ROOT DIMENSIONS OF LANDSCAPE TREE CULTIVARS

by Henry D. Gerhold[1] and Andra D. Johnson[2]

Abstract. Entire root systems of 46 trees, consisting of eight utility-compatible cultivars in four genera, were excavated and measured as to length of longest roots, depth, and dry weight of roots inside and outside standard root ball sizes. Root lengths were longer along rows than across rows, were closely related to trunk diameter, and differed among genera. Roots of *Syringa* cultivars were up to twice as long as those of *Amelanchier*. Depths were more variable, and no differences were detected among genera. The most surprising finding was that 53% to 100% of root biomass would be retained within standard root balls of trees up to 6 cm dbh, and even 29% to 83% retained for trees up to 20 cm. In contrast, previous studies using different methods concluded that only 2% to 9% of roots would be retained in standard root ball sizes.

Key Words. Roots; root length; root depth; root biomass; standard root ball; *Amelanchier* 'Cumulus'; *Amelanchier* Autumn Brilliance®; *Amelanchier* 'Snowcloud'; *Malus* Harvest Gold®; *Malus* 'Professor Sprenger'; *Pyrus calleryana* 'Autumn Blaze'; *Pyrus calleryana* Chanticleer®; *Syringa reticulata* 'Ivory Silk'.

The difficulty of excavating or sampling tree roots has limited our knowledge of root lengths, depths, and proportions retained within standard root balls. Data come mainly from observations of orchard and forest trees (Atkinson 1980; Persson 2002) and from just a few studies of landscape trees in nurseries or several years after transplanting. Roots may extend 1.7 to 7.3 times as far from the trunk as branches (Rogers 1933; Gilman 1998a), and lengths are directly related to trunk diameter (Gilman et al. 1987; Gilman 1988a). Two studies based on root lengths or soil volumes concluded that 91% to 98% of tree roots remain in the nursery upon transplanting (Watson and Himelick 1982; Gilman 1988b). Roots in compacted urban soil were found to be shallower than those in forest or nursery soils (Atkinson 1980; Perry 1982; Gilman et al. 1987).

The excavation of entire root systems in a study of carbon storage by trees (Johnson 2002) made it possible to measure root dimensions related to nursery and transplanting practices. In particular, we wanted to determine how root lengths, depths, and weights were related to standard root balls of various sizes, in relation to trunk diameter.

METHODS

Eight cultivars were chosen to represent a wide range of street trees commonly planted under utility lines, and available locally in central Pennsylvania, U.S.: *Amelanchier* 'Cumulus'; *Amelanchier* Autumn Brilliance®; *Amelanchier* 'Snowcloud'; *Malus* Harvest Gold®; *Malus* 'Professor Sprenger'; *Pyrus calleryana* 'Autumn Blaze'; *Pyrus calleryana* Chanticleer®; and *Syringa reticulata* 'Ivory Silk'. Five trees were randomly selected in each of six cultivars growing in one of three nurseries (Table 1); two sets of five trees of 'Ivory Silk' tree lilac were in two of these nurseries. Nursery soils included silt loam at Nittany Trees and PenCor Nursery, and clay loam and sandy loam at College Gardens Nursery. In addition, six trees of 'Cumulus' serviceberry were growing in clay loam along a borough street in a 244 cm wide tree lawn. Altogether, 46 trees were excavated and measured. Average sizes of the cultivars ranged from 3.8 to 16.1 cm diameter at breast height (dbh), and 3.0 to 6.4 m in height (Table 1).

The entire root system of each tree was excavated using an Air-Spade™ Series 2000 with a 150 scfm/90 psig nozzle (Concept Engineering Group, Inc., Verona, PA) connected to an air compressor. Its high-speed air jet removed soil without damaging fine roots. Lengths of the longest roots along the row and at right angles to the row were measured in both directions and added to express root spread; also the depth of the deepest roots was measured. The roots of each tree were then cut at the trunk and at the point where they would meet the edge of a hypothetical standard root ball (American Association of Nurserymen 1996); the specified root ball diameters ranged from 56 cm to 211 cm, according to the caliper of each tree. The two groups of root segments from each tree were then oven-dried at 105 ± 3°C for 4 to 5 days to a constant weight. A few of the 'Cumulus' serviceberry roots extended underneath the sidewalk or curbing, so their lengths and weights were estimated from dimensions of unimpeded roots that had equivalent diameters at the same distance from the trunk.

The significance of differences in root spread along the row from spread across the row was determined by pairwise t-tests. Regression equations were calculated to examine the relationships of the dependent variables with dbh. Regression lines for root spread were fitted for *Amelanchier, Malus,* and *Syringa*, but not for *Pyrus* because of the narrow range of dbh in this genus.

RESULTS

The spread and depths of roots increased with tree size (Table 1). Also, there were apparent differences in root

Table 1. Means of the root spread along rows and across rows, and deepest roots, with corresponding average dbh and height of cultivars of *Amelanchier*, *Malus*, *Pyrus*, and *Syringa*, located in three nurseries (C = College Gardens, N = Nittany Trees, P = PenCor nurseries), and along a Borough of State College street (B).

Cultivar	Location	Number	Along the row (cm)	Across the row (cm)	Depth (cm)	Dbh (cm)	Height (m)
A. Autumn Brilliance®	C	5	198.2	154.0	24.8	3.86	3.83
A. 'Cumulus'	B	6	406.2	262.0	69.3	16.08	6.41
A. 'Snowcloud'	C	5	89.6	68.0	48.4	4.16	4.03
M. Harvest Gold®	N	5	270.8	202.2	67.6	7.11	4.38
M. 'Professor Sprenger	C	5	240.0	150.0	35.0	3.81	3.02
P. 'Autumn Blaze'	C	5	223.0	193.4	60.4	4.62	3.57
P. Chanticleer®	N	5	155.6	107.4	55.0	5.28	3.83
S. 'Ivory Silk'	N	5	279.2	234.0	58.8	6.65	3.67
S. 'Ivory Silk'	P	5	402.2	311.0	50.0	10.46	4.57

spread among genera (Figure 1 and Figure 2). The roots of *Syringa* were longer than those of *Malus*, which were longer than roots of *Amelanchier* cultivars. Regressions of root spread on dbh accounted for 72% to 91% of the variation. Root depths were not as closely correlated with dbh ($R^2 = 0.30$) as lengths, and depths did not differ among genera (Figure 3).

The spread of roots along rows were in all cases longer, from 15% to 60%, than spread across the row (Table 1). These differences were significant according to t-tests.

The proportion of root biomass retained inside standard root balls was highly variable and tended to decrease with dbh (Figure 4). Trees below 6 cm dbh had from 53% to 100% of their root biomass inside the hypothetical root balls. Between 6 and 20 cm dbh, trees had from 29% to 83% of root biomass inside the root balls. The regression of biomass on dbh explained only 37% of the variability.

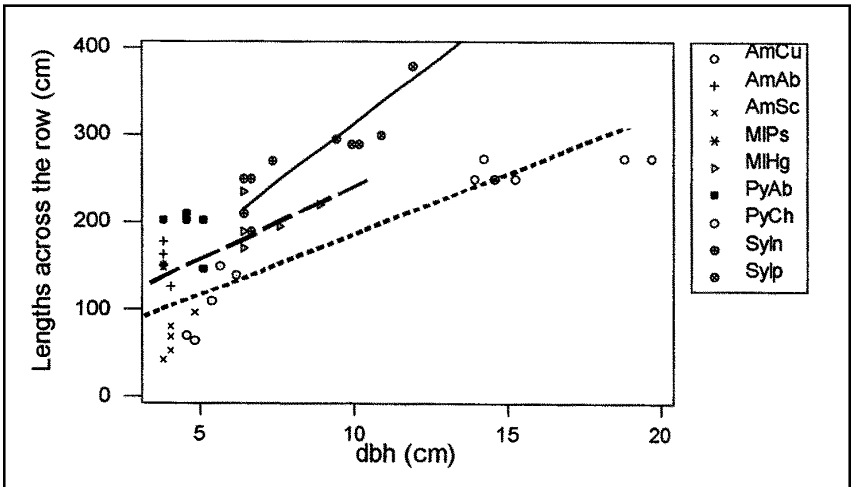

Figure 1. Root spread across the row related to dbh for cultivars of *Amelanchier* 'Cumulus' (AmCu), Autumn Brilliance® (AmAb), and 'Snowcloud' (AmSc); *Malus* Harvest Gold® (MlHg) and 'Professor Sprenger' (MlPs); *Pyrus calleryana* 'Autumn Blaze' (PyAb) and Chanticleer® (PyCh); and *Syringa reticulata* 'Ivory Silk' at Nittany (SyIn), 'Ivory Silk' at PenCor (SyIp). Regressions for *Amelanchier*, small dashed line, Y = 11.9 (dbh) + 66.2, R^2 = 76%; *Malus*, long dashed line, Y = 14.5 (dbh) + 97.2, R^2 = 72%; and *Syringa*, solid line, Y = 21.9 (dbh) + 85.3, R^2 = 78%.

DISCUSSION

The equations for root spread versus dbh of *Syringa* gave results similar to those of Gilman (1988a), who studied larger types of trees, including red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica*), and honeylocust (*Gleditsia triacanthos*). The roots of *Amelanchier*, especially those of the older trees, were only about half as long as those of *Syringa*.

Furthermore, the horizontal configuration of the root systems of trees in nurseries appeared to be oval, not round. The roots of every cultivar in all nurseries were shorter across the row than along the row. This finding could be attributed to weed control practices that kept rows free of other vegetation that would compete with tree roots (Harris 1966; Whitcomb and Roberts 1973). If the oval shape of root systems is typical of trees in nurseries, it could have implications for possibly modifying cultural or lifting practices that affect the portions of roots retained within root balls.

The trees along the borough street also had shorter roots at right angles to the row, but for a different reason. The sidewalk and curbing presented physical barriers that interfered with root elongation. Therefore, the spread of the roots was just slightly greater than the distance from curb to sidewalk.

The study was not designed to compare effects of cultivars or nursery conditions on root dimensions, although either or both could have affected them. The significant regressions

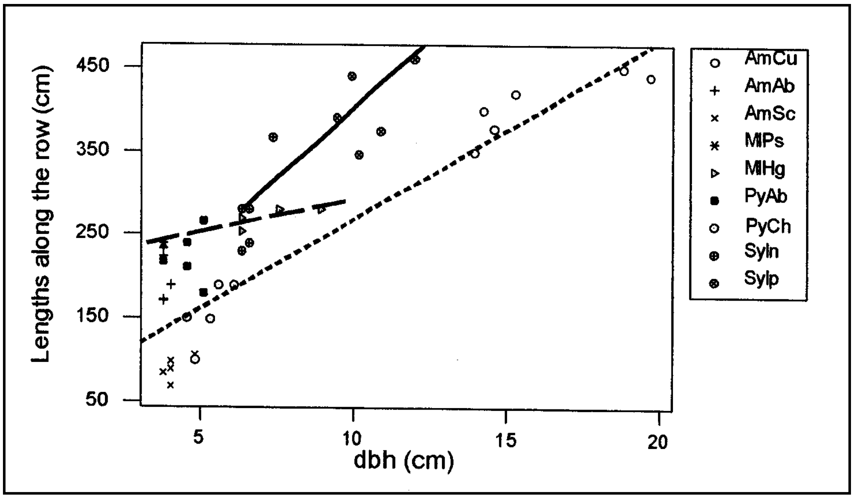

Figure 2. Root spread along the row related to dbh for cultivars of *Amelanchier* 'Cumulus' (AmCu), Autumn Brilliance® (AmAb), and 'Snowcloud' (AmSc); *Malus* Harvest Gold® (MlHg) and 'Professor Sprenger' (MlPs); *Pyrus calleryana* 'Autumn Blaze' (PyAb) and Chanticleer (PyCh); and *Syringa reticulata* 'Ivory Silk' at Nittany (SyIn), 'Ivory Silk' at PenCor (SyIp). Regressions for *Amelanchier*, small dashed line, Y = 21.1 (dbh) + 62.1, R^2 = 86%; *Malus*, long dashed line, Y = 8.9 (dbh) + 206.7, R^2 = 91%; and *Syringa*, solid line, Y = 32.6 (dbh) + 62.0,R^2 = 75%.

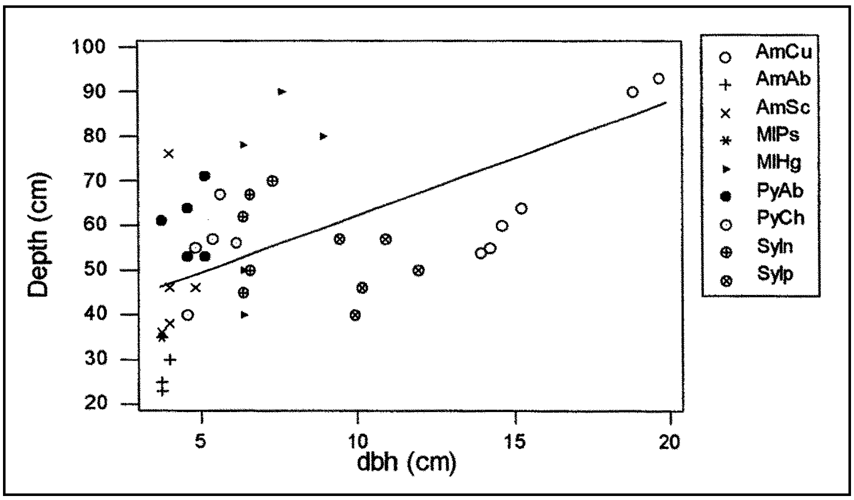

Figure 3. Root depths related to dbh for culivars of *Amelanchier* 'Cumulus' (AmCu), Autumn Brilliance® (AmAb), and 'Snowcloud' (AmSc); *Malus* Harvest Gold® (MlHg) and 'Professor Sprenger' (MlPs); *Pyrus calleryana* 'Autumn Blaze' (PyAb) and Chanticleer (PyCh); and *Syringa reticulata* 'Ivory Silk' at Nittany (SyIn), 'Ivory Silk' at PenCor (SyIp). The regression Y = 2.35 (dbh) + 35.86, slope is significant at = 0.0001, R^2 = 0.30; root MSE = 15.3; standard error of slope = 0.55.

of root spread appear to depend mainly on genera along with dbh, and less on nursery conditions. 'Ivory Silk' tree lilacs had longer roots, and the three serviceberry cultivars had shorter roots than two crabapple cultivars, regardless of their location.

The significant relationship of increasing root depth with tree size, though expected, was dependent mainly on the one cultivar growing along the street and fails to explain most of the variability. Some contrasting depth-to-size relationships between related cultivars were observed. For example, the larger 'Autumn Blaze' Callery pears had shallower roots than the smaller Chanticleer® trees. The Callery pear cultivar with more shallow roots was growing in the Nittany Trees nursery, and the other with deeper roots was in the College Gardens nursery. The opposite was true of the two crabapple cultivars, so it is doubtful that soil differences were responsible. ' Ivory Silk' tree lilacs gave the clearest indication of a possible nursery effect, because the smaller trees at Nittany Trees had deeper roots than the same cultivar at Pencor Nursery. An alternative but less likely explanation is that different root stocks may have caused differences in root depth; however, nothing is known about any of the root stocks.

The most surprising finding is that such a large proportion of the root biomass, from 53% to 100% of the dry weight, would be contained within the standard root ball of trees with a dbh below 6 cm. Even trees that were 6 to 20 cm would have 29% to 83% of the root biomass within the appropriate size root ball. The discrepancy with earlier studies may be due to differences in methodology, tree size and species, and the ways by which root systems may be characterized. Watson and Himelick (1982) concluded, from a model root system of a 10 cm caliper tree representing 88 excavated trees in seven deciduous species, that the soil volume dug by a tree spade would represent only 2% of the volume occupied by all roots, and therefore the root system would be reduced by up to 98%. Similarly, Gilman (1988b) found that 91% to 95% of root lengths would be outside standard root balls of honeylocust, green ash, and poplar (*Populus* × *generosa*) trees 3 years after transplanting. It is difficult to reconcile such large root ball differences between methods based on weight versus length of roots, or weight versus soil volumes occupied by roots. Differences among species in their root structures might account for part of the discrepancy, but probably not most of it.

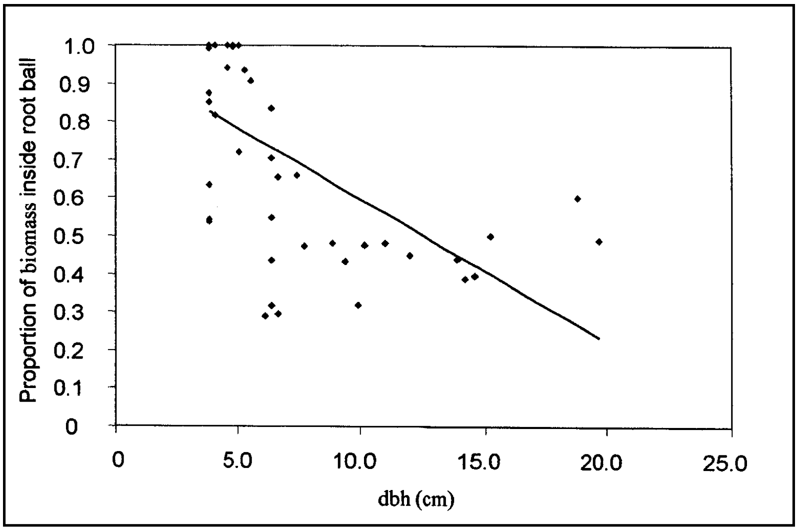

Figure 4. Proportion of root biomass stored inside a standard root ball for individual trees of *Amelanchier*, *Malus*, *Pyrus*, and *Syringa* cultivars. Proportions regressed against diameters (dbh), Y= –0.0374 (dbh) + 0.97, R^2 = 0.37, root MSE = 0.210, significant at = 0.

CONCLUSIONS

The root spread of smaller types of landscape trees in nurseries can be estimated reliably from trunk diameter. The longest roots were 15% to 60% longer along rows than across rows, probably due to practices used to control competing vegetation. Roots of *Syringa* cultivars were up to twice as long as roots of *Amelanchier* cultivars, and those of *Malus* cultivars were intermediate.

Root depths were more variable in relation to trunk diameter than were root lengths. The extent to which cultivars, root stocks, soil characteristics, or nursery practices may have influenced this variability was unclear.

The dry weight of roots retained within standard size root balls was 53% to 100% of the entire root system of trees below 6 cm dbh. Trees 6 to 20 cm in dbh would have 29% to 83% of root biomass within their root balls. These percentages based on weights are much larger than the 2% to 9% within root balls found in previous studies based on root lengths or soil volumes occupied by roots.

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Résumé. Les systèmes racinaires complets de 46 arbres, provenant de huit cultivars de quatre genres différents, ont été excavés et mesurés en regard de la longueur des plus longues racines, de la profondeur, ainsi que de la masse sèche en racines à l'intérieur et à l'extérieur de mottes de dimensions standards. Les longueurs en racines étaient plus élevées le long des allées qu'au travers des allées, étaient reliés intimement au diamètre du tronc, et différaient selon les genres. Les racines des cultivars de *Syringa* étaient jusqu'à deux fois plus longues que celles des *Amelanchier*. Les profondeurs étaient plus variables, mais aucune différence n'a été détectée entre les différents genres. La découverte la plus surprenante a été que 53% de la biomasse racinaire pouvait être retenue à l'intérieur des mottes standards d'arbres dont le diamètre allait jusqu'à 6 cm de DHP, et que 29 à 83% pouvait l'être pour les arbres allant jusqu'à 20 cm de diamètre. En contraste, les études précédentes qui utilisaient des méthodes différentes concluaient que seulement 2 à 9% des racines pouvaient se retrouver à l'intérieur des mottes de racines de dimensions standards.

Zusammenfassung. Von 46 strassentauglichen Baumkultivaren aus 4 verschiedenen Arten wurden die gesamten Wurzelsysteme ausgegraben und die Länge der längsten Wurzeln, die Tiefe und das Trockengewicht innerhalb und ausserhalb des Standartwurzelballens gemessen. Die Wurzeln waren entlang der Reihe länger als quer dazu, waren dicht korreliert zum Stammdurchmesser und differierten unter der verschiedenen Arten. Die Wurzeln von *Syringa*-Kultivaren waren länger als bei *Amelanchier*. Die Tiefe war mehr variabel und es wurde keine Differenz zwischen den Arten festgestellt. Das überraschendste Ergebnis war, dass 53 bis 100 % der Wurzelmasse bei Bäumen bis zu 6 cm BHD innerhalb des Standartwurzelballens waren bzw. 29 bis 83 % bei den Bäumen bis zu 20 cm BHD. Im Gegensatz dazu ergaben früheren Studien , die andere Methoden benutzten, nur einen Anteil von 2 bis 9 % Wurzelmasse innerhalb des Standartballens.

Resumen. Se excavaron y midieron la longitud de las raíces más largas de 46 árboles, pertenecientes a 8 cultivares compatibles en cuatro géneros; así también se midió la profundidad y peso seco dentro y fuera de las bolas o cepellones de raíces de tamaño estándar. La longitud de las raíces fue mayor a lo largo de las hileras de la bola que a través de ellas. Además, estuvieron relacionadas más estrechamente al diámetro del tronco, y difirieron entre géneros. Las raíces de los cultivares de *Syringa* fueron más del doble más largas que las de *Amelanchier*. Las profundidades fueron más variables, y no se detectaron diferencias entre géneros. El hallazgo más sorprendente fue que 53 a 100 por ciento de las biomasas de raíces estaban retenidas dentro de las bolas estándar de los árboles arriba de 6 cm de dap, y aún 29 a 83 por ciento retenidas por árboles arriba de 20 cm. En contraste, los estudios previos utilizando diferentes métodos concluyeron que solamente 2 a 9 por ciento de raíces estarían retenidas en bolas de raíces de tamaños estándar.