Comparison of the Cold Hardiness of Landscape Tree and Shrub Cultivars Growing at Two Disparate Geographic Locations[1]

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Abstract

The stem cold hardiness of 5 tree and 5 shrub cultivars was evaluated monthly from September 1998 through April 1999 on plants growing both at Griffin, GA (33° 15' N), and Chanhassen, MN (44° 50' N), to determine whether cultivar hardiness varied with latitudinal differences in photoperiod and temperature conditions. On September 22, hardiness levels of five of the ten cultivars growing in Georgia were greater than or equal to those of their counterparts growing in Minnesota. After this date, however, all cultivars acclimated much more slowly in Georgia than in Minnesota, with the site-related hardiness differential on November 11 ranging from 13C (23F) for 'Cully' river birch to 25C (45F) for 'Sunrise' forsythia. The forsythia cultivars 'Lynwood Gold' and 'Spring Glory' were seriously injured in the Minnesota planting in early January when outdoor minimum temperatures were between –28 and –31C (–18 and –24F) for several days. All other taxa attained their maximum detected cold hardiness levels by January 13 in Minnesota, while some in Georgia continued to harden through February 10. With the exception of 'Tristis' weeping willow, all of the cultivars attained greater midwinter hardiness levels in Minnesota than in Georgia. All cultivars deacclimated much more rapidly in Georgia than in Minnesota. These results indicate that rates of cold acclimation and deacclimation and maximum midwinter hardiness levels of temperate zone woody plant taxa are strongly influenced by local photoperiod and temperature conditions. To accurately evaluate the geographic range of adaptability of woody plant taxa, cold hardiness evaluations need to be conducted regionally on locally grown plants.

Index words: freezing injury, cold acclimation, photoperiod, landscape plants.

Species used in this study: 'Silver Queen' maple (*Acer saccharinum* L. 'Silver Queen'); Heritage™ river birch (*Betula nigra* L. 'Cully'); 'Lynwood Gold' and 'Spring Glory' border forsythia (*Forsythia* x *intermedia* Zab. 'Lynwood Gold' and 'Spring Glory'); 'Meadowlark' forsythia (*Forsythia* 'Meadowlark'; a hybrid of *F. ovata* x *F. europaea*); 'Sunrise' forsythia (*Forsythia* 'Sunrise'; a hybrid of *F. ovata* x an unidentified *F.* selection); 'Autumn Purple' white ash (*Fraxinus americana* L. 'Autumn Purple'); 'Honey Rose' honeysuckle (*Lonicera* sp. 'Honey Rose'); 'Donald Wyman' crabapple (*Malus* Mill. 'Donald Wyman'); Niobe weeping willow (*Salix alba* L. 'Tristis').

Significance to the Nursery Industry

Laboratory freezing tests provide useful information on the relative cold hardiness of woody landscape plant taxa. However, the results of this study indicate that the environmental conditions to which plants are exposed prior to testing can greatly affect their hardiness level, and consequently, estimates of cultivar hardiness may vary with the geographic location at which test plants are grown. In order to provide nursery and landscape professionals with complete information on the cold tolerance capabilities of woody plant cultivars, hardiness evaluations need to be conducted on plants grown under photoperiod and temperature conditions similar to those of the geographic region(s) where the plants will be established in the landscape.

Introduction

Cold hardiness is a major factor governing the distribution of woody plant species throughout the world (5). Previous studies have demonstrated that provenance greatly affects the responsiveness of some tree and shrub species to photoperiod and temperature cues that induce cold acclimation (1, 3, 4, 7, 12). However, there is little information available on whether the cold hardiness of individual clones varies with the differing environmental conditions of disparate geographic regions. This is a matter of practical significance for horticulturists evaluating the useful geographic range of woody plant cultivars. Quantification of cultivar hardiness is often based upon laboratory freezing tests conducted on plants growing at a single location. If cultivar hardiness varies substantially with latitudinal differences in photoperiod and/or temperature conditions, characterizations of cultivar hardiness developed from plants growing at one site may not accurately describe how plants will perform in other geographic regions. Lindstrom et al. (8) found no consistent relationship between stem hardiness and growing site for clones of red maple (*Acer rubrum* L), white ash (*Fraxinus americana* Marsh.), and Japanese zelkova (*Zelkova serrata* (Thunb.)) growing in Oregon, Georgia, and Maine. However, stems used for hardiness determinations had to be shipped overnight to Georgia for testing, and some deacclimation of the northern-grown plants could have occurred in transit (14). The study did not examine the effect of growing site on timing of acclimation, a critical component of cold hardiness (9).

The objective of this study was to compare the cold hardiness of clonal selections of several tree and shrub species growing at sites in both Minnesota and Georgia to determine whether cold hardiness of the clones varied in response to the differing environmental conditions of these two locations.

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Materials and Methods

Bareroot plants of 5 tree and 5 shrub cultivars were purchased from a single nursery in the spring of 1997 and divided equally for planting at both the University of Minnesota Landscape Arboretum in Chanhassen, MN (44° 50' N latitude; USDA hardiness zone 4a (16)), and the University of Georgia campus at Griffin, GA (33° 15' N; hardiness zone 7b). The cultivars used in this study were 'Silver Queen' silver maple, 'Cully' river birch, 'Lynwood Gold', 'Meadowlark', 'Spring Glory', and 'Sunrise' forsythia, 'Autumn Purple' white ash, 'Honey Rose' honeysuckle, 'Donald Wyman' crabapple, and 'Tristis' weeping willow. Five to 10 plants of each cultivar were planted in prepared nursery beds at both sites in May 1997 and provided with supplemental irrigation throughout the growing season to promote establishment.

Laboratory determinations of hardiness were performed on the following dates in 1998–99: September 22, October 14, November 11, December 9, January 13, February 10, March 3, and April 14. Freezing tests were conducted independently at both sites using controlled temperature freezers. On each sampling date, current year stem tissue was collected, prepared, and frozen as described previously (8, 11). Freezer temperatures were decreased at a rate of < 4C (7F)/hr and six 4-cm (1.57 in) long internode samples of each cultivar were removed from the freezer at 3C (5F) intervals. Six additional cuttings of each cultivar were held overnight under refrigeration at 2C (4F) and served as a control treatment. The range of temperatures used was varied by season to bracket the estimated lethal temperature. Following freezing, samples were thawed at 2C (36F) for 24 hr and then incubated in a water-saturated atmosphere at ambient room temperature [22 ± 2C (72 ± 4F)] for 7 days. Stem sections were cut longitudinally and visually evaluated for injury (oxidative browning of the vascular or cambial tissues) with the aid of a dissecting microscope (8, 11). Variability in injury between samples was observed in some cultivars as treatment temperatures reached lethal levels. The lowest survival temperature (LST) of each cultivar was calculated as the mean of the lowest temperatures at which individual stem samples exhibited no injury (8, 9).

Table 1. Lowest survival temperatures (C) of shoots of 10 tree and shrub cultivars growing both at Griffin, GA, and Chanhassen, MN, in 1998–99.

	Sampling date (1998–99)							
Taxon	**September 22**	**October 14**	**November 11**	**December 9**	**January 13**	**February 10**	**March 3**	**April 14**
Acer saccharinum 'Silver Queen'								
Georgia	–5	–8	–14	–19	–32	–28	–21	–2
Minnesota	–2	–20	–33	–40	–45	–39	–39	–18
Betula nigra 'Cully'								
Georgia	–6	–11	–24	–26	–32	–30	–27	–2
Minnesota	–2	–12	–37	–38	–43	–39	–39	–12
Forsythia 'Lynwood Gold'								
Georgia	–7	–9	–12	–16	–12	–23	–9	–6
Minnesota	–7	–18	–29	–27	F[z]	F	F	F
Forsythia 'Meadowlark'								
Georgia	–7	–12	–14	–15	–20	–27	–12	–2
Minnesota	–9	–18	–32	–32	–36	–36	–33	–16
Forsythia 'Spring Glory'								
Georgia	–6	–9	–12	–14	–20	–23	–12	–7
Minnesota	–9	–18	–29	–27	F	F	F	F
Forsythia 'Sunrise'								
Georgia	–7	–6	–8	–16	–14	–21	–6	NM[y]
Minnesota	–9	–18	–33	–34	–36	–35	–35	–20
Fraxinus americana 'Autumn Purple'								
Georgia	–12	–12	–15	–24	–35	–30	–23	–9
Minnesota	–7	–14	–34	–35	–39	–39	–35	–15
Lonicera 'Honey Rose'								
Georgia	–9	–11	–15	–24	–27	–28	–5	0
Minnesota	–11	–21	–35	–39	–39	–38	–34	–20
Malus 'Donald Wyman'								
Georgia	–10	–12	–12	–26	–28	–28	–21	0
Minnesota	–9	–13	–29	–30	–35	–30	–31	–11
Salix alba 'Tristis'								
Georgia	–3	–9	15	–23	–45	–36	–24	–3
Minnesota	–4	–12	–34	–38	–45	–41	–37	–12

[z]Plants were injured in the field prior to sampling.

[y]No material was available for testing on this date.

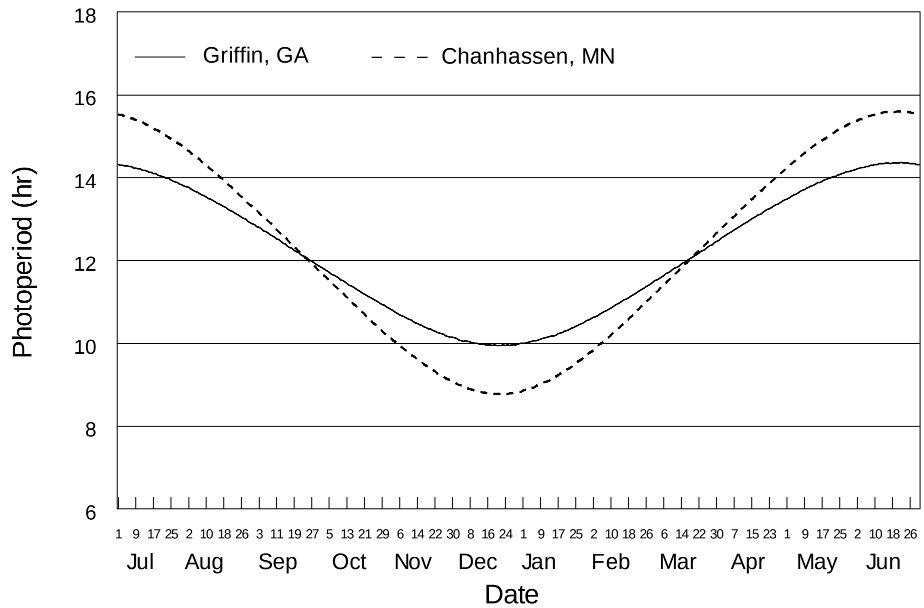

Fig. 1. **Daily photoperiods at Griffin, GA (33° 15' N), and Chanhassen, MN (44° 50' N). Data provided by the United States Naval Observatory, Washington, DC.**

Dates of vegetative bud break and flower opening were recorded so that the effect of location on timing of the onset of active growth could be evaluated along with stem hardiness levels.

Results and Discussion

All of the cultivars exhibited some degree of cold acclimation at both sites on September 22. 'Silver Queen' maple, 'Cully' river birch, 'Autumn Purple' ash and 'Donald Wyman' crabapple were more hardy in Georgia than in Minnesota (Table 1) on this date, possibly due to latitudinal differences in photoperiod. The first stage of cold acclimation in temperate zone woody plant species is triggered by decreasing photoperiods in the fall (20). Although photoperiods at the two sites were approximately equal (12 hr 10 m) on September 22, plants in Georgia experienced shorter photoperiods than those in Minnesota prior to this date due to the narrower amplitude of photoperiod at the lower latitude (Fig. 1). Thus, the greater hardiness of some cultivars in Georgia compared with Minnesota on this date may have resulted from earlier exposure to acclimation-inducing photoperiods.

By October 14, all cultivars were hardier in Minnesota than in Georgia, but the magnitude of the site-related difference varied between cultivars. Hardiness values of 'Silver Queen' maple, 'Honey Rose' honeysuckle and the 4 forsythia cultivars differed most between the 2 sites. LSTs of these 6 cultivars in Minnesota ranged from –18 to –21C (0 and –6F), which is in line with the lower limits of hardiness attained by other species during the photoperiodically-activated first stage of cold acclimation (19, 20). Between September 22 and October 14, minimum temperatures in Minnesota were consistently lower than in Georgia (Fig. 2), and on several occasions were in the 0 to 5C (32 to 41F) range that is reportedly effective at inducing the second stage of cold acclimation in other woody species (3, 18, 20). Thus, the accelerated acclimation of the 6 cultivars in Minnesota relative to Georgia may have been promoted by cooler temperatures in addition to more rapidly decreasing photoperiods. It is unclear why acclimation rates of the 4 other cultivars did not differ as markedly between the two sites. This may simply reflect differing sensitivities of the represented species to variation in the environmental stimuli that promote cold acclimation. Support for this hypothesis comes from the fact that the 4 cultivars of *Forsythia*, the only genus represented by more than one cultivar, all differed substantially in hardiness between the 2 sites on this date.

All cultivars hardened much more rapidly in Minnesota than in Georgia between October 14 and November 11; average acclimation rates for all cultivars at the two sites were 0.58 and 0.15C (1.0 and 0.3F)/day, respectively. Response to local climatic conditions, again, likely accounted for this disparity. Air temperatures during this period were substantially warmer in Georgia than in Minnesota where several hard frosts occurred the week before sampling [–7 and –5C (19 and 23F) on November 5 and 7, respectively]. Occurrence of the first frost has been associated with rapid acclimation of other woody species (19, 20). By contrast, average daily maximum and minimum temperatures in Georgia for the two days prior to sampling were 24 and 13C (75 and 55F), respectively. Cold acclimation of the plants in Georgia at this time appears to have been restricted to the photoperiodically-activated first stage of acclimation (19, 20).

Both of the *Forsythia* x *intermedia* cultivars, 'Lynwood Gold' and 'Spring Glory', experienced lethal cold injury in Minnesota between the December 9 and January 13 sampling dates, likely in response to a minimum temperature of –29C (–20F) on January 9. (The Dec. 9 freezing test estimated the hardiness level of these 2 cultivars at –27C (–17F).) Neither cultivar experienced any cold injury in Georgia where the minimum temperature for the winter was –13C (9F). Neither 'Mealowlark' nor 'Sunrise', which are reportedly more hardy than *F.* x *intermedia* cultivars (2, 10), experienced any cold injury at either site.

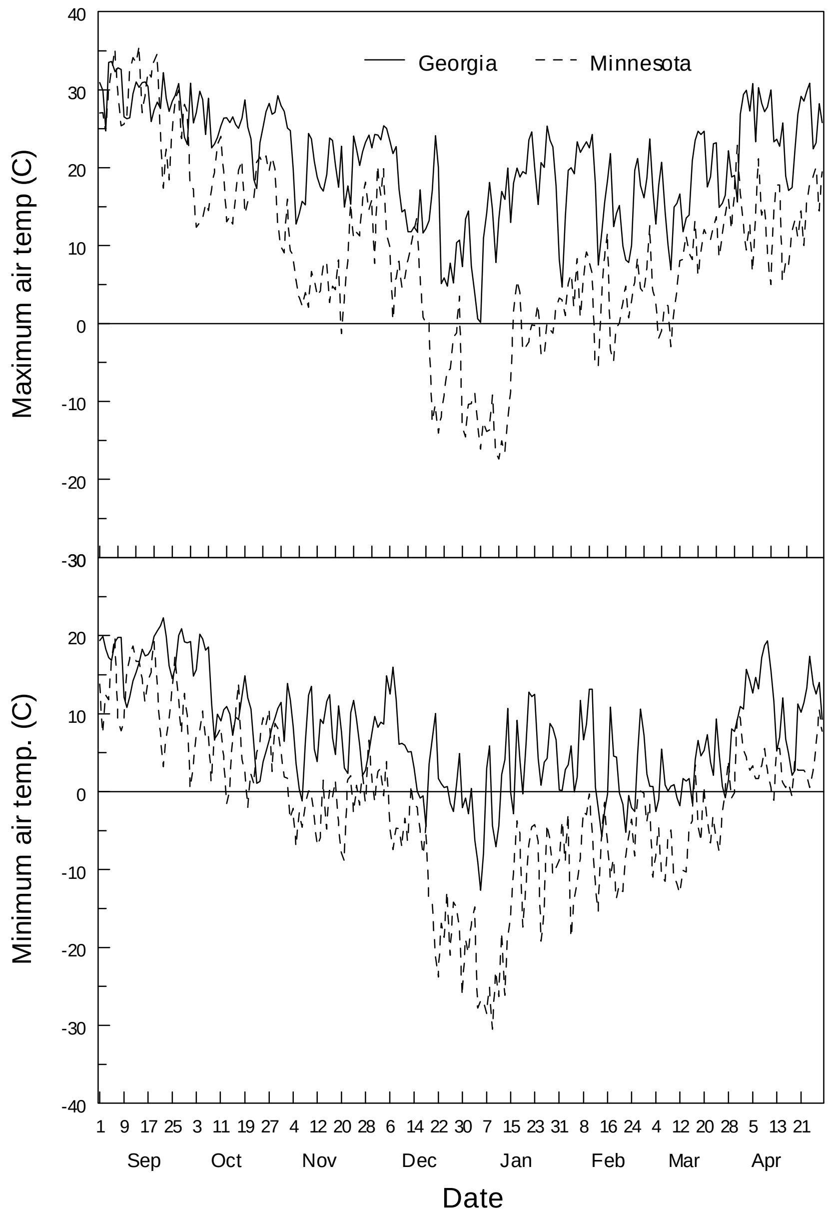

Fig. 2. Daily maximum and minimum air temperatures at Griffin, GA, and Chanhassen, MN, from September 1998 through April 1999.

All of the cultivars attained their maximum detected hardiness levels by January 13 in Minnesota, whereas the 4 forsythia cultivars and 'Honey Rose' honeysuckle continued hardening through February 10 in Georgia. The maximum hardiness levels of all cultivars except 'Tristis' weeping willow were 4 to 15C (7 to 27F) greater in Minnesota than in Georgia (Table 1). One explanation for this is that hardening of the plants in Georgia was attenuated by the frequent occurrence of diurnal freeze-thaw cycles during late-December and early-January (Fig. 2). Differences in daily minimum air temperatures between the two sites also may have affected the maximum hardiness levels attained (daily midwinter minimum temperatures in Minnesota, although warm by historical standards, were substantially colder than in Georgia). However, the effect of subfreezing temperature variations on cold acclimation of woody plants was not evaluated as part of this study and has not, to our knowledge, been reported elsewhere. Regardless of the factor(s) underlying the differences in cultivar hardiness between the two sites, the results of this midwinter test indicate that woody plant taxa may not attain their maximum potential level of cold tolerance under the relatively moderate winter conditions of the southern United States. However, with the exception of the 2 forsythias, the cultivars all hardened sufficiently at both sites to withstand local midwinter minimum temperatures.

'Tristis' weeping willow was the only cultivar to attain the same maximum midwinter hardiness level in Georgia as in Minnesota. Like the other cultivars, it acclimated more slowly in Georgia than in Minnesota through early December. However, 'Tristis' hardened much more extensively than the other cultivars in Georgia between December 9 and January 13, coincident with the occurrence of subfreezing temperatures beginning in mid-December. The basis for 'Tristis" unique response is not known. 'Tristis' may possess a different minimum temperature threshold for optimal hardening than the other cultivars. It may also deacclimate less than the other cultivars when exposed to multiple freeze-thaw cycles in midwinter. Exploring the underlying explanation for this phenomenon was beyond the scope of this study, but our results suggest that 'Tristis' may be useful for studying temperature-regulated cold acclimation processes in woody species.

Site-related differences in timing of deacclimation were cultivar-specific. Although the timing of initiation of deacclimation of some cultivars did not differ between the sites, all of the cultivars remained substantially more hardy in Minnesota than in Georgia during March and April (Table 1). The most rapid deacclimation at both sites occurred between March 3 and April 14. The phenology of all of the cultivars differed markedly between the sites during the late-winter to early-spring period, with plants breaking bud at least 1 month earlier in Georgia than in Minnesota (data not shown). Air temperature reportedly is the primary environmental factor regulating deacclimation rates and initiation of active growth by temperate zone woody plants once internal dormancy has been overcome by chilling (6, 15), and temperature conditions likely accounted for the site-related differences in deacclimation of cultivars in this study. The average daily maximum temperature in Georgia between February 10 and April 14 was 19.1C (66F), compared with 7.9 (46F) in Minnesota. Colder average nighttime temperatures (–3.6C in Minnesota vs 4.9C in Georgia) also may have contributed to maintenance of greater cold hardiness by plants in Minnesota. Studies on several woody species suggest that exposure to chilling or freezing temperatures during the diurnal cycle may restrict plant deacclimation, even when daytime temperatures are sufficiently warm to thaw tissues (6, 11, 17).

The results of this study indicate that timing and rates of acclimation and deacclimation and maximum midwinter hardiness levels of individual woody plant cultivars can differ markedly between geographic locations. Regional hardiness trials are, therefore, essential for accurately assessing the adaptability of woody cultivars to the winter conditions of disparate geographic regions. Evaluating plants at multiple sites also contributes to a more complete characterization of cultivar hardiness. Trials conducted in southern regions where broad winter temperature fluctuations are common (13) can provide useful information on a cultivar's propensity to deacclimate in response to large, midwinter temperature oscillations. Northern trials may be critical for determining a cultivar's maximum cold tolerance capability and predicting the northern limits of its useful range. Additional work is warranted to examine in greater detail the individual and interactive effects of photoperiod and air temperature on cold hardiness of woody plant taxa.

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