in order to evaluate roots. Weight has been used as the means of assessing the amount of roots by most quantitative studies, but it is generally accepted that the capability of the root system to take up water and salts is usually more closely related to surface area or total length than to its weight (Newman, 1966). Newman (1966) stated that line intersection method which is counting the number of intersections between the roots and random straight line when the roots are laid out on a flat surface achieved higher precision than weighing in a given time and it was much quicker than the given measurements. Total root length is measured by $\pi NA/2H$ where N is the number of intersections, A the area within which the roots lie, and H the total length of the straight lines.

Wright and Wright (2004) stated that measuring roots by Horhizotrons is a simple and non destructive method. Roots can be measured by this method under different ranges of rhizosphere conditions. The Horhizotron is made up of 4-wedge shaped glass quadrants. These quadrants allow measurement of roots as they grow and extend away from the original root ball. To evaluate the effect of substrate or root environment on root growth, the substrate in each quadrant can be changed accordingly. Five longest roots on each side of the quadrant can be measured or first 5 root tips hitting the glass of each quadrant can be monitored.

The main objective of this research was to compare container root pruning technology vs traditional container production systems (from seed / cuttings to saleable plant) on :

- Plant growth – to compare the growth of roots and shoots of plants grown in traditional as well as RootMaker® containers.
- Transplant establishment – potential effects of root pruning on establishment success of a plant is when roots leaves the original root ball and exploit surrounding soil and environment and no longer depends on the original

container environment. Hypothesis is that increased root growth rate and density of roots equals greater comparative establishment success.

- Combinations of technologies i.e. possible effects of hybrid systems – using combinations of both RootMaker® containers as well as the traditional ones.

This research evaluates whether root pruning using the RootMaker® production system, has any effect on the growth and quality of the plants compared to traditional containers. It also evaluates whether RootMaker® container production systems are effective or not at the end of the production cycle and do the pruned roots translate into any potential advantages for transplant success and growth of transplanted plants to the landscape or other containers.

2.4 Materials and Methods

On August 30th, 2009, *Quercus coccinea* (scarlet oak) seedlings (150 days after planting), *Catalpa speciosa* liners (180 days after planting) and *Hydrangea macrophylla* 'Penny Mac' liners (150 days after planting) on their own roots were planted from RootMaker® 32 cell tray (RM II - 32, RootMaker® Products Co, Huntsville, AL) 180.2 cm^3 (5.7 cm x 5.7 cm x 10.1 cm) [11 in^3 (2.25 in x 2.25 in x 4 in)] and traditional propagation trays into two different 3.8 l (1 gal) container types. Species were chosen to represent trees and shrubs with different root types and plant diversity. No root pruning was done at transplanting. Plants were transplanted prior to root wrapping but when roots fully exploited and held the integrity of the root ball. Containers used for this research were smooth sided traditional containers (Nursery Supplies INC, Fairless hills, PA) and RootMaker®, system containers [RootMaker®, RootBuilder® II, and RootTrapper® soft sided containers (RootMaker® Producrs Co, Huntsville, AL)]. RootBuilder® II containers can be easily assembled around a bottom disc. Roots are directed outwards towards the hole which are present at the tip of each outwardly projecting funnel on the side walls forcing them to branch and continue the air pruning process. RootTrapper® soft sided containers are fabric containers that prune roots by root tip trapping (Whitcomb, 2003 www.rootmaker.com) (figure 2). At the same time additional seedling of *Quercus rubra* (red oak), *Quercus alba* (White oak) and *Quercus coccinea* (scarlet oak) and rooted liners of *Ilex cornuta* 'Ponderi' (ponder holly), *Ilex* x 'Nellie R. Stevens' (Nellie R. Stevens holly), *Catalpa speciosa*, and *Hydrangea macrophylla* 'Penny Mac' were planted from the RM II – 32 cell trays and the traditional propagation trays into 3.8 l containers as a similar study at a separate location at the Ornamental Horticulture Research Center (OHRC) located in Mobile, AL. Propagation trays from which the liners were transplanted were elevated above the propagation benches on lattice type, open plastic trays to allow air flow beneath the flats to facilitate air root pruning. When the roots of liners fully exploited the propagation containers and roots extended from the bottom of the propagation cells but prior to circling the container walls, the three species at Paterson Greenhouse at Auburn, AL and seven species at the OHRC at Mobile, AL were transplanted to container sizes and times specified in Tables 1, 2 and 3. Containers were placed on a black nursery ground cloth over gravel in full sun and spaced 60 cm (2 ft) apart. Plants were irrigated with overhead sprinklers as needed based on season, plant species and weather conditions.

Substrate used for 3.8 l containers was a blend of pine bark screened to ½ inch and coarse builders sand (7:1, v:v). A slow release fertilizer, Polyon 17-5-11 (N-P_2O_5-K_2O, Harrell's LLC, AL) was incorporated at 5.4 kg.m^{-3} (9.1 lbs.yd^{-3}), Pulverized Dolomitic Limestone (Old Castle Lawn & Gardens, GA 31150) was added at 3.0 kg.m^{-3} (5 lbs.yd^{-3}) and Micromax micronutrients (Scotts-Sierra Horticultural Products Company, OH 43041) at 0.59 kg.m^{-3} (1.0 lbs.yd^{-3}) were uniformly incorporated in the substrate using a substrate mixer (Mitchell Ellis Products Semmes, AL). Weeds were periodically hand pulled from containers as needed.

Twelve liners of each species were transplanted to 3.8 l RootMaker® (RM) and traditional containers (TC) (Classic 300s, Nursery Supplies INC, Fairless Hills, PA) according to six transplant treatments for Catalpa's and four transplant treatments for scarlet oaks and Hydrangea's as outlined in the Tables 1, 2 and 3. All containers were arranged in a completely randomized design by species according to the six treatments specified. Five liners each from RootMaker® and traditional propagation containers were sacrificed to measure the root dry weight. Roots of these liners were separated from shoot at substrate level, washed and placed in a drying oven for 72 hours at 170° F (76.7 °C) and their root dry weights were recorded.

On June 1st, 2010, height and caliper of trees was measured at 15.2 cm (6 in) above the container; and for shrubs, height, width at the widest point and width perpendicular to widest point were measured. Ten plants of Catalpa's [5 from traditional Containers (TC) and 5 from RootMaker® containers (RM) from 3.8 l containers] were transplanted into the Horhizotrons on June 4th, 2010, using the same substrate formulation. Tree height, caliper and width measurements were taken immediately after transplanting. Horhizotrons measurement of root growth under different types of root environments were recorded. They contain 4 wedge-shaped quadrants of glass that extend away from the original plant root ball. The length and width of the Horhizotrons are (60.9 x 60.9 cm) 2 x 2 ft. Horhizotrons were placed on raised benches in the greenhouse. To provide insulation against dramatic temperature fluctuations, walls and a lid of light impermeable foam insulation board (19.1 mm) 0.75 in with aluminum foil on outside and plastic on inside enclosed the Horhizotrons (Wright and Wright, 2004). Root lengths were measured weekly of the five longest roots on each side of the quadrant. New roots grown from the original root ball from each quadrant were harvested on June 29th, 2011 and dried as mentioned above. Dry weights were recorded and analyzed using SAS statistical software (version 9.1, SAS Institute, Cary, N.C.) to test the treatment effect. On June 20th, 2010, all the three plant species, Catalpa's, Scarlet oak's and Hydrangea's were transplanted from 3.8 l containers into 26.5 l (7 gal) (Catalpa's) and 11.4 l (3 gal) (Oak's and Hydrangea's) containers using the same substrate formulation. Oak, and Hydrangea plants from 3.8 l traditional containers were transplanted into the 11.4 l traditional containers (Classic 1200, Nursery Supplies INC, Chambursburg PA) and plants from 3.8 l RootMaker® containers were transplanted into 11.4 l RootMaker® containers. Catalpa plants were transplanted from 3.8 l TC to 26.5 l TC (HPP 700 series, Haviland OH), and plants from 3.8 l RM containers were transplanted to Rootbuilder® II expandable containers that were used to make 26.5 l containers. Containers were placed outside pot-to-pot spacing on the container pad. Hydrangea's were moved under 50% shade. Tree caliper and height were measured for Catalpa's on November 28th, 2010.

On March 3rd, 2011, before transplanting Catalpa plants from 26.5 l containers into 75.7 l (20 gal) containers, a pie shaped section from the root ball was harvested using a 7.6 cm (3 in) equilateral pie shaped wire template. The template was placed on the edge of the circumference of the root ball with a point of the template at or near the surface of the previously 3.8 l transplanted root ball and a vertical section was excised 15.2 cm (6 in) down from the surface. Two and half centimeter (1 in) of the surface roots were removed to avoid possible weed roots that may have been present. A 7.6 cm (3 in) square wire template was used to demarcate an area on the root ball to count the number of root tips inside the demarcated area on opposite sides of the root ball. The first count was made on what was subjectively considered the most dense root accumulation (root count A) and the second count was determined 180° from the first count (root count B) on both sides 2.5 cm (1 in) below the surface of the root ball. Harvested roots were washed to remove the substrate, weighed, and stored in zip lock bags to be scanned later. It was determined that 4 g of roots could fit in the scanning tray without impeding light penetration and thus limiting accuracy of data. Four grams of the roots were randomly sampled from each zip lock bag, weighed, and dyed with Neutral Red Dye (HARLECO®, EMD Chemicals Inc., Gibbstown, NJ). Roots were soaked in the dye for 24 hours to prepare them for scanning. Dyed roots were evenly spread on a transparent tray [20.3 cm x 22.8 cm (8 in x 9 in)] containing water and imaged at a resolution of 400 dpi (dots per inch) using an Epson scanner (Meng-Ben and Qiang, 2009). Root images were analyzed for the root length (cm), root surface area (cm^2), root average diameter (mm) and number of root tips by using WinRHIZO™ software (Basic version, Reagent Instruments, Quebec, Canada).

On March 23rd, 2011, Catalpa trees from 26.5 l containers were transplanted into 75.7 l containers using the same substrate and fertilizer amendments and placed under overhead irrigation on the container pad at 60 cm (2 ft) apart arranged in a completely randomized design according to shifting schedule outline in Table 1. Ten trees from each of TC and RM treatments were transplanted from 26.5 l containers into 75.7 l TC and RootTrapper® containers. Twelve trees each from the 26.5 l RootBuilder® containers (initial transplant sequence TC to RM to RM) and TC (initial transplant sequence RM to TC to TC) were transplanted into 75.7 l TC and RootTrapper® containers, respectively. Twelve trees from the 26.5 l traditional containers were transplanted into 75.7 l traditional containers. Of thirty-one trees, ten trees from 26.5 l RootBuilder® containers were transplanted into 75.7 l traditional containers and remaining twenty-one trees were transplanted into 75.7 l RootTrapper® containers. We shifted Catalpa's into larger containers, but no data was collected on them. On 15th April, 2011, 16 plants of Hydrangea's from the 11.4 l containers (8 from TC and 8 from RM) were transplanted into the Horhizotrons and rest of the plants from the 11.4 l containers were determined to meet the saleable standards set by Florida Grades and Standards for Nursery Stock (Gilman, 1998) for roots and shoots. Profile Greens grade (Profile Products LLC, IL 60089) was used as a substrate in the 4 quadrants of the Horhizotrons to facilitate the ease of root harvest. Horhizotrons were top dressed with 22.0 g (0.05 lbs) of 15-6-12 Harrell's professional fertilizer (N-P_2o_5-K_2O, Harell's LLC, AL) per quadrant at the medium recommended rate of 9.5 $kg.m^{-3}$ (16 $lbs.yd^{-3}$). Irrigation needs were monitored and plants were hand watered by adding 400 ml in all the 4 quadrants and 500 ml to the root ball as needed at each irrigation event. Flower buds were removed from plants so maximum energy would be utilized for the growth of the roots. Roots were observed until 5 root tips hit the glass in all 4 quadrants. On May 31st, 2011, roots were harvested. Roots were cleaned and separated from Profile substrate and kept separately for each quadrant. Fresh weights of the harvested roots were recorded. From the 4 quadrants of the Horhizotrons, the highest and the lowest weight quadrant samples of the roots from each treatment were eliminated and the middle two quadrant root samples were combined. From these combined root samples, 4 g of the roots were randomly selected, dyed and used for scanning for root measurements using the WinRHIZO software and protocol for recording this data. The scanning procedure was done the same way as mentioned earlier using Epson scanner. WinRHIZO software (Basic version, Reagent Instruments, Quebec, Canada) was used to evaluate the root length, surface area, average diameter and the number of root tips. Top growth was cut at substrate surface from the remaining Hydrangea's from 11.4 l containers, dried for 72 hours at 170° F and weighed.

A similar study was conducted at the Ornamental Horticulture Research Center (OHRC) located in Mobile, AL. Same transplant treatments were evaluated with some species differing in the study, Plants used there were red oak, white oak, ponder holly, Nellie R. Stevens holly', Catalpa, scarlet oak, and Hydrangea. All plants were shifted to larger containers as they reached the required stage of growth.

All trees and shrubs were arranged in completely randomized design. Data were analyzed using SAS statistical software (version 9.1, SAS Institute, Cary, N.C.).

Tukey's studentized range test in the GLM procedure at $p < 0.05$ was used for mean separation.

2.5 Results and Discussion

No differences were found in final height and caliper of Catalpa's while in 26.5 l containers as a result of root pruning when plants were shifted into larger containers beginning when the rooted cuttings were planted in 3.8 l containers. Similarly, no differences were observed in the height and caliper of scarlet oaks that were transplanted into 11.4 l RootMaker® (RM) and traditional containers (TC).

Hydrangea's responded to container system treatments with differences seen in the growth index and plant height. Plants were taller when they were transplanted from RM propagation trays to 3.8 l RM containers and from TC propagation trays to 3.8 l RM containers (Table 4). Plants grown using hybrid systems (TC-RM) showed increased growth index (GI) over RM to TC and TC to TC, and had similar GI with plants from RM to RM system (Table 4). Gilman et al. (2010) observed that trees produced in RootMaker® containers had larger caliper and height than the trees in Florida Cool Ring™ (a fabric design container for root pruning) or Jackpot™ (fabric air root pruning container), and trees produced in the RootBuilder® showed increased caliper over trees grown in Jackpot™. Marler and Wills (1996) stated that fewer circling roots were seen on trees in RootBuilder® than the smooth-sided containers for two tropical trees. Fewer circling roots were seen in many Australian tree types which were grown in 20 cm (8 in) diameter Air-Pot™ when compared to the smooth-sided containers 8 months after potting (Moore, 2001).

Gilman et al. (2009), found that in spite of root pruning that occurred each time trees were potted into larger containers, the height and caliper of *Quercus virginiana* 'SDNL' Cathedral Oak® was not affected. In a recent study researchers found that the amount of roots growing into substrate outside the original root ball was enhanced as a result of light cutting of circling roots of shrubs (Blanusa et al., 2007). In contrast Gilman et al. (1996) showed redistribution of cut roots of Burford holly (*Ilex cornuta* 'Burfordii') roots at planting, but no increase in number of roots were found when compared with non-pruned controls. March and Appleton (2004) found no differences in shoot and root dry weight for *Quercus rubra* (red oak) when different types of air root pruning containers were used.

Romero et al., (1986) analyzed root development of Caribbean pine (*Pinus caribaea*) grown in a copper-carbonate treated container and found that root pruned seedlings had more lateral roots, larger stem diameter, finer and more fibrous root system than the control seedling. However, the major benefits of chemical root pruning occurred after transplanting (Barnett and McGilvary, 2001). *Pinus halepensis* seedling quality was improved by coating containers with basic cupric carbonate without causing visible phytotoxicity symptoms. Chemically root pruned seedlings survived no better than non treated seedlings two years after field planting, but exhibited higher stem volume and annual growth of the stem volume (Tsakaldimi and Ganatsas, 2006).

In this study weekly root measurements in Horhizotrons showed no differences in the root length of five longest roots of Catalpa's among different treatments. Total dry weights of roots indicated that root pruning did not affect the root dry weight of

Catalpa’s and hence no differences were apparent among the two container production systems as this stage of growth.

Wright and Wright (2004) used Horhizotron technique on *Buxus microphylla* ‘Green Beauty’ (boxwood) and *Kalmia latifolia* ‘Olympic Wedding’ (mountain laurel) and found that the roots of boxwood grew at an angle of 45° and roots of mountain laurel grew parallel to the substrate surface. Roots of plants in the Horhizotrons grew (10.2 to 15.2 cm) 4 to 6 inches over 2 to 3 months. Hydrangea’s and Catalpa’s had different root systems. Roots of Catalpa’s were large, coarse and darker whereas roots of Hydrangea’s were finer and transparent (visual observation). Harvested and scanned roots of Hydrangea's showed no differences in the root length, root diameter, or number of root tips. But differences were observed in the root surface area where roots from TC had more root surface area which was 215.0 cm^2 than those in RM which was seen to be 199.3 cm^2. As there were no further transplant shifts for Hydrangea’s top growth dry weight was measured but there were no differences between the RM and TC systems.

When the root tips were counted on the opposite sides of 26.5 l Catalpa plants using 3 in x 3 in square template, there were differences among the RM, TC and the hybrid systems. Plants grown in the 26.5 l Rootbuilder® II had more root tips than the plants which were transplanted in to 26.5 l TC (Table 5). Rootbuilder® II and RootTrapper® containers (fabric air root pruning containers) are part of the RM

Once the pie shaped sample of the roots were harvested, prepared and scanned, there were no differences between the pure Rootmaker® (RM to RM to RM) and the traditional (TC to TC to TC) systems from the sampled roots for the root surface area, root average diameter, root length, and number of root tips (Table 6). There were, however, differences in root surface area and root length between the traditional system (TC-TC-TC) and one of the hybrid systems (RM-TC-TC) where roots in traditional system had more root surface area and root length than the hybrid system (RM-TC-TC), but were equal to TC-RM-RM and pure system RM-RM-RM. This was a different result from hydrangea growth from the earlier 1 gal shift sequence where TC to RM showed increased growth index in RM to TC and TC to TC, but not RM to RM (Table 4). Number of root tips of Catalpa in the hybrid system (RM-TC-TC) was lower in number than root tips of TC-RM-RM and pure system RM-RM-RM, but were equal to the pure traditional system. Root diameter in the hybrid system (RM-TC-TC) was the largest diameter when compared to both pure systems and hybrid system TC-RM-RM (Table 5 and 6).

Materechera et. al. (1992) observed that root tips of plants grown in soil with a compacted layer had larger diameters than those from uncompacted soil. More increased root diameters and relative root diameters were seen in tap rooted species than fibrous rooted species. They also stated that a larger proportion of thicker roots penetrated the strong layer at the interface when compared to the thinner roots. The capability of the root system to take up water and salts is usually more closely related to root surface area or total root length than to root weight (Newman, 1966). So, increased numbers of smaller roots with greater total surface area can potentially provide an advantage for uptake of water and nutrients during establishment, while larger diameter roots can find easier access to surrounding soils under more compacted conditions. More, finer outward facing root tips at the soil/substrate interface may compensate for size of thicker roots with greater numbers ready to access the surrounding soil with greater water uptake potential. Establishment is accomplished when roots from the container move into the surrounding soil and the plant no longer relies on the limited resources of the confined substrate and is accessing resources from the surrounding soil.

As mentioned earlier, a similar study was conducted at the Ornamental Horticulture Research Center (OHRC) located in Mobile using similar species red oak, white oak, ponder holly, Nellie R. Stevens holly, Catalpa, scarlet oak, and Hydrangea. Only shoot evaluation was done for these plants. After the data analysis, no differences were found in the height, caliper, width's and Growth Indices of these plants.

Different methods for root evaluation used in past research were used in this study, but there were contradictions in the results among the various root assessment methods. There is a difference in the traditional measuring of root fresh or dry weights compared to the root parameters measured in sampled root systems from the whole root ball and measuring root tips at the surface vs. root tips in sampled sections of interior vs. surface areas of the rootball. In future research, more work will be done to isolate root tips at surface of the root ball, root tips at the end of the roots after transplant and growth into the surrounding soil. Samples of the whole root ball system will be used to determine if relevant differences are seen in the root measurements of total mass compared to other growth parameters. Appropriate methods of these root assessments that offers the best correlation to growth and establishment of container plants will be selected. WinRHIZO analysis of root tip number, total length, total surface area, and average diameter will be done on the substrate surface root tips, end roots after transplant and middle roots to determine the same. The question arises as to whether when roots are measured to evaluate potential for transplant success, is it more important to have more root tips at the surface of the original root ball shortly after transplant? Or, is it more important to have greater root mass, diameter or surface area at the transplanted root ball surface/soil interface or sampled or total mass, average diameter, surface area length and root tip number measured after a longer root growth and establishment period?

This research is a part of an ongoing process. In case of plants grown at Horticulture Research Center (OHRC) located in Mobile, root evaluation will be carried out in near future. We are still trying to determine and will continue the research in order to see which root measurement or measurements will be most reliable predictor for transplant success.

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Table 1. Transplant shift sequence for *Catalpa speciosa.*

<table>
<tr><th>Treatment</th><th>1st Shift (propagation cells to #1 containers) August 30th, 2009 Approximately 180 dap</th><th>2nd Shift (#1 container to #7 RootBuilder® II containers) June 20th, 2010 Approximately 480 dap</th><th>3rd shift (#7 containers to #20 RootTrapper® containers) March 23rd, 2011 Approximately 750 dap</th><th rowspan="7">During the 2nd shift 5 Plants from #1 TC and RM containers were transplanted into the Horhizotrons .</th></tr>
<tr><td>1</td><td>TC – TC[z]</td><td>TC – TC</td><td>TC – TC</td></tr>
<tr><td>2</td><td>TC – TC</td><td>TC – TC</td><td>TC – RM</td></tr>
<tr><td>3</td><td>TC – RM</td><td>RM – RM</td><td>RM – RM</td></tr>
<tr><td>4</td><td>RM – TC</td><td>TC – TC</td><td>TC – TC</td></tr>
<tr><td>5</td><td>RM – RM</td><td>RM – RM</td><td>RM – TC</td></tr>
<tr><td>6</td><td>RM - RM</td><td>RM – RM</td><td>RM – RM</td></tr>
</table>

[z] TC = Traditional Container, RM = RootMaker® Container. RootBuilder® II and RootTrapper® soft sided containers are a part of RootMaker® system.

Table 2. Transplant shift sequence for *Hydrangea macrophylla* 'Penny Mac'.

Treatment	1st Shift (propagation cells to #1 containers) August 30th, 2009 Approximately 150 dap	2nd Shift (#1 gal container to #3 containers) June 20th, 2010 Approximately 450 dap	8 plants from each, #3 TC and RM containers were transplanted into the Horhizotrons
1	TC – TC[z]	TC – TC	
2	TC – RM	RM – RM	
3	RM – TC	TC – TC	
4	RM – RM	RM – RM	

[z]TC = Traditional Container, RM = RootMaker® Container.

Table 3. Transplant shift sequence for *Quercus coccinea.*

Treatment	1st Shift (propagation cells to #1 containers) August 30th, 2009 Approximately 150 dap	2nd Shift (#1 gal container to #3 containers) June 20th, 2010 Approximately 450 dap
1	TC – TC^{z}	TC – TC
2	TC – RM	RM – RM
3	RM – TC	TC – TC
4	RM – RM	RM – RM

^{z}TC = Traditional Container, RM = RootMaker® Container.

Table 4. Effect of RootMaker® (RM), Traditional (TC) Container systems and hybrid shift sequence of systems on the Growth Index (GI) and height (HT) of *Hydrangea macrophylla* 'Penny Mac'

Treatment	HT (cm)	GI[y] (cm)
TC-TC[z]	36.0 b[x]	32.0 b
TC-RM	46.2 a	38.1 a
RM-TC	31.8 b	27.4 c
RM-RM	46.5 a	36.6 ab

[Z] TC = Traditional Container, RM = RootMaker® Container

[y]Growth Index =(height + maximum width + perpendicular to maximum width) / 3

[x]Lowercase letters denote mean separation using Tukey's studentized range test with GLM procedure at $p < 0.05$ (version 9.1, SAS Institute, Cary, N.C.)

Table 5. Effect of RootMaker® (RM), Traditional (TC) Container systems and hybrid shift sequence of systems on the number of root tips (RT) on opposite sides (A and B) of the root ball of *Catalpa speciosa* finished in #7 containers.

Treatment	RTA[y]	RTB[x]
TC-TC-TC[z]	40.0 b[w]	31.1 b
TC-RM-RM	70.3 a	57.1 a
RM-TC-TC	37.6 b	26.9 b
RM-RM-RM	62.6 a	49.6 a

[z]TC = Traditional Container, RM = RootMaker® Container. Here the shift sequence was from propagation trays to #1 containers to #7 containers.

[y]RTA- 1st side of container

[x]RTB – opposite side of container to RTA

[w]Lowercase letters denote mean separation using Tukey's studentized range test with GLM procedure at $p < 0.05$ (version 9.1, SAS Institute, Cary, N.C.)

Table 6. Effect of of RootMaker® (RM), Traditional (TC) Container systems and hybrid shift sequence of systems on the root length (RL), surface area (SA), average diameter (AD) and number of root tips (RT) of *Catalpa speciosa* finished in #7 containers after root scanning.

Treatment	RTB[y]			
	RL (cm)	SA (cm^2)	AD (mm)	RT
TC-TC-TC[z]	1073.3 a[x]	109.3 a	0.30 b	5793 ab
TC-RM-RM	1076.2 a	100.6 ab	0.31 b	6391 a
RM-TC-TC	765.5 b	87.5 b	0.39 a	3950 b
RM-RM-RM	1051.8 ab	98.6 ab	0.31 b	6599 a

[z]TC = Traditional Container, RM = RootMaker® Container. Here the shift sequence was from propagation trays to #1 containers to #7 containers

[y] RTB – root tips on the opposite side to RTA

[x]Lowercase letters denote mean separation using Tukey's studentized range test with GLM procedure at $p < 0.05$ (version 9.1, SAS Institute, Cary, N.C.)

A B

Figure 1. Root growth of Catalpa speciosa in Horhizotrons after transplanting from 1 gal RootMaker® (A) and traditional (B) containers.

A

B

Figure 2. Images of RootBuilder® II (A) and RootTrapper® (B) containers which are part of the RootMaker® system.