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Cold Storage Method Affects Root and Shoot Water Potential of Bare-root Hawthorn and Maple Trees[1]

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Abstract

Desiccation of bare-root tree seedlings during storage can result in reduced growth and poor quality after transplanting. For 12 weeks, shoot and root water potentials of bare-root Norway maple (*Acer platanoides* L.) and Washington hawthorn (*Crataegus phaenopyrum* Medic.) seedlings were measured in response to four cold storage treatments: whole plant exposed, roots exposed, shoots exposed, whole plant covered. In another experiment, water loss was measured from stem sections of both species during four weeks of cold storage. Shoot and root water potentials decreased during storage regardless of treatment or species. For maple, shoot and root water potentials of the exposed shoot treatment were the same as the whole plant covered treatment. In contrast, hawthorn shoot and root water potentials of the exposed shoot treatment were lower (more negative) than for the whole plant covered treatment. Most of the water stress experienced by roots and shoots of both species accumulated during the first six weeks of storage. Water loss was greater for hawthorn stem sections than for maple during the first two weeks of storage. Results indicated that while protection of roots of all bare-root stock reduces water loss, sensitive species such as Washington hawthorn require both root and shoot protection to minimize water loss.

Index words: desiccation, water stress.

Species used in this study: Norway maple (*Acer platanoides* L.); Washington hawthorn (*Crataegus phaenopyrum* Med.).

Significance to the Nursery Industry

Cold storage of bare-root nursery stock after fall lifting is a common nursery tree production practice that allows for greater flexibility in spring shipping and availability of planting stock. A reduction in the quality of cold-stored nursery stock results when seedlings are subjected to desiccation during storage, shipping, or post-transplant re-establishment. This study analyzed the impact of cold storage treatments on the desiccation of bare root Norway maple (desiccation tolerant) and Washington hawthorn (desiccation sensitive). This research demonstrated that hawthorn stems are more susceptible to water loss during cold storage than Norway maple stems. Roots of both species were susceptible to desiccation during cold storage. While growers should take precautions to protect the roots of all bare-root stock from desiccating conditions, desiccation sensitive species such as hawthorn require both root and shoot protection to minimize water loss.

Introduction

Bare-root tree seedlings are commonly harvested during autumn and early winter, placed in cold storage, and shipped in the spring. Storage conditions and packaging methods in storage can affect desiccation stress and the subsequent physiological quality of bare-root trees (11). The desiccation tolerance of bare-root nursery stock differs dramatically among species (3, 10). Englert et al. (2) found differences in the dieback and survival of *Quercus rubra* L. and *Crataegus phaenopyrum* Medic. when entire seedlings were subjected to a 48-hr drying period; however, overall water loss rates for these species were similar. Insley (4) attributed the drying rate and survival variation between *Nothofagus obliqua* Mirb. and *Acer platanoides* L. to species root morphology differences. Most growers only protect the roots during storage (1, 6, 8) even though stem water loss is high for some species (4). The desiccation sensitive nature of *Crataegus phaenopyrum* (Washington hawthorn) and desiccation resistant nature of *Acer platanoides* (Norway maple) have been well documented (2, 7). There are, however, no reports on the relative contribution of shoots and roots to water stress development in storage for desiccation tolerant and resistant species. The objective of this study was to determine the relative impact of either shoot or root exposure during bare-root storage on water stress development in a sensitive and resistant species.

Materials and Methods

On January 14, 1993, 2-year-old *Acer platanoides* and *Crataegus phaenopyrum* bare-root seedlings (approx. 24–36 in; 61–91 cm) were received in Blacksburg, VA, from Lawyer Nurseries, Plains, MT. Seedling bundles were wrapped in plastic sheeting inside cardboard boxes with the roots of each bundle packed in moistened, shredded newsprint. Transit time was five days. Trees were sorted for uniformity and 144 of each species were placed on wooden racks in a walk-in cooler maintained at 70% ± 5% relative humidity and 2°C (35°F). When seedlings were placed into cold storage one of the following four treatments were randomly allocated to each tree: 1) whole plant covered in which the entire seedling was enclosed in a sealed 3-layer storage bag (Union Camp Corp., Tifton, GA), 2) shoot exposed with seedling roots enclosed in a storage bag sealed around the stem just above the root collar, 3) roots exposed with shoots enclosed in a storage bag sealed just below the root collar and 4) entire seedling exposed (no storage bag). Storage bags were compressed during plant insertion to minimize air space within the bag; all trees were placed horizontally on racks.

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On January 28, February 11, February 28, March 11, March 28 and April 11 (2, 4, 6, 8, 10, and 12 weeks in storage, resp.) six hawthorn and six maple trees from each treatment were removed from cold storage. Shoot water potential (Stwp) and root water potential (Rtwp) were measured on three seedlings from each species-treatment combination. The remaining three seedlings from each combination were placed on a lab bench and allowed to air-dry at 24°C (75°F) and 35% ± 5% relative humidity for 12 hr after which Stwp and Rtwp were measured. Stem xylem and root water potential were measured using a portable pressure chamber (Model 3005, SoilMoisture Equipment Corp., Santa Barbara, CA) on stem sections (10.2 cm [4 in] length; 5 mm [0.2 in] diameter) and root sections (7.6 cm [3 in] length; 5 mm [0.2 in] diameter) excised from each tree.

Data for all measured variables were subjected to analysis of variance procedures. A factorial set of treatments: 2 species, 4 cold storage treatments, 6 storage durations was replicated three times using a completely randomized design. Desiccation time (0 hr vs. 12 hr) data were analyzed separately. Mean separation of treatment effects was performed by Duncan's multiple range test (P = 0.05). Slope of the least squares was determined for storage treatments over time for each species.

A second group of two-year-old hawthorn and maple seedlings were used to determine stem water loss rates. Twelve randomly selected seedlings of each species were removed from cold storage after one, two, three, and four weeks, and 13 cm (5 in) stem segments containing four buds were removed from each plant. Internodal stem diameter was measured at three points with a microcaliper to establish average stem diameter; we assumed the stems were approximately cylindrical. The average diameter and stem length (measured to the nearest 0.1 cm) were converted to approximate surface area. Cut stem surfaces were sealed with melted paraffin wax. Stem segments were then placed in cold storage maintained at 2°C (35°F) and 80% ± 5% RH. Water loss was determined gravimetrically over a 4-week period and expressed on a stem surface area basis (mg H_2O/cm^2). This experiment was repeated using the same experimental procedure except that buds were removed from hawthorn and maple stem segments and incisions sealed with parafin.

Table 1. Analysis of variance of the effect of cold storage duration, storage wrap method and desiccation treatment on shoot and root water potential of Norway maple and Washington hawthorn.

		Desiccation time[z]			
		0 hr		12 hr	
Source	d.f.	Shoot Ψ[y]	Root Ψ	Shoot Ψ	Root Ψ
Species (Spec)	1	**	**	**	**
Storage Duration (SD)	5	**	**	**	**
Storage Trt (Trt)	3	**	**	**	**
Spec × SD	5	*	**	**	**
Spec × Trt	3	**	**	NS	*
SD × Trt	15	**	**	NS	NS
Spec × SD × Trt	15	*	**	NS	NS

[z]Trees were air dried at 24°C (75°F) and 35% relative humidity.

[y]NS, *, ** nonsignificant, or significant at P ≤ 0.05, or 0.01 level, respectively.

Results and Discussion

Root Water Potential. Species, storage duration, and storage treatment affected Rtwp and Stwp (Table 1). Root water potential of hawthorn seedlings before placement into storage was –0.8 MPa which indicated that trees were not stressed during lifting and shipping (Table 2). Generally, hawthorn Rtwp decreased with increased time in storage for all treatments with most of the decrease occurring in the first six weeks in storage (Table 2). At the end of 12 weeks, the rate of decrease in water potential values for the whole plant exposed, and roots and shoots exposed treatments (slopes = –0.26, –0.26, –0.24, respectively) were greater than the whole plant covered treatment (slope = –0.12). Relative to the root exposed treatments, the shoot exposed (roots covered) treatment was effective in maintaining a higher water potential for the first eight weeks. But by week 10, water potentials for the shoot exposed and root exposed treatments were similar.

As with Washington hawthorn, Norway maple Rtwp decreased with storage time (Table 3). Root water potential values for storage treatments were clearly segregated into two groups: 1) treatments providing root covering (whole

Table 2. Influence of cold storage duration and storage treatment on root water potential of Washington hawthorn.

	Root Ψ (-MPa)						
		Storage duration (weeks)					
Storage treatment	Initial Ψ[z]	2	4	6	8	10	12
Whole plant exposed	0.8 a[y]	1.9 ab	2.6 b	3.6 a	3.6 ab	4.0 a	4.0 a
Roots exposed	0.8 a	2.4 a	3.2 a	3.8 a	4.0 a	4.0 a	4.0 a
Shoots exposed	0.8 a	1.2 c	1.8 c	2.8 b	3.2 b	3.5 a	3.6 a
Whole plant covered	0.8 a	1.4 bc	2.0 c	2.2 c	2.1 c	2.0 b	2.6 b

[z]Mean pre-storage Ψ, n = 5.

[y]Means in columns followed by the same letter are not significantly different as determined by Duncan's multiple range test, P = 0.05.

Table 3. Influence of cold storage duration and storage treatment on root water potential of Norway maple.

	Root Ψ (-MPa)						
		Storage duration (weeks)					
Storage treatment	Initial Ψ[z]	2	4	6	8	10	12
Whole plant exposed	0.7 a[y]	2.2 a	2.4 b	2.8 a	3.6 a	3.8 a	3.8 a
Roots exposed	0.7 a	1.9 a	3.1 a	3.3 a	3.4 a	3.4 a	3.5 a
Shoots exposed	0.7 a	1.0 b	1.3 c	1.2 b	1.4 b	1.8 b	1.5 b
Whole plant covered	0.7 a	0.8 b	1.0 c	1.0 b	1.3 b	1.6 b	1.7 b

[z]Mean pre-storage Ψ, n = 5.

[y]Means in columns followed by the same letter are not significantly different as determined by Duncan's multiple range test, P = 0.05.

plant covered, shoots exposed), and 2) treatments with roots exposed (whole plant exposed, roots exposed) (Table 3). Water potentials for trees completely covered and with shoots exposed were the same for each storage duration, and with the exception of week four, roots exposed and whole plant exposed treatments were the same. At each storage duration, Rtwp for shoots exposed and whole plant covered treatments were less than values for roots exposed and whole plant exposed treatments.

Root water potential, for both species and all storage treatments that were exposed to a 12 hr drying period at each storage duration, decreased over time (P = 0.01, data not shown). For each species, Rtwp decreased during the 12 hr desiccation period for all storage durations. At each sample date, maple Rtwp values were –0.4 to –0.7 MPa higher (P = 0.01) than hawthorn, however the difference between the 0 and 12 hr desiccation treatment (both species) decreased as the duration of storage increased. For example, after two weeks in storage Rtwp of hawthorn without a post-storage desiccation treatment averaged –1.7 MPa compared to –2.9 MPa for trees exposed to a 12 hr desiccation treatment; after 12 weeks of storage, values averaged –3.5 MPa and –3.9 MPa, respectively.

Shoot Water Potential. Hawthorn Stwp decreased with increased storage duration for each storage treatment (Table 4). Water potentials of completely covered trees were the same as trees of other storage treatments for the first four weeks in storage. However, Stwp of completely covered trees remained relatively constant after four weeks in storage and were higher than potentials for the other treatments which decreased throughout the study. Relative to the pre-storage –1.1 MPa value, Stwp at week twelve increased 109% for the whole plant covered treatment whereas the increase for other treatments was ≥ 209% (Table 4). Shoot water potentials for the shoots exposed treatment were the same as for the roots exposed and whole plant exposed treatments throughout the study.

Maple Stwp for all storage treatments decreased with increasing storage duration (Table 5). Similar to root water potentials, maple Stwp were segregated according to storage method. With the exception of week four, potentials for the shoots exposed and whole plant covered treatments were higher than the roots exposed and whole plant exposed treatments. Water potential values for trees in the shoots exposed treatment were the same as the whole plant covered treatment for all storage durations.

Trends in Stwp over time and for species of stored trees receiving a 12 hr desiccation treatment were similar to trends for Rtwp data (data not shown). For each species, the decrease in Stwp during the 12 hr desiccation period was at least 1.3 MPa for all storage durations. Maple Stwp values were higher (P = 0.05) than hawthorn at each storage duration.

Stem Water Loss. Water loss from hawthorn and maple stem segments was highest during the first week of storage and decreased thereafter (Table 6.). Hawthorn water loss was higher than maple during the first two weeks of storage; however, values for weeks 3 and 4 were the same for both species. Similar results were obtained when the experiment was repeated using internodal stem segments containing no buds (data not shown).

Relative to storage treatment and duration for both species, trends in Rtwp were very similar to trends in Stwp. High positive correlations between root and shoot water potentials have been demonstrated in other species (9). Generally, water stress increased with storage duration regardless of species or storage method. Storage duration and the various storage treatments affected water stress in the bare-root trees and provides a possible explanation for the two-way and three-way interactions (Table 1). Maple seedlings that were completely covered or with their shoots exposed showed the lowest decrease in root or shoot water potential throughout the study (Tables 3 and 5). Root and shoot water potentials for shoots exposed and whole plant covered treatments were the same which indicated that water loss from maple stems was minimal and possibly related to stem morphology. In contrast, hawthorn Rtwp and Stwp of the shoots exposed treatment were usually much lower than trees completely covered (Tables 2 and 4). In maple, Rtwp of trees with shoots exposed decreased 114% throughout storage while in hawthorn there was a 350% decrease for the same treatment. This finding indicated that Washington hawthorn

Table 4. Influence of cold storage duration and storage treatment on shoot water potential of Washington hawthorn.

	Shoot Ψ (-MPa)						
		Storage duration (weeks)					
Storage treatment	Initial Ψ[z]	2	4	6	8	10	12
Whole plant exposed	1.1 a[y]	1.6 a	2.3 a	3.0 a	3.1 a	3.1 a	4.0 a
Roots exposed	1.1 a	1.5 a	1.9 a	2.9 a	2.8 a	3.0 a	4.0 a
Shoots exposed	1.1 a	1.3 a	2.1 a	2.4 a	2.7 a	2.8 a	3.4 a
Whole plant covered	1.1 a	1.5 a	2.2 a	2.0 b	1.8 b	2.0 b	2.3 b

[z]Mean pre-storage Ψ, n = 5.

[y]Means in columns followed by the same letter are not significantly different as determined by Duncan's multiple range test, P = 0.05.

Table 5. Influence of cold storage duration and storage treatment on shoot water potential of Norway maple.

	Shoot Ψ (-MPa)						
		Storage duration (weeks)					
Storage treatment	Initial Ψ[z]	2	4	6	8	10	12
Whole plant exposed	0.9 a[y]	1.5 a	2.0 a	3.1 a	3.1 a	2.8 a	3.1 a
Roots exposed	0.9 a	1.4 a	2.1 a	2.3 b	2.9 a	3.2 a	3.2 a
Shoots exposed	0.9 a	0.7 b	1.5 ab	1.4 c	1.7 b	2.1 b	2.0 b
Whole plant covered	0.9 a	0.8 b	1.0 b	1.1 c	1.6 b	1.8 b	1.8 b

[z]Mean pre-storage Ψ, n = 5.

[y]Means in columns followed by the same letter are not significantly different as determined by Duncan's multiple range test, P = 0.05.

Table 6. Water loss from Washington hawthorn and Norway maple stem segments during cold storage[z,y].

Species	Water loss (mg/cm²/week)			
	Storage duration (weeks)			
	1	2	3	4
Hawthorn	19.7 a	16.6 a	10.8 a	6.1 a
Maple	14.0 b	11.4 b	10.3 a	7.2 a

[z]Water loss during 4 weeks cold storage at 2°C, 80% ± 5% RH.

[y]Mean separation by *t* test at P = 0.05. Same letter within column indicates no significant difference.

stems were very susceptible to water stress while dormant which may be due to a morphological aspect that allows for a relatively high degree of moisture loss. Exposure of bare-root trees to a 12 hr desiccation treatment resulted in a substantial decrease in root and shoot water potential, regardless of storage treatment. Thus, minimizing water stress by proper storage methods can be negated by a relatively brief exposure to desiccating conditions during planting. Water loss through lenticels has been shown to contribute to overall water loss of stem tissue (5). Analysis of hawthorn and maple stem lenticel number and distribution yielded no pattern or significant difference between species (unpublished data). Data herein, however, does indicate that in early storage hawthorn stem tissue lost more water than maple (Table 6) which may be related to hawthorn stem dieback (personal observation). In support of this contention, Englert et al. (2) found that an application of film-forming antidesiccant compounds to Washington hawthorn stems reduced water loss and increased survival rates.

Results of this and other work (3) support the contention that roots of seedling nursery stock are extremely vulnerable to desiccation stress. Although protection of roots for all bare-root stock is imperative, desiccation sensitive species such as hawthorn require both shoot and root protection to minimize water stress.

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