Bare Root Liner Production Can Alter Tree Root Architecture[1]

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Abstract

Typical nursery production practices, such as root pruning and transplanting, can alter tree root architecture and contribute to root systems that are too deep. In a study of field-grown liner production, root architecture was examined at each stage of the production process, from first year seedlings or rooted cuttings, through 4 to 5 year old branched liners. Depth and diameter of structural roots were recorded on ten replications each of *Acer saccharum*, *Gleditsia triancanthos*, *Pyrus calleryana*, and apple seedling rootstocks; *Platanus* 'Columbia' clonal rooted cuttings; and apple EMLA 111 clonal rootstock produced by mound propagation. By the time the liners reached marketable size, most natural lateral roots emerging from the primary root were lost. Simultaneously, adventitious roots were produced deeper on the root shank at the pruned end of the primary root. These changes in architecture result in the formation of an 'adventitious root flare' that is deeper in the soil than a natural root flare. The depth of this new root flare is dependent upon nursery production practices and may influence the ultimate depth of structural roots in the landscape.

Index words: root pruning, root regeneration, adventitious roots, transplanting.

Species used in this study: *Acer saccharum*, *Gleditsia triancanthos*, *Pyrus calleryana*, *Malus spp.* seedling rootstocks, *Platanus acerifolia* 'Columbia' clonal rooted cuttings, and *Malus spp.* EMLA 111 clonal root stock.

Significance to the Nursery Industry

Root depth of landscape trees has received increasing attention from all professions within the green industry in recent years, stemming from concerns over inadequate survival and growth of urban trees. One factor contributing to deep root systems is the alteration of root architecture during field-grown liner production. Deep root systems may not be problematic in nursery soils, which are chosen for their suitability for growing trees. When these trees are planted in urban landscapes known for their poor quality soils, survivability and health of trees can be reduced. Understanding how production techniques influence root architecture will allow growers to produce higher quality plants.

Introduction

Root architecture refers to the structural organization or spatial arrangement of a plant's root system (11). Natural root architecture development begins as the primary root emerges from the seed and grows downward into the soil, followed by the development of lateral roots just below the junction of the primary root and the hypocotyl (4). The growth rate of the primary root eventually slows and the growth rate of laterals increases (3, 6).

Most nurseries use processes such as undercutting, harvesting, root pruning, and transplanting in the production of field-grown liners. These procedures can ultimately alter the natural architecture of the root system. Root pruning is one production practice that has been used for many years to increase the survival and growth of young plants (7). When a root is pruned, adventitious roots are generated from callus tissue around the pruned area behind the dead cells (10, 17). Growth of these new adventitious roots is often very vigorous (9), consequently becoming a major part of the root system. The dominance of adventitious roots generating from the severed root end is of particular interest because these result in a pronounced change in architecture that may ultimately influence performance in the landscape.

The depth of roots systems of landscape trees is a growing concern in the industry because deep root systems can lead to poor establishment or eventual decline and death of trees (1, 5, 18). In some cases up to two thirds of nursery stock and newly planted trees were found to be too deep (13, 16). This frequency in the landscape has led to increased attention to the causes of deep structural roots. Although improper planting can increase the depth of root systems, many steps in the production of landscape trees can also contribute to deep root system. This study investigates the changes in root architecture associated with common methods used for landscape tree propagation and liner production that may influence depth of structural roots in landscape trees. The objectives of this study were to investigate 1) the fate of natural lateral (root flare) roots along the primary root or cutting, and 2) the formation of adventitious roots at the pruned end of the primary root or cutting.

Materials and Methods

At the end of the 2005 growing season, ten replications of six commonly used species of street trees were arbitrarily selected from normal nursery stock of J. Frank Schmidt and Sons Co., Boring, OR. Each species was propagated according to the typical protocol in use at the nursery for that species. Five stages of field liner production were included: seedling/cutting, undercut (if applicable), one, two, and three years after transplanting. Only five replications were analyzed at the one year after transplanting stage because of availability. Trees were shipped to the Morton Arboretum for analysis. Six different species were chosen based on their root system characteristics and the methods used to propagate

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Table 1. **Species, rooting characteristics, and steps in nursery production prior to being transplanted into liner production fields. In the three years following transplanting, production methods are identical for all rootstock**

		Prior to transplanting	
Species	**Root characteristics**	**–2 Years**	**–1 Year**
Gleditsia triancanthos	Strong primary roots	Seedling bed	Undercut[z]
Acer saccharum	Branching roots	Seedling bed	Undercut
Pyrus calleryana	Deep oblique roots		Seedling bed
Malus spp. (Domestic)	Fibrous roots		Seedling bed
Platanus × *acerifolia* 'Columbia'	Rooted cutting[y]		Cutting bed
Malus spp. ELMA 111	Clonal root stock[y]	Mound bed	Cutting bed[x]

[z]Grown for second year in seedling bed after undercutting.

[y]Lateral roots are adventitious.

[x]Sprouts cut from mound bed and placed in cutting bed for second year.

them (Table 1). An overview of general nursery production practices follows.

Summary of seedling production process. Four of the rootstocks in this study are propagated from seed in densely planted beds in the field (Table 1). Domestic apple (*Malus spp.*) and pear (*Pyrus calleryana*) seedlings are grown in the seedbed for one year. Honeylocust (*Gleditsia triancanthos*) and sugar maple (*Acer saccharum*) seedlings are undercut at the end of the first year and left in the seedbed to grow for a second year. The undercutting process is performed by drawing a blade through the soil approximately 10 cm (4 in) deep to cut the primary root and encourage branching of the root system. The seedlings are then mechanically harvested and held in temperature and humidity controlled storage facilities over the winter. During the storage period, roots are pruned to encourage branching and facilitate handling and mechanical planting. The primary root of each seedling is pruned at approximately 10 cm (4 in). Lateral roots, and adventitious roots on undercut stock, are pruned at approximately 2.5 cm (1 in). The following spring, seedlings are planted at original soil line depth into liner rows at 30 cm (12 in) spacing within rows and 1.5 m (60 in) between rows. The next spring, one year after the seedlings were transplanted, all trees are pruned back to a low natural bud or grafted bud if a cultivar, sometimes referred to as 'stubbing down'. The scion bud develops into a single-stemmed liner in one season, referred to as a 'whip'. Whips can be harvested or grown for an additional year to develop into 'branched liners', as the final stage of production.

Summary of clonal production process. Mound propagation of clonal rootstock is represented by EMLA 111 (*Malus spp.*). The basal portions of sprouts growing from a parent plant are covered with sawdust (8). Adventitious roots develop on the covered portion of the sprout. After one year, the rooted shoot is cut from the parent plant, transplanted into a cutting bed, and grown for another year. Plants are then harvested, stored, and transplanted paralleling seedling rootstock liners.

Propagation of clonal hardwood cuttings is represented by Columbia Planetrees (*Platanus* × *acerifolia*, 'Columbia'). Cuttings are stuck in the cutting bed in the spring, grown for one year and then harvested. The remainder of the production process is similar to seedling rootstock liners. Tops of planetrees are pruned back to the lowest bud rather than grafting.

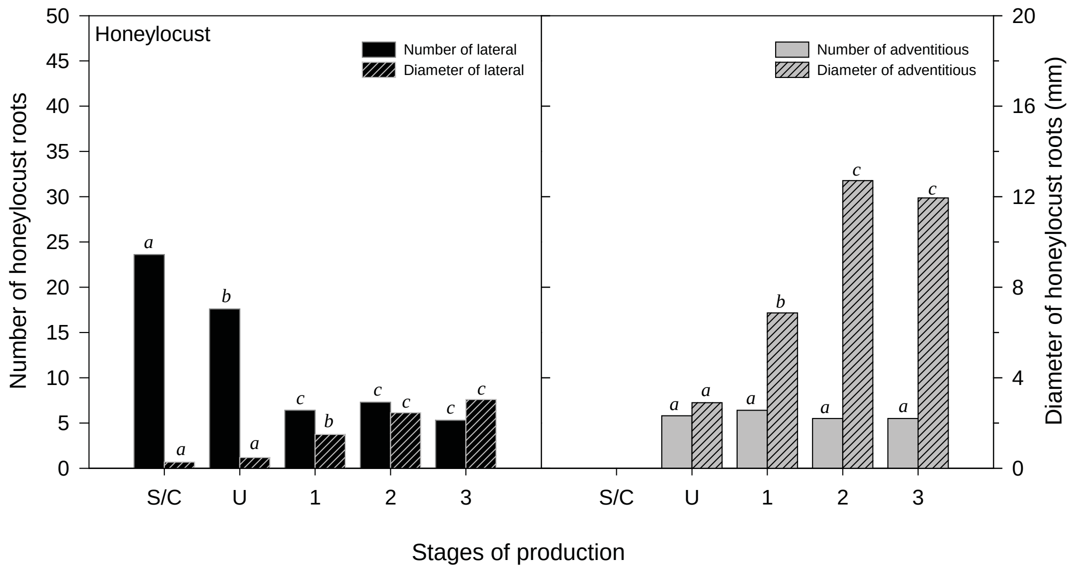
Root architecture. To describe root architecture, the diameter of each lateral root emerging from the primary root or cutting between the soil line and 10 cm (3.9 in) depth was recorded, as well as the diameter of each adventitious root regenerating from the pruned end. Roots were measured as close to the primary root as possible, but beyond the basal swelling (when present) on larger roots.

Clonal EMLA 111 rootstock required a slight modification of the measurement procedures used above. While buried in sawdust, the EMLA 111 rootstock developed clusters of hundreds of tightly packed fine, hair-like roots along the buried portion of the stem. The abundant small roots within the cluster did not persist into successive years, and were impractical to measure at less than 0.5 mm (0.02) in diameter. Only roots 1.0 mm (0.04 in) diameter or greater within the clusters, or growing outside of the clusters, were measured.

Statistics. Each rootstock was analyzed separately using one way analysis of variance (ANOVA) performed at ($P < 0.05$) and means separated using the Holm-Sidak procedure ($P < 0.05$), in SigmaStat v. 3.0, (Systat Software Inc., San Jose, CA).

Results and Discussion

Lateral roots. The average number of lateral roots decreased during production for all rootstocks, though at different stages. Undercutting honeylocust and sugar maple resulted in a 25 and 20% decrease in the number of lateral roots respectively during the second year in the seedling bed, though only marginally significant in sugar maple ($P = 0.052$). During the first year after transplanting, there were further significant decreases of lateral roots in these two rootstocks, 63 and 62%, respectively (Fig. 1). Though not undercut, pear seedling rootstock responded similarly during the first year after transplanting, with a > 50% loss of lateral roots (Fig. 2). Mechanical damage and desiccation of lateral roots during harvesting and transplanting, and drying of surface soils after planting (personal communication, Keith Warren, J. Frank Schmidt and Sons, Co.) are possible contributors to the large loss of lateral roots. The loss of lateral roots following undercutting may be due to minor mechanical disturbances during the undercutting process, especially to the smallest roots. Growth of lateral roots has also been shown to be more sensitive to scarce carbohydrate supply than the tap root (14, 19). The same relationship may also be true between lateral roots and adventitious roots produced from the tap



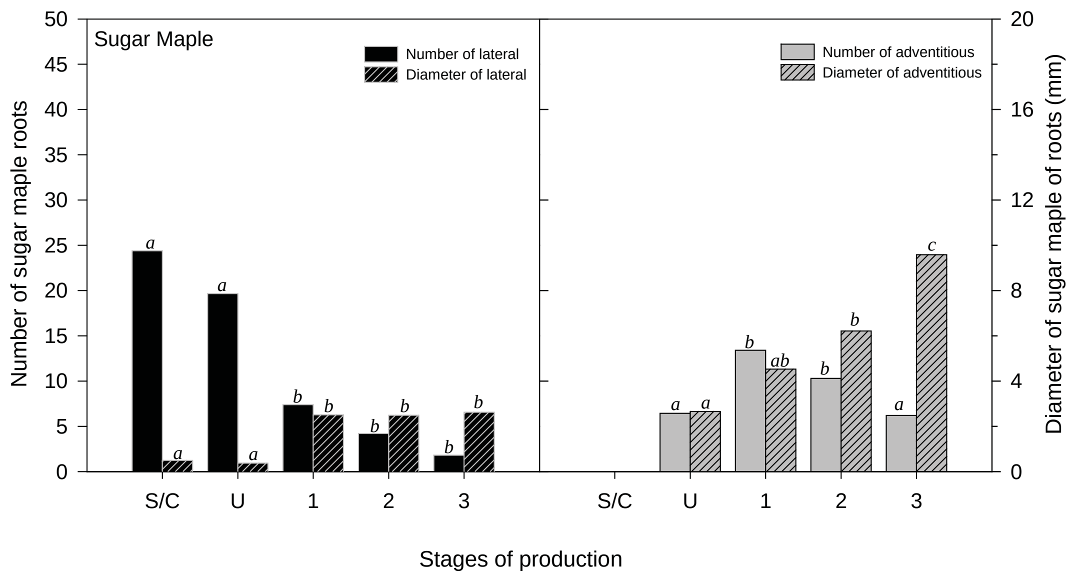


Fig. 1. Mean number and diameter of lateral roots in the first 10 cm of primary root, and adventitious roots at the pruned end of the primary root/cutting of honeylocust and sugar maple over several production stages. S/C = 1 year after seedling or cutting stage; U = 1 year after undercutting; 1 = 1 year after transplanting; 2 = 2 years after transplanting; 3 = 3 years after transplanting. Means across bars of the same color and pattern with different letters are significant (Holm-Sidak method, *P* < 0.05).

root. There was no further significant change in the number of roots in any of these three seedling rootstocks in the last two years of production.

There was a similar decrease in the number of lateral roots in both seedling domestic apple and EMLA 111 apple rootstocks, but not until the second year after transplanting. Lateral root losses were 84 and 78%, respectively (Fig. 3). It is not clear why only the two apple rootstocks did not lose significant numbers of lateral roots until the second year after transplanting, one year later than other seedling rootstocks. There was no further significant change in the number of roots in the last year of production for either apple rootstock.

Planetree, propagated by cuttings, is unlike other rootstocks in this study. Less than two adventitious lateral roots were produced per tree in the first year, with no significant change in number at any time during production (Fig. 2).

The average diameter of lateral roots increased over time for all rootstocks, though at different stages (Figs 1, 2, and 3). In honeylocust, the diameter of lateral roots significantly increased in all three years after transplanting. Sugar maple lateral roots increased in diameter only during the first year after transplanting. Pears, seedling and EMLA apple lateral roots increased in diameter only in the second year after transplanting. Planetree lateral roots did not increase in diameter until three years after transplanting.

For most rootstocks, the increase in lateral root diameter occurred concurrently with the loss of large numbers of lateral roots (Figs 1, 2, and 3). The loss of small roots may have created a bias in the average increase in diameter. Categorizing the roots into size classes revealed that the significant increases in average diameter after transplanting were a result of the loss of large numbers of small roots, rather than the real growth of the few persisting larger roots

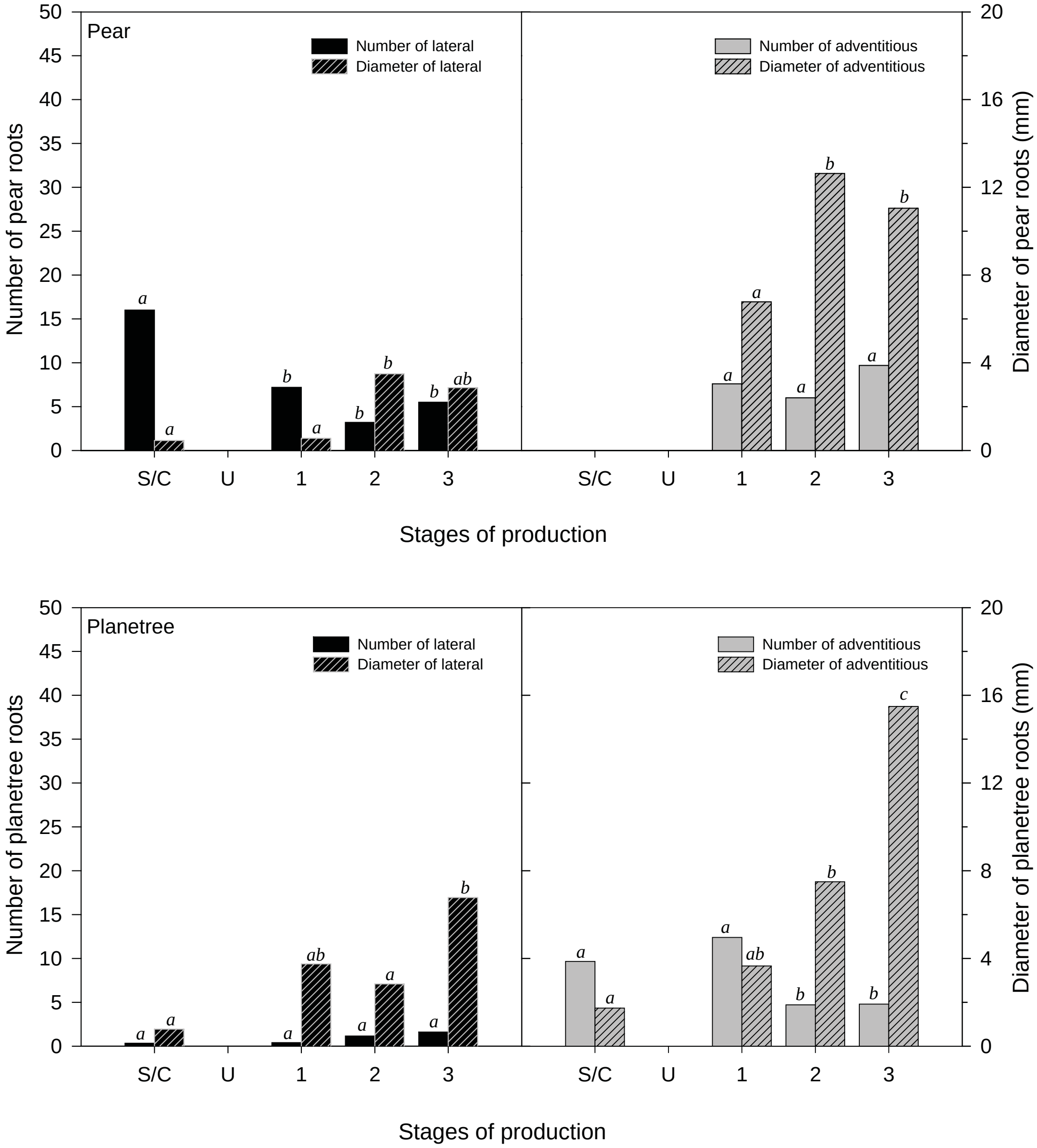


Fig. 2. Mean number and diameter of lateral roots in the first 10 cm of primary root, and adventitious roots at the pruned end of the primary root/cutting of pear and planetree over several production stages. S/C = 1 year after seedling or cutting stage; U = 1 year after undercutting (not required by these species); 1 = 1 year after transplanting; 2 = 2 years after transplanting; 3 = 3 years after transplanting. Means across bars of the same color and pattern with different letters are significant (Holm-Sidak method, *P* < 0.05).

(Table 2). Using sugar maple rootstock as an example, the average diameter of all lateral roots appeared to increase 500 percent from 0.5 mm (0.02 in) at the seedling stage to 2.5 mm (0.1 in) one year after transplanting (Fig. 1). The number of small lateral roots [< 3 mm (0.12 in) diameter] decreased from approximately 24 to only five roots per tree during the same time period. When only the persisting, larger roots [≥ 3 mm (0.12 in) in diameter] are included in the average, the diameter did not increase over time. The same is true for all other species except ELMA 111 apple (Table 2).

By the time all species of rootstocks were harvested as branched liners, three years after transplanting, there were fewer than three lateral roots larger than 3 mm (0.12 in) per tree. Given the small number, and lack of growth of these remaining lateral roots, there appears to be little chance they could develop into a normal root flare of up to eleven roots per tree (2, 12).

Adventitious roots. When the primary root is pruned, adventitious roots are produced around the end of the primary root or cutting. The number of honeylocust and pear adventitious roots did not change throughout production. The number of sugar maple and EMLA 111 apple roots significantly increased temporarily one year after transplanting, then decreased again to a number similar to the seedling/cutting stage three years after transplanting. Seedling apple and planetree significantly decreased two years after transplanting (Figs 1, 2, and 3).

The average diameter of adventitious roots increased over time for all rootstock though at different stages (Figs 1, 2, and 3). Both sugar maple and planetree significantly increased the second and third year after transplanting, while ELMA 111 apple and pear increased only the first year after transplanting. Honeylocust adventitious root diameter increased both the first and second year after transplanting

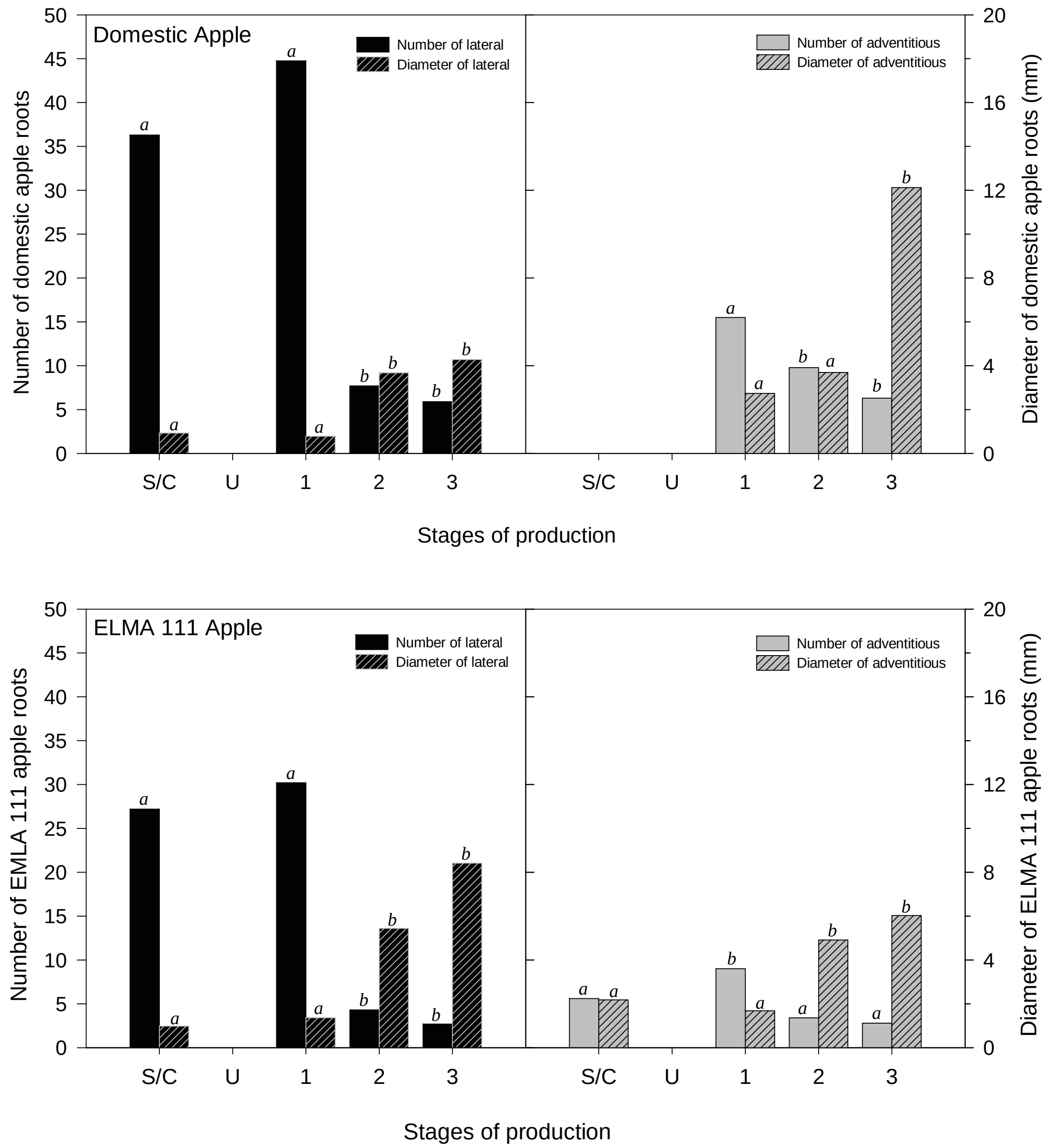


Fig. 3. **Mean number and diameter of lateral roots in the first 10 cm of primary root, and adventitious roots at the pruned end of the primary root/cutting of domestic seedling and M111 apple (no undercut stage) over several production stages. S/C = 1 year after seedling or cutting stage; U = 1 year after undercutting (not required by these species); 1 = 1 year after transplanting; 2 = 2 years after transplanting; 3 = 3 years after transplanting. Means across bars of the same color and pattern with different letters are significant (Holm-Sidak method, *P* < 0.05).**

and seedling apple did not increase until three years after transplanting. In contrast to the situation with lateral roots where persisting roots did not increase in diameter over time, and the average diameter increase of persistent adventitious roots was real and not influenced by the loss of small roots (data not shown).

At the final stage of production, or the third year after transplanting, most rootstocks had an average of 5 to10 vigorous adventitious roots at the pruned end the primary root of each seedling or cutting. EMLA 111 apple stock was the exception with only three roots (Fig. 1, 2, and 3).

The architecture of the six rootstocks in this study was altered by typical nursery practices. By the time the trees reached marketable size as whips and branched liners, the number of persisting natural lateral roots on upper 10 cm (4 in) of the primary root (usually 2 to 3 per tree) was insufficient to form a root flare in the natural location. The adventitious roots at the pruned end (usually 5 to10 per tree) were 2 to 4 times larger than the remaining lateral roots and growing rapidly. Given that there are approximately three times the number of adventitious roots at the cut end, and they are approximately three times the size of the remaining natural laterals and growing vigorously, they begin to dominate the root system even as young liners. These vigorous adventitious roots at the cut end of the primary root develop into an 'adventitious root flare' (ARF) which supplants the natural root flare and is somewhat deeper in the soil than a natural root flare.

The depth of the ARF depends on the length of the primary root after root pruning in the nursery. The primary root is commonly pruned to approximately 10 cm (4 in). As the roots produced at the end thicken, and begin to form a root flare, the distance between the soil surface and the structural roots is soon reduced to an acceptable level of 7.5 cm (3 in)

Table 2. Mean number and diameter of lateral roots occurring on the first 10 cm (4 in) of the main root of six commonly used species of street trees, during the first three years of nursery field production[z]. Many smaller diameter roots are lost following transplanting. There are fewer larger roots and their growth is minimal. There appears to be little chance they could develop into a normal root flare.

	Number < 3 mm	Number ≥ 3 mm	Diameter ≥ 3 mm	Number < 3 mm	Number ≥ 3 mm	Diameter ≥ 3 mm
	Planetree			**Sugar Maple**		
Seedling/cutting	0.33a	0.00a	—[y]	24.10a	0.30a	3.67a
1 yr after transplanting	0.20a	0.20a	5.00a	5.00b	2.40a	6.15a
3 yr after transplanting	0.00a	1.60b	6.78a	0.80b	1.00a	3.43a
	F = 0.88 P = 0.466	F = 4.69 P = 0.011	F = 2.07 P = 0.210	F = 46.53 P < 0.001	F = 1.60 P = 0.194	F = 2.96 P = 0.069
	ELMA111 apple			**Pear**		
Seedling/cutting	26.50a	0.70a	3.69a	15.50a	0.50a	4.00a
1 yr after transplanting	27.20a	3.00b	3.05a	6.80b	0.40a	3.50a
3 yr after transplanting	0.20b	2.50b	9.94b	3.00b	2.50b	3.94a
	F = 34.01 P < 0.001	F = 6.13 P = 0.002	F = 7.06 P = 0.001	F = 19.34 P < 0.001	F = 4.67 P = 0.008	F = 3.08 P = 0.056
	Domestic apple			**Honeylocust**		
Seedling/cutting	35.20a	1.10a	5.04a	23.60a	0.00a	—[y]
1 yr after transplanting	42.00a	2.75b	4.83a	5.20b	1.20ab	3.78a
3 yr after transplanting	3.10b	2.80a	5.62a	3.40b	1.90b	4.57a
	F = 27.08 P < 0.001	F = 5.19 P = 0.004	F = 0.317 P = 0.813	F = 32.98 P < 0.001	F = 10.07 P < 0.001	F = 3.62 P = 0.031

[z]Means within columns for each rootstock with different letters are significantly different (Holm-Sidak method, $P < 0.05$).

[y]Contains no roots in that size class and treated as missing data.

or less (15). If the primary root is pruned substantially longer the ARF may be too deep when the liners are planted in the landscape nursery and ultimately in the landscape. A deep ARF may not be detrimental at a nursery with well drained soil, but may reduce tree vigor and survival when planted into landscapes with dense, poorly drained soil (16).

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