Evaluating Recovery of Cupressaceae Taxa After Flooding at Contrasting Temperatures[1]

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Abstract

Chamaecyparis are ornamental plants that are used extensively in temperate-zone landscapes worldwide. However, due to their low tolerance to environmental stresses *Chamaecyparis* often perform poorly in urban landscapes. The objective of this research was to evaluate rootstocks of selected *Cupressaceae* taxa to determine their adaptability to poor drainage and high temperatures found commonly in urban landscapes. To accomplish this objective, 10 taxa (*Chamaecyparis*, *Platycladus*, *Thuga* spp., and x *Cupressocyparis leylandii)* were grown in 2.8 liter (#1) black plastic containers with a pinebark:sand (8:1 by vol) medium for 19 weeks in two greenhouses with 9/15 hr day/night temperatures of either 22/18C (72/64F) or 30/26C (86/79F). Half the plants in each greenhouse were flooded for 4 weeks. Root relative growth rate (RGR) was a better indicator of plant performance under flooded conditions compared to shoot RGR. At 22/18C (72/64F), root RGR of *Chamaecyparis thyoides* and *Thuja* 'Green Giant' only declined 10% and 11% between nonflooded and flooded plants, respectively. *Chamaecyparis obtusa* and x *Cupressocyparis leylandii* had the largest percentage decline in root RGR from nonflooded to flooded plants with 71% and 213%, respectively. *Chamaecyparis thyoides* had the highest root RGR at 30/26C (86/79F) in both nonflooded and flooded conditions with a 19% decrease in root RGR between nonflooded and flooded. *Chamaecyparis lawsoniana* and *T.* 'Green Giant' were ranked 2 and 3 in flooded conditions at 30/26C (86/79F); however, percentage decline increased to 43% and 46%, respectively. At this temperature, the remaining seven taxa had greater than 50% decline in root RGR in flooded conditions compared to nonflooded plants. In nonflooded conditions, shoot and root RGR of all species decreased from 22/18C (72/64F) to 30/26C (86/79F) except for *Chamaecyparis thyoides*. The shoot and root RGR of *Chamaecyparis* thyoides grown in 22/18C (72/64F) and 30/26C (86/79F) were similar in nonflooded conditions. *Chamaecyparis thyoides* demonstrated excellent tolerance to flooding and temperature and could be a desirable understock for other *Chamaecyparis* when grown in poorly drained locations.

Index words: environmental stress, falsecypress, whitecedar, arborvitae, landscape, hypoxia, root.

Taxa used in this study: *Chamaecyparis lawsoniana* (A. Murr.) Parl, Lawson falsecypress; *Chamaecyparis nootkatensis* (D. Don) Spach, Alaska cedar; *Chamaecyparis obtusa* (Siebold & Zucc.) Endl., Hinoki falsecypress; *Chamaecyparis pisifera* (Siebold & Zucc.) Endl., Sawara falsecypress; *Chamaecyparis thyoides* (L.) BSP, Atlantic whitecedar; x *Cupressocyparis leylandii* Dallim & A. B. Jacks, Leyland cypress; *Platycladus orientalis* (L.) Franco, Oriental arborvitae; *Thuja occidentalis* L., eastern arborvitae; *Thuja* 'Green Giant' arborvitae; *Thuja plicata* J. Donn ex D. Don, giant arborvitae or western redcedar.

Significance to the Nursery Industry

Chamaecyparis are landscape plants used extensively in temperate-zone landscapes worldwide. However, poor adaptability to extremes of heat or flooding often limits use of these plants in stressful sites. This research identified a wide range of tolerance to root-zone flooding and temperature among different members of the Cupressaceae that are potential understocks for *Chamaecyparis*. Grafting may provide an effective means for enhancing adaptability and tolerance to environmental and biological stresses by exploiting superior taxa for use as rootstocks. Additional research is currently focusing on interspecific and intergeneric graft compatability among selected species and clones.

Introduction

The genus *Chamaecyparis* includes many desirable and commercially important taxa. Although there are only six to seven species in the genus, the taxa vary considerably with over 240 cultivars of *Chamaecyparis lawsoniana* alone (14). Unfortunately, many *Chamaecyparis* taxa are native to cool, temperate climates and may perform poorly in stressful landscape situations, particularly under conditions of poor drainage (hypoxia), high temperatures, and presence of *Phytophthora* pathogens (5, 12). *Chamaecyparis lawsoniana* and *Chamaecyparis nootkatensis*, for example, are both native to the cool climate of the Pacific Northwest United States and often have poor survival in less than ideal landscape settings. In addition, Weathers (21) offered anecdotal evidence that *Chamaecyparis obtusa* will not survive in clay soil in the mid-south (Durham, NC) region of the United States.

For a variety of reasons, urban soils often have poor drainage resulting in saturated soils for extented periods (4). In well-structured soils, a day or two of heavy rainfall and high temperatures can induce anaerobic conditions in spring and summer, when plant growth rates and microbial activity are high (9). These short-term anaerobic periods may cause damage to root systems. However in urban soils, waterlogging and anaerobiosis may occur for extended periods (11), causing severe restrictions to root growth and even death of the plant. Raulston (18) stated that the key to plant adaptability in many landscape situations was root survival under hot, wet conditions.

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Tree response to flooding varies with duration, season, temperature, and plant tolerance of flooding. Flooding during the growing season is usually more harmful since growing roots have high oxygen requirements combined with high rates of respiration (20). The capacity of water to hold oxygen also decreases with increasing temperature (3). A reduction of photosynthesis and stomatal conductance are often early indicators of tree stress to flooding (17). Longer term responses include inhibition of shoot, cambial, and root growth and often, death of trees (13). However, flooding usually reduces the root:shoot ratio reflecting greater reduction of roots than of shoots (13).

Grafting scions of poorly adapted plants onto superior rootstocks is one approach for engineering plants with greater environmental adaptability. Since *Chamaecyparis* exhibit considerable ecological latitude, with some species growing in cool climates (e.g., *Chamaecyparis nootkatensis*) while others are native to hot, boggy conditions (e.g., *Chamaecyparis thyoides*) (10), the selection of stress-tolerant rootstock may have particular merit. Disease resistance also differs considerably among species of *Chamaecyparis*. *Chamaecyparis lawsoniana* is extremely susceptible to *Phytophthora lateralis* Tucker & Milbrath, whereas *Chamaecyparis formosensis* Matsum., *Chamaecyparis nootkatensis*, *Chamaecyparis pisifera*, *Chamaecyparis taiwanensiss* Masemune & Suzuki, *Chamaecyparis thyoides*, and x *Cupressocyparis leylandii* are resistant (12). *Chamaecyparis lawsoniana* is also susceptible to *Phytophthora cinnamomi* Rands (19).

Opportunities for rootstock selection for *Chamaecyparis* also extend beyond this genus. Limited experimentation has shown that *Chamaecyparis* can be grafted onto a range of different genera. Blomme and Vanwezer (1) reported initial graft success of up to 90% when grafting *Chamaecyparis nootkatensis* onto *Platycladus orientalis* (syn. *Thuja orientalis*). Menerve and Istas (15) reported satisfactory graft compatibility of *Chamaecyparis obtusa* 'Loenik' (syn.'Graciosa') on *Thuja occidentalis*, *Cupressus arizonica* Greene 'Conica' on *Platycladus orientalis*, and *Chamaecyparis lawsoniana* 'Stewartii' and 'Spek' on *Chamaecyparis pisifera* 'Plumosa Aurea' (though growth was reduced) over a 2-year period. Menerve and Istas (15) further reported poor survival for *Cupressus arizonica* 'Conica' on *Thuja occidentalis* or *Thuja plicata*, and for *Chamaecyparis obtusa* 'Loenik' on *Platycladus orientalis*. Survival and compatibility of *Chamaecyparis lawsoniana* grafted on *Chamaecyparis formosensis* or *Chamaecyparis thyoides* were reported to be excellent over a 2-year period, but grafts on *Chamaecyparis nootkatensis* or *Chamaecyparis pisifera* were unsatisfactory (12). Blomme and Vanwezer (2) recommended propagating difficult-to-root cultivars of *Chamaecyparis obtusa*, including 'Aurea Youngii', 'Gracilis', and 'Loenik', by grafting them on *Thuja occidentalis*, *Platycladus orientalis* or *Chamaecyparis lawsoniana*. Therefore, the objective of this research was to evaluate candidate rootstocks for *Chamaecyparis* with greater adaptability to poor drainage (inundation) under contrasting temperature regimes.

Materials and Methods

Stem cuttings of each taxa investigated in this study were collected in early December 1999 from the JC Raulston Arboretum, Raleigh, NC, and the Biltmore Estate, Asheville, NC. In April, 70 rooted cuttings of each taxa were potted into 2.8 liter (#1) black plastic containers in a pinebark:sand (8:1 by vol) substrate amended with 0.9 kg cu m (2 lbs cu yd) dolomitic limestone and placed on a gravel pad at the NC State University Horticulture Field Laboratory, Raleigh. Containers were irrigated daily with 1.3 cm (0.5 in) of water, applied via overhead irrigation at the rate of 1.6 cm/hr (0.6 in/hr). Plants were fertilized twice a week with a 20N–4.4P–16.4K water soluble fertilizer (Peters 20–10–20) at the rate of 100 mg/liter (ppm) N.

A preliminary study was conducted to determine length of flooding that would stress the selected species without 100% mortality. In April, five plants of each taxa were placed in a greenhouse with 9/15 hr day/night temperatures of 24 ± 4C/16 ± 4C (75 ± 7F/61 ± 7F) under natural irradiance and flooded for 7, 14, 21, 28, 35, or 42 days. Results from the study indicated that flooding for 28 days was adequate to stress the plants without 100% mortality.

On June 1, plants were moved to the Southeastern Plant Environment Laboratory (NC State University Phytotron) and two 9/15 hr thermoperiods were initiated the following day (day 0) using controlled-environment greenhouses. The thermoperiods were 22/18C (72/64F) or 30/26C (86/79F). Plants were arranged in a 10 × 2 factorial in a randomized complete block design using 12 single plant replications per treatment in each thermoperiod. The two main factors were 10 taxa (*Chamaecyparis lawsoniana*, *C. nootkatensis*, *C. obtusa*, *C. pisifera*, *C. thyoides*, x *Cupressocyparis leylandii*, *Platycladus orientalis*, *Thuja occidentalis*, *T.* 'Green Giant', and *T. plicata*) and two flooding periods (0 or 28 days). The two thermoperiods were treated as separate experiments. At day 0, five plants of each taxon were separated into shoots and roots to determine initial shoot and root dry weights. Before flooding, all plants were fertilized every other day with standard Phytotron nutrient solution (6). Plants were watered with deionized water on remaining days. Flooding was accomplished by inserting the growing container into an identical container lacking drainage holes, resulting in the substrate being covered by 2 cm (0.8 in) of water. Flooding began July 31 (day 61). During flooding, all plants received only deionized water. After 28 days, flooding was terminated and watering and fertilizing as described previously were continued for 77 additional days.

On October 15, shoots (aerial tissue) were removed. Roots were placed over a screen and washed to remove substrate. Shoots and roots were dried at 62C (144F) for 7 days and weighed. Shoot and root relative growth rate (RGR) for each species was calculated as follows:

$$RGR = (\ln w2 - \ln w1) \div (t2 - t1),$$

where w1 and w2 are plant part dry weight in grams at t1 (week 1) and t2 (week 19).

Data were subjected to analysis of variance procedures. Mean separations were performed using Fishers protected least significant difference (LSD) procedure at $P = 0.05$.

Results and Discussion

Plants that were not flooded had 100% survival regardless of species and temperature (Table 1). Flooded plants of *Chamaecyparis thyoides, Chamaecyparis lawsoniana*, and *Thuja occidentalis* also had 100% survival regardless of temperature. Three additional taxa (*P. orientalis*, *T.* 'Green Gi-

Table 1. **Effect of flooding on survival of selected Cupressaceae taxa under two contrasting temperature regimes.**

	Survival (%)			
	22/18C (72/64F)		30/26C (86/79F)	
Taxa	**Nonflooded**	**Flooded**	**Nonflooded**	**Flooded**
Chamaecyparis lawsoniana	100	100a[z]	100	100a
C. nootkatensis	100	67d	100	58e
C. obtusa	100	92b	100	67d
C. pisifera	100	92b	100	92b
C. thyoides	100	100a	100	100a
x *Cupressocyparis leylandii*	100	83c	100	92b
Platycladus orientalis	100	100a	100	92b
Thuja 'Green Giant'	100	100a	100	83c
T. plicata	100	100a	100	75d
T. occidentialis	100	100a	100	100a

[z]Mean (n = 12) separation within columns for flooded plants by Fisher's protected LSD at $P = 0.05$.

ant', and *T. plicata*) of flooded plants in 22/18C (72/64F) had 100% survival, whereas no additional species of flooded plants in 30/26C (86/79F) had 100% survival. Minore (16) reported that *T. plicata* was very tolerant of summer flooding for 4 to 8 weeks. *Chamaecyparis nootkatensis* had the lowest survival at 22/18C (72/64F) (67%) and 30/26C (86/79F) (58%) under flooded conditions. Survival data indicated several candidates could be used for flood-tolerant rootstocks. However, basing rootstock selection on visual observations along can be misleading as months to years may go by before necrosis and/or death are seen (13).

At 22/18C (72/64F), *Chamaecyparis pisifera*, *C. lawsoniana*, and *C. thyoides* were ranked in the top three in both nonflooded and flooded conditions (Table 2); however, the shoot RGR of these three plants were not significantly greater than all other species. Shoot RGR of *C. lawsoniana*, *C. pisifera*, and *C. thyoides* declined 11%, 3%, and –1% between nonflooded and flooded plants, respectively (Table 2). *Thuja occidentalis*, *C. obtusa*, and x *Cupressocyparis leylandii* had the largest decline in shoot RGR from nonflooded to flooded plants 24%, 25%, and 59%, respectively. Based on shoot RGR, the most flood tolerant species were *C. pisifera*, *C. lawsoniana*, and *C. thyoides.*

At 30/26C (86/79F), shoot RGR of *Chamaecyparis thyoides* (11%) and *Chamaecyparis pisifera* (17%) had the smallest percentage decline from nonflooded to flooded conditions (Table 2). *Chamaecyparis thyoides* was expected to perform well in hot, flooded conditions since it is normally

Table 2. **Effect of flooding on shoot relative growth rate (RGR) of selected Cupressaceae taxa under two contrasting temperature regimes.**

	Shoot RGR ($mg \cdot g^{-1} \cdot week^{-1}$)				
Taxa	**Nonflooded**	**Rank**	**Flooded**	**Rank**	**Decline (%)[z]**
			22/18C (72/64F)		
C. pisifera	110a[y]	1	107a	1	3
C. lawsoniana	98ab	2	87b	3	11
C. thyoides	90bc	3	91ab	2	–1
T. "Green Giant'	88bc	4	76bcd	5	14
T. plicata	83cd	5	67cde	6	19
T. occidentalis	76cde	6	58def	7	24
Platycladus orientalis	72def	7	80be	4	–11
C. nootkatensis	63ef	8	53ef	8	16
C. obtusa	59f	9	44f	9	25
x *Cupressocyparis leylandii*	39g	10	16g	10	59
			30/26C (86F/79F)		
C. pisifera	94a	1	78a	2	17
C. thyoides	91a	2	81a	1	11
Platycladus orientalis	91a	3	67ab	3	26
C. lawsoniana	87ab	4	67ab	4	23
T. 'Green Giant'	85ab	5	59b	5	31
T. plicata	77b	6	23de	9	70
T. occidentalis	61c	7	36cd	6	41
C. obtusa	61c	8	42c	7	31
C. nootkatensis	59c	9	36cd	8	39
x *Cupressocyparis leylandii*	25d	10	15e	10	40

[z]Percentage decline = [(RGR nonflooded – RGR flooded) ÷ RGR nonflooded] × 100.

[y]Mean (n = 12) separation within columns within temperatue regime for nonflooded and flooded plants by Fisher's protected LSD at $P = 0.05$.

Table 3. **Effect of flooding on root relative growth rate (RGR) of selected Cupressaceae taxa under two contrasting temperature regimes.**

Taxa	Root RGR ($mg \cdot g^{-1} \cdot week^{-1}$) Nonflooded	Rank	Flooded	Rank	Decline (%)[z]
	22/18C (72/64F)				
C. lawsoniana	103a[y]	1	81ab	2	21
C. thyoides	97a	2	87a	1	10
C. nootkatensis	69b	3	31cd	6	55
T. 'Green Giant'	65cb	4	58bc	3	11
T. plicata	54bcd	5	43cd	5	20
T. occidentalis	47cde	6	28c	7	40
C. pisifera	40de	7	24d	8	40
Platycladus orientalis	33ef	8	43cd	4	–30
x *Cupressocyparis leylandii*	16fg	9	–18e	10	213
C. obtusa	14g	10	4e	9	71
	30/26C (86/79F)				
C. thyoides	97a	1	79a	1	19
C. lawsoniana	74b	2	42b	2	43
T. 'Green Giant'	50c	3	27bc	3	46
C. nootkatensis	49c	4	–2efg	7	104
T. plicata	46cd	5	–25h	10	154
Platycladus orientalis	46cd	6	23bcd	4	50
C. pisifera	30de	7	3def	6	90
T. occidentalis	25ef	8	9cde	5	64
x *Cupressocyparis leylandii*	15g	9	–23gh	9	253
C. obtusa	9f	10	–13fgh	8	244

[z]Percentage decline = [(RGR nonflooded – RGR flooded) ÷ RGR nonflooded] × 100.

[y]Mean (n = 12) separation within columns within a temperature regime for nonflooded and flooded plants by Fisher's protected LSD at $P = 0.05$.

found in freshwater swamps or bogs, wet depressions, and stream banks (5, 10). *Thuja plicata* had the largest percentage decline (70%) when grown at 30/26C (86/79F). In general, percentage decline from nonflooded to flooded plants was greater at 30/26C (86/79F) compared to 22/18C (72/64F). This result might be expected since the capacity of water to hold oxygen also decreases with increasing temperature combined with increasing rates of respiration (3).

At 22/18C (72/64F), similar to shoot RGR, root RGR of *Chamaecyparis lawsoniana* and *Chamaecyparis thyoides* were least affected by flooding with a 21% and 10% decline between nonflooded and flooded plants, respectively (Table 3). The good growth recovery of *Chamaecyparis lawsoniana* after exposure to flooded conditions was surprising considering its poor performance in landscape plantings. This result indicates that poor landscape adaptability of *C. lawsoniana* may have less to do with intolerance to poor drainage and more with intolerance to other stresses (e.g., *Phytophthora*). Even though shoot RGR of *Chamaecyparis pisifera* was high when flooded, root RGR of this species declined 40% when flooded, indicating that root growth would be a better indicator of plant tolerance to short-term flooding than shoot growth. *Chamaecyparis obtusa* and x *Cupressocyparis leylandii* had the largest decline in root RGR from nonflooded to flooded plants 71% and 213%, respectively (Table 3).

At 30/26C (86/79F), root RGR of *Chamaecyparis thyoides* was significantly greater than all other taxa (Table 3) whether nonflooded or flooded. *Chamaecyparis thyoides* also had the smallest percentage decline (19%) from nonflooded to flooded of all taxa. *Thuja* 'Green Giant' and *C. lawsoniana* also grew well when flooded at 22/18C declining 11% and 21% compared to nonflooded plants, respectively. However, even though root RGR of *C. lawsoniana* and *T.* 'Green Giant' were also ranked 2 and 3 in flooded conditions at 30/26C (86/79F), percentage decline climbed to 43% and 46%, respectively. Data herein support conclusions of Weathers (21) that *Chamaecyparis obtusa* is a poor choice for clay soils in the mid-south since root RGR of *Chamaecyparis obtusa* declined 244% when grown at 30/26C (86/79F) in flooded soils. The remaining six species had greater than 50% decline in root RGR in flooded conditions at 30/26C (86/79F) compared to nonflooded plants. Both shoot and root RGR of *Chamaecyparis thyoides* were similar between 22/18C (72/64F) and 30/26C (86/79F) in nonflooded plants, whereas shoot and root RGR of all other species in nonflooded conditions decreased from 22/18C (72/64F) to 30/26C (86/79F).

Recent taxonomic/molecular data have provided new insights into the taxonomic relationships of taxa in the Cupressaceae. Gadek et al. (8) presented compelling evidence that *Chamaecyparis nootkatensis* should be reclassified in the genus *Cupressus*. Considering this, other species of *Cupressus*, *Cupressus* hybrids, and even *Juniperus* spp. could be candidate understocks for *Chamaecyparis* (*Cupressus*) *nootkatensis*. Farjon et al. (7) have recently proposed to unite *Chamaecyparis nootkatensis* with a newly discovered species in a new genus *Xanthocyparis* (7). These findings may help explain why *Chamaecyparis lawsoniana* has demonstrated poor graft compatibility with *Chamaecyparis nootkatensis* (12).

This research documented a wide range of tolerance to root-zone flooding among different taxa of Cupressaceae under two temperature regimes, indicating potential opportunities for using more stress tolerant rootstocks to propagate different taxa in this family. *Chamaecyparis thyoides* demonstrated excellent tolerance to flooding and temperature and could be a desirable understock for other *Chamaecyparis* when grown in poorly drained locations. However, long-term graft compatibility between these taxa needs to be determined. Preliminary grafting studies have shown good short-term graft (2 years) compatibility of *Chamaecyparis lawsoniana* 'Golden Showers' on *Chamaecyparis thyoides* 'Emily'. However, plants of *Chamaecyparis lawsoniana* 'Oregon Blue' grafted on *Chamaecyparis thyoides* 'Emily' are showing considerable overgrowth of the scion at the graft union and poor anchorage. These observations indicate that graft compatibility could be clonal-specific between particular species.

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