Growth and Water Relations of Kentucky Coffee Tree and Silver Maple Following Transplanting[1]

Roger Kjelgren[2] and Brenda Cleveland[3]
Department of Plant and Soil Science
Southern Illinois University, Carbondale, IL 62901

Abstract

Following transplanting we monitored growth and water relations over two years in Kentucky coffee tree (*Gymnocladus dioica* (L.) C. Koch) and silver maple (*Acer saccharinum* L.). Field-grown, well-established trees transplanted in place were compared to non-transplanted control trees. Predawn water potential was measured twice each month for two growing seasons, as well as midday stomatal conductance and water potential. Shoot elongation, leaf size, diameter growth, and total leaf area were determined both years. Less total leaf area as a result of transplanting apparently moderated total tree transpiration in both species. Reduced tree transpiration allowed stomatal conductance and predawn water potential to reach levels equal to non-transplanted trees in both species during periods of high rainfall. During low-rainfall periods water relations of transplanted Kentucky coffee tree (KCT) declined more than silver maple (MAP) relative to the control trees. Compared to non-transplanted trees, transplanting reduced growth of KCT more than that of MAP the first year. In the second year, when growing-season rainfall was less than half of the first year, the relative effect of transplanting on growth of the two species was reversed, indicating that KCT was more drought tolerant. These results suggested that deciduous balled-and-burlapped trees transplanted while dormant self-regulate water loss by reducing transpiring leaf area the following growing season.

Index words: stomatal conductance, water potential.

Species used in this study: Kentucky coffee tree (*Gymnocladus dioica* (L.) C. Koch); silver maple (*Acer saccharinum* L).

Significance to the Nursery Industry

The results of this study show that deciduous trees transplanted while dormant can transpire at rates similar to non-transplanted trees when water is available despite losing most of their root system. This is due to less transpiring leaf area that reduces total water loss and places less demand on the root system. The extent to which reduced leaf area helps a transplanted tree avoid water stress will vary with species. Compared to established trees in dry environments where supplemental watering is necessary, transplanted trees need less water in accordance with less leaf area but at greater frequencies due to a smaller root system. These results would be less applicable to trees transplanted in leaf, and would also suggest that root loss from transplanting may not directly affect photosynthetic rates of individual leaves. Our conclusions support the general recommendation of minimal pruning at transplanting since the tree compensates for root loss by producing less leaf area. Furthermore this reduced leaf area probably balances carbon assimilation with new root production and tree establishment.

Introduction

Established trees harvested from a nursery, or moved within a landscape, lose most of their root system during transplanting and thus initially take up water from a truncated soil volume (4, 6, 11). Transplanted trees must then balance water loss and carbon gain of leaf production against carbon loss and water gain from root production until roots are established in native soil. Since uptake quickly depletes water from the limited soil volume (12), transplanted trees would appear to become water stressed more rapidly than trees with intact root systems (6). Water stress results in stomatal closure that reduces transpiration but also limits photosynthesis (3, 7), which in turn can hinder establishment. Our understanding of the physiology and water relations of larger trees that lose much of their root system during transplanting is incomplete. The physiological impact of severe root loss on transplanted trees is an unnatural act with no natural analog. Water management options of transplanted trees have consisted of either reducing demand by pruning (9) or increasing supply with irrigation. Information on physiology and water relations following transplanting can suggest avenues for improved management practices. This study investigated how root removal during transplanting affected subsequent tree water relations and crown development.

Materials and Methods

Experimental setup. The study was conducted in a field nursery on a uniform Hosmer silt loam (fine-silty, mixed, mesic Typic Fragiudalf) soil with a 1–2% slope with a water holding capacity of approximately 0.2 m/m (2.4 in/ft) in the 0.6 m (2 ft) topsoil layer, underlain by a poorly drained clay layer. The study species were Kentucky coffee tree (KCT), and silver maple (MAP) that had received no irrigation since planting. The two species had been planted independent of one another in two rows, in 1984 for KCT and 1987 for MAP, spaced 10 m (33 ft) apart on approximately 3 m (9.8 ft) between-tree spacing within the row. Because the study was imposed on an existing planting, normal statistical randomization procedures to reduce variability could not be applied. These trees were selected because soil uniformity, close proximity, and similar size (38–51 mm [1.5–2 in] caliper, 3–4 m [9.8–13.1 ft] height) suggested minimal variability. Prior to budbreak, mid-March 1990, four trees of each species were hand dug and root balls sized to trunk diameter according to standard recommendations (2). A root

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[2]Assistant Professor. Current address: Department of Plants, Soils, and Biometeorology, Utah State University, Logan UT 84332

[3]Former graduate assistant.

ball was completely formed for each tree, but was not burlapped, and then replanted in place. To avoid severing roots of the four non-transplanted trees of each species, the transplanted trees were grouped adjacent to one another. Trees were irrigated immediately after planting to settle the soil, and no fertilizer was applied through the course of the experiment.

Data collection. Predawn water potential (Ψ) was measured on three leaves per tree every 1.5-2 weeks during both growing seasons. Maple leaves and KCT leaflets were excised from each tree before dawn (8), immediately sealed in aluminum bags to halt water loss, and measured within an hour of excision in the laboratory with a pressure chamber (Model Arimad II, Kfar Charuv-Water Supply Accessories, Israel). Dawn-to-dusk water relations were studied under clear-sky conditions on two dates in 1990. Stomatal conductance (g_s) was measured with a steady-state porometer (Model 1600, LI-COR Inc. Lincoln NE) and Ψ was also measured as previously described for predawn Ψ. For each tree, g_s was measured on four fully sunlit, representative leaves (MAP) or sub-leaflets (KCT), alternating between species and transplanting treatments through the day. In 1991 g_s and Ψ were measured between 12 noon and 2 PM following the previously described procedures on dates concurrent with predawn Ψ.

Leaf area, shoot elongation, and trunk growth were measured each growing season. Different methods were used to determine leaf area for the two species. For MAP all the leaves were hand-harvested each year, and a random 20-leaf subsample removed from the bulk sample. Area of the subsample was measured with a leaf area meter (Model LI-3000 LI-COR, Lincoln, NE), and all foliage was dried at 60°C (140°F) for two days and then weighed. Total tree leaf area was calculated as subsample leaf area plus the product of subsample specific leaf area (m^2/g) and bulk leaf weight. Leaf area of KCT was determined by counting the total number of bipinnately compound leaves on each tree and then harvesting 10 leaves per tree. Leaflets per leaf, and subleaflets per leaflet, were counted and average subleaflet area was measured. Total tree leaf area was calculated as the product of average (subleaflet area), (# subleaflets/leaflet), (# leaflets/leaf), and (# leaves/tree). At the end of the second season all trees were cut at ground level and annual trunk growth measured on a 25 mm (1 in) thick cross section of trunk removed 0.3 m (12 in) above the cut. Shoot elongation was measured on ten primary shoots per tree, except in 1991 as MAP crowns were accidentally destroyed before measurements could be taken.

Data analysis. Growth responses over both years and 1991 water relations means were compared by analysis of variance. Because of large variances, treatment means of growth responses were log-transformed prior to analysis. Because of restriction error in assigning treatments to individual trees, significant differences between species were calculated with SPECIES * TRANSPLANT as the appropriate error term in F-tests. Comparisons of differences in growth between years used SPECIES * TRANSPLANT * YEAR as the error term. Separate pair-wise tests compared differences between transplant treatments within a species and year using the model error term generated by the statistical software (SAS Inst. Inc., Cary, NC).

Results and Discussion

Transplanting had a larger effect on growth than water relations, but the two were interrelated. Growth was substantially reduced in transplanted trees of both MAP and KCT (Table 1). Trunk growth of transplanted trees of both species was several times lower than the non-transplanted controls in 1990, but partially recovered relative to the controls in 1991. Shoot elongation was also substantially reduced both years in transplanted KCT and MAP. Reduced vascular tissue as a result of less trunk growth and less elongation in the transplanted trees was manifested in canopy size 5–8 fold less in 1990, diminishing to 2–3 fold less in 1991. Total canopy leaf area the first year was reduced nearly 90% and 80% for KCT and MAP, respectively. The transplanting effect on individual leaf size varied between species, as that of transplanted KCT was much lower than the controls while there was little difference between the two MAP treatments. This clearly reflected the vastly different leaf structure of the two species, as all components of the bipinnately compound KCT leaves were affected compared to the simple MAP leaves. We detected significant differences in growth between years only for combined species response (significance levels not shown). Trunk growth and total leaf area increased in transplanted KCT from 1990 to 1991 while declining in both MAP treatments and staying constant in non-transplanted KCT. This was possibly related to low rainfall in 1991, 98 mm (3.8 in), compared to the corresponding period in 1990, 232 (9.1 in) (Fig. 1).

Transplanting had less effect on water relations than we expected (Fig. 1). Predawn Ψ of both transplanted and con-

Table 1. Trunk growth, total tree leaf area, single leaf area and shoot elongation for transplanted and non-transplanted (control) Kentucky coffee tree (KCT) and silver maple (MAP) over two seasons, plus-or-minus standard error.

	Trunk growth, mm		Total leaf area, m^2		Single leaf area cm^2		Shoot elongation, cm	
Treatment	1991	1990	1991	1990	1991	1990	1991	1990
KCT transplanted	1.3 ± 0.2	0.8 ± 0.1	9.23 ± 1.79	3.39 ± 0.84	494 ± 34	209 ± 57	5.5 ± 0.1	24.7 ± 2.5
KCT control	4.3 ± 0.9	3.7 ± 0.4	26.11 ± 5.11	26.01 ± 3.69	899 ± 110	939 ± 95	18.7 ± 3.6	75.7 ± 28.4
MAP transplanted	2.6 ± 0.6	3.5 ± 1.1	5.60 ± 0.56	4.68 ± 0.87	30 ± 3	42 ± 10	—	26.6 ± 5.6
MAP control	5.8 ± 0.6	13.6 ± 1.0	19.26 ± 1.94	22.30 ± 3.05	33 ± 3	68 ± 8	—	114.1 ± 110.0
Species	**[z]	**	*	ns	**	**	—	ns
Transplant effect within species								
KCT	**	**	**	**	**	**	**	ns
MAP	**	**	**	**	ns	ns	—	**

[z]Differences between treatment combinations are not significant (ns) or significant at 0.05 (*) or 0.01 (**).

Table 2. **1991 midday stomatal conductance and water potential for transplanted and non-transplanted (control) silver maple and Kentucky coffee tree plus-or-minus standard error.**

Treatment	June 18	July 16	July 25	August 1
	Conductance, mmol m^{-2} s^{-1}			
KCT transplanted	57 ± 6	41 ± 3	40 ± 6	133 ± 20
KCT control	210 ± 54	164 ± 39	198 ± 59	104 ± 22
MAP transplanted	132 ± 17	74 ± 17	107 ± 40	58 ± 17
MAP control	165 ± 18	144 ± 24	163 ± 60	120 ± 38
Species	ns[z]	ns	ns	ns
Transplant effect within species				
KCT	*	*	*	ns
MAP	ns	ns	ns	ns
	Water Potential, MPa			
KCT transplanted	−1.80 ± 0.04	−2.42 ± 0.42	−2.81 ± 0.04	−2.6 ± 0.10
KCT control	−2.20 ± 0.62	−2.28 ± 1.85	−2.60 ± 0.08	−2.1 ± 0.09
MAP transplanted	−1.41 ± 0.03	−1.87 ± 0.21	−2.02 ± 0.11	−2.2 ± 0.10
MAP control	−1.39 ± 0.06	−2.23 ± 1.61	−2.46 ± 0.13	−1.8 ± 0.12
Species	ns[z]	*	**	*
Transplant effect within species				
KCT	ns	ns	*	ns
MAP	ns	ns	*	ns

[z]Differences between treatment combinations are not significant (ns) or significant at 0.05 (*) or 0.01 (**).

trol trees generally declined in concert during dry periods both years, but in 1990 and through most of 1991 predawn Ψ of both KCT treatments was more negative than MAP. These differences between species may have been related to

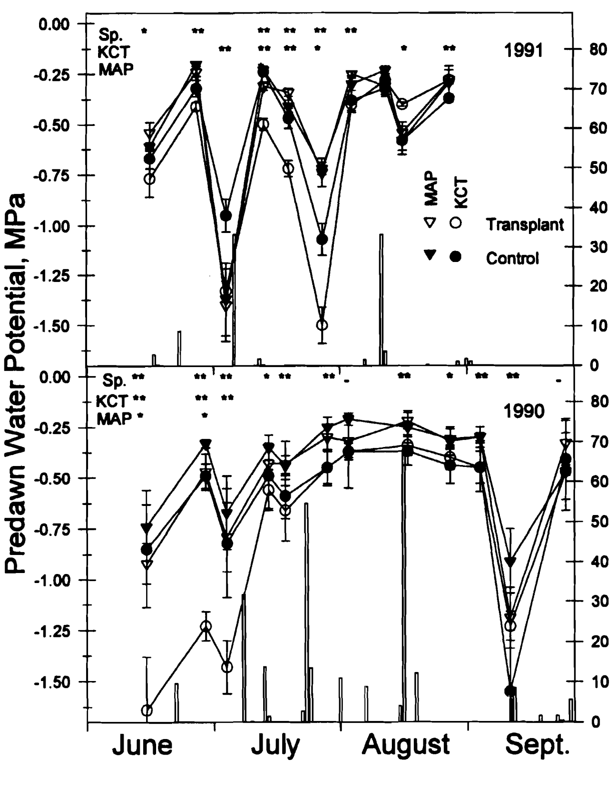

Fig. 1. **Predawn water potential means plus standard error and rainfall for transplanted and non-transplanted (control) silver maple (MAP) and Kentucky coffee tree (KCT) over two seasons. Treatment means without bars have small error terms that are obscured by data points. For any sampling date significant differences at 0.05 (*) or 0.01 (**) between species means, and transplant means within a species, are indicated along upper x axis over that date. Absence of asterisks indicates no significance.**

their characteristic root systems, as during transplanting we observed several large, deep roots but fewer lateral roots in KCT, compared to a more fibrous and horizontally-oriented MAP root system. The sparse KCT root system possibly had less surface area for water uptake than the many smaller, lateral MAP roots. Except immediately after transplanting, possibly due to initial lack of fine roots, there was no significant effect of transplanting on predawn Ψ in either species during high-rainfall periods. During a rain-free period in mid-to-late July, 1991, however, transplanted KCT was 0.4–0.5 MPa more negative than the control trees while there was no effect on MAP.

Similarly, transplanting did not have a large effect on daytime g_s and leaf Ψ. Stomatal conductance of transplanted trees of both species was lower than the non-transplanted trees, when predawn Ψ declined during rain-free periods, in mid-July 1990 (data not shown) and through midseason 1991 (Table 2). These differences in g_s were not evident on later sampling dates following periods of rainfall both years, indicating that transpiration rates of transplanted trees at these times were probably similar to the controls. There was even less effect on daytime Ψ, as only on two dates, mid-July 1990 for KCT (data not shown) and on July 25 1991 (Table 2) during low-rainfall periods, was midday Ψ of the transplanted trees significantly lower than the control trees. Species differences in Ψ were larger, as on both dates midday values were 0.7 to 0.8 MPa more negative in KCT than MAP. Consistent with their coarser root system and similar to predawn Ψ, root-leaf hydraulic resistance may have been greater in KCT (10).

Transplanting reduced transpiring leaf area that in turn reduced total tree water loss, even when g_s and transpiration rates were similar to non-transplanted trees. Similar to the results of Abod and Webster (1), such self regulation of water loss moderates internal water deficits and soil-water depletion. This occurred in transplanted KCT and MAP, allowing normal stomatal opening when soil moisture was adequate and likely benefiting carbon uptake. In terms of resource allocation the transplanted tree produces less foliage that functions normally rather than more but less-functional foliage. Despite reduced total water loss, water stress, as indicated by reduced g_s, still occurred more frequently than the controls during low-rainfall periods in transplanted trees, particularly in KCT in 1991. This was likely due to the limited amount of soil moisture in the soil transplanted with the roots (12). Reduced g_s would also help moderate soil-water depletion during low-rainfall periods by reducing transpiration rates, but it would likely inhibit photosynthesis to the detriment of root growth. This response appeared to vary between species. Generally KCT seemed to be more drought tolerant than MAP, since its growth was less affected by low rainfall in 1991. In particular, while growth and water relations were initially more affected, transplanted KCT growth recovered faster following transplanting during a dry year. In a wet year MAP may recover from transplanting more rapidly.

These responses have several management implications. Self regulation of transpiring leaf area suggests that severe shoot pruning of transplanted balled-and-burlapped trees to balance transpiration with the reduced root system is not necessary and would probably reduce photosynthetic area, hindering root development and tree establishment (1). This is consistent with current pruning recommendations (5), but in certain instances, such as transplanting deciduous trees in leaf, harvesting an undersized root ball, or if irrigation were not available in arid conditions, pruning top growth to balance the roots may help reduce water stress following transplanting. Reduced crown size would suggest that transplanted trees need correspondingly less irrigation water. As indicated by transplanted KCT in 1991, development of water-stress severity is more rapid for transplanted trees since they have a truncated root volume and poor hydraulic contact with the native soil moisture (12). Consequently irrigation frequency would probably need to be increased compared to a non-transplanted tree. These management implications would apply primarily to deciduous trees transplanted during dormancy that can moderate new growth in response to root loss.

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