

Leaf Water Relations and Plant Development of Three Freeman Maple Cultivars Subjected to Drought

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ABSTRACT. Little is known about drought stress resistance of Freeman maples (*Acer ×freemanii* E. Murray), which are hybrids of red maples (*A. rubrum* L.) and silver maples (*A. saccharinum* L.). The objective of our study was to measure plant growth and leaf water relations of 'D.T.R. 102' (Autumn Fantasy), 'Celzam' (Celebration), and 'Marmo' Freeman maples subjected to drought. Plants grown from rooted cuttings were subjected to four consecutive cycles of water deficit followed by irrigation to container capacity. Average stomatal conductance at container capacity for all cultivars was 255 mmol·s⁻¹·m⁻² in the first drought cycle and 43 mmol·s⁻¹·m⁻² during the fourth drought cycle. Predawn and midmorning leaf water potentials of droughted plants at the end of the fourth drought cycle were 1.16 and 0.82 MPa more negative than respective values for control plants. Osmotic potential of leaves at full turgor was -1.05 MPa for controls and -1.29 MPa for droughted plants, indicating an osmotic adjustment of 0.24 MPa. Root and shoot dry mass and leaf area were reduced similarly by drought for all cultivars, while Celebration exhibited the least stem elongation. 'Marmo' treated with drought had the lowest root-to-shoot ratio and the greatest ratio of leaf surface area to root dry mass. Autumn Fantasy had the lowest ratio of leaf area to stem xylem diameter. Specific leaf mass of drought-stressed Autumn Fantasy was 1.89 mg·cm⁻² greater than that of corresponding controls, whereas specific masses of Celebration and 'Marmo' leaves were not affected by drought. Leaf thickness was similar among cultivars, but leaves of droughted plants were 9.6 μm thicker than leaves of controls. This initial characterization of responses to drought illustrates variation among Freeman maples and suggests that breeding and selection programs might produce superior genotypes for water-deficient sites in the landscape.

Urban trees are exposed to excess and deficit soil moisture, but drought generally is considered the more serious threat (Clark and Kjellgren, 1990; Whitlow and Bassuk, 1987). Urban surfaces and compacted soils diminish infiltration of precipitation into tree root zones, and turf and other vegetation compete with trees for available water. Graves and Dana (1987) showed that urban soils were at higher temperatures than soils of natural areas, and the heat load of urban soils may promote faster evaporation of soil water. Because water deficits are prevalent in many landscapes, more information is needed about the resistance to water deficits of tree taxa with potential for use in urban areas.

Freeman maples (*Acer ×freemanii* E. Murray) are hybrids of red maples (*Acer rubrum* L.) and silver maples (*Acer saccharinum* L.), two species commonly found in urban areas. Freeman (1941) made the first controlled crosses of red and silver maples in 1933. More recently, many cultivars presumed to be the result of natural hybridizations of red and silver maple have been marketed as Freeman maples. Although such cultivars are sometimes promoted as stress-resistant alternatives to red maples and ornamentally superior to silver maples (Bachtell, 1989), there is little information on responses of Freeman maples to drought.

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Drought resistance among red maples has been the topic of previous research in greenhouse (Abrams and Kubiske, 1990; Nash and Graves, 1993; Townsend and Roberts, 1973) and field studies (Abrams, 1988; Briggs et al., 1986). We are not aware of studies that describe drought resistance in silver maples or Freeman maples, yet these species are considered adapted to stressful sites where other species may perish (Dirr, 1990). Santamour (1993) has questioned whether silver maple is more stress resistant than red maple and cautions that we should not assume Freeman maples possess a greater degree of stress resistance because of their lineage. There are few reports of experiments that involve Freeman maples subjected to stress. Wilkins et al. (1995) concluded that 'Autumn Flame' and 'Schlesinger' red maple and 'Jeffersred' Freeman maple were more resistant to high root-zone temperature than 'Franksred' red maple and 'Indian Summer' Freeman maple. Zhang et al. (1997) found that stem cuttings of 'Autumn Flame' red maple were more heat resistant than cuttings of 'Indian Summer' Freeman maple.

For many taxa, drought stress can change stomatal resistance (Havis, 1980; Hennessey et al., 1985), alter osmotic and leaf water potential (Abrams and Kubiske, 1990; Ranney et al., 1991), decrease leaf surface area (Borghetti et al., 1989; Hennessey et al., 1985), alter dry matter partitioning (Graves and Wilkins, 1991; Joly et al., 1989), and increase specific leaf mass (Joly et al., 1989). These responses represent ways that tissues can resist low water potentials, and they have been used to assess drought resistance. The objective of our research was to measure the growth and leaf water relations of three Freeman maple cultivars exposed to drought.

Materials and Methods

HANDLING STOCK PLANTS. Stock plants of 'D.T.R. 102' (Autumn Fantasy), 'Celzam' (Celebration), and 'Marmo' Freeman maples

were potted between 19 Mar. and 10 Apr. 1996 and grown in a greenhouse with a natural photoperiod at Ames, Iowa (42°N latitude). Tap water with N at 10.8 mol·m⁻³ from Peters Excel all-purpose 21N-2.2P-16.6K fertilizer (Scotts, Marietta, Ga.) was applied weekly to container capacity and had a pH of 6.0 to 6.6. All subsequent references to fertilization are at this rate and from this source.

PROPAGULE PRODUCTION AND MAINTENANCE. Plants were propagated by taking 5-cm-long, single-node stem cuttings from actively growing stock plants on 20 May, 24 July, and 8 Aug. 1996. Epidermis on the basal 1 cm of the stem of each cutting was removed with a razor blade, and the cutting was dipped in Hormodin no. 3 rooting powder (MSD AGVET, Merck & Co., Rahway, N.J.). Cuttings were rooted in coarse perlite by using subirrigation (Zhang and Graves, 1995), grown under natural photoperiod, irrigated twice weekly with tap water, and fertilized to container capacity weekly. Greenhouse environmental conditions were monitored 5 d per week between 1000 and 1300 HR CST with a steady-state porometer (LI-1600; LICOR, Lincoln, Nebr.). Average midday air temperature during rooting ranged from 19.0 to 25.9 °C, average relative humidity (RH) was 32% to 79%, and average photosynthetic photon flux (PPF) was 26 to 668 μmol·s⁻¹·m⁻². After 4 weeks, cuttings were potted in round, plastic pots (15.2-cm bottom diameter, 20.0-cm top diameter, 15.7-cm height) in 2,250 cm³ of 3 coarse perlite : 1 medium vermiculite (by volume). Potted cuttings were placed in a greenhouse under high-intensity discharge lamps with a 16-h photoperiod and fertilized to container capacity every other day. Two weeks later, the original pair of leaves was removed, and 1 week after leaf removal a new shoot was removed if more than one had begun to develop. The day before treatments began we fertilized all plants, measured shoot length from apex to shoot base, and labeled petioles of youngest fully expanded leaves. Treatments began 46, 27, and 29 d after we potted cuttings for the first, second, and third replications of the experiment, respectively. Average midday air temperature for potted cuttings before treatments began was 19.7 to 30.3 °C, average RH was 30% to 78%, and average PPF was 98 to 583 μmol·s⁻¹·m⁻².

TREATMENTS. Stomatal conductance, leaf temperature, air temperature, and PPF were measured daily between 0700 and 1100 HR on the youngest fully expanded leaf of each plant with the steady-state porometer. Container mass was measured daily, and this value was used to calculate daily evapotranspiration. Volume of evapotranspiration was supplied to controls each morning as tap water, and additional tap water was added slowly as necessary to attain container capacity. Minimum leachate was lost from each container. We provided control plants with 200 mL of supplemental irrigation between 1300 and 1700 HR to prevent water stress during the third and fourth drought cycles. Volumetric moisture content of the rooting medium, based on changes in the apparent dielectric constant, also was measured daily with a Theta Probe (model HH1, model ML1 sensor; Delta-T Services, Cambridge, England) at 6 cm below the rooting medium surface. Moisture content values were used to decide when to terminate drought cycles. When rooting medium moisture content declined to 0.100 m³·m⁻³, the first drought cycle was terminated by irrigating to container capacity with tap water that contained fertilizer. When rooting medium moisture content of all drought plants of a cultivar declined to 0.100 m³·m⁻³, we fertilized corresponding controls. The youngest fully expanded leaf of each plant was selected and labeled for use to determine stomatal conductance after all cultivars completed each drought cycle. Moisture content values for completion of the second, third, and fourth cycles were 0.060, 0.020, and 0.020 m³·m⁻³, respectively. Individual plants that finished the fourth drought cycle were irrigated and allowed to begin a fifth drought cycle so that destructive harvest could occur at the

same time for all plants. Experiments were completed before any drought plants required additional irrigation. Average midday air temperature during experiments was 19.2 to 27.9 °C, average RH was 23% to 81%, and average PPF was 54 to 445 μmol·s⁻¹·m⁻².

WATER RELATIONS. Predawn (0300 HR) and midmorning (0900 HR) leaf water potentials (Scholander et al., 1965) were measured the morning after a plant completed the fourth drought cycle. The pair of youngest fully expanded leaves of the stressed plant and a randomly selected control of that cultivar were used. At 0700 HR of the same morning we removed the next fully expanded pair of leaves for pressure-volume curve determination. These leaves were one node basipetal to leaves used for predawn and midmorning measurements of water potential. Pressure-volume curves were derived from measurements taken on a single leaf, but two leaves were prepared for this procedure as a safeguard. Petioles of these leaves were cut under

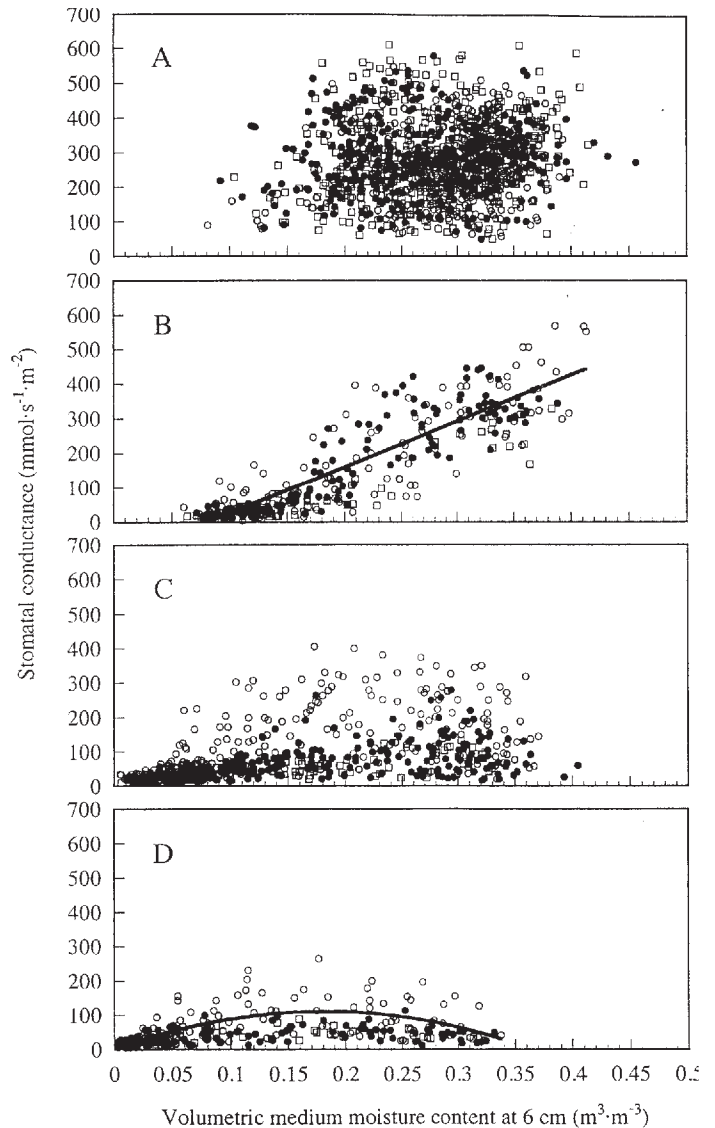


Fig. 1. Stomatal conductance as a function of volumetric moisture content of the rooting medium for well-irrigated controls (A), and for drought-stressed plants during cycle one (B), cycles two and three (C), and cycle four (D). Drought cycles two and three were combined because regression analysis showed they were not different. Plots include data from all cultivars of Expt. 1 (○), Expt. 2 (●), and Expt. 3 (□). Regression function for drought cycle one: stomatal conductance = -112.5 + 1316(moisture content); $r^2 = 0.76$. Regression function for drought cycle four: stomatal conductance = 8.0 + 809(moisture content) - 2,245(moisture content)²; $r^2 = 0.29$.

deionized water. Leaves were placed in jars with petioles immersed in deionized water. Jars were wrapped in plastic bags and placed in a refrigerator at 4 °C for at least 28 h to rehydrate leaves. A pressure chamber (PMS Instruments, Corvallis, Ore.) was used to develop pressure-volume curves (Tyree and Hammel, 1972), and osmotic potential at full turgor was obtained by using SAS PROC REG (SAS Institute, Cary, N.C.) applied to the linear portion of the curve.

DESTRUCTIVE HARVEST. Destructive harvest occurred after the final plant completed the fourth drought cycle. Stem length from apex to shoot base and xylem diameter 1 cm above the shoot base were measured. Leaf surface area was measured with an area meter (LI-3100). A 0.413-cm² disc was cut from the remaining youngest fully expanded leaf of each plant for specific mass determination. Discs were taken from the same interveinal position for each lamina and dried at 67 °C for 2 to 7 d before dry mass was measured and specific mass was calculated. Dry mass of leaves, shoots, and washed roots was determined after drying for 2 to 7 d at 67 °C.

MICROSCOPY. A leaf sample (1 × 0.5 cm) was cut from the youngest remaining fully expanded leaf during destructive harvest, preserved in formalin–acetic acid–ethanol (Berlyn and Miksche, 1976), and dehydrated in an ethanol–tertiary butyl alcohol series. The 0.5-cm² sample area was added to the leaf surface area measurement obtained for each plant during destructive harvest. After being embedded in Paraplast (Oxford Labware, St. Louis), samples were cut into transverse sections 10 μm thick. Sections were stained with safranin-fast green (Berlyn and Miksche, 1976) and viewed at 200× on an Olympus BH2 light microscope to measure leaf thickness.

EXPERIMENTAL DESIGN AND DATA ANALYSIS. Treatments were applied in a factorial arrangement with two irrigation treatments (control and drought) and three cultivars. Rooted cuttings were assigned randomly to treatments and placed on a greenhouse bench in a completely randomized design. There were five replications per treatment combination in the first two experiments and two replications per treatment combination in the third. Data were analyzed using SAS. Analyses of variance (ANOVA) were performed by using the General Linear Model. Means of dry masses, leaf water potentials, osmotic potentials at full turgor, specific leaf mass, and dry mass ratios were separated by using Fisher's LSD ($P = 0.05$). Predicted values of stomatal conductance and osmotic potential at full turgor were determined using PROC REG.

Results

For each cultivar and experiment combination we plotted stomatal conductance as a function of moisture content of the rooting medium for all drought cycles. Stomatal conductance decreased from the first to fourth drought cycles in stressed plants for all cultivars (Fig. 1). Of the nine plots of the first drought cycle, six were best fit by positive linear regressions and the other three by positive quadratic lines. For plots of the fourth cycle, all nine were best fit by negative quadratic regression lines. We used SAS PROC REG to predict the value of

stomatal conductance at a moisture content near container capacity (0.300 m³·m⁻³) for the line that best fit each plot. We found that drought cycle affected conductance ($P > F = 0.0001$), with no difference among cultivars. Predicted values of stomatal conductance at a moisture content of 0.300 m³·m⁻³ for the first to fourth drought cycles were 255, 125, 129, and 43 mmol·s⁻¹·m⁻², respectively (LSD_(0.05) = 40). Plants wilted at a root-zone moisture content of 0.100 m³·m⁻³ in the first cycle, but during the fourth cycle a moisture content of 0.030 m³·m⁻³ or below coincided with incipient wilting. There was no plant death or leaf loss caused by drought, despite wilting that persisted for >24 h for some plants.

After four cycles of drought, predawn and midmorning leaf water potentials of all cultivars were similar. Predawn and midmorning water potentials of droughted plants were 1.16 and 0.82 MPa more negative, respectively, than those of controls (Table 1). Drought also affected leaf osmotic potential at full turgor similarly for all cultivars, with osmotic potentials of plants in the stress treatment 0.24 MPa more negative than those of controls (Table 1).

Drought reduced shoot dry mass, root dry mass, and leaf surface area by 64%, 43%, and 58%, respectively, and there was no cultivar effect (Table 1). Celebration had the least stem elongation (Table 2). 'Marmo' had the lowest root-to-shoot ratio and greatest ratio of leaf surface area to root dry mass, and Autumn Fantasy had the smallest ratio of leaf surface area to stem xylem diameter (Table 2). Autumn Fantasy exhibited a greater increase in specific leaf mass in response to drought than the other two cultivars (Table 3). Leaves of drought-stressed plants were thicker than those of control plants (83.6 vs. 74.0 μm, respectively), regardless of cultivar.

Discussion

Nurseries market Freeman maples as stress-resistant alternatives to red maples, yet there has been no research to document this, nor has attention been given to the potential for genetic diversity in stress resistance among Freeman maple genotypes. With increased emphasis on sustainable and stress-resistant landscapes, inappropriate marketing of Freeman maples could lead to use in urban areas that parallels the prevalence of red maples and silver maples there already. Santamour (1993) has warned that basing assumptions of the stress resistance of Freeman maples solely on their lineage is unwise. Our research addresses these issues by providing initial characterization of the drought-stress resistance of three genotypes of Freeman maple.

Leaf water relations of Autumn Fantasy, Celebration, and 'Marmo' responded similarly to drought. Stomatal conductance was influenced strongly by moisture content of the rooting medium and by repeated cycles of drought (Fig. 1). Regression analysis of stomatal conductance as a function of moisture content of the rooting medium revealed that stomatal conductance increased linearly with increasing moisture content of the rooting medium during the first drought cycle. The same analysis was

Table 1. Dependent variables for which there were no cultivar differences. Average predawn and midmorning water potentials, osmotic potential at full turgor, shoot and root dry mass, and leaf surface area of control and drought-stressed 'D.T.R. 102' (Autumn Fantasy), 'Celzam' (Celebration), and 'Marmo' Freeman maples. Each value represents the mean from three experiments, each composed of five or two replications per irrigation–cultivar treatment combination. Means were separated using Fisher's LSD ($P = 0.05$).

Treatment	Leaf water potential (MPa)		Leaf osmotic potential at full turgor (MPa)	Dry mass (g)		Leaf surface area (cm ²)
	Predawn	Midmorning		Shoot	Root	
Control	-0.20	-1.03	-1.05	52.3	9.9	5316
Drought	-1.36	-1.85	-1.29	18.7	5.6	2217
LSD _(0.05)	0.29	0.13	0.09	13.7	2.3	825

completed for the fourth drought cycle, and we found a negative quadratic relationship. We combined the plots of stomatal conductance as a function of moisture content for all cultivars and experiments to illustrate these trends (Fig. 1). The negative quadratic relationship in the fourth drought cycle shows a lag in stomatal conductance recovery after the irrigation that terminated the third drought cycle. Jones (1983) stated that stomata may take days to recover as a plant rehydrates after drought, and the time for recovery is related to the duration and severity of stress. This is consistent with what we have observed. Plants that have been exposed to previous stress may show a limited capacity for stomatal opening (Close et al., 1996). The low stomatal conductance we observed throughout the fourth drought cycle could be explained by such preconditioning. Despite highly curtailed stomatal conductance during the fourth drought cycle, there was no plant death or leaf desiccation or abscission. Medium moisture content of $\approx 0.100 \text{ m}^3 \text{ m}^{-3}$ in the first drought cycle caused severe foliar wilting and some shoot tip wilting, yet these moisture contents did not cause any wilting in the fourth drought cycle. This suggests that plants were able to adjust to deficit irrigation.

Turgor maintenance by active accumulation of solutes in leaves, termed osmotic adjustment, can help sustain rates of photosynthesis and carbon assimilation during drought. In our study, osmotic potential of drought-stressed plants at full turgor was 0.24 MPa more negative than that of controls (Table 1). Osmotic adjustment in Freeman maples has not been reported previously, and there are conflicting reports regarding osmotic adjustment in red maples. Nash and Graves (1993) found no osmotic adjustment in 'Franksred' red maple after nine cycles of deficit irrigation. Abrams and Kubiske (1990) found a difference in osmotic potential at full turgor of 0.15 MPa between predrought and peak drought conditions for red maple seedlings native to a bog area, but no changes were seen in seedlings native to upland sites. Because Freeman maple lineage includes red maple, we might hypothesize that Freeman maples should display similar variability for osmotic adjustment, yet the three cultivars we used responded similarly. If solute accumulation in leaves of drought-stressed plants increases leaf diffusive resistance, this might account for the differences in stomatal conductance between the first and fourth drought cycles. Additional testing of Freeman maples and red maples and information about turgor maintenance in silver maple are needed to determine the extent to which generalizations about the role of osmotic adjustment in these species can be made.

Predawn and midmorning leaf water potentials of the three

cultivars were affected similarly by drought. A low predawn leaf water potential reflects limited water available to roots or an inefficient water conducting system (Close et al., 1996; Nash and Graves, 1993). At the end of the fourth drought cycle, predawn leaf water potentials of control plants were less negative than those of drought-stressed plants, indicating that drought-stressed plants could not eliminate internal water deficits during the dark period (Table 1). Leaf water potential data show differences between effects of our irrigation treatments and illustrate the severity of the stress we imposed (Table 1). For example, the lowest leaf water potentials of 'Franksred' red maple during nine cycles of drought were -0.9 MPa predawn and -1.7 MPa at midday (Nash and Graves, 1993), which are less negative than the corresponding values for Freeman maples in our study.

Autumn Fantasy, Celebration, and 'Marmo' responded similarly to drought for shoot dry mass, root dry mass, leaf surface area (Table 1), and leaf thickness, but responses differed for stem elongation and specific leaf mass (Tables 2 and 3). Stem elongation of drought-stressed Celebration was only 72% of that for Autumn Fantasy and 69% of that for 'Marmo' (Table 2). Conservative shoot growth during drought could be advantageous, especially if root growth is promoted, but cultivars that sustain shoot growth during drought may have greater marketability. Celebration controls had greater specific leaf mass than Autumn Fantasy and 'Marmo' controls (Table 3). Autumn Fantasy was the only cultivar that exhibited a significant increase in specific leaf mass during drought (Table 3). Specific leaf mass can be affected by leaf thickness, cell density, and cell arrangement. An increase in laminar specific mass could represent an effective drought-resistance mechanism because it could allow photosynthesis to increase without a concomitant increase in leaf area and stomate number, both of which could increase transpiration. Nash and Graves (1993) found that severely droughted 'Franksred' red maples had a specific leaf mass that was $1.8 \text{ mg} \cdot \text{cm}^{-2}$ greater than that of plants maintained at container capacity, and Abrams and Kubiske (1990) showed that specific leaf mass varied among red maple seedlings from different sources when grown under favorable conditions. Our leaf thickness data suggest that the increase in specific mass of drought-stressed Autumn Fantasy leaves cannot be attributed to an increase in thickness alone because the cultivar \times irrigation treatment interaction was not significant. Cell density and spacing could not be consistently determined from our leaf samples but might be among the factors responsible for differences in specific mass.

Root-to-shoot ratio and the ratios of leaf surface area to root dry mass and leaf surface area to stem xylem diameter all reflect the

Table 2. Mean stem elongation, root-to-shoot ratio, ratio of leaf surface area to root dry mass, and ratio of leaf surface area to stem xylem diameter for 'D.T.R. 102' (Autumn Fantasy), 'Celzam' (Celebration), and 'Marmo' Freeman maples subjected to four consecutive cycles of drought. Each value represents the mean from three experiments, each composed of five or two replications per irrigation-cultivar treatment combination. Means were separated using Fisher's LSD ($P = 0.05$).

Dependent variable	Stem elongation (cm)	Root-to-shoot ratio	Ratio of leaf surface area to root dry mass ($\text{cm}^2 \cdot \text{g}^{-1}$)	Ratio of leaf surface area to stem xylem diam ($\text{cm}^2 \cdot \text{mm}^{-1}$)
Genotype				
Autumn Fantasy	57	0.28	451	426
Celebration	41	0.29	417	486
Marmo	60	0.21	583	475
LSD _(0.05)	11	0.03	72	47
Irrigation treatment				
Control	87	0.20	563	575
Drought	19	0.32	404	350
LSD _(0.05)	9	0.03	59	39

Table 3. Mean laminar specific mass of 'D.T.R. 102' (Autumn Fantasy), 'Celzam' (Celebration), and 'Marmo' Freeman maples. Youngest fully expanded leaves were used for specific leaf mass determination. Control plants were maintained by daily irrigation to container capacity. Drought plants were subjected to four consecutive cycles of deficit irrigation separated by irrigation to container capacity. Each value represents the mean from three experiments, each composed of five or two replications per irrigation-cultivar treatment combination. The overall LSD_(0.05) for comparisons among treatment means is 1.04.

Treatment	Freeman maple genotype		
	Autumn Fantasy	Celebration	Marmo
	Specific leaf mass (mg·cm ⁻²)		
Control	7.55	9.27	8.02
Drought	9.44	9.56	7.60

balance between tissues that govern water loss, absorption, and transport. High root-to-shoot ratios could reflect a heightened capacity for the collection of water by a root system, thereby maintaining the shoot in a well-hydrated condition (Joly et al., 1989). Autumn Fantasy and Celebration had greater root-to-shoot ratios than 'Marmo' by 0.07 and 0.08, respectively (Table 2). Joly et al. (1989) found that drought-stressed Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seedlings had root-to-shoot ratios 0.36 greater than well-irrigated plants. Nash and Graves (1993) found no change in root-to-shoot ratio between drought-stressed and control 'Franksred' red maples.

In our study, drought-stressed plants had lower ratios of leaf area to root dry mass than controls, indicating that drought led to a more conservative balance between water-losing and water-obtaining tissues. Joly et al. (1989) found a similar trend in Douglas-fir. 'Marmo' had the highest ratio of leaf surface area to root dry mass. One dry gram of drought-stressed 'Marmo' root system supported 132 and 166 cm² more leaf area than 1 g of roots of Autumn Fantasy and Celebration, respectively (Table 2). Drought-stressed plants of Autumn Fantasy differed from drought-stressed Celebration and 'Marmo' for the ratio of leaf surface area to stem xylem diameter. A millimeter of stem xylem of drought-stressed plants of Autumn Fantasy supported 60 and 49 cm² less leaf area than Celebration and 'Marmo', respectively (Table 2). Assuming no difference in xylem water transport capabilities among cultivars, this indicates a more favorable ratio of water transport to leaves and shoots. In contrast, Joly et al. (1989) reported a greater ratio of leaf surface area to sapwood area for drought-stressed Douglas-fir seedlings compared to control seedlings, but this was attributed to smaller stem diameters of stressed plants rather than an increase in leaf surface area. Controls in our study had a greater ratio of leaf surface area to stem xylem diameter by 225 cm²·mm⁻¹ over drought-stressed plants (Table 2).

Although drought-stressed plants of Autumn Fantasy and Celebration behaved similarly for root-to-shoot ratio and ratio of leaf surface area to root dry mass, Autumn Fantasy had a more favorable ratio of leaf area to stem xylem diameter, and drought-stressed leaves of only this cultivar had an increased specific mass in response to drought. The consistency with which Autumn Fantasy favorably expressed drought-resistance mechanisms suggests that this cultivar may adjust to sites prone to water deficit. The uniformity of osmotic adjustment among Freeman maples and the capacity of drought-stressed Freeman maples to increase root-to-shoot ratios provide the rationale for direct comparison of the drought resistance of Freeman maples and red maples.

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