

Water Loss and Survival of Stem Cuttings of Two Maple Cultivars Held in Subirrigated Medium at 24 to 33 °C

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Additional index words. heat resistance, asexual propagation, *Acer rubrum*, *Acer ×freemanii*

Abstract. We determined transpiration rate, survival, and rooting of unmisted, softwood cuttings of 'Autumn Flame' red maple (*Acer rubrum* L.) and 'Indian Summer' Freeman maple (*Acer ×freemanii* E. Murray). Effects of perlite at 24, 30, and 33 °C were assessed to determine whether responses of cuttings would be consistent with cultivar differences in resistance to root-zone heat previously shown with whole plants. During 7 d, cutting fresh mass increased by ≈20% at all temperatures for 'Autumn Flame' red maple, but fresh mass of 'Indian Summer' Freeman maple decreased by 17% and 21% at 30 and 33 °C, respectively. The percentage of cuttings of 'Indian Summer' that were alive decreased over time and with increasing temperature. Transpiration rate decreased during the first half of the treatment period and then increased to ≈1.1 and 0.3 mmol·m⁻²·s⁻¹ for 'Autumn Flame' and 'Indian Summer', respectively. Mean rooting percentages over temperatures for 'Autumn Flame' and 'Indian Summer' were 69% and 16%, respectively. Mean rooting percentages at 24, 30, and 33 °C over both cultivars were 74%, 29%, and 25%, respectively. Over temperatures, mean root count per cutting was 41 and seven, and mean root dry mass per cutting was 4.9 and 0.4 mg, for 'Autumn Flame' and 'Indian Summer', respectively. Use of subirrigation without mist to root stem cuttings was more successful for 'Autumn Flame' than for 'Indian Summer'. Temperature × cultivar interactions for cutting fresh mass and the percentage of cuttings remaining alive during treatment were consistent with previous evidence that whole plants of 'Autumn Flame' are more heat resistant than plants of 'Indian Summer'. Mass and survival of stem cuttings during propagation in heated rooting medium may serve as tools for screening for whole-plant heat resistance among maple genotypes.

Urbanization results in atmospheric heat islands (Viskanta et al., 1977) and concomitant heating of the upper 50 cm of tree root zones (Graves and Dana, 1987; Johnson et al., 1975). Temperatures ≥30 °C have been documented in tree root zones in metropolitan areas of the Midwestern United States and can be supraoptimal for growth of some taxa of trees planted in city landscapes. Wilkins et al. (1995b) found plant dry mass, stem length, and foliar chlorophyll content of plants of 'Autumn Flame' red maple were similar at 28 and 34 °C. In contrast, plants of 'Indian Summer' Freeman maple had lower mass, shorter stems, and less chlorophyll at 34 °C than at 28 °C. This difference illustrates the potential to select heat-resistant genotypes of maple for use at planting sites characterized by high temperatures. Methods used previously for studying the resistance to high root-zone tem-

perature of selected cultivars may be unsatisfactory for screening a large population of genotypes because whole plants must be cultured for several weeks in expensive apparatus.

Softwood cuttings are used to propagate cultivars of red maple and Freeman maple because >50% of budded and grafted plants can fail within 1 year (Fare et al., 1990; Moller, 1985). Zhang and Graves (1995) obtained a higher rooting percentage and more root mass for softwood cuttings of 'Franksred' (Trademark = Red Sunset) red maple treated with subirrigation than for cuttings provided intermittent mist. Resistance to desiccation may influence rooting success of subirrigated cuttings because the method does not involve foliar misting or high relative humidity (RH). Wilkins et al. (1995a) found that only 40% of the leaf area of 'Indian Summer' Freeman maple remained functional after rooted cuttings were removed from mist, whereas 94% of the leaf area of 'Autumn Flame' red maple was functional. Thus, leaves of 'Autumn Flame' seem more resistant to desiccation than leaves of 'Indian Summer'. Environmental conditions, including temperature, affect the water relations and rooting of cuttings (Grange and Loach, 1983). Use of rooting media at 18 to 25 °C is optimal for rooting stem

cuttings of most temperate species (Loach, 1988); higher temperatures may promote desiccation by decreasing water transport through the cut stem before rooting and by reducing the rate of root development.

Consistency among genotypes in responses of whole plants and stem cuttings to root-zone heat might validate using responses of cuttings to temperature of rooting media during propagation to screen genotypes for heat resistance. Therefore, the primary objective of this research was to determine transpiration rate, survival, and rooting of unmisted, softwood cuttings of 'Autumn Flame' red maple and 'Indian Summer' Freeman maple held in subirrigated rooting medium at 24, 30, and 33 °C. Replacing mist with subirrigation during commercial propagation could reduce water use, deter disease, lower cost, and prevent the leaf desiccation that can occur after rooted cuttings of red maple and Freeman maple are removed from mist (Wilkins et al., 1995a). Because the effectiveness of this method has only been assessed for 'Franksred' red maple (Zhang and Graves, 1995), and because cultivars of red maple and Freeman maple vary in response to traditional propagation methods with mist (Wilkins et al., 1995a), the secondary objective of this research was to determine the success of using the subirrigation method with two additional cultivars.

Materials and Methods

Softwood cuttings of 'Autumn Flame' red maple and 'Indian Summer' Freeman maple were made from the fifth through ninth youngest nodes of elongating branches of stock plants grown in a greenhouse. The stock plants had been produced from stem cuttings and were exposed to natural photoperiods at 42°N lat. Stem sections had one or two nodes. The basipetal pair of leaves of two-node cuttings was removed so all cuttings had one pair of leaves. Stem length between the node with leaves to the basipetal cut end was 7 cm. Stems were dipped in tap water and then coated with talc containing 1*H*-indole-3-butyric acid (IBA) at 8 g·kg⁻¹ (Hormodin #3; MSD-AGVET, Rahway, N.J.).

Subirrigation was provided in vessels designed for control of root-zone temperature. Each vessel consisted of a stainless steel beaker (diameter = 12 cm, height = 16 cm, volume = 1.9 L) filled to ≈1 cm from the top with coarse-grade perlite. Each beaker was surrounded on its sides and bottom by a polyvinyl chloride (PVC) shell. Temperature-regulated water was pumped from an electronic bath (RTE 111; Neslab, Newington, N.H.) into a network of flexible tubing that delivered the water to the vessels. Water entered each PVC shell through a port near its base. A valve at this port permitted regulation of water flow rate. An additional port near the top of each PVC shell was fitted with tubing through which water flowed back to the water bath. Actual temperatures adjacent to the cut ends of stems were 24.2 ± 0.4, 29.8 ± 0.2, and 32.6 ± 0.5 °C for the treatments designated as 24, 30, and 33 °C, respectively.

Received for publication 24 June 1996. Accepted for publication 7 Sept. 1996. Journal Paper No. J-16938 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Project No. 3229, and supported by Hatch Act and State of Iowa funds. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
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Cuttings were inserted into the perlite such that the node with leaves was at the surface and the basipetal cut end was 7 cm below the surface of the perlite. Two cuttings of one cultivar were placed at opposite sides of each beaker, both 3 cm from the inside wall. The fresh mass of one randomly selected cutting in each vessel was determined before insertion. One week later, cuttings that had been weighed were removed, weighed again, and discarded. Percentage of gain or loss in fresh mass of cuttings after 1 week was calculated by dividing the difference in fresh mass at day 7 and day 0 by the fresh mass on day 0. Cuttings visually estimated to have $\leq 75\%$ of the surface area of their leaves desiccated were considered living and were counted on days 6, 12, and 21.

Subirrigation solution was provided continuously to the cuttings during the rooting period. Transparent tygon tubing was sealed to the single, watertight drainage channel at the center of the bottom of each vessel. The tubing extended horizontally from the drainage channel to the side of each vessel and then was extended vertically along the outside wall of each PVC jacket. Subirrigation with 50% Hoagland #1 solution (Hoagland and Arnon, 1950) that contained 50 mM Fe as Fe-EDDHA was accomplished by adding solution to the surface of the perlite. The level of solution accumulated in the bottom of the containers was indicated by the height of solution in the tubing. A 6-cm height was maintained to ensure that irrigation solution was kept 2 cm below the basal ends of the cuttings in the perlite (Zhang and Graves, 1995).

The experiment was performed twice, once in each of 2 years. Cuttings were taken and treatments began on 18 May 1994 and 29 May 1995. Experiments were conducted in greenhouses where four 400-W high-pressure sodium lamps 1.3 m above the top of cuttings provided supplementary irradiance during 16-h photoperiods during both experiments. Midday photosynthetically active radiation, measured with a LI-185 quantum photometer (LI-COR, Lincoln, Neb.), ranged from 200 to 450 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Temperature of air adjacent to the cuttings, determined with a model X4Q Tempscribe temperature reader (Bacharach, Pittsburgh) was maintained between 23 and 27 °C during both experiments. Midday RH, measured by using a model 22-9030 Serdex humidity reader (Bacharach), ranged from 46% to 58% during both experiments.

A randomized block design with two cultivars and three temperatures was used. Cultivars were 'Autumn Flame' and 'Indian Summer'. Temperature treatments were 24, 30, and 33 °C maintained at the cut ends of the stems. There were two blocks during both years. Each block had four replications of the factorial combination of six treatments. Perlite temperature adjacent to the cut ends of the stems was monitored by using a copper-constantan thermocouple within a stainless steel probe. Transpiration rate of one of the two leaves on each cutting that was not removed after the first week was measured at 1400 HR central standard time every 3 to 4 d during

1995 with a LI-1600 steady-state porometer (LI-COR). Rooting percentage and the number of roots on the cutting that remained in each vessel after the first week were determined on day 21. Roots were removed from the cuttings on day 21, and root mass was determined after samples dried at 67 °C for 2 d. Data were tested with an analysis of variance appropriate for the factorial design after data expressed as percentages were transformed to the arcsin of the square root. Mean separation was done by using Fisher's LSD at $P \leq 0.05$.

Results

There were temperature \times cultivar interactions for percentage of change in fresh mass after 7 d and for the percentage of cuttings alive on days 6, 12, and 21. Cutting fresh mass of 'Autumn Flame' increased by $\approx 20\%$ at all temperatures (Table 1). However, there was no change in fresh mass of 'Indian Summer' at 24 °C, and fresh mass decreased by $\approx 20\%$ at 30 and 33 °C, respectively (Table 1). Temperature did not affect the percentage of cuttings alive for 'Autumn Flame' on days 6 and 12, but the percentage of cuttings alive for 'Indian Summer' decreased over time and with increasing temperature (Table 1). By day 21, there was a higher percentage of cuttings alive for 'Autumn Flame' than for 'Indian Summer' at all temperatures (Table 1). Temperature did not affect transpiration rate, and there was no temperature \times cultivar interaction (data not shown). Transpiration rate of both cultivars decreased during the first half of the treatment period (Fig. 1). By day 21, the transpiration rate of 'Autumn Flame' had increased to ≈ 1.1 $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, whereas transpiration of 'Indian Summer' was ≈ 0.3 $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Fig. 1).

Cultivar and temperature affected rooting percentage after 21 d, and there was no interaction between these main effects. Over all temperatures, the mean rooting percentages for 'Autumn Flame' and 'Indian Summer' were 69% and 16%, respectively (LSD = 29). Mean rooting percentages at 24, 30, and 33 °C over both cultivars were 74%, 29%, and 25%, respectively (LSD = 12). Only the cultivar main effect was significant for the number of roots and root dry mass per cutting. Averaged over all temperatures, 'Autumn Flame' and 'Indian Summer' had 41 and seven roots per cutting (LSD = 19), respectively. Mean root dry mass of 'Autumn Flame' and 'Indian Summer' over

all temperatures was 4.9 and 0.4 mg (LSD = 4.3), respectively.

Discussion

Interactions between temperature and cultivar for cutting fresh mass and the percentage of cuttings remaining alive during treatment were consistent with previous evidence that whole plants of 'Autumn Flame' red maple are more heat resistant than plants of 'Indian Summer' Freeman maple. The loss in fresh mass and reduced survival of 'Indian Summer' exposed to the higher temperatures contrasted with gains in mass and uniform survival of 'Autumn Flame' at all temperatures (Table 1). Likewise, 34 °C in the root zone reduced dry mass, stem length, and chlorophyll content of whole plants of 'Indian Summer', while 'Autumn Flame' was not affected (Wilkins et al., 1995b). Consistency between previous research with whole plants and this study of cuttings suggests that heat resistance of maples can be assessed within 7 d by screening unmisted stem cuttings held in rooting medium kept at ≥ 30 °C for changes in mass and survival.

Cultivar differences in heat resistance may be related to the climate of their geographic origins. 'Indian Summer' Freeman maple was selected at the Morgan Arboretum, St. Anne De Bellevue, Que., Canada (Santamour and McArdle, 1982). This area, located in U.S. Dept. of Agriculture (USDA) hardiness zone 4b, is in the northern portion of the native range of red maple and silver maple (*Acer saccharinum* L.), the parents of Freeman maples (Preston, 1989). Average annual minima in this area are as low as -32 °C (USDA, 1990). Although its native seed source is unknown, 'Autumn Flame' was selected for cultivation in Oregon and consistently develops desirable autumnal leaf color in Alabama (Fare et al., 1990). This cultivar is recommended for use in areas as mild as USDA hardiness zone 9a, where average annual minima reach only -7 °C (Wandell, 1994). Thus, 'Autumn Flame' may be better adapted than 'Indian Summer' to climatic conditions in the southern portion of the geographical area where red maple, silver maple, and hybrids of these species occur in nature (Krahl et al., 1993).

Trends in fresh mass change and cutting survival (Table 1) may have resulted from cultivar differences in the transport of water

Table 1. Gain (+) or loss (-) in fresh mass after 7 days and percentage of cuttings living after 6, 12, and 21 days for unmisted stem cuttings of 'Autumn Flame' red maple and 'Indian Summer' Freeman maple in subirrigated perlite held at 24, 30, or 33 °C.^a

Temp of rooting medium (°C)	Fresh mass change after 7 days (%)		Percentage of cuttings alive					
	Autumn Flame	Indian Summer	Day 6		Day 12		Day 21	
			Autumn Flame	Indian Summer	Autumn Flame	Indian Summer	Autumn Flame	Indian Summer
24	+21	0	100	94	100	63	75	31
30	+20	-17	100	56	100	38	50	13
33	+18	-21	94	44	94	0	69	0

^aValues are means of 16 observations from two replicate experiments done in 1994 and 1995. All data were transformed to the arcsin of the square root before analysis of variance was performed. Fisher's LSD ($P \leq 0.05$) for values for fresh mass change and percentage of living cuttings are 12 and 31, respectively.

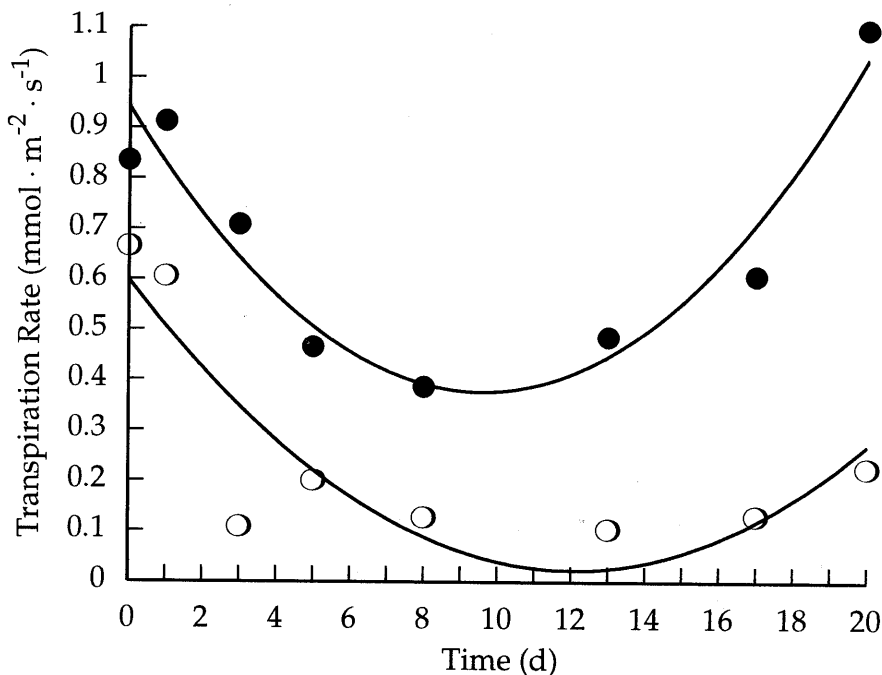


Fig. 1. Mean foliar transpiration rate of stem cuttings of 'Autumn Flame' red maple (●) and 'Indian Summer' Freeman maple (○) held in subirrigated perlite without mist for 21 d. Eight single-cutting replications were treated with 24, 30, and 36 °C in the perlite. Temperature and the temperature × cultivar interaction did not affect transpiration rate. Therefore, data for the three temperatures were combined for both cultivars, and values are means of 24 replicates. Transpiration rate of 'Autumn Flame' = $0.94 - 0.117(d) + 0.006(d^2)$, $r^2 = 0.91$. Transpiration rate of 'Indian Summer' = $0.60 - 0.095(d) + 0.004(d^2)$, $r^2 = 0.78$.

through cuttings. Although the transpiration rate of both cultivars decreased during the first half of the treatment period, transpiration rates were consistently higher for 'Autumn Flame' than for 'Indian Summer' (Fig. 1). The decrease in transpiration rate during the first half of treatment suggests that there was reduced water uptake through stems or increased diffusive resistance to water loss from leaves. Leaf relative water content of subirrigated, unmisted stem cuttings of 'Charm' chrysanthemum [*Dendranthema × grandiflorum* (Ramat.) Kitamura] also decreased during the first half of a 14-d propagation period, and subsequent increases in relative water content coincided with root initiation (Graves and Zhang, 1996). Likewise, the increase in transpiration rates of 'Autumn Flame' and 'Indian Summer' during the latter half of treatment probably followed root formation. The relatively low rooting percentage and root mass of 'Indian Summer' may explain why its transpiration did not increase to rates near those observed on days 0 and 1.

Despite consistently higher transpiration rates for 'Autumn Flame' red maple than for 'Indian Summer' Freeman maple (Fig. 1), the relatively large leaves of 'Indian Summer' may have made cuttings particularly susceptible to desiccation. By measuring the surface area of fully expanded leaves on stock plants of the two cultivars on day 0 during 1995, we estimated the mean surface area of one leaf blade on 'Autumn Flame' and 'Indian Summer' to be 47 and 129 cm², respectively. Dirr (1990) and Wandell (1994) also noted that leaves of 'Autumn Flame' are particularly small. Mean transpiration rate of 'Autumn

Flame' and 'Indian Summer' on day 0 were 0.84 and 0.67 mmol·m⁻²·s⁻¹, respectively (Fig. 1). Multiplying these rates by twice the estimated surface area of one leaf and by 3600 indicates that 28.4 and 62.2 mmol of water were lost per hour from the two leaves on a cutting of 'Autumn Flame' and 'Indian Summer', respectively. These estimates of foliar water loss are consistent with cultivar differences in change in fresh mass after 7 d and changes in cutting survival during treatment (Table 1). Wilkins et al. (1995a) found that only 40% of the leaf surface area of single-node cuttings of 'Indian Summer' was viable 22 d after cuttings were removed from a propagation bench where mist was applied. In contrast, 78% of the leaf surface area of 'Jeffersred' (trademark = Autumn Blaze) Freeman maple was viable even though root development on cuttings of 'Indian Summer' and 'Jeffersred' was similar. Our results and those of Wilkins et al. (1995a) indicate that the leaves of 'Indian Summer' are unusually prone to desiccation injury during propagation.

Our results provide new information about the success of propagating red maple and Freeman maple cultivars by using unmisted, subirrigated stem cuttings. Rooting percentages in this study were lower than percentages reported previously for these cultivars. Wilkins et al. (1995a) found that 92% of 'Autumn Flame' red maple and 85% of 'Indian Summer' Freeman maple single-node cuttings rooted when provided intermittent mist. Stems of cuttings in that study were shorter than the stems we used. Also, Wilkins et al. (1995a) subirrigated cuttings collectively in flats rather than in separate vessels. Therefore, differ-

ences in subirrigation techniques, stem length, or the capacity of leaves of cultivars to withstand a lack of mist could account for the lower rooting percentages we found. Temperature of the rooting medium had not been regulated during previous studies on the subirrigation technique or on rooting cuttings of these maple cultivars. All temperatures used in this experiment may have been above optimal.

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