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The Effects of Air-Root Pruning on Seedlings of Species with Taproots

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Abstract

Cultural practices that influence the development of the root system shortly after germination can have a lasting impact on the quality of container-grown nursery crops. Standard plastic containers have been shown to promote crooks in primary roots and root circling, potentially leading to girdling roots, and overall decreases in plant quality. Taxa that exhibit a prominent taproot are particularly susceptible. This phenomenon poses a significant issue for species predominantly propagated by seed in container nurseries. Alternative container products that employ air-root pruning techniques may provide a solution, however, these products are often expensive and thorough investigations of their influence on coarsely-rooted taxa are lacking. This study explores the influence of air-root pruning, in comparison to culture in standard plastic containers, on vegetative growth responses and root architecture of seedlings shortly after germination of eight species of woody plants that exhibit taproot development. At the conclusion of the study, all air-pruned taproots lacked crooks or circling, whereas deflection of the taproots was observed in each of the controls. Significant differences in the vegetative growth responses were not observed.

INTRODUCTION

Woody plants that are claimed to be difficult to produce are often associated with the morphology of their roots (Burkhart, 2006). These root systems generally consist of coarse roots or a root system dominated by a taproot, which display minimal fibrous-root branching (Gilman, 1990a). As a result, these plants may exhibit reduced transplant success and a resistance to standard growing methods (Gilman, 1990a; Jacobs et al., 2009). Numerous taxa are noted for this attribute, including species belonging to the genera *Carya* (Dirr, 2009*)*, *Nyssa* (Stephens and Sutton, 2015), *Pinus* (Gilman, 1990a), *Xanthoceras* (Dirr, 2009), and others. Many of these taxa are important for use in urban landscapes as ornamental plants (Dirr, 2009). Interestingly, some common species utilized in managed landscapes, such as *Gymnocladus dioicus*, exhibit taproot development yet are amenable to traditional production and transplant techniques. This contrasting evidence suggests that our understanding of how taproots influence transplant success and the responses of taproots to manipulation and disturbance are poorly understood.

Alternative production practices such as root manipulation through careful root pruning (Carlson, 1974; Geisler and Ferree, 1984; Harris et al., 2001; McGraw and Smith, 1998) or the use of plant growth regulators (Crunkilton et al., 1994; Prager and Lumix, 1983) have been explored for use in modifying the root systems of some species deemed "difficult-to-transplant".

Root pruning has shown to be an effective tool to encourage root branching, create a denser root ball, and enhance shoot growth rates over time (Gilman, 1990b). Undercutting is one such technique employed in the field production of juvenile trees in the nursery. This practice utilizes a blade instrument to sever the taproot at a specific depth in the soil. Root pruning via undercutting has shown to alter root morphology and improve post-transplant survival for some taxa (Schultz and Thompson, 1990; Mullin, 1966). However, the responses of species belonging to different genera range broadly. For example, taproots of species belonging to the genus *Carya* are known to regenerate after pruning (Miller, 2017), whereas taproots of *Quercus* spp. generally do not.

Furthermore, some taxa respond differently to root pruning performed at various stages in development (Zhang et al., 2015). Other factors such as genetic variability within a species can also influence generalizations about growth responses to root manipulation (Kalliokoski et al., 2008). Studies that explore these techniques generally focus on plants past their first year of development. Experiments conducted to examine the effects of root manipulation shortly after germination, during initial root development, are lacking. However, the few studies that exist provide evidence that this area of research merits further study (Harris et al., 2001; Zhang et al., 2015).

While root-pruning techniques have been shown to be effective tools for manipulating the roots of some taxa, there are some disadvantages. Mechanical root pruning, especially in field-production nurseries, can act as a vector for soil-borne pathogens. In addition, these techniques are often not viable for application in container nurseries where the implementation of these practices would be more time consuming and expensive.

As alternatives, numerous container technologies taking advantage of air-root pruning have emerged. Air-root pruning is the use of containers with open, or highly-porous, surfaces. Upon root extension within these regions of the container, root tips are exposed to the air and desiccate. Desiccation of the root meristems is claimed to promote increased, proximal root branching and is also often claimed to eliminate serious root deflection within a container. It is suspected that increasing the number of roots within the container can ease transplant shock in taxa that are often difficult to transplant while simultaneously providing a higher quality plant without girdling roots. We questioned whether air-pruning techniques implemented shortly after germination could be effectively utilized to circumvent root-architecture issues with a diverse array of taxa that exhibit taproot development.

Our objectives were to:

- determine how air-root pruning influences root and shoot development compared to standard plastic containers,
- establish a baseline understanding of how unrelated taxa respond to air-root pruning, and
- quantify the effects of air-root pruning on morphological responses often associated with high-quality nursery stock.

MATERIALS AND METHODS

The species examined in this study include *Aesculus glabra*, *Carya glabra*, *Juglans nigra*, *Nyssa sylvatica*, *Pinus koraiensis*, *Quercus montana*, *Ungnadia speciosa*, and *Xanthoceras sorbifolium*. Seeds of *N. sylvatica* and *P. koraiensis* were purchased from Sheffield's Seed Company (Locke, New York). Seeds of *C. glabra*, *J. nigra*, and *Q. montana* were collected from wild populations in Ithaca, New York. Seeds of *A. glabra* and *X. sorbifolium* were acquired through the North Central Regional Plant Introduction Station (Ames, Iowa) through the National Plant Germplasm System. Seeds of *U. speciosa* were donated by The Huntington Botanical Gardens (San Marino, California).

Seeds were mixed with moistened, shredded peat and sealed in plastic bags. With the exception of *P. koraiensis*, seeds were stratified for 200 days in a cooler maintained at 4 ^{o}C. Seeds of *P. koraiensis* were warm stratified at 24 ^{o}C for 50 days followed by cold stratification at four degrees Celsius for 150 days.

After stratification, 25 seeds of each species were randomly assigned to a treatment (control or air prune). Seeds assigned to the control treatment were communally sown 2 cm deep into standard #7 nursery containers and seeds assigned to the air prune treatment were communally sown 2 cm deep in custom-made wooden containers measuring 61 cm × 30.5 cm × 15.24 cm (Figure 1).

Containers were constructed using cedar wood frames and the bottom of each container was composed of 0.635cm mesh wire. All containers were filled with 12.7 cm of LM6 potting medium. Containers were placed on a greenhouse bench in a completely randomized design. Plants were grown for 67 days. During this growing period, plants were irrigated twice weekly with a water-soluble fertilizer (21–5–20 plus Epsom) solution at a concentration of 300 ppm and once weekly with clear water. Taproots of seedlings grown in cedar containers were air pruned by growing out of the potting medium through the openings of the mesh bottom. Taproots of seedlings grown in standard #7 nursery containers grew to the bottom of the container and deflected, forming a "j" root.

Figure 1. Air-root pruning container.

At the conclusion of the growing period, seven seedlings were chosen at random for data collection. Data were gathered by washing the soilless media from the roots of each plant in order to measure the following growth responses and inspect the architecture of each root system. The location of the cotyledon scar, or in the case of seedlings of *P. koraiensis* the zone of transition from hypocotyl tissue to root tissue, was used as standardized locations for taking measurements of growth responses. Stem height was measured from the most distal shoot meristem to the standardized location. Stem caliper was measured at 2 cm above the standardized location using a digital caliper tool. Root length was determined for primary roots by measuring the distance from the standardized location to the most distal root meristem. First-order lateral roots were counted by hand. Any lateral roots less than or equal to 2 mm in diameter were considered. Five plants of each treatment combination were destructively harvested in order to measure leaf surface area, root mass, and shoot mass. All leaves were removed from each seedling and measured using a LICOR leaf surface area meter in order to determine leaf surface area (cm^2). Shoots and roots were oven dried and weighed to determine their respective masses. Shoots and roots were separated at the standardized location.

All data were analyzed using JMP Pro® 14 software (JMP® Version 14. SAS Institute, Inc., Cary, North Carolina, USA).

RESULTS AND CONCLUSIONS

All air-pruned taproots lacked crooks or circling (Figure 2), whereas deflection of the taproots was observed in each of the controls (Figure 3). According to Tukey's Honestly Significant Difference test, mean stem height, stem caliper, root length, number of first-order lateral roots, leaf surface area, root mass and shoot mass were not significantly different between controls and air-root pruned seedlings for each taxon (Table 1). Although the differences in first-order lateral root counts and root mass were not significant, it was clear that the development of these root systems were different between treatments. In the case of *C. glabra*, the fleshy taproot was not as long and significant extension of the first-order lateral roots had occurred in the air-pruned seedlings (Figure 4). Similarly, seedlings of *Pinus koraiensis* that were air-root pruned exhibited longer first-order lateral roots, however, the number of first-order lateral roots was not different from controls (Figure 5).

Figure 2. Roots of *Xanthoceras sorbifolium*. Control (left) and air-root pruned (right).

Figure 3. Roots of *Aesculus glabra*. Control (right) and air-root pruned (left).

Table 1. effects of air-root pruning on plant growth.

Taxon	Treatment	Stem Height[z] (cm)	Stem Caliper[y] (mm)	Root Length[x] (cm)	First-order lateral Root Count[w]	Leaf Surface Area (cm^2)	Root Mass (g)	Shoot Mass (g)
Aesculus glabra	Control	13.6	4.9	22.5	50.0	254.9	3.4	2.7
	Air Pruned	8.9	4.8	10.1	49.9	228.2	4.9	2.7
Carya glabra	Control	10.1	2.2	23.6	72.0	111.1	0.9	0.6
	Air Pruned	7.8	2.8	10.1	66.0	94.2	1.3	0.7
Juglans nigra	Control	41.9	6.1	37.4	75.0	1811.6	3.1	10.1
	Air Pruned	38.6	6.6	11.4	54.1	-	-	-
Nyssa sylvatica	Control	19.6	2.1	17.9	24.3	91.3	0.2	0.4
	Air Pruned	14.2	2.4	14.4	23.9	101.5	0.2	0.5
Pinus koraiensis	Control	6.7	1.7	12.8	10.7	11.0	0.1	0.3
	Air Pruned	5.4	2.0	10.4	13.0	12.9	0.1	0.3
Quercus montana	Control	21.1	2.2	30.7	51.3	207.7	0.6	1.6
	Air Pruned	18.6	2.3	9.5	40.4	199.7	0.6	1.3
Ungnadia speciosa	Control	15.8	2.9	28.4	48.9	358.5	0.7	2.6
	Air Pruned	19.5	3.0	11.6	33.0	578.1	1.2	4.5
Xanthoceras sorbifolium	Control	33.9	4.2	28.4	38.4	604.7	2.6	4.6
	Air Pruned	37.6	4.4	11.1	29.3	551.0	3.3	4.9

[z] Cotyledon scar to standardized location.
[y] Measured 2 cm above the standardized location.
[x] Standardized location to most distal root meristem.
[w] Fibrous first-order lateral roots (<2mm diameter)

Figure 4. Seedlings of *Carya glabra*. Control (left) and air-root pruned (right).

Figure 5. Seedlings of *Pinus koraiensis*. Control (left) and air-root pruned (right).

Many of the species examined in this study exhibit determinate growth. We question whether this factor influenced the lack of variability in growth responses such as stem height. In a follow up study, we intend to grow replicate seedlings for a second growing season to determine if air-root pruning shortly after germination positively influences vegetative growth within this timeframe.

In this study the effects of air-root pruning on seedlings shortly after germination of eight species of woody plants exhibiting taproot development were examined. By comparing unrelated taxa of horticultural interest, this study provides a broad baseline of responses for nursery growers to consider when determining if air-pruning techniques should be implemented. Because the air-pruning flats were of simple design, this study may also encourage nursery growers to develop their own air-root pruning implements in order to accommodate their cropping cycle, infrastructure, and budget. Based on these results, we conclude that air-root pruning flats should be considered for germinating taxa with taproots in order to reduce undesirable root architecture and promote the production of high-quality seedlings.

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