

IRRIGATION AND CONTAINER TYPE IMPACT RED MAPLE (*ACER RUBRUM* L.) 5 YEARS AFTER LANDSCAPE PLANTING

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Abstract. The objective of this research was to compare red maple (*Acer rubrum* L.) root and canopy growth 5 years after landscape planting from seven different container designs maintained under two irrigation regimes. Trees planted from low-profile air root-pruning containers had larger trunks 5 years after landscape installation than those planted from regular air root-pruning containers, wood boxes with cupric hydroxide coating, or standard black plastic containers with cupric hydroxide coating. Despite significant differences in root weight and amount of deflected roots among container types when trees were planted in the landscape, root number, root depth, and radial root distribution around the trunk were identical 5 years after planting from all container types. However, frequency of irrigation in the first 24 weeks following planting had a significant effect on root system structure even 5 years later. Frequent irrigation resulted in larger trunks, more roots, greater root cross-sectional area, and a more uniform radial root distribution. The increase in root growth on frequently irrigated trees occurred exclusively in the top 30.5 cm of soil. Codominant stems 4 years after planting were equally common, regardless of production method and irrigation treatment. With the exception of the low-profile air root-pruned container, the reduction in root defects on the outer surface of root balls grown in containers designed to reduce defects appeared to provide no measurable benefit to trees 5 months or 5 years after planting into the landscape. Irrigation management after planting had a more positive impact on landscape root growth and distribution than container type.

Key Words. Container production; air root pruning; chemical root control; deformed roots; transplanting; planting; root depth; root morphology; root modification; landscape.

Plants grown in standard plastic containers for too long often have deformed roots that are kinked or grow along the sides or bottom of the root ball. Many alternative container types have been designed to reduce the incidence of deformed roots. These options typically utilize one or more of the following: air root-pruning technology, special-

ized container shapes, bottomless containers, nonwoven fabrics, mechanical deflection, or chemical manipulation (Brass et al. 1996; Marler and Willis 1996).

The type of nursery container used during production can have a dramatic impact on root morphology of container-grown plants (Arnold 1996; Gilman 2001). Copper compounds applied to the interior surface of plastic containers reduced root deflection on many woody species (Struve et al. 1994) and caused an increase (Beeson and Newton 1992), decrease (Arnold and Struve 1993), or no effect (Martin and Bhattacharya 1995) on root:shoot ratio. Roots in porous-walled plastic containers stopped growing when they reached the container wall–substrate interface (Privett and Hummel 1992). This resulted in less root circling compared to nonmanipulated root systems grown in standard containers (Gilman 2001; Marshall and Gilman 1998). Roots in square containers had fewer circling roots than those in standard round plastic containers (Warren and Blazich 1991).

Many studies on conifer seedlings show that root deflection in containers can contribute to long-term growth problems after planting in the forest (Nichols and Alm 1983). Young hardwood liners grown in alternative containers and transplanted to the landscape produced either more (Arnold 1996; Brass et al. 1996) or the same amount (Brass et al. 1996) of roots as trees raised in standard containers. Our past work showed that root and canopy growth were similar among #15 container types 5 months after landscape planting (Marshall and Gilman 1998). The objective of this study was to compare root and canopy growth on the same group of trees 5 years after planting.

MATERIALS AND METHODS

In February 1995, red maple (*Acer rubrum* L.) 3.8 L seedling trees were planted in seven container types. The seven container types were (1) 66 L (#15) standard black plastic container (SBPC), 41 cm diameter × 43 cm deep (Lerio Corp., Mobile, AL), (2) 66 L (#15) SBPC treated on interior surfaces with Cu(OH)₂ at a rate of 100 g/L latex carrier (Spin Out™, Griffin Corp., Valdosta, GA), (3) low-profile black plastic container measuring 58 cm diameter × 33 cm deep (Lerio Corp.), (4) corrugated aluminum air root-pruning container (ARPC), 43 cm diameter × 41 cm deep (Accelerator, Hold-Em, Inc., West Palm Beach, FL), (5) low-profile corrugated

aluminum ARPC, 56 cm diameter \times 30 cm deep, (6) wooden, square container constructed of untreated pine, 42 \times 42 \times 42 cm (Ridge Pallets, Bartow, FL), and (7) wooden, square container treated on interior surfaces with Spin Out™ before planting. Each corrugated aluminum ARPC was perforated with holes of two types: round, 3.2 mm diameter; and rectangular, 6.3 mm \times 25.4 mm, with rounded ends. ARPCs were bottomless and were placed on a nonwoven fabric cloth (style S700, 110 mil thickness, Hold-Em, Inc., West Palm Beach, FL).

After 70 weeks in production, the 3.9 cm caliper, 2.8 m tall trees were planted into a field in Gainesville, Florida, U.S., of well-drained Millhopper sand in USDA hardiness zone 8b (average minimum temperature 11°C, average maximum temperature 41°C), as described in Marshall and Gilman (1998). Trees received one of two irrigation regimes, frequent or infrequent, for the first 24 weeks (May through October 1996) after planting. All trees were irrigated to saturation each day the first week after planting. On the frequent irrigation schedule, trees received 38 L of water daily during weeks 2 through 9, then every other day during weeks 9 through 24. On the infrequent schedule, trees received 38 L of water once in weeks 2 and 3, every third day during weeks 4 through 9, every 10 days during weeks 10 through 19, then no irrigation. Water was applied to a 1 m diameter circle around the trunk. A scheduled irrigation was not applied if 6.3 cm or more of rain fell since the previous irrigation. No irrigation was applied October 1996 through April 1998. April 1998 began a 3-year dry period when rainfall was more than 127 cm below normal (normal annual rainfall is 132 cm). From April 1998 through February 2001, all trees received 38 L of water three times per day four days per week during the growing season, and 41 L of water once per day three days per week during the dormant season. Water was applied to a 2 m diameter circle around the trunk. This was done to encourage vigor and was not needed for survival.

Fourteen trees from each of the two irrigation treatments (2 from each production method \times 7 production methods \times 2 irrigation treatments = 28 trees) were measured for presence of codominant stems in fall 1999. Stems 2.54 cm and greater, measured 2.8 m from the soil, were recorded. Diameters were converted to cross-sectional area assuming a circular cross section. The number of stems greater than 75% of the area of the largest stem was recorded for each tree.

Thirty-five trees, five from each container type and 17 (frequent irrigation) and 18 (infrequent irrigation) from each of the two irrigation schedules, were harvested February 26, 2001, by digging the root balls with a 203 cm tree spade. Soil was washed from the root balls with high-pressure water. The root systems were characterized by counting each root end larger than 9 mm in diameter that

was cut by the blades of the tree spade and recording its diameter, depth in the root ball (distance from soil surface), and compass direction around the trunk to the nearest 5 degrees. The 360-degree circle around the trunk was divided into eight, 45-degree sections. Radial root distribution was measured by calculating the number of 45-degree sections without roots. Trunk caliper at 30.5 cm above the soil surface was also recorded.

Depth in the root ball was included as a factor in the analysis of root numbers and root cross-sectional area data. Two-way analysis of variance (ANOVA), with container type and depth in the root ball as factors, was performed using SAS general linear models procedure (SAS Institute 1992). Next, two-way ANOVA was performed with irrigation frequency and depth in the root ball as factors. Two-way ANOVA was performed with container type and irrigation frequency as factors. Means were compared using Duncan's multiple range test when the main effect was significant at the 5% level. The difference in the number of codominant stems for irrigation treatments and container types was compared with the t-test. Contrasts (5% level) were used to clarify the nature of interactions.

RESULTS AND DISCUSSION

There were no interactions between container type and irrigation. There was a significant effect of container type on trunk cross-sectional area 5 years after planting (Table 1). Despite being more stressed in the weeks following landscape installation (Marshall and Gilman 1998), trees planted from low-profile air root-pruning containers had larger trunks than those planted from regular air root-pruning containers, wood boxes with cupric hydroxide coating, or standard black plastic containers with cupric hydroxide coating. Trees planted from untreated wood boxes had greater trunk area than those from boxes with cupric hydroxide. Perhaps trees such as red maple, which develop a shallow root system in the landscape regardless of soil type (Gilman and Kane 1990; Wilson 1964) respond best when planted from a root-manipulated, low-profile root ball. Low-profile containers position roots close to the soil surface so that there are no deep roots that have to make their way to the landscape soil surface to proliferate. Roots at the bottom of a traditionally shaped container (about as tall as they are wide) would have to grow up to near the soil surface before they proliferate; this could be the reason why trees from three of the five standard dimensioned containers grew slowest.

On the other hand, live oaks (*Quercus virginiana* L.) planted from low-profile air root-pruning containers grew similar to trees planted from three other deeper container types in the 30 months following landscape installation (Gilman 2001). Perhaps drought-tolerant trees capable of deep rooting, such as live oak, do not benefit by planting

Table 1. Trunk cross-sectional area of *Acer rubrum* produced in seven container types after 5 years in the landscape^z.

Container type	Trunk cross-sectional area (cm ²)
SBPC	158 abc ^y
Copper-coated SBPC ^x	140 bc
Low-profile BPC ^w	167 abc
ARPC ^v	117 bc
Low-profile ARPC	222 a
Wooden box	178 ab
Copper-coated wooden box	105 c

^zAverage trunk cross-sectional area at planting = 11.9 cm².

^yNumbers followed by the same letter are not significantly different at $\alpha = 0.05$.

^xSBPC = standard black plastic container.

^wBPC = black plastic container.

^vARPC = air root-pruning container.

from low-profile containers because roots that are at the bottom of the traditional container can simply grow into the deeper layers of landscape soil (Marshall and Gilman 1997).

Despite significant differences in root weight and amount of deflected roots among container types when trees were planted (Marshall and Gilman 1998), root number, distribution of roots among depth classes, and number of 45-degree sections around the trunk without roots (radial root distribution) were identical 5 years after planting from all container types. Although no method of evaluating root deformations (circling and kinked roots) on these trees was devised, there appeared to be little difference among container types in the quality of the root systems. Many roots appeared to be adventitious in nature, emerging either from the trunk base or emerging near the trunk from existing main roots after trees were planted in the landscape. These grew more or less from the root flare straight out from the trunk into the landscape just under the soil surface without defects because they were generated after the trees were planted into the landscape. Some may also have emerged behind the kinked or circling portion of the roots. Adventitious root formation above circling roots in red maple has been reported previously (Gilman and Kane 1990). It is unknown whether trees lacking the capability of developing adventitious roots will respond similarly. Perhaps older trees or trees that were more root-bound than the ones used in this study would have responded differently. Our trees were 3.9 cm caliper whereas industry standards allow up to 5 cm caliper in #15 containers (AAN 1996). Some deflected roots appeared to be grafted to other roots of the same tree.

Practitioners report that roots circling the trunk as a result of deep planting can girdle the trunk, causing the tree to slowly decline, or the tree may blow over due to poor root distribution around the trunk (Johnson and Hauer 2000). Perhaps the small diameter (up to 6 mm) of the circling roots

on the 2-year-old #15 container size trees used in this study was not sufficient to result in permanent root deformation 5 years later. Older trees might have set more of their permanent adventitious roots while in the container. If the permanent roots were initiated in the container instead of in the landscape, there may be a greater chance of deformed root system affecting growth or stability.

Frequency of irrigation in the first 24 weeks following landscape installation had a more discernible ($P < 0.05$) effect on red maple root system structure 5 years later than did container type. Frequently irrigated trees grew significantly larger trunk cross-sectional area (175 cm²) than infrequently irrigated trees (137 cm²). This finding contrasts with long-term growth on live oak, which was not affected by irrigation applied only in the months following planting (Marshall and Gilman 1997). Perhaps trees tolerant of wet sites, such as red maple, are more responsive to irrigation in the months following planting than more drought-tolerant trees such as live oak. Codominant stems in red maples 4 years after planting were equally common regardless of irrigation treatment (data not shown).

The number of roots 5 years after landscape planting that were less than 40 mm diameter and root cross-sectional area (all root sizes combined) in the top 30 cm of soil were both greater in trees irrigated more frequently (Table 2), even though irrigation treatments were discontinued 4.5 years earlier. At the deeper soil depths, there were no differences in root growth (number and cross-sectional area) between irrigation treatments. Large roots (> 40 mm diameter) were not affected by irrigation treatment. A shallower root system developed on burford holly (*Ilex cornuta* 'Burfordii'), a shrub, planted into a landscape, when they were irrigated every 1 to 4 days compared to those irrigated every 10 to 14 days (Gilman et al. 1996b). The current study showed that irrigating red maple trees frequently after landscape installation resulted in enhanced root growth in the shallow soil depths compared to irrigating infrequently. Green and Watson (1989) also found enhanced sugar maple (*Acer saccharum* L.) root growth in the shallow depths when conditions were improved for root growth with application of mulch to the soil surface.

Red maple trees frequently irrigated during the 24 weeks after planting generated twice the root system weight into the landscape soil in the first 5 months after planting (Marshall and Gilman 1998). By 5 years after planting, trees frequently irrigated had about 50% more root cross-sectional area than those that received infrequent irrigation after planting, even though both treatments received the same rainfall and irrigation for the last 4.5 years (Table 2). Marshall and Gilman (1997) showed greater root number on frequently irrigated container grown live oak trees 3 years after landscape installation compared to those that received infrequent irrigation, but they found no difference

in root cross sectional area. Fabiao et al. (1995) found that irrigation increased belowground biomass several years after planting, but the effect disappeared after 6 years. Perhaps that effect was occurring for the red maple trees in this study.

Deeper roots proliferated in the infrequent irrigation treatment (about 30% of the total number of roots were more than 30 cm deep compared to 16% for frequently irrigated trees), probably due to lack of sufficient soil moisture closer to the surface (Table 2). The trunk cross-sectional area may have been smaller for infrequently irrigated trees because roots were forced to grow at deeper soil layers.

The number of 45-degree sections containing no roots was greater ($P < 0.05$) for trees irrigated less frequently (1.4 per tree) than for those receiving frequent irrigation (0.7 per tree). This finding indicates that frequent irrigation in the first 24 weeks following planting resulted in a more uniform radial root distribution. Large spaces around the trunk lacking roots could increase the chances for tree failure later as it grows taller (Nichols and Alm 1983), but it is not known whether the gaps associated with infrequent irrigation in this study were large enough to meaningfully affect tree stability.

This study indicated that red maple irrigated infrequently the first 24 weeks after planting developed less trunk growth and less of a root system 5 years after planting compared to trees that received frequent irrigation. Regular irrigation in the 24 weeks after landscape planting provided for a doubling of root growth 5 months after landscape planting (Marshall and Gilman 1998). The current study

showed that about half of this increase persisted 5 years later and trunks were 35% larger. Red maple trees in container types such as the low-profile air root-pruning container may be better suited for planting in landscapes than red maples from some other container types. With the exception of the low-profile air root-pruned container, the reduction in root defects on the outer surface of root balls grown in containers designed to reduce defects appeared to provide no measurable benefit to trees 5 months or 5 years after planting into the landscape. Irrigation management after planting had a more positive impact on landscape root growth and distribution than container type.

Irrigation management in the months after planting had a large impact on live oak survival (Gilman 2001; Gilman et al. 1996a) but little impact on long-term top growth of surviving trees, probably because site factors control growth rate once trees are established. For red maple installed into a landscape in spring in the southeast United States from #15 containers, irrigating with 38 L once a day for 7 days then every third day for 2 months, then 3 times a month for 3 months appears to establish trees successfully with 100% survival, but they grow slower than trees more frequently irrigated during the first 24 weeks after planting. The growth-enhancement effects of irrigation in the 24 weeks after planting still remained 5 years after planting, even though irrigation treatments were discontinued 4.5 years earlier. Irrigation needs to be applied only to the root ball and to a small area around the root ball after planting for 100% survival.

Table 2. Number of roots 5 years after planting of different diameter size classes and total root cross-sectional area at three depths below the soil surface on *Acer rubrum* irrigated frequently or infrequently in the first 24 weeks after landscape planting.

Irrigation frequency	Soil depth (cm)	No. of roots < 20 mm diameter	No. of roots 20 to 40 mm diameter	No. of roots > 40 mm diameter	Total no. of roots	Total root cross-sectional area (cm ²)
Frequent ²	< 30	24.2	11.2	1.5	37.0	140.1
Frequent	30 to 60	3.0	0.5	0.1	3.6	8.2
Frequent	> 60	1.4	0.6	0.1	2.1	7.5
Infrequent ³	< 30	13.9	6.7	0.8	21.3	74.9
Infrequent	30 to 60	3.3	0.9	0.2	4.5	14.1
Infrequent	> 60	4.6	1.1	0.2	5.9	15.5
Significance of treatment effects at $\alpha = 0.05$						
Soil depth		*	*	*	*	*
Irrigation frequency		*	NS	NS	*	NS
Soil depth x irrigation frequency		*	*	NS	*	*
Contrasts						
Frequent vs. infrequent < 30 cm depth		*	*	NS	*	*
Frequent vs. infrequent 30 to 60 cm depth		NS	NS	NS	NS	NS
Frequent vs. infrequent > 60 cm depth		NS	NS	NS	NS	NS

²Frequent = 37.8 L applied daily for 9 weeks, then every other day through week 24.

³Infrequent = 37.8 L applied daily for 1 week, once in weeks 2 and 3, every third day weeks 4 through 9, every 10 days weeks 10 through 19.

*Effect is significant at $\alpha = 0.05$.

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Résumé. L'objectif de cette recherche était de comparer la croissance des racines et de la cime de l'éclaircie rouge (*Acer rubrum* L.) sur une période de cinq ans après la plantation, et ce à partir de plants produits dans sept types différents de contenants et deux régimes différents d'irrigation. Les arbres plantés à partir de contenants à profil bas pour la taille aérienne des racines avaient des troncs plus gros cinq ans après leur mise en terre, et ce par rapport à ceux produits en contenants réguliers pour la taille aérienne des racines, ceux en boîtes de bois avec un enduit d'hydroxyde cuprique, ou encore ceux en contenants standards en plastique noir avec un enduit d'hydroxyde cuprique. En dépit des différences significatives dans la masse racinaire et la quantité de racines en spirales parmi les différents types de contenants lorsque les arbres étaient plantés sur le site, la quantité de racines, la profondeur et la distribution radiale autour du tronc de ces dernières étaient identiques cinq ans après la plantation, et ce pour tous les types de contenants. Néanmoins, la fréquence de l'irrigation dans les 24 premières semaines après la mise en terre avait un impact significatif sur la structure du système racinaire, et même cinq ans après. Une irrigation fréquente résulte en des troncs plus gros, plus de racines, une plus grande surface racinaire en coupe transversale ainsi qu'une distribution radiale en racines plus uniforme. Pour les arbres fréquemment irrigués, l'augmentation en croissance racinaire se produisait exclusivement dans les 30,5 premiers centimètres de sol. Les tiges codominantes étaient équivalentes entre elles quatre ans après la plantation, peu importe la méthode de production et le type d'irrigation. À l'exception du contenant à profil bas pour la taille aérienne des racines, la diminution en défauts chez les racines avec des contenants conçus pour réduire ce type de défauts, et ce au-dessus de la surface de la motte de racines, n'apparaissait pas se concrétiser en résultats positifs mesurables cinq mois ou cinq ans après la plantation. La gestion de l'irrigation après la plantation avait un impact plus positif sur le développement des racines et sur leur distribution après la plantation que le type de contenant de production.

Zusammenfassung. Das Ziel dieser Studie war, das Wachstum von Wurzel- und Kronenwachstum von Rotahorn nach 5 Jahren des Auspflanzens aus 7 verschiedenen Kulturformen unter 2 verschiedenen Bewässerungssystemen zu vergleichen. Die Bäume aus einem Niedrigprofilcontainer hatten nach 5 Jahren größere Stämme als die Bäume aus regulären Containern, Holzboxen mit Kupferoxidüberzug oder Standardcontainer mit Kupferoxidüberzug. Ungeachtet deutlicher Unterschiede im Wurzelgewicht und der Menge an angelenkten Wurzeln zwischen anderen Containertypen, wenn die Bäume ins Freiland verpflanzt wurden, war die Wurzelanzahl, -tiefe und radiale Verteilung

um den Stamm fünf Jahre nach der Verpflanzung bei allen Containerpflanzen gleich. Trotzdem hatte die Bewässerungsfrequenz in den ersten 24 Wochen nach der Verpflanzung auch nach 5 Jahren einen deutlichen Einfluß auf das Stammwachstum. Regelmäßige Bewässerung führte zu stärkeren Stämmen, mehr Wurzeln, größerem Wurzel Durchmesser und einer gleichmäßigeren Wurzelverteilung. Die Zunahme des Wurzelwachstums von regelmäßig bewässerten Bäumen trat ausschließlich in den oberen 30 cm Boden auf. 4 Jahre nach der Pflanzung zogen die Kodominanten Stämmlinge gleich, unabhängig von der Produktions- oder Bewässerungsmethode. Mit Ausnahme der Niedrigprofilcontainer, konnte die Reduktion der Wurzeldefekte auf dem äußeren Wurzelballen keinen messbaren Vorteil für die Bäume nach 5 Monaten oder 5 Jahren nach der Verpflanzung in die Landschaft bringen. Das Bewässerungsmanagement nach der Pflanzung hatte mehr positive Einflüsse auf die Wurzelverteilung und das Wachstum als der Containertyp.

Resumen. El objetivo de esta investigación fue comparar el crecimiento de las raíces de maple rojo (*Acer rubrum* L.) y el crecimiento de la copa, cinco años después de la plantación, en siete diferentes diseños de contenedores mantenidos bajo dos regímenes de riego. Los árboles plantados en contenedores con poda de raíz tuvieron troncos más grandes cinco años después de la instalación, que los plantados en contenedores regulares (cajas de madera con una capa de hidróxido de cobre). A pesar de las diferencias significativas en el peso de las raíces y cantidad de raíces deflectadas entre los tipos de contenedores, cuando los árboles fueron plantados en el terreno, el número, profundidad y distribución radial de las raíces alrededor del tronco fueron idénticas, cinco años después de la plantación en todos los tipos de contenedores. Sin embargo, cinco años después, la frecuencia del riego en las primeras 24 semanas siguientes a la plantación tuvo un significativo efecto en la estructura del sistema de raíces. La frecuencia del riego resultó en troncos grandes, más raíces, mayor área transversal de las mismas, y una mayor distribución radial. El incremento en el crecimiento de las raíces sobre la frecuencia de los árboles regados ocurrió exclusivamente en la parte superior de 30.5 cm de suelo. Cuatro años después de la plantación, los tallos codominantes fueron igualmente comunes sin importar el método de producción y el tratamiento de riego. Con la excepción de los contenedores de poda de raíces, la reducción en los defectos de las raíces en la superficie exterior de la bola del cepellón, no produjo beneficios mensurables cinco años después de la plantación. El manejo del riego después de la plantación tuvo un impacto positivo en el crecimiento y en la distribución de las raíces, mejor que el tipo de contenedor.