RELATIONSHIP BETWEEN STREET TREE DIAMETER GROWTH AND PROJECTED PRUNING AND WASTE WOOD MANAGEMENT COSTS

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Abstract. Total pruning time, waste wood stack time, waste wood yield, and average annual diameter growth rates were determined for various diameter classes (4-16 inch; 10-40 cm) of honeylocust (*Gleditsia tricanthos*), green ash (*Fraxinus pennsylvanica*), Norway maple (*Acer platanoides*), and littleleaf linden (*Tilia cordata*). Pruning time increased at a rate of 6 minutes per diameter inch (2.5 cm) and waste wood stack time increased at a rate of 1.5 minutes per diameter inch (1.5 cm) for all species combined. Waste wood yields increase at a rate of 3 pounds per minute pruning for all species combined. Maintenance costs and waste wood yields were higher for honeylocust than for green ash, littleleaf linden, and Norway maple.

More and more urban trees are being planted throughout the United States as communities replace lost elms and other trees, or seek to increase their stock of street and park trees. Sievert (10) noted that communities often have active planting programs, but are not appropriating funds for maintenance, such as pruning. Elected officials tend to place a high priority on tree planting while many city foresters place maintenance in a higher priority than planting.

Current aggressive urban tree planting programs will result in a significant increase in urban tree populations in the next decade. These trees will demand maintenance such as pest management, damage repair and cultural care, but most time and money will need to be spent on pruning. Kielbaso and others (1,2) noted that on average, 30% of a City's tree care budget is allocated to pruning. In 1992, 43% of Milwaukee's tree care budget was allocated to pruning (8), while in Toledo, Ohio, O'Brien and others (7) found that 50% of tree maintenance time was spent pruning street trees.

After planting, street trees must first have the lower branches removed to increase sidewalk and street clearance. As they grow they will need selective pruning to develop structurally sound branch scaffolding, and as mature trees, they will need maintenance pruning, which requires removal of dead, dying, and declining branches in the interest of public safety (9). Street trees should be pruned once every five years based on a marginal cost/return analysis in Milwaukee (3).

As street trees grow, pruning time increases and the amount of waste wood generated by pruning increases, but the rates of increase are unknown (6). Long term budget planning must consider these increasing maintenance costs. To address these questions, we conducted a study in Milwaukee to determine pruning time and waste wood yield by tree diameter for four common street tree species. Additionally, we measured diameter growth rates of these trees and, using a computer simulation, projected the long term diameter growth rate of a population of street trees.

Methods

Milwaukee contains the distribution of diameter classes and the age structure of a street tree population required for the study. Honeylocust (*Gleditsia tricanthos*), most frequent cultivars 'Shademaster' and 'Skyline'; green ash (*Fraxinus pennsylvanica*), most frequent cultivars 'Marshall's

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Seedless' and 'Summit'; littleleaf linden (*Tilia cordata*), most frequent cultivar 'Greenspire'; and Norway maple (*Acer platanoides*), most frequent cultivar 'Emerald Queen'; were selected because they represent a majority of species planted in Milwaukee over the past two decades.

Milwaukee's street tree population is on a five-year pruning cycle with each quarter section (160 acres) being pruned once every five years. Within each quarter section trees are managed by a block system, i.e., all trees are of the same species on any given city block.

Quarter sections scheduled for pruning were randomly selected. From November 1991 to January 1992 trees within selected quarter sections were pruned by three city arborists. National Arborist Association Pruning Standards (5) were followed to insure uniformity between arborists. Trees were climbed by rope and saddle and pruned until ten trees per species within each of seven two-inch diameter classes (4-16 inch; 10-40 cm) were obtained. Since not enough littleleaf lindens were available in the sixteen-inch (40 cm) diameter class, this species was sampled to a maximum fourteen-inch (35 cm) diameter class.

Each tree's pruning time and waste wood stack time was measured and recorded for each diameter class. Waste wood was then chipped, bagged and weighed. An increment core was taken from each sample tree at approximately one-foot (30 cm) above ground, and the annual growth rate for the past 10 years measured.

Regression analysis was used for each species and combined species to determine the relationship between pruning time versus diameter, waste wood stack time versus diameter, waste wood yield versus diameter, and average annual diameter growth versus diameter. Values for each species and combined species are the mean of all trees in each diameter class.

Projecting future pruning and waste wood yields must be based on the mean annual growth of a street tree population, not on the growth rates of individual trees. To determine the mean annual growth rate of a population of trees, where trees are being removed and replaced, the average annual diameter growth determined in this study was used in *URBAN FOREST*, a street tree management computer simulation (4).

Results and Discussion

Pruning time. Pruning time for all species increased as diameter increased (Figure 1A). More time was spent pruning honeylocust and the least amount of time was spent pruning Norway maple.

Pruning times are relatively clustered for all species up to the eight-inch (20 cm) diameter class. Beyond eight inches, pruning time increases more rapidly for honeylocust (Figure 1A). For example, average pruning time for a sixteen-inch (40 cm) honeylocust is 116 minutes, while average pruning time for a sixteen-inch (40 cm) Norway maple and green ash are 64 minutes and 85 minutes, respectively. When pruning times are

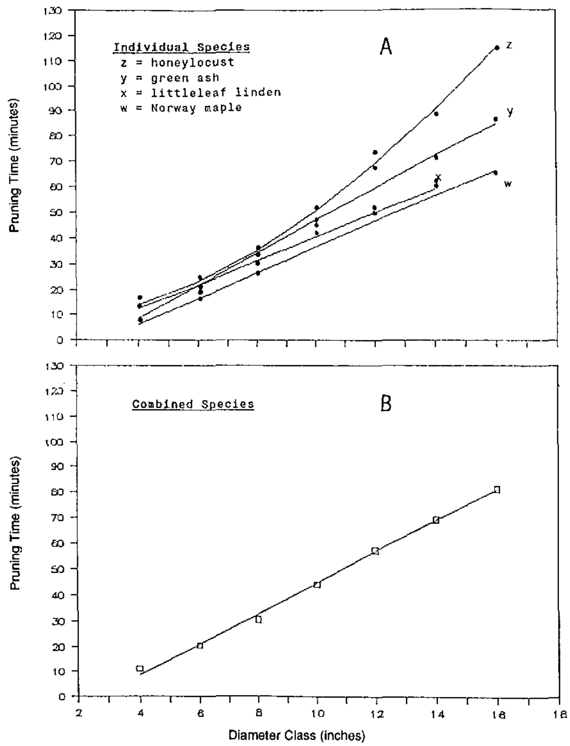

Figure 1. Relationship between pruning time and diameter for individual species (A) of honeylocust (z); green ash (y); littleleaf linden (x); and Norway maple (w); and all species combined (B). Regression functions for honeylocust, Y=4.80+0.73(X)+0.38(X^2) [R^2=0.997]: for green ash, Y=-16.36+6.34(X) [R^2=0.991]: for linden, Y=-6.21+4.67(X) [R^2=0.974]: for maple, Y=-13.35+4.99(X) [R^2=0.986]: for all species combined, Y=-15.12+6.00 (X) [R^2=0.9997]

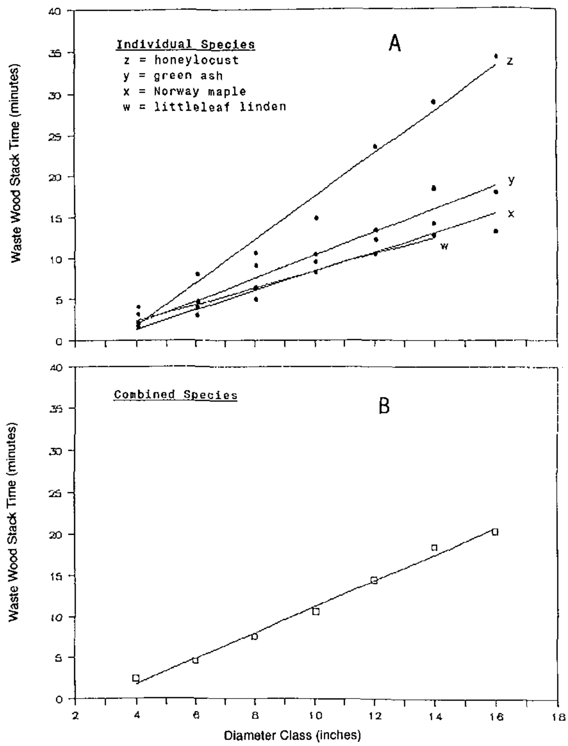

Figure 2. Relationship between waste wood stack time and diameter for individual species (A) of honeylocust (z); green ash (y); littleleaf linden (w); and Norway maple (x); and all species combined (B). Regression functions for honeylocust, Y=-8.71+2.62(X) [R^2=0.974]: for green ash, Y=-1.67+1.39(X) [R^2=0.963]: for linden, Y=-1.67+1.01(X) [R^2=0.978]: for maple, Y=-3.20+1.16(X) [R^2=0.918]: for all species combined, Y=-15.12+6.00 (X) [R^2=0.9997]

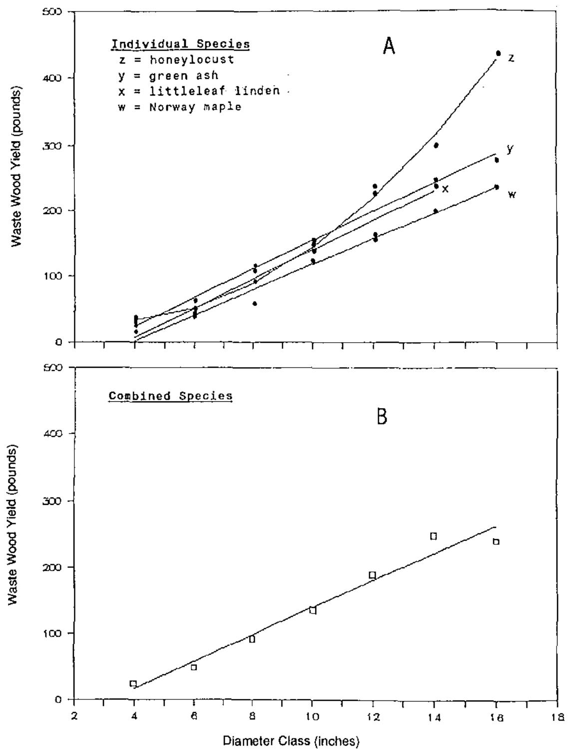

Figure 3. Relationship between wastew wood yield and diameter for individual species (A) of honeylocust (z); green ash (y); littleleaf linden (x); and Norway maple (w); and all species combined (B). Regression functions for honeylocust, Y=55.09-14.8(X)+2.38(X^2) [R^2=0.989]: for green ash, Y=-64.34+22.04(X) [R^2=0.979]: for linden, Y=81.78+22.29(X) [R^2=0.883]: for maple, Y=-74.95+19.35(X) [R^2=0.983]: for all species combined, Y=-64.46+20.43 (X) [R^2=0.968]

combined for all species there is a 6 minute increase in pruning time for each one inch (2.5 cm) increase in tree diameter (Figure 1B).

Waste wood stack time. All waste wood removed from individual trees was stacked curbside for later chipping. Waste wood stack time for all species increased with an increase in diameter (Figure 2A). Stacking time for honeylocust is longer than for green ash, littleleaf linden, and Norway maple. Waste wood stack time for green ash, littleleaf linden, and Norway maple increases at a slower rate through all diameter classes than honeylocust (Figure 2A). When waste wood stack times were combined for all species, there was an average increase of 1.5 minutes for each one inch (2.5 cm) increase in tree diameter (Figure 2B).

Waste wood yield. Waste wood yield increased with increasing tree diameter (Figure 3A). Waste wood yields for green ash, littleleaf linden, and Norway maple were linear through all diameter classes (Figure 3A), while honeylocust showed an increasing rate of yield beyond the eight-inch (20 cm) class.

Higher waste wood yields for honeylocust in the larger diameter classes parallels the higher pruning times and waste wood stack times for honeylocust in these diameter classes (Table 1). Specific gravity (green weight) of honeylocust is .60; Norway maple, .56; green ash, .53; and littleleaf linden, .32 (11). The specific gravity of honeylocust contributes to its higher waste wood yield, but other factors, such as the need for more corrective pruning, also contribute.

For all species combined, approximately 3 lbs (1.4 kg) of waste wood was removed for every minute spent pruning. For individual species waste wood yields per minute are; honeylocust 2.8 lbs (1.3 kg); green ash, 3.2 lbs (1.5 kg); littleleaf linden, 2.6 lbs (1.2 kg); and Norway maple, 2.8 lbs (1.3 kg). There is a 20.5 lb (9.3 kg) increase in waste wood yield for each one inch (2.5 cm) increase in diameter for all species combined (Figure 3B).

Growth analysis. Average annual diameter growth for the 10 previous years was measured for each tree sampled. For green ash, honeylocust and Norway maple, there was an increase in annual diameter growth up to the twelve-inch (30 cm) diameter class, and a reduction in annual diameter growth beyond the twelve-inch diameter class. Average annual diameter growth for littleleaf linden up to the fourteen-inch diameter class showed a linear relationship (Figure 4A).

When diameter classes were combined, the annual diameter growth by species was green ash, 0.52 inches (1.32 cm); honeylocust, 0.50 inches (1.27 cm); Norway maple, 0.44 inches (1.12 cm); and littleleaf linden, 0.40 inches (1.02 cm). Average annual diameter growth for all species combined was 0.50 inches (1.27 cm). Similar average annual diameter growth rates were found in four other Wisconsin communities (4).

The regression for all species combined in Figure 4B shows the predicted average annual growth increment that can be expected for each increase in diameter class. Average annual diameter growth increases to the twelve-inch (30 cm) diameter class followed by reductions in the fourteen-inch (35 cm) and sixteen-inch (40 cm) diameter classes.

Simulated population growth. *URBAN FOREST* computer simulation (4) was run for 100 years using an annual diameter growth rate of 0.50 inch and historic mortality rates by diameter class in Milwaukee. A street tree data file of 9,000 street trees was used in the simulation (tree data collected from Milwaukee and Waukesha, Wisconsin). The number of trees planted each year

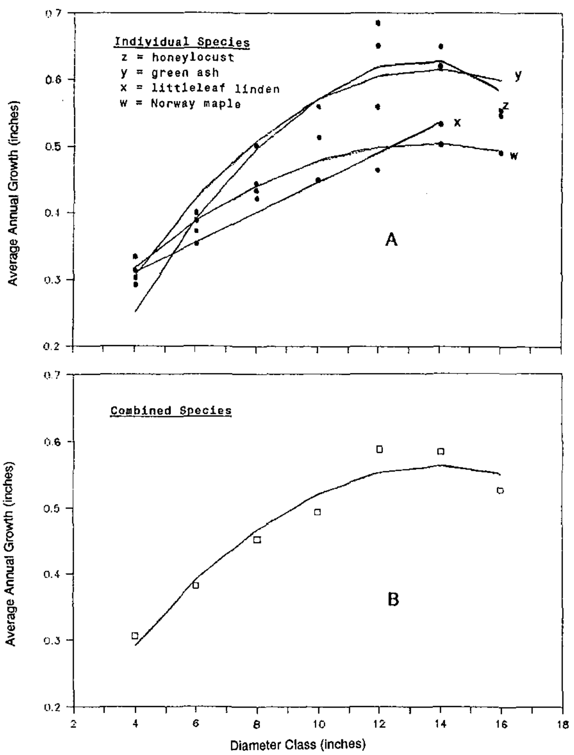

Figure 4. Relationship between average annual growth and diameter for individual species (A) of honeylocust (z); green ash (y); littleleaf linden (x); and Norway maple (w); and all species combined (B). Regression functions for honeylocust, $Y=-0.12+0.11(X)-0.004(X^2)$ [$R^2=0.888$]: for green ash, $Y=-0.15+0.09(X)-0.003(X^2)$ [$R^2=0.871$]: for linden, $Y=0.22+0.02(X)$ [$R^2=0.917$]: for maple, $Y=0.13+0.054(X)-0.002(X^2)$ [$R^2=0.923$]: for all species combined, $Y=0.041+0.079(X)-0.003(X^2)$ [$R^2=0.948$]

was equal to the number of trees removed the previous year. *URBAN FOREST* output includes the average diameter of the street tree population after each yearly run. These data were plotted at five year intervals (Figure 5). Average diameter increased for the first sixty-five years and then declined to year eighty five, where the average diameter stabilized at 12.9 inches (32.8 cm). The high point in the curve is due to the large number of small trees at the start of the simulation. The increase in the mean diameter of the entire stand is less than the growth rate of individual trees because tree attrition in larger diameter classes is replaced by small transplants. Assuming no

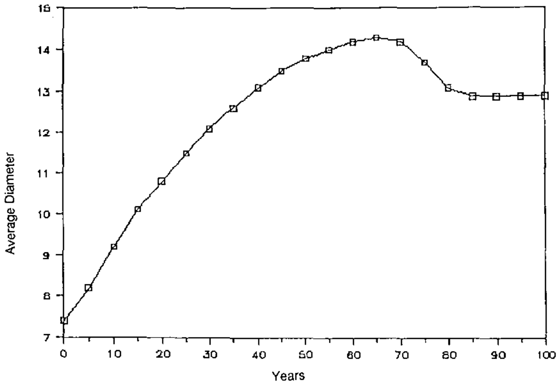

Figure 5. Simulated tree population mean diameter changes over time, removals = replacements.

catastrophic losses, the average diameter of a street tree population will eventually stabilize as replacements offset diameter growth.

Maintenance time and species. Based on pruning time, stacking time and waste wood yield, honeylocust is the most expensive tree to maintain. The order of decreasing maintenance time for the three remaining species is green ash, littleleaf linden and Norway maple. Nowak (6) evaluated pruning needs for eleven species in eleven cities and found Norway maple to have greater pruning needs than honeylocust. Based on Nowak's study honeylocust appears to require less pruning than Norway maple, but when pruning time is measured, the cost is greater for honeylocust.

Conclusion

All four species show predictable increases in pruning and stacking time, and waste wood yield as they increase in size. Honeylocust shows a more rapid increase in pruning time, stacking time and waste wood yield when compared with green ash, littleleaf linden and Norway maple. Although this will be reflected in higher maintenance costs for honeylocust, care should be taken not to *eliminate it, or any species, from future street tree* planting based solely on maintenance cost. Maintenance cost is only one of many factors that should be considered when making species selections.

For all species combined, pruning time increased at the rate of six minutes per diameter inch (2.5 cm); yielding 3 lbs. (1.4 kg) of waste wood for every minute spent pruning. Stacking time increases at a rate of 1.5 minutes per inch (2.5 cm) increase in tree diameter.

The average growth rate is 0.50 inch (1.75 cm) per year. When this rate is used in a computer

Table 1. Comparison by diameter class of pruning time, stacking time, waste wood yield, and average annual growth for honeylocust, green ash, Norway maple, and littleleaf linden.

Dbh class	Pruning time	Stacking time	Waste wood yield	Av. ann. diam.growth
Inches	Minutes		Lbs	Inches
		Honeylocust		
4	12.8[z]	3.9	31.5	0.29
6	24.8	7.6	49.2	0.35
8	35.9	10.4	103.6	0.44
10	48.1	14.3	130.9	0.56
12	71.3	22.9	238.1	0.69
14	88.2	28.8	289.8	0.62
16	115.8	34.5	438.1	0.56
		Green ash		
4	8.7	1.7	23.7	0.33
6	21.6	4.3	65.0	0.39
8	33.4	9.1	111.0	0.50
10	46.4	9.7	143.8	0.51
12	65.0	12.7	230.4	0.66
14	69.6	17.8	240.0	0.65
16	84.5	17.5	278.7	0.55
		Norway maple		
4	8.7	1.4	16.9	0.31
6	14.7	3.0	40.0	0.40
8	23.0	4.7	59.3	0.42
10	38.6	10.2	121.7	0.44
12	47.7	12.0	153.3	0.53
14	59.0	14.2	195.5	0.50
16	64.1	13.2	243.1	0.48
		Littleleaf linden		
4	12.4	3.1	25.8	0.30
6	19.9	3.6	41.3	0.37
8	29.5	6.5	91.6	0.43
10	44.0	8.2	148.9	0.44
12	46.1	10.1	155.6	0.46
14	61.2	13.0	240.8	0.53

z Values are the mean of ten trees per diameter class.

simulation of street tree growth, mortality and replacement; the population mean growth rate slows over time, eventually stabilizing at zero. Growth projections, coupled with pruning time, stacking time and waste wood yield, can substantially aid city tree managers in forecasting long range pruning costs.

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Résumé. Le temps total d'élagage, le temps d'empilage des résidus de coupe, la production de résidus de coupe et le taux de croissance annuel en diamètre étaient évalués pour diverses classes de diamètres de févier inerme (*Gleditsia triacanthos*), de frêne de Pennsylvanie (*Fraxinus pennsylvanica*), d'érable de Norvège (*Acer platanoides*) et de tilleul à petites feuilles (*Tilia cordata*). Les résultats indiquent un accroissement significatif du temps d'élagage, du temps d'empilage des résidus de coupe et de la masse de résidus de coupe produit lorsque le diamètre augmente, cela pour chaque espèce. Les coûts d'entretien et la masse produite de résidus de coupe sont significativement plus élevés pour le févier inerme, suivis du frêne de Pennsylvanie, du tilleul à petites feuilles et de l'érable de Norvège. Les coûts futurs d'élagage et la masse de résidus produits sont projetés à partir d'analyses de croissance des quatre espèces.

Zusammenfassung. Die absolute Zeit für den Rückschnitt, die Zeit, um das Abfallholz zu stapeln, das Gewicht des geschnittenen Holzes und das durchschnittliche jährliche Dickenwachstum wurde für verschiedene Durchmesserklassen von Gleditschie (*Gleditsia triacanthos*), Grüne Esche (*Fraxinus pennsylvanica*), Spitzahorn (*Acer platanoides*) und Winterlinde (*Tila cordata*) gemessen. Die Ergebnisse zeigen einen deutlichen Anstieg der Zeitdauer für Rückschnitt und Holzaufstapeln und das Holzgewicht, je mehr der Durchmesser bei jeder Art zunimmt. Die Erhaltungskosten und die Holzernte sind deutlich höher bei Gleditschie, gefolgt von Grüner Esche, Winterlinde und Sptizahorn. Die Kosten für Rückschnitt und Schnittholzernte in der Zukunft werden basierend auf den Wachstumsanalysen der vier Arten projeziert.