ROOT GROWTH BENEATH SIDEWALKS NEAR TREES OF FOUR GENERA1

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Abstract

Four genera of trees from 4 different plant families located in the City of Cincinnati, Ohio were examined: *Gleditsia* (honeylocust), *Koelreuteria* (golden raintree), *Quercus* (oak), and *Zelkova* (zelkova). The trees were planted in tree lawns 3.5 meters (11.5 ft) or less in tree lawn width. Approximately 1100 sidewalk joints near the trees planted within the last 20 years were observed for the presence of a root. The incidence of 1 or more roots, 1cm (3/8 in) in diameter or larger growing under the sidewalk at sidewalk joints within 1.8 m (6 ft) of the main stem was noted.

The probability of finding a root growing underneath the sidewalk was modeled against the time since the tree was planted, trunk diameter and tree lawn width. It was noted that the probability of finding a root approached 100% as trunk diameter approached 30 cm (12 inches) with some variation between genera. *Gleditsia* developed roots growing beneath the sidewalk at the smallest trunk diameter, followed by *Zelkova, Koelreuteria*, and *Quercus*. Time since planting and tree lawn width were less significant predictors of root presence than trunk diameter. Overall, *Quercus* produced the fewest roots of the four genera that were detected beneath the sidewalk.

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Key Words: *Gleditsia, Koelreuteria Quercus, Zelkova*, root growth, tree lawn, trunk diameter, sidewalk damage.

Introduction

Research has demonstrated that different species of trees can produce root systems of substantially different-size over time (Costello, *et al*., 1997; Schroth, 1995). Peper (1998) observed that some tree species are associated with damage to sidewalks within shorter time periods after planting than others. One method that is currently used by cities to reduce the damage from tree roots is the application of root barriers (McPherson 2000, Barker 1995, Costello et al. 1997). When root barriers are used, roots eventually grow beneath the barrier (Barker 1995[a,b, c]; Barker and Peper 1995, Peper 1998) and thus barriers might be expected to delay but not eliminate the damage.

Sandfort (2000) had empirically observed differences in performance by some of the trees that they were using in Cincinnati. It was decided to examine some of the common trees planted in the city to seek trends associated with different rates of tree root growth. If root pruning and installation of root barriers could be delayed, it might be possible to "buy time" in the effort to reduce tree-related sidewalk failures. Delaying preventative measures would allow the city to spread the tree installation costs out over time and it would also allow the city to prioritize preventative maintenance so the trees that posed the greatest likelihood of interfering with the sidewalk could be addressed first.

Materials and Methods

Trees were selected for the study based on genera, frequency and date of planting, number planted as well as previous experience in use. Data were obtained from City of Cincinnati planting records. Trees from four plant families were selected for the study. These included: *Gleditsia triacanthos,* in the family Fabaceae; *Quercus* species in the red oak group (*Q. rubra, Q. palustris, Q. shumardii, Q. phellos, Q. acutissima, Q. imbricaria, and Q. nigra)* in Fagaceae; *Zelkova serrata* in the Ulmaceae; and *Koelreuteria paniculata* in the Sapindaceae.

Initial considerations for determining which species to study were trees that were planted between 1981 and 1997 and genera with a sample population of at least 100 trees. The trees selected are inclusive of the entire population of the trees and sites in Cincinnati that met these criteria and were known to the City of Cincinnati Park Board to have been planted at a specified time. *Quercus* is the only genus where observations were made on multiple species. This was necessary because *Quercus* is a large genus and multiple species in this genus have been planted on the streets in Cincinnati. No single species was available in sufficient quantities for this study. Species of *Quercus* were limited to the red oak group since the species listed have similar uses in urban situations (Sydnor and Cowen 2001). The City of Cincinnati has regularly planted sufficient numbers of a single species from each of the other three genera for study. Observations were made during the summers of 1999 and 2000.

The following data were recorded for each tree for this analysis: name of the street and approximate address of the tree's location; year planted; width of tree lawn; presence or absence of a root greater than 1 cm in diameter within 20 cm (8 in) of the surface that was growing beneath the sidewalk at joints within 1.8m (6 ft.) of the tree; and diameter of main stem at 1.4 m (4.5 ft) above the ground (DBH). All trees are assumed to have been planted at approximately 4-6cm (1.5-2.5 in) DBH, as this is the size normally purchased by Cincinnati for planting on city streets.

For the purpose of this article, the term "sidewalk joint" refers to one of the pre-designed failure points in the sidewalk or an expansion joint. A nursery spade was used to dig to a depth of approximately 20-25 cm (8-10 in) immediately adjacent to the joint on the tree lawn side of the sidewalk. The presence or absence of a root at least 1 cm (3/8 in) in diameter growing underneath the walk was noted. The width of the area (e.g. the "sample hole") observed for a root was approximately 25 cm (10 in) wide with the joint located approximately in the center. The data reflect roots within approximately 12 cm (5 in) of the joint. The data were binary, so if one or more roots were observed in this area it was recorded as "true" for the presence of a root or "false" for the absence of roots.

The DBH of each tree was measured. The date of planting and size of the tree at planting were determined using Cincinnati planting records and the assistance of employees from the Cincinnati Park Board. Tree lawn widths in this study were selected to be smaller than 3.5 m (11.5 ft) in width. Under normal conditions research has shown that tree roots will grow at a rate of 30-70 cm (12-27 in) per year (Watson and Himelick 1982, Watson 1985). Taking into account root growth rates and standard root ball sizes for 5 cm (2 in) trees, 3 years was assumed to be sufficient time for tree roots to begin to outgrow the tree lawns selected for study.

The probability of finding a 1 cm or larger root at a sidewalk joint within 1.8 meters (6 ft) of a tree at a given DBH (in inches) was calculated and modeled using linear regression analyses. Similar models were also made on the mean probability of finding a root at given number of years from planting and at a given tree lawn width (in meters). Means from the models were used as the models are intended to apply collectively to groups of trees of a given age or DBH class, rather than to an individual tree chosen at random. Binary logistic regression was used to compare the relative incidences of positive root probes between genera for trees planted between 5 and 13 years previously.

Results and Discussion

DBH vs. Probability of a Root: Regression models were performed on joints next to trees ranging from the lowest diameter in the study, the 2.5-5 cm (1-2 in) class, to the diameter where the probability of 1 cm or larger root underneath a joint became 100%. Root presence at the sidewalk joints in this study reached 100% when the trees reached 27-35 cm (11-14 in.) DBH. This ranged from about 27 cm (11 in) for most genera to about 35 cm (14 in) for *Quercus.* While *Koelreuteria* also approached 100% root presence at 27 cm (11 in), the sample pool did not include sufficient numbers of trees above 27 cm (11 in) to confirm a strong pattern for that genus (Figure 1).

When the probability of a root was modeled against the DBH of the tree all models indicated that diameter class (inches) was a significant predictor ($P < 0.05$) of root presence under the sidewalk (Figure 1). *Gleditsia* and *Koelreuteria* had R^2 values of 89% and 61% respectively while *Quercus* and *Zelkova* had R^2 values of 30% and 50% respectively (Table 2). *Quercus* showed the weakest relationship between diameter and root probability, this may be due to several factors: *Quercus* was the only genus where multiple species were represented, was planted in the widest tree lawns, and produced fewer positive root probes on average compared with the other three genera as shown in Table 3. When the DBH was modeled for all of the joints and all genera in the study the r^2 was 75% with $P < 0.001$. It is also interesting to note that the slopes of the regression lines for the various genera was fairly consistent between 0.06 and 0.08. Data on *Quercus* and *Gleditsia* are comparable to Gilman (1988) that showed that trunk diameter was a reasonable predictor of root radius. Gilman noted that the r^2 for DBH as a predictor of root radius for *Gleditsia triacanthos* was 0.79 and for *Quercus virginiana* was 0.41.

Time since planting vs. probability of a root: Figure 2 shows the models generated for the probability of finding a root as predicted by time. Time proved to be a less reliable predictor of root presence than DBH. For some genera, tree ages were not as well distributed as diameters. This suggests that differences in site conditions played a role in tree growth. When root probability was modeled using time (years) as a predictor, only *Quercus* demonstrated statistical significance at alpha=0.05. Except for *Quercus,* P-values for the time models were lower than in the DBH models (Figure 2). Table 2 shows that r^2 values for the time models were notably lower for *Gleditsia, Koelreuteria,* and for "all genera" relative to the DBH models. The r^2 for *Quercus* was slightly higher for the time model than DBH, but oaks still had an r^2 below 50%. The r^2 for the *Zelkova* time model did not change substantially from the DBH model and remained near 50%. However, all these differences, both in statistical significance and r^2 between the DBH and time models, are small enough that they can be attributed to sample variation. As was the case with diameter, *Gleditsia* appeared to form roots the earliest, *Zelkova* the next earliest followed by *Quercus* and *Koelreuteria.* However, the differences between the genera for these models may be attributable to sample variation. The slopes of the regression lines for the various genera in the time models was more variable than in the DBH models, varying between 0.03 and 0.07.

Tree lawn width vs. probability of a root: . Previous data has suggested that the distance between the tree and the sidewalk (as might be influenced by tree lawn width) does have some effect on tree-related sidewalk failure (Parresol et al. 1996). Holding DBH relatively constant, root probability at 407 joints was modeled using tree lawn width as a predictor. Trees were selected in from the center of the range of diameter classes used in the study, specifically the 15-20 cm (6-8 in) diameter classes. Tree lawn widths in this model ranged from less than 1 meter to 3 meters. The resulting adjusted r^2 value for the model was 0.0%. When weighted regression was used to account for variations in sample size at the different tree lawn width levels, the resulting adjusted r^2 value for the model was 30.8%, and significance was low with $P = 0.15$ (Figure 3). Tree lawn width proved to be a poor predictor of root presence in this case. It is interesting to note however, that when binary logistic regression was performed on the data, the Hosmer-Lemeshow goodness of fit test was 0.992 with a $P < 0.001$. The data appeared to show a fairly linear, inverse relationship until tree lawns reached 3 meters in width. Twenty-four sidewalk joints in tree lawns 3 – 3.5 meters showed an unusually high root presence. No explanation was apparent that explained the deviation, however, the number of joints in this range was low enough that it did not adversely affect the Hosmer-Lemeshow goodness of fit test for the binary regression model.

Differences between Genera: Binary logistic regression was used to compare the relative incidences of positive root probes between genera for trees planted roughly 5 to 12 years previously (Table 3). Only oak showed significant differences in root presence from the other genera (alpha <= 0.05). Oak had on average the fewest positive root probes of the three. Marginal difference was shown between *Gleditsia* and *Koelreuteria* (Alpha = 0.065), with *Koelreuteria* producing fewer positive root probes.

No data was available on *Quercus* planted 12 years earlier or on *Zelkova* planted 5 years earlier. As a result comparisons reflect data on *Quercus* 5-13 years since planting and for *Zelkova* 6-12 years after planting.

Practical Applications: These data suggest that root presence beneath sidewalk joints within 1.8 meters (6 ft) of trees, as defined by the study criteria, approaches 100% as trees approach 25-30 cm (10-12 in) in diameter. Data for all genera show that the probability of finding roots begins to exceed 50% between 10 and 25 cm (5 and 10 in) DBH. Preventative maintenance might be planned to target trees before they reach a consistent 25-cm in diameter. Probability of roots for *Gleditsia* and *Zelkova* begins to exceed 50% shortly after the trees reach 13 -20 cm (5-8 in) in diameter. *Quercus* and *Koelreuteria* were, less aggressive than *Gleditsia* and *Zelkova.* *Quercus* appeared to be the least aggressive of the four genera (Table 3). Recall that the trees in this study were all planted at approximately 5 cm (2 in) DBH. Neither the diameter nor time models demonstrate significant differences between genera that exceeded sample variation. Sample variation may be attributable to the different species of trees producing roots of different diameters and differences in site conditions that might affect the rate of root development over time.

Previous research in Cincinnati (D'Amato et al. in press) suggests that the condition of the adjacent sidewalk may also determine the likelihood of finding roots under a sidewalk during the first 20 years after planting. That study shows that cracked sidewalks are more likely to favor oxygen dissemination into the soil under the sidewalk and are associated with increased root growth. That knowledge, when combined with the data from this study, suggests that aggressively rooted species planted in older cracked sidewalks would require the earliest intervention to delay sidewalk failure related to tree root growth. Conversely, less aggressively rooted species planted near newer or well-constructed sidewalks with few cracks allows for a delay in preventative measures such as root pruning or root barrier installation.

The City of Cincinnati expects sidewalks to have a service life of 20 to 25 years (Sandfort, 2000). Previous research in Cincinnati (Sydnor et al. 2000) found that the incidence of tree-related sidewalk failure during the first 20 years was fairly low. Preventative measures for less aggressive species such as oak may not be cost effective if trees are planted near well-constructed, intact or new sidewalks and the goal is to prevent tree-related failure during the intended 20-25 year service life of the sidewalk.

Urban foresters must ultimately use their experience with the species of trees that they are planting, and their knowledge of the sidewalk conditions and construction techniques employed to build sidewalks in their area. This information should be used to make decisions such as: which tree species would benefit from delayed root barrier installation; which species should be treated early after planting; and which species may not benefit at all from such treatments. The models provided here are intended to assist city foresters in developing guidelines for citywide planning and preventative maintenance aimed at reducing sidewalk damage associated with tree roots. Armed with the information in this report, city foresters will have additional information on which to base a decision.

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Table 1. Summary data for four genera of trees detailing mean tree lawn size, mean time from planting, and number joints observed**.**

Genus	**Mean Tree Lawn Size meters (feet)**	**Mean Time Since Planting (years)**	**Number of Joints Observed**
Gleditsia	1.6 (5.3)	11.0	282
Koelreuteria	1.4 (4.6)	10.6	234
Quercus	2.3 (7.4)	9.8	384
Zelkova	2.1 (6.8)	9.0	225
All: Total	**- -**	**- -**	**1125**
Mean	**2.0 (6.5)**	**10.1**	**281**
Median	**1.9 (6.2)**	**9.0**	**- -**
Std. Dev.	**0.5 (1.8)**	**3.7**	**- -**

Table 2. Simple linear regression r^2 values for the probability of roots at sidewalk joints within 1.8m (6 feet) of tree as predicted by time since planting and trunk diameter.

Genus	Adjusted r^2 (DBH)	Adjusted r^2 (Time)	P-value: DBH as a predictor of root prob.	P-value: Time as a predictor of root prob.
Gleditsia	88.7%	80.0%	<0.01	0.10*
Koelreuteria	61.1%	44.9%	<0.01	0.06*
Quercus	30.2%	38.1%	0.03	0.02
Zelkova	49.6%	54.1%	0.02	0.06*
All Trees	**75.5%**	**62.1%**	**< 0.01**	**< 0.01**

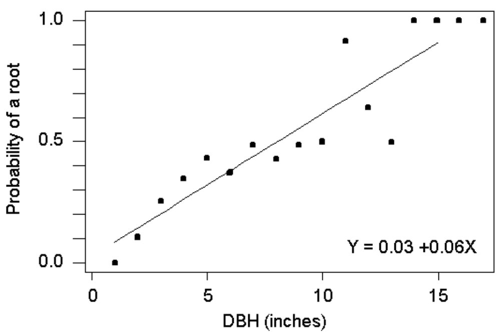
*** Denotes model that is not significant at the 95% level.**

Table 3. Differences in root incidence at sidewalk joints within 1.8 meters of trees of 4 genera. Percent positive root probes, years since planting, number of joints observed and p-values for differences between genera. [a] Observations not available for *Zelkova* at year 5 and *Quercus* at year 12.

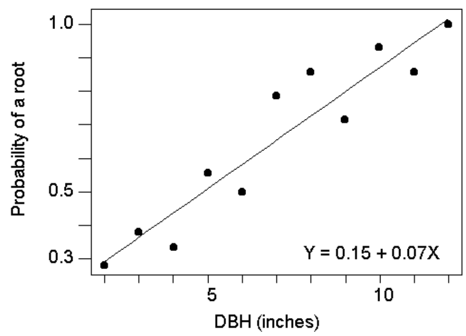
Genus	Positive Root Probes Raw %	Years since Plant.	# Obs.	P-Values for differences (Binary Regression)			
				Gleditsia	***Zelkova***	***Koelreut.***	***Quercus***
Gleditsia	83	5-12	212	- -	0.092	0.065	< 0.001
Zelkova	60	6-12[a]	197	0.092	- -	0.806	< 0.001
Koelreuteria	55	5-12	162	0.065	0.806	- -	< 0.001
Quercus	27	5-13[a]	347	< 0.001	< 0.001	< 0.001	- -

Figure 1. Probability of finding a root greater than 1cm at a sidewalk joint within 1.8 meters of a tree planted in a tree lawn less than 3.5 meters in width. All analyses are significant at the 95% (P=0.05) level or greater.

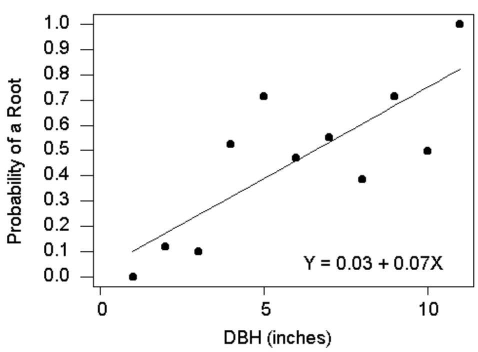
a. Probability of a root as predicted by DBH for all genera (r^2 = 75.5%):



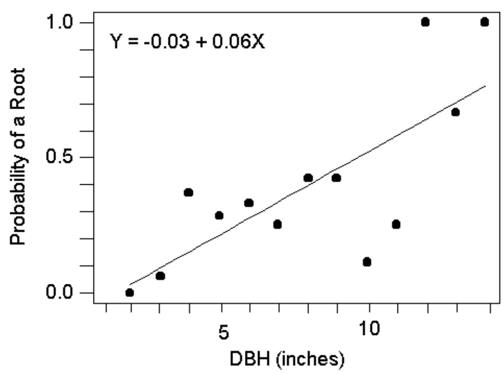
b. Probability of a root as predicted by DBH for *Gleditsia* (r^2 = 88.7%)



c. Probability of a root as predicted *Koelreuteria* (r^2 = 61.1%)



d. Probability of a root as predicted by DBH for by DBH for *Quercus* (r^2 = 30.2%)



e. Probability of a root as predicted by DBH for *Zelkova* (r^2 =49.6%)

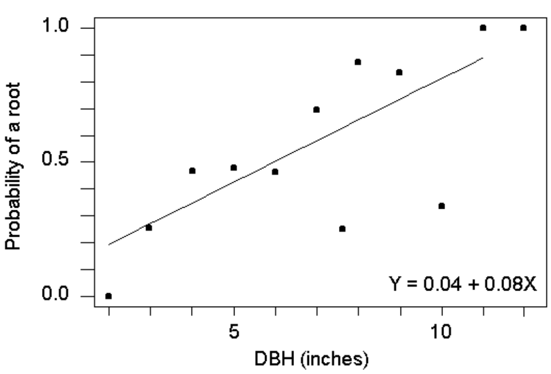
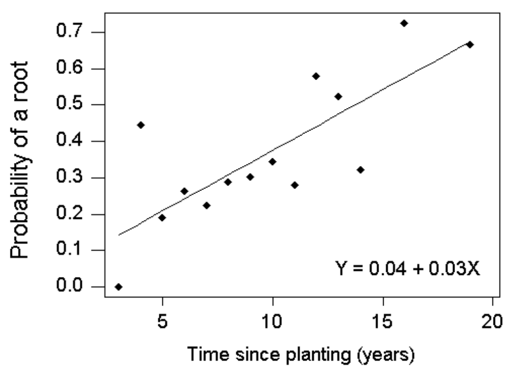
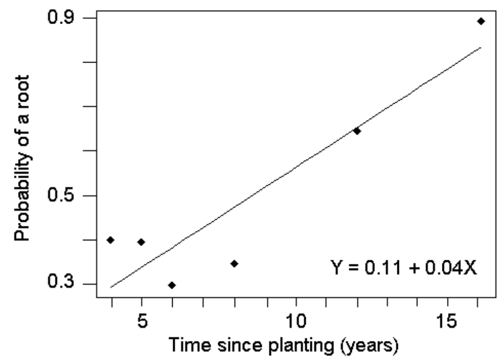


Figure 2. Probability of finding a root greater than or equal to 1 cm at a sidewalk joint within 1.8 meters of a tree planted in a tree lawn less than 3.5 meters in width as predicted by years since planting. Analyses are significant at the 95% (P=0.05) level or greater except where noted.

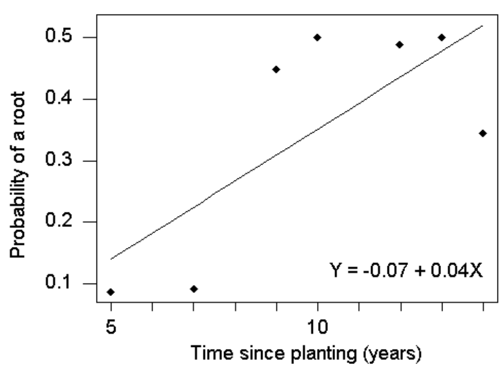
a. Probability of a root as predicted by Time for all genera (r^2 = 62.1%)



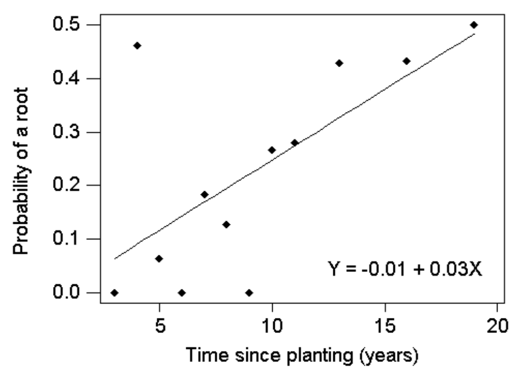
b. Probability of a root as predicted by time for *Gleditsia* (r^2 = 80.0%*)



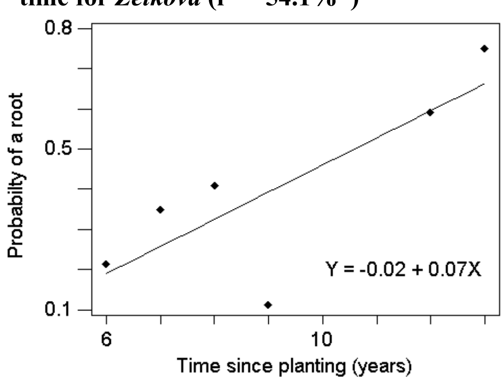
c. Probability of a root as predicted by time for *Koelreuteria* (r^2 = 44.9%*)



d. Probability of a root as predicted by time for *Quercus* (r^2 = 38.1%)

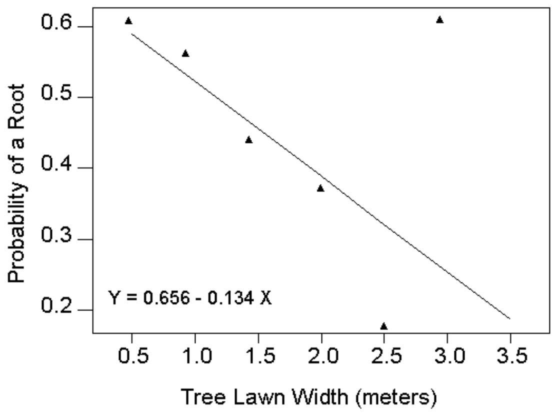


e. Probability of a root as predicted by time for *Zelkova* (r^2 = 54.1%*)



*** Indicates that the model is not significant at the 95% level.**

Figure 3 - Probability of a root as predicted by tree lawn width for 15-20cm (6-8 in) DBH class trees. Weighted linear regression analysis (r^2 = 30.8%):**



**** Linear regression not significant at alpha <=0.05 . Binary logistic regression showed a Hosmer-Lemeshow goodness of fit of 0.992 with P < 0.001. The binary regression equation is: Y = 0.654 – 0.280 X.**