Effect of Transplanting on Water Relations and Canopy Development in *Acer*[1]

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Abstract

Transplanting large-caliper trees frequently leads to poor tree growth and survival. A longitudinal study of the changes in water relations and canopy development was conducted to study this effect. Pruning and watering were used to test the recovery of maple trees following transplanting. Water potential (ψ), transpiration rate (t_r), and leaf area index (LAI) were the measured dependent variables. In the summer after transplanting, date and treatment significantly affected LAI, t_r and mid-day ψ in *Acer truncatum*. In this species, trees receiving a post-transplant pruning treatment in combination with watering did not significantly differ in t_r and mid-day ψ from non-transplanted controls, although LAI did differ between these treatments. In both *A. truncatum* and *A. tataricum ginnala*, treatment and day interacted significantly on pre-dawn ψ. While the seasonal patterns differed between species, the most negative pre-dawn ψ measurements were made four months after transplanting. In the spring following transplanting, significant differences due to prior-year treatment were again measurable in mid-day ψ in leaves of *A.tataricum ginnala*. In that species, mid-day ψ of the transplanted control trees differed from non-transplanted controls. Transplanting led to a measurable, long-term water stress. Pruning and watering in combination partially relieved that stress. Leaf area index was markedly affected by transplanting. It is suggested that this readily-measurable variable could be useful in assessing recovery from transplant stress.

Index words: pruning, root-pruning, transplant shock, water relations, plant canopy.

Species used in this study: *Acer tataricum ginnala* (Amur maple), *Acer truncatum* (Trident maple).

Significance to the Nursery Industry

Large-caliper trees (2 inches and above) are frequently specified in landscape installations. While nursery production of these trees is manageable, digging and installation have been problematic. Trees frequently fail to thrive and sometimes die in the years following installation. Using a 45-inch (1.2 m) tree spade, we studied the effects of transplanting dwarf maple trees under controlled conditions. The study demonstrated that transplanting leads to long-term water stress on dwarf maple trees. The stress was measurable for more than a year after transplanting. Stress had a noticeable effect on leaf size and overall canopy development. Leaf development appeared to be related to transplanting and could be useful to gauge the duration of 'transplant shock' and the effectiveness of post-transplant treatments. To test this hypothesis, we tested the effects of pruning and watering on tree development after transplanting. Pruning in combination with watering improved tree water potential as well as canopy closure at the end of the study. These treatments caused maple trees to appear more similar to non-transplanted controls, although some differences in leaf canopy could still be measured in the spring following transplanting.

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Introduction

Trees are a vital component of urban landscapes. Unfortunately, the average life span of a street tree is only about ten years (3, 5). Low survival rates and shortened life spans result from the environmental stresses of compacted soils (2) and the elevated soil and air temperatures in urban areas (17, 22). These environmental conditions are magnified by the transplanting process.

In moving field grown trees, a hydraulic tree spade is generally used. Unfortunately, only a small percentage of the root system can be harvested, even when using a tree spade of recommended size (6, 20). This occurs because much of the root system extends beyond the dripline (19).

Trees undergo 'transplant shock,' which is thought to occur as a result of an inability of the root system to supply sufficient water to the rest of the plant (7, 11). This inability to provide water is exacerbated if the transplanted tree is undergoing shoot elongation at the time of transplanting. Trees are also stressed by low levels of carbohydrates, thus reducing energy reserves available for root regeneration, limiting long-term water uptake (20). Exposure to drought may decrease photosynthetic rates by causing stomatal closure in order to reduce transpiration (10), or can damage the photosynthetic apparatus (8). Limiting transpiration is a mechanism that can function to conserve soil water and avoid low leaf water potential (ψ) (12). The decrease in transpiration rate that occurs following stress suggests that water uptake is reduced, or diffused resistance by leaves occurs (21). Visible post-transplant symptoms are much like those induced by drought: reduced shoot extension, smaller new leaves, scorched older leaves, stem dieback and death (7).

It has been suggested by Watson (18) that trees can remain water stressed until the root system is restored to the original pre-transplant size. This may take as long as ten years in large trees. Some plants may only have a limited capacity for recovery if previous exposure to stress has left them weakened (1, 22). Gilman (6) notes that a transplanted tree will take about one year per 2.5 cm (1 in) of trunk caliper to regenerate the root system to pre-transplant size. This is a common 'rule of thumb' in the nursery industry in the mid-Atlantic region.

Until the root system has restored itself, transplanted trees must balance the water loss and carbon gain of photosynthesis against the carbon loss and limited water gains from root production (10). A disruption of the natural balance of root absorptive area to transpiring leaf area may predispose transplanted trees to water stress (11, 15). The water demand requires that some roots remain moist (6), a challenge for a reduced root system in hot, compacted soils, without irrigation. As a consequence of transplant induced water stress, trunk growth is limited, and transpiring leaf area is reduced (10). Reduced leaf size and leaf abscission continue to suppress overall tree vigor until a new root to shoot balance can be restored and water stress alleviated (20). If roots cannot penetrate the compacted soil, the root system may remain 10 percent of its size prior to digging and planting (19).

The effects of water stress are important. Decreased conductance of water through root systems and smaller stem diameters can result from a severe drought (7). Short periods of moderate drought stress can result in greater hydraulic resistances (14). Greater root hydraulic resistances could be attributed to increased resistance across cell membranes, or xylem cavitation (7). This increased resistance to water flow can reduce turgor pressure in expanding cells and cell growth (4), leaf size (7, 12), and shoot and root dry masses (13). Leaf abscission, as a result of drought, may reduce leaf area (12). Recovery can take time. Stomatal recovery following drought is related to the duration and severity of stress (9, 22). Long-term survival of urban trees depends on their capacity to withstand both excessive and deficient soil moisture (12).

Most commonly, practices intended to aid in tree establishment come after transplanting. Dormant top pruning has been practiced as a method of reducing transpiring leaf area and thereby conserving water until the plant is able to reestablish the pre-transplant root to shoot balance (5).

This project was designed to test the relationships between post-transplant water stress, canopy development and water relations. In particular, we were interested in testing whether water stress could be measured in the transplant year even when trees were well-watered.

The project began with a preliminary study conducted on *Malus*. This study showed little effect of water, nutrient or hormonal applications. Photosynthetic rates and leaf nutrient levels were generally not significantly different among treatments until three months after transplanting. Significant differences in LAI were quite dramatic in our preliminary study. This finding led to the evolution of the research project into a physiological study of transplant stress, conducted on *Acer*. This transplant research was not void of cultural practice, as top pruning, water, and a combination of the two were used to determine if management affected recovery. In this study, the goal was to understand the physiology of transplant stress, thus aiding in the development of management strategies to reduce stresses. In so doing, it was important to determine an effective measure of stress. The hypothesis was that the act of transplanting would expose trees to stresses not faced by control (non-transplanted) trees, and that application of water or top pruning could offset such stresses. We were also interested in a related, but more-applied question: Could we identify a simple, readily-measurable variable that could be used to test the effectiveness of post-transplant treatments on large-caliper trees?

Materials and Methods

Research was conducted at the Western Maryland Research and Education Center, Keedysville, MD. The site is located in the piedmont at about 190 m (625 ft) above sea level in USDA Plant Cold Hardiness Zone 6. Soil is a Hagerstown loam (typic hapludalf, fine, mixed, mesic), a fertile, well-drained, limestone-derived soil, suited to nursery crop production.

Plant material. Trees used in the study were grown from seed initially collected at the U.S. National Arboretum, Washington, DC, in 1991. Trees were grown using standard nursery practices of fertilizer, overhead irrigation and herbicide during 1993–1997. However, trees were not root pruned during that period. Prior to transplanting, trees were assigned to blocks by trunk circumference. Tree calipers ranged from 2 in (5 cm) to 3 in (7.5 cm).

During the first two weeks of April 1997, 24 field-grown *Acer* trees (12 *Acer truncatum* and 12 *Acer tataricum ginnala*) were transplanted using a 45 in (1.2 m) tree spade. This was prior to leaf emergence. Trees were moved approximately 150 m (492 ft) to a blocked study site and reset at 4 × 6 m (13 × 17 ft) into planting holes dug by the same tree spade. Three trees of each species were also left in the original nursery rows as non-transplanted controls.

All trees were irrigated for the three days immediately following their transplant, with 80 liters (21 gal) of water using Treegator® bags (Spectrum Products, USA). After this initial watering, three trees of each species were randomly assigned to one of four treatments. Treatments were transplanted control, top pruning (about 20 percent canopy removal by thinning-out cuts), water (provided by Treegator® drip irrigation at a rate of 80 liters (21 gal) per week), and water combined with top pruning. During the month after transplanting, normal rainfall occurred [3 in (7.6 cm)]. Droughty conditions did not begin until early June.

Three weeks after transplanting, physiological measurements began. Measurements were continued throughout the summer of 1997 and again in April and May 1998, during the period of shoot extension growth.

Monitoring equipment. A Scholander Pressure Chamber (PMS Instruments, Model 1003, Corvallis, OR) was used for measurement of predawn (0600 hrs) and midday (1300 hrs) leaf water potentials. One new, fully-expanded, shade leaf of each tree was harvested and placed in the chamber. Gas pressure was increased until visible water formed at the cut surface of the petiole.

Leaf canopy was measured as leaf area index (LAI) using the LiCor Plant Canopy Analyzer (LiCor, LAI-2000, Lincoln, NE). Prior to each measurement, the analyzer was calibrated to full sun, above the tree canopy. It was then placed in the lowest ¼ of the canopy, and measurements were taken in four, evenly spaced locations along a transect within this area. These four readings were integrated by the LiCor instrument to provide a measure of LAI. Data were taken from April until September. In January 1998, LAI was again recorded on the defoliated trees. These values were subtracted from the measured LAI to give a corrected LAI.

Table 1. Effects of treatment and day on the transpiration rates, leaf area index (LAI) and leaf water potential (ψ) measured in *Acer truncatum* during the 1997 growing season. (Data shown are the means for the entire growing season.)

Independent variables	*Acer truncatum*			
	Transpiration ($\mu g\ cm^{-2}s^{-1}$)	LAI	Pre-dawn ψ (MPa)	Mid-day ψ (MPa)
Treatment				
Untransplanted control	8.26a[z]	4.46a	–0.13a	–0.48a
Transplanted control	3.92b	1.91bc	–0.31c	–0.74b
Top pruning	3.77b	1.50c	–0.25bc	–0.65b
Water	5.58ab	2.31b	–0.19ab	–0.65b
Water + top pruning	6.75ab	2.30b	–0.15ab	–0.47a
ANOVA (P value)				
Treatment	0.0119*	0.0001***	0.0136*	0.0035**
Date	0.0001***	0.0001***	0.0001***	0.0001***
Treatment × Day	0.9569[NS]	0.9840[NS]	0.0197*	0.2507[NS]

[z]Means followed by same letter not statistically different (P = 0.05).

*Significant at (P ≤ 0.05) , **Significant at (P ≤ 0.01), ***Significant at (P ≤ 0.001) and [NS] not significant.

During the August, September, and October 1997 measurement dates, a LiCor Steady State Porometer (LiCor LI-1600) was used to measure transpiration rates (t_r) at midday. The porometer was fitted with a small-aperture insert, 1600-06. Photosynthetically active radiation (PAR) was closely monitored such that conditions of measurement were consistent from tree to tree.

Similar measurements were begun the second week of April 1998. Predawn and midday water potentials (ψ) were measured on the trees using the methods from the previous summer. The leaves used to record midday ψ were collected and saved to determine leaf area. Following this initial day of data collection, biweekly measurements of predawn and midday ψ, t_r and leaf area were taken on each tree of both species until the last week of May.

Statistical analyses. The Mixed Models program of Statistical Analysis Software was used to determine if differences existed among treatments. Data for each *Acer* species were analyzed separately. The model for each species was analyzed as a treatment by day factorial, using a repeat measures procedure. Treatment-by-day interaction was tested in each species. A least significant difference (LSD) test at the 5% level was used to separate treatment means.

Results and Discussion

Field observations and statistical analyses. The summer of 1997 was unusually hot and dry. Rainfall during the summer of 1997 was 135 mm (5.3 in), well below the 20-year average of 248 mm (9.8 in). During the summer following transplanting, visible symptoms of water stress were seen on *Acer tataricum ginnala* but not on *A. truncatum*. Leaves of *A. tataricum ginnala* appeared wilted during the dry periods, but then regained turgor following rains. Leaves of *A. truncatum* appeared turgid throughout the summer.

Table 2. Effects of treatment and date on the transpiration rate, the leaf area index (LAI) and leaf water potential (ψ) measured in of *Acer tataricum ginnala* during the 1997 growing season. (Data shown are the means for the entire growing season.)

Independent variables	*Acer tataricum ginnala*			
	Transpiration ($\mu g\ cm^{-2}s^{-1}$)	LAI	Pre-dawn ψ (MPa)	Mid-day ψ (MPa)
Treatment				
Untransplanted control	6.84a[z]	5.00a	–0.21a	–0.66a
Transplanted control	2.77c	1.50b	–0.34b	–1.32c
Top pruning	3.34bc	1.08c	–0.30ab	–1.11bc
Water	5.88ab	1.38bc	–0.23ab	–0.97b
Water + top pruning	6.44a	1.22bc	–0.20a	–1.00b
ANOVA (P value)				
Treatment	0.0334*	0.0001***	0.1083[NS]	0.0001***
Date	0.0024**	0.0001***	0.0001***	0.0001***
Treatment × Day	0.4552[NS]	0.0135*	0.0034**	0.0012**

[z]Means followed by same letter not statistically different (P = 0.05).

*Significant at (P ≤ 0.05) , **Significant at (P ≤ 0.01), ***Significant at (P ≤ 0.001) and [NS] not significant.

With the exception of pre-dawn water potential, treatment and date did not interact in *A. truncatum* in 1997 (Table 1). On the other hand, interactions on most measured variables were found on *A. tataricum ginnala* in 1997 (Table 2).

Transpiration rates, 1997. Transpiration rates of *A. truncatum* and *A. tataricum ginnala* showed a similar pattern in 1997 (Tables 1 and 2). Analyses of variance for both species did not show a significant treatment-by-day interaction. There were significant main effects of treatment and day for both species. The most significant main effect for each species was day, indicating that transpiration was more dependent on changes in weather than treatment.

For *A. tataricum ginnala*, trees treated with water alone or combined with top pruning transpired at rates which were not significantly greater from those of non-transplanted control trees (Table 2). Trees of these three treatments transpired at rates nearly twice that of the transplanted control and top pruned only trees.

Treatment means measured on *Acer truncatum* indicated that watered trees and watered plus top pruned trees had t_r not significantly different from the non-transplanted control trees (Table 1).

Leaf area indices, 1997. In *A. truncatum*, there were no significant treatment-by-day interactions but significant main effects of both treatment and day on LAI. The main effect of treatment was the most significant (F-value = 33.34). No treatment increased LAI to a level equal to that of the non-transplanted control.

A similar pattern was also found in *A. tataricum ginnala*, although day and treatment interacted in that species (Table 2). Leaf area indices of *A. tataricum ginnala* also increased throughout the 1997 growing season (data not shown).

Leaf water potentials, 1997. Analysis of variance of pre-dawn water potentials of both *Acer* species showed significant treatment-by-day interactions in pre-dawn leaf water potentials. In *A. truncatum* (Table 1), both treatment and day significantly affected predawn ψ. In both species transplanted controls had predawn ψ more negative than all other treatments after periods of heat and drought stress. In *A. tataricum ginnala* (Table 2) there was a significant main effect of day but no significant main effect of treatment. This effect of day was expected, as trees became increasingly more water-stressed through the season as a result of a drought. The treatment-by-day interaction appeared to be related to rainfall. When drought stress was low after a rain, all treatments appeared to have similar predawn ψ. Following periods of prolonged drought and heat, predawn ψ differed among treatments.

For *A. truncatum* (Table 1), the interaction of treatment-by-day was not significant for midday ψ, but the main effects of treatment and day both were. It was expected that daily weather conditions would affect midday ψ. For *A. truncatum*, the treatment water plus top pruning did not differ significantly from the non-transplanted control, and the midday ψ of both were significantly less negative than the midday ψ measured in the other treatments.

In *A. tataricum ginnala*, midday ψ for 1997 appeared similar to those measured in *A. truncatum*. There was a significant treatment-by-day interaction on midday ψ in *A. tataricum ginnala* as well as significant main effects of both treatment and day (Table 2).

Acer tataricum ginnala, 1998. The study was resumed in the spring of 1998 with a series of measurements in April and May. At that time, transpiration rates of *A. tataricum ginnala* (Table 3) and *A. truncatum* were similar. Significant day effects on transpiration rates were found in both species, indicating the greater importance of day than treatment on early-season transpiration rates.

No treatments applied in 1997 had a significant effect on predawn ψ in 1998 (Table 3). The midday ψ of 1998 for *A. tataricum ginnala* was affected significantly by day. This was unexpected since the effect of treatment on midday ψ had only approached significance in the previous season. In *A. truncatum*, only a significant main effect of day was found in midday ψ (data not shown).

Individual leaf areas measured in April and May of 1998 in *A. tataricum ginnala* showed a significant treatment-by-day interaction as well as significant main effects of both

Table 3. Effects of treatment and day on transpiration rate, leaf area and water potential of *Acer tataricum ginnala* leaves measured in spring, 1998. (Data shown are the means of all measurement days).

Independent variables	***Acer tataricum ginnala***			
	Transpiration ($\mu g\ cm^{-2} s^{-1}$)	**Leaf area (cm^2)**	**Pre-dawn ψ (MPa)**	**Mid-day ψ (MPa)**
Treatment				
Untransplanted control	11.48	14.87a[z]	–0.07a	–0.15a
Transplanted control	8.55	9.68b	–0.12b	–0.31b
Top pruning	7.81	10.04b	–0.08ab	–0.23ab
Water	7.34	10.12b	–0.06a	–0.25ab
Water + top pruning	10.25	9.58b	–0.08ab	–0.26ab
ANOVA (P value)				
Treatment	0.2560[NS]	0.0001***	0.1126[NS]	0.0426*
Date	0.0001***	0.0001***	0.0001***	0.0197*
Treatment × Day	0.4115[NS]	0.0144*	0.4203[NS]	0.3954[NS]

[z]Means followed by same letter not statistically different (P = 0.05).

*Significant at ($P \leq 0.05$) , **Significant at ($P \leq 0.01$), ***Significant at ($P \leq 0.001$) and [NS] not significant.

treatment and day (Table 3). No treatment applied to transplanted trees during the previous summer increased mean leaf area to a size similar to that of the non-transplanted control trees. In *A. truncatum*, the water and top-pruned treated trees' mean leaf areas were not significantly different from those of the non-transplanted control trees. These trees had significantly greater leaf areas in spring, 1998 than the other three treatments (data not shown).

It was found that for nearly every dependent variable measured, non-transplanted control trees exhibited less stress than those trees which were transplanted. This is clear indication that the act of transplanting results in a profound, long-term water stress to the tree, which can be measured beyond the season of transplanting. The significant treatment-by-day interactions seem to illustrate that stress is caused by transplanting and is modulated by rainfall and temperature conditions during the season.

Knowing that transplanted trees were under a stress to which non-transplanted control trees had not been exposed, the next step was to determine the clearest measure of stress. Of all the dependent variables measured, leaf area index (1997), individual leaf area (1998), and midday water potential (1997 and 1998) showed the greatest consistent differences in response to treatment. Consequently, these variables were deemed the most appropriate indicators of treatment success in overcoming transplant stress.

When measuring water potential, the significantly more negative midday ψ of transplanted trees versus those of non-transplanted controls, appears to be offset by the effects of water application. Both the water and top-pruned and water-treated trees had significantly less negative midday ψ than the transplanted controls, and were approaching the levels of the non-transplanted control trees.

Struve and Joly (16) studied the effects of root pruning in the greenhouse to simulate transplant stress on red oak seedlings. They found that new stem length and leaf number were not affected by root pruning. By the end of their experiment, pre-dawn ψ, net assimilation rate and stomatal conductance were not affected. They found leaf area was the variable most affected by root pruning. They concluded that adjustment to transplanting occurs primarily by reducing leaf surface area, reducing whole plant water use without altering per unit photosynthetic gas exchange. Our research agrees with Struve and Joly's (16) hypothesis and validates their greenhouse findings in the field.

As a result of transplanting, individual leaf size and LAI of trees are significantly reduced. Measurements of LAI and individual leaf areas, while still significantly different, showed that water and top pruning, and water alone began to become more similar to the non-transplanted control trees than did the transplanted controls.

Transplanting causes a stress that results in increased ψ and reduced turgor (4). As a result, diffused resistance increases and transpiration rates decrease (14). Consequently, trees are subjected to secondary stresses of reduced water uptake, reduced whole plant photosynthesis and decreased LAI. With this decrease in LAI, sensible heat on the trunk is increased, leading to cambial kill (2, 19). These stresses then continue through subsequent years until the LAI recovers to a pre-transplant balance (19). Water or water and top pruning appears to be helpful in reducing these stresses by speeding recovery from 'transplant shock.' This transplant-induced water stress is essential in its effects on water potential, and thus affects turgor pressure, which is the driving force for early season leaf expansion. That early-season water stress ultimately affects total leaf area for the transplant year and beyond.

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