Responses to High Root-zone Temperature Among Cultivars of Red Maple and Freeman Maple[1]

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Abstract

Two experiments were conducted to determine whether genotypes of red maple (*Acer rubrum* L.) and Freeman maple (*A.* x *freemanii* E. Murray) differ in responses to high root-zone temperature. During the first experiment, dry mass of 'Franksred', 'October Glory', and 'Schlesinger' red maple, 'Indian Summer' Freeman maple, and selections from Arkansas, Maine, and Wisconsin were similar at 24, 28, and 32C (75, 82, and 90F), but dry mass at 36C (97F) was only 22% of that at 28C (82F). 'Autumn Flame', 'Franksred', 'October Glory', and 'Schlesinger' red maple and 'Indian Summer' and 'Jeffersred' Freeman maple differed in responses to 34C (93F) during the second experiment. Stem length and plant dry mass were higher at 28C (82F) than at 34C (93F) for all cultivars except 'Autumn Flame' and 'Jeffersred', and the extent to which 34C (93F) decreased the length of the longest third-order root ranged from 50% for 'Autumn Flame' to 90% for 'Indian Summer'. The higher root-zone temperature decreased transpiration by as little as 25% for 'Jeffersred' to as much as 89% for 'Franksred', and 34C (93F) reduced leaf chlorophyll content of only 'Indian Summer' and 'Jeffersred'. These results indicate that 'Franksred' and 'Indian Summer' are relatively sensitive while 'Autumn Flame', 'Jeffersred', and 'Schlesinger' are relatively resistant to high root-zone temperature.

Index words: heat resistance, stress physiology, water relations, chlorophyll.

Species used in this study: red maple (*Acer rubrum* L.); Freeman maple (*Acer* x *freemanii* E. Murray).

Significance to the Nursery Industry

Temperatures exceeding 30C (86F) occur in root zones at urban planting sites and in nursery containers. High root-zone temperatures may decrease life spans of trees by direct heat injury or by increasing the sensitivity of tissues to other stresses. We examined 'Autumn Flame', 'Franksred', 'October Glory', and 'Schlesinger' red maple (*Acer rubrum* L.), 'Indian Summer' and 'Jeffersred' Freeman maple (*A.* x *freemanii* E. Murray), and selections from Arkansas, Maine, and Wisconsin for responses to root-zone heat. Growth was impaired for all genotypes exposed to 36C (97F), but cultivars differed in the extent to which 34C (93F) affected stem elongation, dry mass, transpiration, and leaf chlorophyll content. 'Autumn Flame', 'Jeffersred', and 'Schlesinger' were relatively resistant and 'Franksred' and 'Indian Summer' were relatively sensitive to high root-zone temperatures under our greenhouse conditions. If field trials confirm these trends, the use of genotypes resistant to high root-zone temperature at urban sites prone to high soil temperature might increase the longevity of trees in urban landscapes.

Introduction

Root-zone temperatures are higher at tree planting sites in urban centers than in nearby suburban and rural areas (5). Soils near street tree planting pits may be particularly prone to episodes of high temperature because of the transfer of heat from concrete and asphalt surfaces (5, 10). Temperatures exceeding 30C (86F) have been observed in the upper 10 cm (4 in) of soils at street tree sites, and there may be less temperature stratification in urban soils than forest soils (5). Particularly high root-zone temperatures have been documented at planting sites adjacent to buried utility steam channels (3). High and potentially lethal root-zone temperatures also occur in nursery media during production of containerized stock (12).

Optimal root-zone temperature varies among and within species of woody plants (1, 8, 9). Cultivars of red maple and Freeman maple are common in urban landscapes in the United States (14). Red maple is indigenous from southern Canada to Florida and from the east coast west to Minnesota, Iowa, and Texas (20). Shoot and root growth of red maple clones from Florida were similar among plants with root zones at 18, 24, and 30C (64, 75, and 86F), but 36C (97F) decreased stem elongation, shoot and root dry mass, and leaf osmotic potential (6). Provenance tests indicate genotypes from different origins vary physiologically and morphologically (18, 19), but genotype effects on responses to heat have not been reported. Cultivars of Freeman maple, hybrids of red maple and silver maple (*A. saccharinum* L.), resemble red maple and are marketed as alternatives to cultivars of red maple (17). However, little is known about the resistance of Freeman maple selections to environmental conditions common at urban planting sites. The objective of this study was to characterize differences among cultivars of red maple and Freeman maple in response to high root-zone temperature.

Materials and Methods

Experiment one. Single-node cuttings from glasshouse-grown stock plants of 'Franksred', 'October Glory', and 'Schlesinger' red maple, 'Indian Summer' Freeman maple, and three selections from a U.S. Dept. of Agriculture breeding program (USDA 55410, 56022, and 56023) were rooted in perlite under intermittent mist in a glasshouse for 18 days during May of 1991. Plants of the cultivars were obtained from J. Frank Schmidt and Son Co., Boring, OR. USDA

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55410, 56022, and 56023 were grown from seed collected in Wisconsin, Arkansas, and Maine, respectively.

Uniformly rooted cuttings were transferred singly on May 28 to 1.9 liter (0.5 gal) stainless-steel beakers filled with half-strength, aerated Hoagland solution #1 (11) with Fe as Fe-EDTA (pH = 5.6). The beakers were housed within polyvinyl chloride vessels that allowed heated water from adjacent baths (Models 2095 and 2161, Forma Scientific, Marietta, OH) to circulate around the sides and bottoms of the beakers. Constant treatments of 24, 28, 32, and 36C (75, 82, 90, and 97F) (±1C (1.8F)) in the root zone were initiated on June 4 (day 0). A datalogger with thermocouples mounted adjacent to plant shoots indicated air in the glasshouse ranged from 22 to 42C (72 to 108F). Maximum photosynthetically active radiation, determined by using a quantum sensor (LI-COR, Lincoln, NE), was 1100 $\mu mol/s \cdot m^2$. Four replicate plants at each temperature for 'Franksred', 'Indian Summer', and USDA 56022, and six replicates for the other genotypes, were arranged in a completely randomized design. Deionized water was added to vessels once daily to maintain solution volume. Solutions were replaced on day 21. Stem length of each plant was determined on days 7, 14, 21, 28, 35, 42, and 44. Plants were harvested on day 45. The percentage of plants in each treatment that had not initiated new shoots was determined. Dry mass was determined after shoot tissues not present on the rooted cuttings when treatments began and all roots were dried at 65C (149F) for 3 days. Data were analyzed by using an analysis of variance (ANOVA) for a completely randomized design with a factorial combination of four root-zone temperatures and seven maple genotypes. Percentages of shoot initiation by genotype and temperature were compared with Pearson's Chi-square test (13), and means for plant dry mass were separated by using the least-squares means procedure of the Statistical Analysis System (SAS) (SAS Institute, Cary, NC).

Table 1. Genotype (over root-zone temperatures) and root-zone temperature (over genotypes) effects on the percentage of rooted cuttings that developed new shoots, and the mean stem length and dry mass of plants that developed new shoots.

Treatment	Plants that developed new shoots (%)	Mean plant dry mass (g)
Genotype		
'Franksred'	81a[z]	4.9a[y]
'Indian Summer'	88a	3.0ab
'October Glory'	67a	2.1bc
'Schlesinger'	75a	1.9bc
USDA 55410	17b	0.3c
USDA 56022	75a	1.3bc
USDA 56023	42ab	4.4a
Root-zone temperature (C/F)		
24/75	72a	2.9a
28/82	72a	3.8a
32/90	64ab	2.7a
36/97	33b	0.6b

[z]Values followed by the same letter within the column and treatment are not different using Pearson's Chi-square test for goodness of fit.

[y]Means followed by the same letter within the column and treatment are not different using the least-squares means procedure of the Statistical Analysis System.

Experiment two. Cuttings of 'Autumn Flame', 'Franksred', 'October Glory', and 'Schlesinger' red maple and 'Jeffersred' and 'Indian Summer' Freeman maple were held under mist as described for experiment one for 32 days. Rooted cuttings were transferred to aerated, half-strength Hoagland solution #1 at 20 to 24C (68 to 75F) on May 8, 1992. Plants were placed singly in culture vessels in half-strength, aerated Hoagland solution #1 10 days later. Two plants of each cultivar were assigned to each of 12 blocks such that plants were uniform in size within blocks. One plant of each cultivar in each block was assigned randomly to 28C (82F) and 34C (93F) in the root zone. Treatments began on June 9. Nutrient solutions were replenished once daily and replaced once weekly. Midday photosynthetically active radiation in the glasshouse during treatments was 200 to 350 $\mu mol/s \cdot m^2$. Natural radiation was supplemented from 6 a.m. to 10 p.m. (EST) by 1000-watt high-pressure sodium lamps 1.5 m (4.9 ft) above the plants. Minimum, mean, and maximum air temperatures during treatments were 21, 27, and 34C (70, 80, and 93F).

Transpiration rate of plants in four blocks was measured at the middle of the photoperiod on six days by using a LI-COR 1600 steady-state porometer (LI-COR, Lincoln, NE). One of the two leaves present when cuttings were taken was used on days 1 and 8 of treatment because no other fully expanded leaves were available. The youngest fully expanded leaf was used on days 13, 20, 28, and 30. Chlorophyll content of disks from the youngest fully expanded leaf of plants from three of the four blocks used for transpiration was determined on day 32 (15, 16). Shoot length and shoot and root dry masses were determined on day 34 as described for experiment one. The length of the longest third-order root without lateral root development also was measured. ANOVA for a randomized complete block design was used to analyze data, and the least significant difference between means within cultivars was determined by using SAS.

Results and Discussion

The percentage of rooted cuttings that developed new shoots varied among genotypes and root-zone temperatures during experiment one. Shoot initiation ranged from 17% for USDA 55410 to 88% for 'Indian Summer', and 36C (97F) reduced shoot initiation across genotypes (Table 1). The temperature-by-genotype interaction was not significant ($P \leq 0.05$) for plant dry mass and stem length. Plant dry mass across all temperatures ranged from 0.3 g for USDA 55410 to 4.9 g for 'Franksred', and the total dry mass of plants with root zones at 36C (97F) was 84% less than the dry mass of plants at 28C (82F) over all genotypes (Table 1). Stem length increased over time for all plants with root zones ≤ 32C (90F), and stem length did not differ at any time at these temperatures (data not presented). Stems of all plants at 36C (97F) increased in length until day 21. There was no increase in stem length between days 21 and 44. On day 44, the mean stem length across genotypes at 36C (97F), 8 cm (3 in), was less than ($P \leq 0.05$) the mean of plants at the other three temperatures, 33 cm (13 in).

There was a temperature-by-cultivar interaction for stem length (Fig. 1A), dry mass (Fig. 1B), and the longest third-order root (Fig. 1C) of plants in the second experiment. Stem length and dry mass were higher with 28C (82F) than with 34C (93F) in the root zone for all cultivars except 'Autumn Flame' and 'Jeffersred'. The extent to which the higher root-

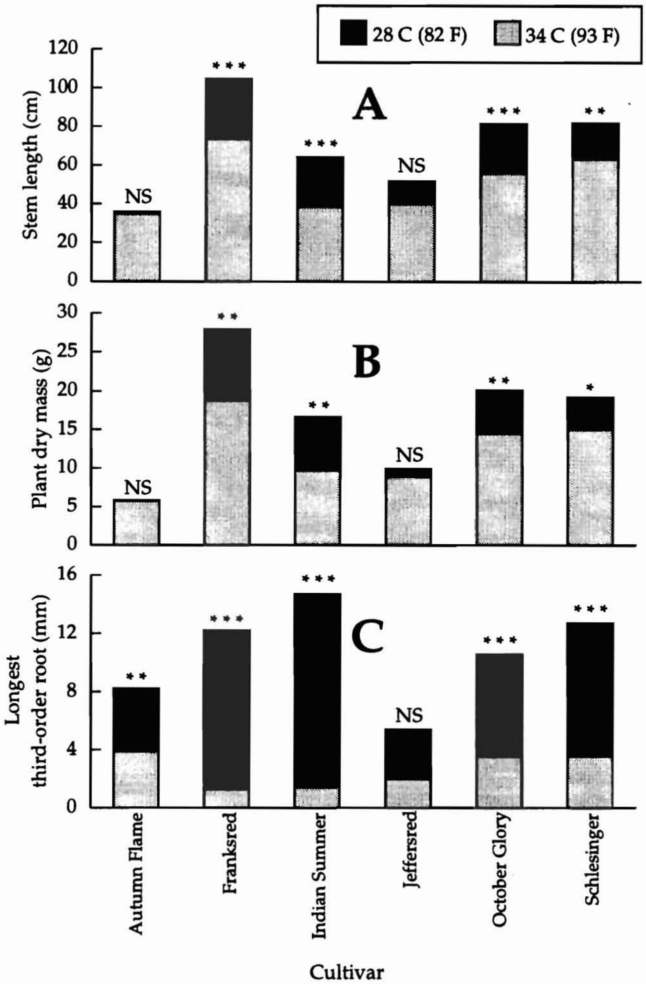

Fig. 1. **Mean stem length on day 33 of treatment (A), plant dry mass (B), and longest unbranched third-order root (C) of plants of six cultivars of red maple or Freeman maple. Values are means of 12 replicates. Means of plants with root zones at 28C (82F) are represented by the total length of each histogram. The lightly shaded areas represents the means of plants with 34C (93F) in the root zone. NS, *, **, and *** signify that differences between means at the two temperatures within cultivars and dependent variables are not significant, and significant at the 0.05, 0.01, and 0.001 probability levels, respectively.**

zone temperature decreased the length of the longest third-order root ranged from 50% for 'Autumn Flame' to 90% for 'Indian Summer' (Fig. 1C). Transpiration rates of plants at the two root-zone temperatures were not different on days 1, 8, and 13 (data not presented). Plants at 34C (93F) transpired at lower rates than those at 28C (82F) on days 20, 28, and 30. Differences in transpiration between temperature treatments increased over time (data not presented). The cultivar-by-temperature interaction was significant only on day 30, when the heat-induced reduction in transpiration ranged from 25% for 'Jeffersred' to 89% for 'Franksred' (Table 2). The higher root-zone temperature reduced the chlorophyll content of leaves of 'Indian Summer' and 'Jeffersred' but had no effect on other cultivars (Table 2).

Our results are consistent with another report of effects of 36C (97F) in the root zone on red maple and provide new information on cultivar differences in resistance to 34C (93F).

Table 2. **Effect of root-zone temperature on foliar transpiration rate and chlorophyll content of cultivars of red maple and Freeman maple. Values are means of four (transpiration) or three (chlorophyll) replications.**

Cultivar	Root-zone temperature (C/F)	Transpiration rate on day 30 ($mmol/m^2 \cdot s$)	Leaf chlorophyll content (mg/g)
Autumn Flame	28/82	11	0.92
		**[z]	NS
	34/93	6	1.14
Franksred	28/82	18	1.05
		**	NS
	34/93	2	0.71
Indian Summer	28/82	16	1.23
		**	*
	34/93	5	0.63
Jeffersred	28/82	12	1.32
		*	*
	34/93	9	0.53
October Glory	28/82	17	0.76
		**	NS
	34/93	4	1.09
Schlesinger	28/82	15	0.95
		**	NS
	34/93	8	0.97

[z]NS, *, and ** signify that differences between means at the two temperatures within cultivars and dependent variables are not significant, and significant at the 0.05, 0.01 probability levels, respectively.

The lack of temperature-by-genotype interactions during experiment one indicates genotypes responded similarly to root-zone temperatures of 24C (75F) to 36C (97F) (Table 1). The strong impact of 36C (97F) on growth is consistent with a previous study in which this treatment reduced plant dry mass of red maple from Florida to 40% of the growth at 24C (75F) (6). Growth was not reduced by 30C (86F) in that study, and effects of temperatures between 30C (86F) and 36C (97F) were not evaluated. Data on dry mass from experiment one indicate 32C (90F) in the root zone is not supraoptimal and that 36C (97F) is supraoptimal for diverse genotypes of red maple and Freeman maple. Thus, experiment one indicates that the minimum root-zone temperature at which growth of these maples is reduced significantly is above 32C (90F) and no higher than 36C (97F).

Cultivar differences in response to root-zone heat were illustrated during experiment two. Stem length (Fig. 1A) and dry mass (Fig. 1B) data suggest 'Autumn Flame' and 'Jeffersred' are more resistant than the other four cultivars we studied to 34C (93F) in the root zone. Apparent differences in heat resistance may be due to differences in physiological heat tolerance or to differences in the capacity to avoid stress. The relatively slow growth of 'Autumn Flame' and 'Jeffersred' regardless of temperature (Fig. 1A and B) may represent an avoidance mechanism. Treating the slower-growing cultivars for greater durations in future experiments might result in percentage growth reductions similar to those of the faster-growing cultivars in this experiment. Differences in the extent to which 34C (93F) reduced the length of the longest third-order root (Fig. 1B) represent additional evidence that heat resistance varies among cultivars. In addition to being shorter, third-order roots on plants at 34C (93F) appeared thicker than those on plants at 28C (82F), particularly for 'Franksred' and 'Indian Summer'. There also appeared to be fewer third-order roots at the higher temperature, but root thickness and number were not quantified.

Several factors might explain reduced growth at 34 and 36C (93 and 97F). Shoot water potential of red maple decreases with increasing temperature in the root-zone from 18 to 36C (64 to 97F) (6), and root water flux of woody plants can be reduced by 34C (93F) (7). Impaired water transport might have diminished transpiration of all cultivars during experiment two (Table 2). Internal water deficits or direct heat injury to root tissues, particularly root tips (2), might have altered hormone relations and promoted bud set and leaf epinasty. Terminal bud set on plants of all genotypes at 36C (97F) and on plants of 'Franksred', 'Indian Summer', and 'October Glory' at 34C (93F) accompanied the cessation of stem growth. Leaf epinasty was observed on plants of 'Franksred', 'Indian Summer', and 'October Glory' at 34C (93F). Impaired water transport also might have reduced nutrient uptake. Cultivars of apple (*Malus domestica* Borkh.) had lower concentrations of P, Mg, Ca, Mn, Fe, Zn, Cu, and B with root zones at 34C (93F) compared with plants at 20 to 25C (68 to 77F) (1), and maintaining root zones at 34C (93F) reduced the Fe content of leaves of three woody species (4). Nutrient content of plants in our experiments was not determined, but we observed chlorosis of young leaves of 'Indian Summer' and 'Jeffersred' during experiment two. The reduced chlorophyll at 34C (93F) of these cultivars (Table 2) suggests that plants were deficient in Fe or Mn.

The relationship between response to root-zone heat during experiment two and the geographic origin of the cultivars is unclear. 'Indian Summer' originated in Quebec, Canada (17), and 34C (93F) in the root zone reduced growth (Fig. 1) and decreased transpiration and foliar chlorophyll by 69% and 49%, respectively (Table 2). The origin of the other cultivars is not certain, but field experience has led to recommendations that 'Franksred' be used in U.S.D.A. hardiness zones 4 through 7 and that 'Autumn Flame' be used in zones 5 through 8 (21). These guidelines are consistent with our data that indicate 'Autumn Flame' is more heat resistant than 'Franksred'. 'Schlesinger' and 'October Glory', however, are recommended for areas no warmer than zones 7 and 8, respectively (21). Yet 'October Glory' showed more highly significant reductions in stem length and dry mass (Fig. 1) and had a higher percentage reduction in transpiration at high temperature than 'Schlesinger' (Table 2). Therefore, recommended areas for planting based on average annual minimum temperatures may not be reliable indicators of resistance to root-zone heat.

These experiments provide initial evidence that cultivars of red maple and Freeman maple differ in resistance to high root-zone temperature. Additional studies on genotypic differences in heat responses as well as macro- and micro-level data on the occurrence of supraoptimal root-zone temperatures are necessary before planting recommendations based on the heat resistance of cultivars can be made.

Literature Cited

1. Behboudian, M.H., W.R. Graves, C.S. Walsh, and R.F. Korcak. 1994. Water relations, mineral nutrition, growth, and ^{13}C discrimination in two apple cultivars under daily episodes of high root-medium temperature. Plant and Soil 162:125–133.

2. Carmi, A. and J. van Straden. 1983. Role of roots in regulating the growth rate and cytokinin content in leaves. Plant Physiol. 73:76–78.

3. Graves, W.R. 1994. Urban soil temperatures and their impact on tree growth. J. Arboriculture 20:24–27.

4. Graves, W.R. 1991. Growth and iron content of three legume tree species at high root-zone temperature. J. Arboriculture 17:313–317.

5. Graves, W.R. and M.N. Dana. 1987. Root-zone temperature monitored at urban sites. HortScience 22:613–614.

6. Graves, W.R., M.N. Dana, and R.J. Joly. 1989. Root-zone temperature affects growth and water status of red maple. J. Amer. Soc. Hort. Sci. 114:406–410.

7. Graves, W.R., M.N. Dana, and R.J. Joly. 1991. Water use and growth of honey locust and tree-of-heaven and high root-zone temperature. HortScience 26:1309–1312.

8. Gur, A., B. Bravdo, and Y. Mizrahi. 1972. Physiological responses to supraoptimal root temperatures. Physiol. Plant. 27:130–138.

9. Gur, A., Y. Mizrahi, and R.M. Samish. 1976. The influence of root temperature on apple trees. II. Clonal differences in susceptibility of damage caused by supraoptimal root temperature. J. Hort. Sci. 51:195–202.

10. Halverson, H.G. and G.M. Heisler. 1981. Soil temperatures under urban trees and asphalt. U.S.D.A. Forest Service Research Paper NE–481.

11. Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Calif. Agr. Expt. Sta. Circ. 347.

12. Ingram, D.L. 1981. Characterization of temperature fluctuations and woody plant growth in white poly bags and conventional black containers. HortScience 16:762–763.

13. Johnson, R. and G. Bhattacharyya. 1985. Statistics principles and methods. John Wiley & Sons, New York, NY.

14. Kielbaso, J.J. 1990. Trends and issues in city forests. J. Arboriculture 16:69–76.

15. Moran, R. 1982. Formulae for determination of chlorophyllous pigments extracted with N,N-dimethylformamide. Plant Physiol. 69:1376–1381.

16. Moran, R. and D. Porath. 1980. Chlorophyll determination in intact tissues using N,N-dimethylformamide. Plant Physiol. 65:478–479.

17. Santamour, F.S., Jr. and A.J. McArdle. 1982. Checklist of cultivated maples. J. Arboriculture 8:110–112.

18. Townsend, A.M. 1977. Characteristics of red maple progenies from different geographic areas. J. Amer. Soc. Hort. Sci. 102:461–466.

19. Townsend, A.M., J.W. Wright, W.F. Beineke, R.P. Guries, and C.A. Mohn. 1982. Early patterns of flowering, winter injury, and flushing of red maple progenies grown in five locations. Can. J. For. Res. 12:814–821.

20. Walters, R.S. and H.W. Yawney. 1990. *Acer rubrum* L. Silvics of North America. Vol. 2. Hardwoods. Agricult. Handbook 654:60–69.

21. Wandell, W.N. 1989. Handbook of landscape tree cultivars. East Prairie Publishing, Gladstone, IL.