Tree Seedling Root Architecture Alteration by Tap Root Pruning[1]

Shanon Hankin, Marvin Lo, Frank Balestri, Gary Watson[2]

Abstract

Nursery production of strong taprooted woody plants typically includes pruning to interrupt taproot development. To discern the impact this practice could have on seedling root architecture, we quantified changes to root architecture after taproot pruning and restriction separately in Catalpa (*Catalpa speciosa*) and Kentucky coffee tree (*Gymnocladus dioicus*). Taproot pruning resulted in a large and significant increase in the number of new, vertically oriented roots from the cut end of the primary root (regenerated taproots) in both species. Catalpa seedlings, which produced many strong laterals on unpruned taproots, showed greater reduction in lateral root number and size after taproot pruning than Kentucky coffee tree (with fewer and smaller natural lateral roots). The two species responded differently to restriction of the single, unpruned taproot by container depth (15, 30, 60 cm). For catalpa, with more shallow laterals naturally, the number of laterals was not significantly changed by restriction of the taproot by air pruning at any container depth, but lateral diameter was reduced by the 15 cm-deep container and biomass was reduced by the 30 cm-deep container, compared to the 60 cm-deep container. For Kentucky coffee tree with fewer natural laterals, restricting the taproot at 15 cm significantly increased the number and diameter of lateral roots compared to the 30 and 60 cm-deep containers, suggesting that restricting the taproot could increase the number of laterals in species that naturally produce fewer. Restricting multiple taproots on root-pruned plants generally did not affect lateral root development for either species, but this may have been due to the low number of lateral roots on those root systems.

Index words: root architecture, nursery production, urban soils.

Species used in this study: Catalpa [*Catalpa speciosa* (Warder) Warder ex Engelm.]; Kentucky coffee tree [*Gymnocladus dioicus* (L.) K. Koch].

Significance to the Horticulture Industry

Nursery field production of trees with strong taproots has traditionally included taproot pruning to make them easier to transplant. In this study, taproot pruning resulted in a large and significant increase in the number of new, but still vertically oriented, roots from the cut end of the primary root (regenerated taproots) in two species. Catalpa seedlings, which produced many strong laterals on unpruned taproots, showed greater reduction in number and size of lateral roots after taproot pruning than Kentucky coffee tree (with fewer and smaller natural lateral roots). The two species responded differently to restriction of the single, unpruned taproot by container depth. For catalpa, with more laterals naturally, the number of laterals was not significantly changed when the taproot was restricted by container depth. For Kentucky coffee tree, with fewer natural laterals, restricting the taproot at 15 cm significantly increased the number of lateral roots compared to the deeper containers, suggesting that restricting the taproot could increase the number of laterals in species that naturally produce fewer. Restricting multiple taproots on root-pruned plants did not affect lateral root development for either species, but this may have been due to the low number of lateral roots on the regenerated taproots. Taproot pruning can result in the initiation of multiple, new rapidly growing vertical roots from the cut end and fewer lateral roots. Restricting taproot development and minimizing root regeneration from the end, similar to what occurs with air pruning, can result in more lateral roots. Trees with more lateral roots dominating could be more transplantable and better suited to dense, poorly drained urban soils (where they are often planted). This research focused on one-year-old seedlings of two species; more extensive research is needed to support these results, to investigate taproot pruning responses in other species, and to monitor trees throughout later stages of production. Documenting better performance of trees with more lateral roots in the landscape could help justify additional costs of producing them.

Introduction

Nursery growers are guided by best practices when producing plants. These are developed through experience, but growers can lack a thorough understanding of how the plants are responding to those practices, especially in root systems which cannot be easily seen. Those practices are also primarily focused on producing the trees, with less understanding of how the trees will perform once planted in the landscape.

Nursery production of woody species with strong taproots has traditionally included taproot pruning (e.g. undercutting, air pruning, or transplanting) to interrupt taproot development and encourage a more branched root system, so that plants are easier to harvest and transplant (Davidson et al. 1988). However, root pruning typically results in the initiation of multiple new, rapidly growing roots from the cut end (Gilman et al 2010, Harris et al. 2001, Hewitt and Watson 2009) that are orientated in a direction similar to the original root (Horsley 1971). In the case of pruned taproots, the new roots are often vertically

[1]Received for publication January 22, 2019; in revised form April 11, 2019. J. Frank Schmidt Family Charitable Foundation provided financial support. Possibility Place provided materials and maintenance of plants in their nursery.

[2]The Morton Arboretum, Lisle, IL 60532, corresponding author gwatson@mortonarb.org.

Fig. 1. Species respond differently to primary root pruning. These examples show how some produce rapidly growing roots from the cut end while few natural laterals survive (*Acer negundo,* left). In others, lateral roots persist and grow rapidly while growth of new roots from the cut end is more modest (*Zelkova serrata*, right). Soil line at upper arrow. Regenerated roots from cut end at lower arrow.

oriented like the original root. Even if having multiple vertical roots, instead of a single larger taproot, makes the tree easier to harvest and more transplantable, the structural root system dominated by multiple deep vertical roots may not be well suited to urban soils. The American Standards for Nursery Stock (Anonymous 2014) includes nothing on taproot pruning practices, or on the orientation of the structural roots in the root ball when harvested.

Pruning the primary root (referred to as the taproot in species where growth is especially strong), is a customary practice when seedlings are transplanted during field nursery production. This practice has been observed to result in new, fast growing roots from the cut end, along with a reduction in the number and size of natural laterals (Fig. 1) (Hewitt and Watson 2009). The objective of this study was to quantify initial changes in root architecture after taproot pruning of two species of seedlings to gain a clear understanding of whether this common practice can encourage a favorable root system, ideally with more lateral roots, that will be better suited to heavy, poorly drained urban soils.

Materials and Methods

In order to explore the root system response to taproot pruning and restriction, two species with strong taproots, but different lateral root characteristics as seedlings, were chosen: *Catalpa speciosa* and *Gymnocladus dioicus*. Catalpa seedlings have stronger lateral root development than Kentucky coffee tree seedlings (Watson, unpublished data).

Taproot pruning was accomplished by pruning the emerging radicle of young seedlings to 2 cm (0.8 in) in length as soon as possible after they reached that length. This was intended to be similar to nursery production systems that germinate seeds in shallow flats with wire mesh bottoms to air prune taproots. Most lateral root development would have to originate on the new roots initiated from the cut end rather than from the small remaining portion of the original taproot.

After germination and taproot pruning, seedlings were transplanted into 50 cm-diameter containers (Root-Builder®, RootMaker® Products Company, LLC, Still-water, Oklahoma) filled with a commercial peat and composted pine bark substrate. The taproot restriction study used three container depths: 15, 30, and 60 cm (6, 12, and 24 in). The bottomless containers were placed on wire mesh platforms to air prune the taproot when it reached the bottom. For each species, one container of each depth was planted with ten seedlings evenly spaced (Fig. 2). Ten seeds were germinated directly in a second set of three containers for the undisturbed (control) treatment. The taproot pruning study used only 60 cm (24 in) deep containers, also planted with 10 root-pruned, or directly seeded, plants. At the end of the growing season, number, diameter, and length of taproots and lateral roots were recorded in cm, as well as dry weight of roots and shoots in g (without leaves). Biomass was estimated as basal diameter multiplied by the length of all the individual roots on each tree with no specific unit.

All data was analyzed using non-parametric tests in R, a programming language for statistical computing (R Development Core Team 2008). Two-sampled t-tests were performed using the Kolmogorov-Smirnov test, and one-way analysis of variance tests were performed using permutation tests in the lmPerm package (Wheeler 2010).

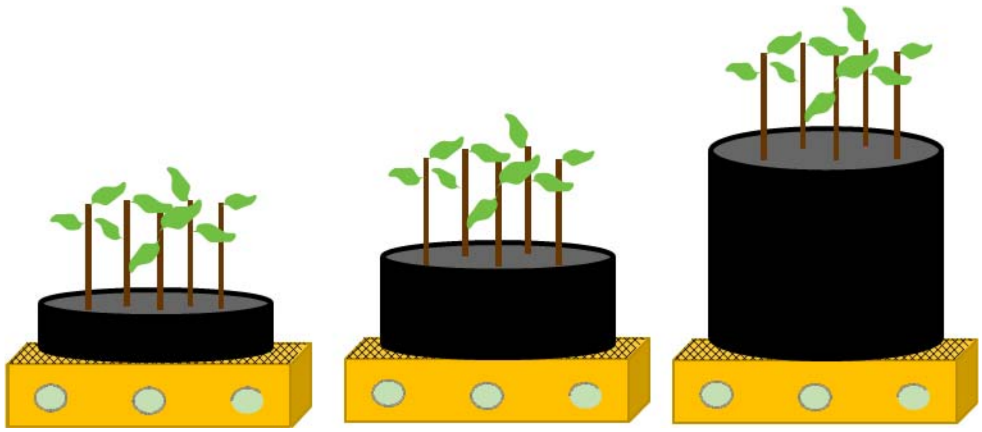

Fig. 2. Three container depths were used in the two experiments. The taproot pruning study used only 60 cm (24 in) deep containers so not to inhibit taproot growth. The taproot restriction study used three depths of containers to restrict taproot growth at three depths, 15, 30 and 60 cm (6, 12, and 24 in).

Results and Discussion

Taproot Pruning

Taproot Development. Taproot pruning resulted in a significant increase in the number of new, vertically oriented roots from the cut end of the primary root (regenerated taproots) in both species (360 and 456% for Catalpa and Kentucky coffee tree, respectively; Fig. 3a), compared to the single, unpruned taproot treatment. Single unpruned taproots were significantly larger in diameter than the mean diameter of the multiple individual regenerated taproots for both species (60 and 62% for Catalpa and Kentucky coffee tree, respectively; Fig. 3b). The estimated biomass of the multiple regenerated taproot system was significantly greater than the single unpruned taproot (233 and 293% for Catalpa and Kentucky coffee tree, respectively; Fig. 3c). The increased number of taproots more than compensated for their smaller individual size.

Lateral Root Development. Catalpas had significantly more (264%; Fig. 4a) and larger (165%; Fig. 4b) lateral roots on the unpruned, single taproot root systems, compared to those with the taproot-pruned and multiple regenerated taproots. Estimated lateral root biomass was significantly greater on the unpruned taproots, as well (510%; Fig. 4c). Almost no laterals originated on the small section of taproot above the point where the taproot was pruned at 2 cm deep on both species (data not shown).

Kentucky coffee trees had far fewer lateral roots than catalpa overall. There was no difference in the number of laterals between pruning treatments, though the trend with the very small numbers was for more laterals on unpruned taproots, similar to catalpa (Fig. 4a). Biomass also showed no difference between seedlings that were root-pruned and those that were not (Fig. 4c). Since there were so few Kentucky coffee tree plants with any lateral roots at all, especially when the taproot was pruned, statistical analysis for lateral root diameter was not possible.

Taproot Restriction

The taproot pruning study was designed so that the single or multiple taproots would not be affected by reaching the bottom of the 60 cm (24 in) deep container used, which is not typical of container production systems. This second study tested the effect of restricting taproot development with air pruning so that there would be little, if any, new root development. When taproots reached the bottom of 15 or 30 cm (6 or 12 in) deep containers, they

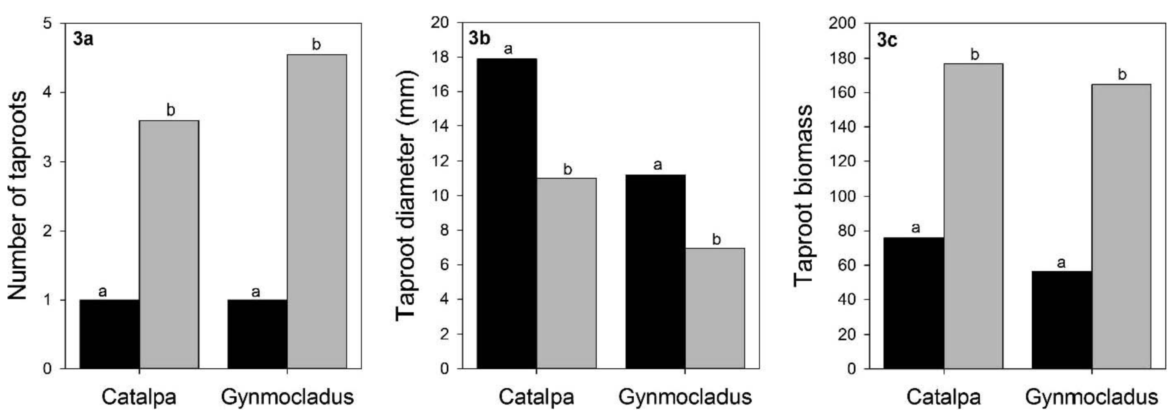

Fig. 3. For container-grown plants, taproot pruning resulted in multiple taproots (a) that were smaller individually (b), but had greater estimated biomass as a whole (c), compared to the single unpruned taproot. Biomass is a calculated value without specific units. Means with the same letter are not significantly different based on a t-test. ■ Taproot not pruned, ■ Taproot pruned.

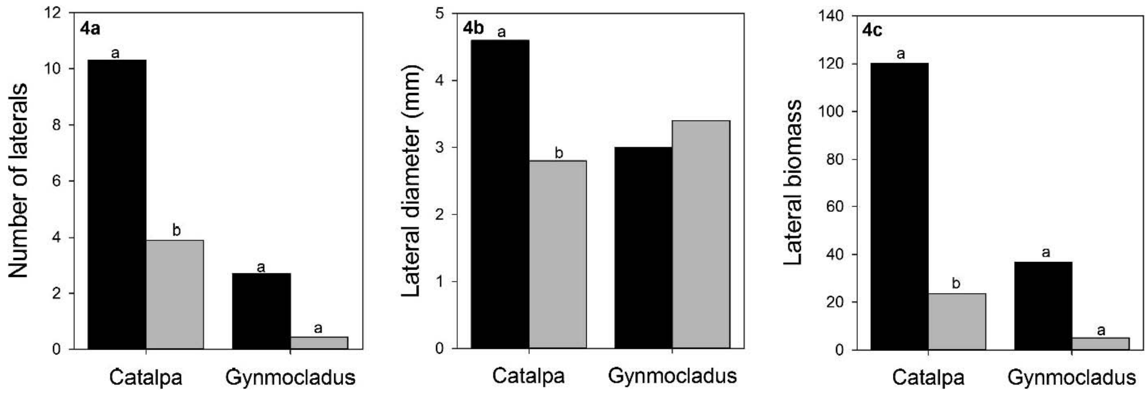

Fig. 4. For container-grown plants, taproot pruning in catalpa reduced lateral root development (fewer (a), smaller (b) and less biomass (c)). Kentucky coffee trees produced very few lateral roots and there were no significant differences between taproot pruning treatments. Means with the same letter are not significantly different based on a t-test. ■ Taproot not pruned, ■ Taproot pruned.

were air pruned. Taproots in the 60 cm (24 in) deep containers did not reach the bottom.

Lateral Root Development – Unpruned Taproot. When catalpa taproots were not pruned, the number of laterals was not affected by container depth restriction of the taproot. Over 85% of the lateral roots originated in the upper 15 cm (6 in) of the unpruned taproot in the deeper containers (data not shown), therefore reducing the length of the taproot below 15 cm (6 in) would not be likely to greatly reduce the number of lateral roots.

Catalpa lateral root diameter was reduced by the 15 cm deep container. Biomass was reduced significantly only by the 30 cm container compared to the 60 cm container (P=0.048). The 15 cm container value was even lower than in the 30 cm container, but not significantly different than the 60 cm container (P=0.068; Table 1). High variability in root system measurements can cause such inconsistencies. The reduction in lateral root size (diameter and biomass) may be a result of competition between the large number of roots of this species in the relatively smaller container volume.

Restricting the single, unpruned taproot of Kentucky coffee tree at 15 cm (6 in) significantly increased the number and diameter of lateral roots. Compared to catalpa, this species normally produces very few lateral roots as a young seedling (Watson, unpublished data). This data suggests that restricting growth of the taproot could increase that naturally low number. If consistent in other taprooted species with few natural laterals, using practices that air prune the taproot and inhibit regenerated root growth from the end, could produce better lateral root systems than the current practice of mechanically pruning the taproot and allowing roots to rapidly regrow there.

The lack of difference in biomass of Kentucky coffee tree lateral roots, even though there were more and larger diameter lateral roots in the 15 cm (6 in) container compared to the deeper containers, may be a result of reduced lateral root length, a component of the estimated biomass calculation. Length was reduced by approximately 50 percent with each decrease in container depth (volume; data not shown). It may be possible that Kentucky coffee tree lateral root length was more sensitive than diameter to the increased competition in the smaller containers.

Kentucky coffee tree data from another, more limited, study (Watson, unpublished data) did not support this increase of laterals in the 15 cm pot. Further research with this and other taprooted species with naturally weak laterals is needed to fully understand the effects of taproot restriction.

Table 1. Lateral root development with and without taproot pruning.

	Catalpa				Kentucky coffeetree			
Container depth	Taproot not pruned		Taproot- pruned		Taproot not pruned		Taproot- pruned	
				Number				
15 cm	12.5	a[z]	1.0	a	10.0	a	1.7	a
30 cm	9.2	a	1.9	a	2.3	b	1.3	a
60 cm	10.3	a	3.9	a	2.7	b	0.4	a
				Diameter				
15 cm	3.7	b	3.0	a	4.5	a	3.0	a
30 cm	4.3	ab	2.9	a	3.2	b	2.9	a
60 cm	4.6	a	2.8	a	3.0	b		
				Biomass				
15 cm	652	ab	42	a	527	a	51	a
30 cm	681	b	47	a	189	a	60	a
60 cm	1201	a	236	a	367	a	51	**a**

[z]Values within columns with the same letter are not significantly different based on a t-test.

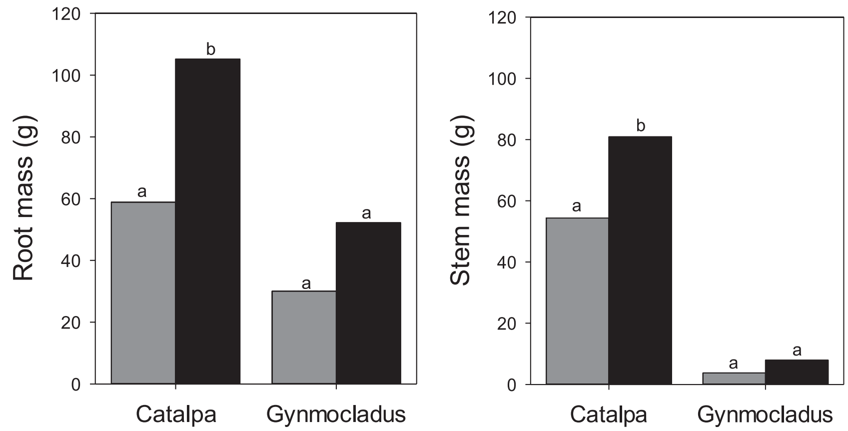

Fig. 5. For container-grown plants, taproot pruning generally resulted in larger plants. Means with the same letter are not significantly different based on a t-test. ■ Taproot not pruned, ■ Taproot pruned.

Lateral Root Development – Pruned Taproot. Lateral root number, diameter, and biomass were not significantly affected by taproot restriction in root-pruned trees of either species (Table 1). This is most likely due to the small number of lateral roots on tap root-pruned plants (1-4 per plant). Comparison of lateral root diameter of taproot-pruned Kentucky coffee trees was limited to comparison of only 15 and 30 cm (6 and 12 in) deep containers, due to the lack of a sufficient number of plants with any lateral roots at all in the 60 cm (24 in) deep container.

Plant Size

Root and shoot dry weight of catalpas were larger when the taproot was pruned (Figure 5). The larger, whole root system size, measured directly as mass, was consistent with the larger estimated biomass calculated for both taproots and lateral roots, which would likely support larger plants above ground.

Root and shoot dry weight of Kentucky coffee trees were not significantly different, although there appeared to be a similar trend as catalpa toward larger plants after root pruning (Figure 5). The increased number and biomass of regenerated taproots alone did not produce a significant increase in overall size of the root system.

In summary, root architecture can be altered by taproot pruning, resulting in multiple taproots, fewer lateral roots, and greater root system biomass. Instead of decreasing taproot development, pruning can increase it. If more of the plant's resources are shifted to taproot growth, less may be available for lateral root growth.

Catalpa seedlings naturally produce many strong laterals on unpruned taproots and therefore showed the greatest reduction after taproot pruning. Species such as Kentucky coffee tree with fewer weaker lateral roots naturally may not be affected as much by taproot pruning. Tests of additional species are needed.

The young catalpa trees grew significantly larger when taproot-pruned, compared to those that were not. Kentucky coffee trees appeared to show a similar trend. Though this may be desirable for the grower, the altered root architecture may be less suitable for disturbed urban soils. On compacted, poorly drained urban soils where the best environment for root growth is near the surface, trees with a stronger lateral root system near the surface when planted are likely to perform better.

Literature Cited

Anonymous. 2014. American Standard for Nursery Stock, ANSI Z60.1. AmericanHort, Columbus, Ohio, USA. 97p. https://www.americanhort.org/page/standards. Accessed March 25, 2019.

Davidson, H., R. Mecklenberg, and C. Peterson. 1988. Nursery Management: Administration and Culture. Prentice Hall, Englewood Cliffs, New Jersey, USA. P.285-286.

Gilman, E.F., C. Harchick, and M. Paz. 2010. Root ball shaving improves root systems on seven species in containers. J. Environ. Hort. 28:13–18.

Harris, J.R., J.K. Fanelli, A.X. Niemiera, and R.D. Wright. 2001. Root pruning pin oak liners affects growth and root morphology. HortTechnology 11:49–52.

Hewitt, A. and G.W. Watson. 2009. Bare root liner production can alter tree root architecture. J. Environ. Hort. 27:99–104.

Horsley, S.B. 1971. Root tip injury and development of the paper birch root system. For. Sci. 17: 341–348.

R Development Core Team. 2008. R: a language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. Available from http://www.R-project.org.

Wheeler, B. 2010. lmPerm: Permutation tests for linear models. R package version 1.1-2. Available from http://CRAN.R-project.org/package=lmPerm.