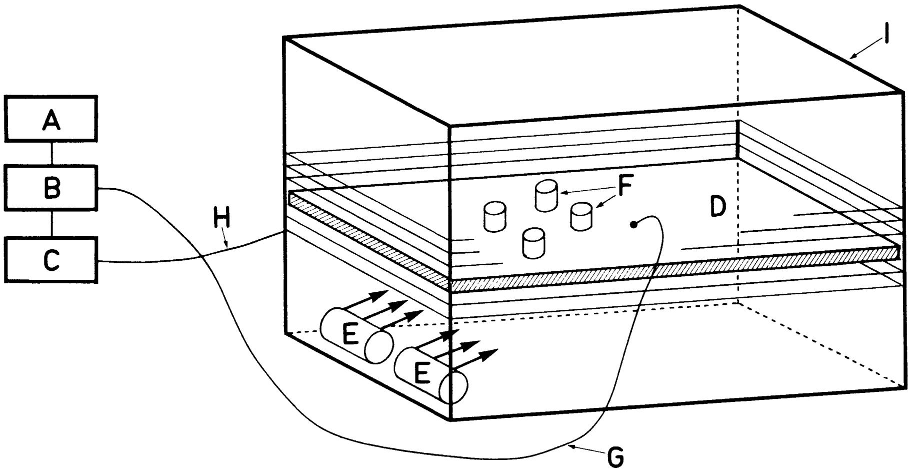

Fig. 1. Components of the freezer system described. A. Data-Trak programmer. B. Thermac temp controller. C. phaser. D. 1.25 cm thick aluminum bar. E. squirrel cage type fans. F. aluminum weighing pans. G. 24 gauge copper-constantan thermocouple sensor. H. 120v heating cable (560 watts). I. deep freeze.

An aluminum bar, 1.25 cm thick, is then fixed in place 30 cm from the top, allowing 4 cm space between the outside edge of the aluminum bar and the inside wall. Two squirrel cage type fans are located at the bottom of the chest to ensure air circulation across the bottom of the aluminum plate.

The control system is a Programmer-Controller model 5500/624A (Research Incorporated, Minneapolis, Minn.), which is a combined package of a FGE 5500 Data-Trak programmer and the Thermac model 624A temp controller. The programmer uses a 24 gauge copper-constantan thermocouple sensor located at the center of the aluminum bar. Power for the heating cable is supplied by a phaser (Research Incorporated Model 632) which is regulated by the proportional controller.

A less expensive temp control system (less than $100) is the MSD model STC-20 series proportional temp controller (MSD, Montreal, Canada). This module uses a thermistor sensor with a response curve suitable for the operating temp range, and a manual potentiometer for the set point control.

Samples to be frozen are placed in aluminum weighing pans (size dictated by size of sample) on the aluminum bar in the freezer, and covered with moist sand. The sand, which invariably freezes just below 0°C, serves as an ice nucleator for the samples, thereby preventing extreme supercooling. The moisture content of the tissue can be controlled by adding varying amounts of water to the sand and allowing time for the water content of the tissue to equilibrate. Heat which is liberated from the sample during freezing is also quickly conducted away by the moist sand and the aluminum bar. The system can be used to simulate the natural freezing of underground tissue in nature where the soil is a very efficient heat sink. Also, the system has been used for freezing tissue cultures aseptically since the aluminum dishes and sand can readily be sterilized by autoclaving.

The system gives temp control between +50° and −85°C. Use of the proportional controller in combination with the aluminum bar and the sand provide more accurate, uniform (±0.5°C) spatial temp control and greater response capabilities than most modified-compressor type freezer systems.

Literature Cited

1. Garber, M. P. and P. L. Steponkus. 1976. Alterations in chloroplast thylakoids during cold acclimation. *Plant Physiol.* 57:681-686.
2. Gusta, L. V. and D. B. Fowler. 1977. Factors affecting the cold survival of winter cereals. *Can. J. Plant Sci.* 57:213-219.
3. Olien, C. R. 1967. Freezing stresses and survival. *Annu. Rev. Plant Physiol.* 18:387-408.
4. Pomeroy, M. K. and D. B. Fowler. 1973. Use of lethal dose temperature estimate as indices of frost tolerance for wheat cold acclimated under natural and controlled environments. *Can. J. Plant Sci.* 53:485-494.
5. Quamme, M. A., D. R. Evert, C. Stushnoff, and C. J. Weiser. 1972. A versatile temperature control system for cooling and freezing biological materials. *HortScience* 7:24-25.
6. Scott, K. R. 1966. Use of liquid nitrogen in a winter hardiness test chamber for fruit trees. *Can. J. Plant Sci.* 46:691-693.
7. Shearman, L. L., C. R. Olien, B. I. Marchetti, and E. H. Everson. 1973. Characterization of freezing inhibitors from winter wheat cultivars. *Crop Sci.* 13:514-519.
8. Warner, D. O., J. W. Schmidt, and V. A. Johnson. 1969. Correlation of artificial crown freezing survival with natural survival in winter barley. *Barley Genetics* II:364-377.

HortScience 13(2):172–174. 1978

Root Hardiness of Container-grown Ornamentals[1]

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Abstract. **Root hardiness of numerous woody ornamentals was determined after artificial acclimation. In the species tested, the killing temperatures of young roots ranged from −3° to −11°C while that of mature roots ranged from −8° to −23°. The relative hardiness of young roots was not necessarily indicative of the relative hardiness of mature roots.**

In recent years, nurserymen have become increasingly aware of the advantages in production and retailing container-grown nursery stock. Containerized trees and shrubs are also utilized in landscape situations such as when areas where soil is limited or non-existent. However all segments of the industry in cold northern environments share the common problem of winter survival of container-grown stock. Early investigators demonstrated that root hardiness is considerably less than shoot hardiness of the same plant (1, 9). The differences in hardiness between shoots and roots can exceed 70°C in white pine (5), 28° in *Taxus cuspidata* (4), and at least 15° in several ornamental shrubs (3, 6, 7, 8, 12). While this difference in hardiness does not normally manifest itself in winter survival of field-grown stock, it can be the limiting factor to winter survival of container-grown stock since the roots are subjected to much lower temp. For instance, when air temp between 15° and −30° was recorded, soil temp at an 8 cm depth varied between 12° and −6° while temp in the center of an

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[1] Received for publication July 14, 1977. Department of Agronomy Series Paper 1226. This work was supported, in part, by contributions from the N.Y. State Nurserymen's Association, N.Y. State regional associations, individual nursery firms, the American Rhododendron Society, and the Horticultural Research Institute.

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exposed 8.8 liter container varied between 15° and −15° (10). Knowledge of the root hardiness of various ornamental species, while sparse, is receiving increased attention (2). Such knowledge is essential for nurserymen to select species which can be successfully overwintered under non-heated conditions, to employ minimum heat to overwinter tender species, and to select the most appropriate species for utilization in containers in the landscape.

Actively-growing containerized woody ornamentals, 2 to 3 years old, were obtained in late August from several commercial nurseries on Long Island, N.Y., and the Cornell Univ. test gardens. The plants were in either 4.4 or 8.8 liter containers, depending on the species. The plants were placed in a controlled environment growth chamber at 21°C (day)/15.5° (night), 10-hr photoperiod (20 klx intensity). After 4 to 5 weeks, they were transferred to an 8-hr photoperiod (6 klx) at a constant temp of 1.5° for 6 to 7 weeks. Roots were freed from the growing medium by first mechanically disrupting the loose or larger particles, then immersing the root ball in water and gently separating the roots, and finally rinsing off the smallest particles with a slow stream of water. Root systems were divided into young roots (defined as the small non-lignified roots immediately adjacent to and including the root tips) and mature roots (defined as darker, lignified roots with larger diam). Such a distinction was difficult to make in the fibrous root systems of Ericaceous species so representative samples, including roots ranging in diam from 5 to about 2 mm, were taken as a pooled sample.

Root samples were placed in capped vials and then frozen in methanol-water baths electronically programmed to cool at a rate of 2.8°C/hr. The baths were held isothermally at the desired freezing temp for at least 2 hr and then thawed at a rate of 5.6°/hr. Killing temp were determined using the modified ninhydrin technique (11), assuming that a release of 35% of the total ninhydrin-reactive compounds represented the killing temp. Killing temp were determined for 4 individual plants of each species.

Killing temp of the root systems of the species tested were categorized to indicate the relative hardiness of the root systems (Tables 1, 2); the fibrous roots of Ericaceous species were included with the young roots of other species. In the species tested, the killing temp of young roots was never lower than −11°C while that of mature roots was as low as −23°. In no single species was the killing temp of young roots equal to that of mature roots. Furthermore, in some cases,

Table 1. Relative hardiness ratings of mature roots of selected woody ornamental plants[z] based on killing point determinations following artificial acclimation.

Species	Killing point (°C)
Very tender −4°C	
Buxus sempervirens L.	−3
Cotoneaster microphyllus Lindl.	−4
Ilex cornuta Lindl. & Paxt. cv. Dazzler	−4
Pyracantha coccinea Roem. cv. Lalandei	−4
Mahonia bealei Carr.	−4
Tender (−5° to −7°)	
Cotoneaster dammeri Schneid.	−5
Euonymus fortunei Hand.—Mazz. v. vegeta	−5
Hypericum sp. L.	−5
Ilex crenata cv. Helleri	−5
Ilex cv. Nellie Stevens	−5
Ilex x *meserveae* Hu cv. Blue Boy	−5
Ilex opaca Ait.	−5
Cornus florida L.	−6
Euonymus kiautschovica Loes (*E. patens*)	−6
Ilex cv. San Jose	−6
Magnolia stellata Maxim	−6
Leucothoe fontanesiana Sleum[y]	−7
Rhododendron prunifolium Millais[y]	−7
Viburnum plicatum Thunb. v. *tomentosum*	−7
Cotoneaster dammeri cv. Skogsholmen	−7
Rhododendron cv. Hino Crimson[y]	−7
Euonymus alata Sieb. cv. Compacta	−7
Slightly Hardy (−8° to −9°)	
Stephanandra incisa Zabel cv. Crispa	−8
Rhododendron Exbury Hybrid[y]	−8
Taxus x *media* Rehd. cv. Hicksii	−8
Koelreuteria paniculata Laxm.	−9
Kalmia latifolia L.[y]	−9
Pieris japonica D. Don.[y]	−9
Rhododendron schlippenbachii Maxim.	−9
Rhododendron cv. Purple Gem[y]	−9
Hardy (−10° to −12°)	
Rhododendron catawbiense Michx. cv. Roseum Elegans[y]	−11
Juniperus conferta Parl.	−11
Juniperus horizontalis Moench. cv. Plumosa	−11
Juniperus squamata D. Don. cv. Meyeri	−11

[z] Scientific names are those used in Hortus III, Macmillan, 1976.

[y] Fibrous rooted.

Table 2. Relative hardiness ratings of mature roots of selected woody ornamental plants[z] based on killing point determinations following artificial acclimation.

Species	Killing point (°C)
Slightly Hardy (−8° to −10°)	
Ilex crenata Thunb. cv. Helleri	−8
Pyracantha coccinea Roem, cv. Lalandei	−8
Cotoneaster dammeri Schneid.	−8
Hypericum sp. L.	−8
Ilex cv. San Jose	−8
Ilex cornuta Lindl. & Paxt. cv. Dazzler	−8
Euonymus kiautschovica Loes. (*E. patens*)	−9
Ilex cv. Nellie Stevens	−10
Hardy (−11° to −15°)	
Euonymus fortunei Hand.—Mazz. v. vegeta	−11
Mahonia bealei Carr.	−11
Cotoneaster dammeri cv. Skogsholmen	−11
Cornus florida L.	−12
Cotoneaster microphyllus Lindl.	−13
Ilex x *meserveae* Hu cv. Blue Boy	−13
Ilex opaca Ait.	−13
Magnolia stellata Maxim.	−13
Viburnum plicatum Thunb. v. *tomentosum*	−14
Euonymus alata Sieb. cv. Compacta	−14
Very Hardy (−18° or lower)	
Juniperus squamata D. Don. cv. Meyeri	−18
Stephanandra incisa Zabel cv. Crispa	−18
Juniperus horizontalis Moench. cv. Plumosa	−20
Koelreuteria paniculata Laxm.	−20
Taxus x *media* Rehd. cv. Hicksii	−20
Juniperus conferta Parl.	>−23

[z] Scientific names are those used in Hortus III, Macmillan, 1976.

the relative hardiness category of mature roots was quite different from that of young roots. Thus, the relative hardiness of young roots cannot be inferred from the hardiness of mature roots or vice versa. For example, *Mahonia bealei* has very tender (−4°) young roots but hardy (−11°) mature roots. Similarly, *Stephanandra incisa* cv. Crispa had slightly hardy (−8°) young roots but very hardy (−18°) mature roots. There were also species whose young roots were considered very tender to tender (−5° to −7°) but whose mature roots were only slightly hardy (−8° to −10°). These included the *Ilex crenata* cultivars, and *Hypericum* sp. Finally, the 3 *Juniperus* species tested had hardy young roots and very hardy mature roots.

In testing woody ornamentals for root hardiness levels one is faced with definite limitations in terms of the ability to test many plants, due to the seasonality of hardiness development. A solution to this problem would be to determine the conditions which would promote acclimation at any time of year. However, in order to equate this artificial acclimation to natural acclimation, a similarity in killing temp obtained for a specific cultivar using both methods must be demonstrated. A comparison of the data for cultivars used in both this study and that of Havis (2) reveals that the killing temp found for mature roots in this study are similar to the temp found by Havis. In the case of the Ericaceous plants there were some differences probably because of the predominance of younger root tissue in the samples prepared for this study. Nevertheless, it appears that the artificial conditions used here produced hardiness comparable to that attained naturally.

Young roots are more susceptible to injury and death due to low temp than are the mature roots of the same cultivar. Havis (2) concluded from his observations that the killing temp was generally that of the mature roots and that the small portion of young roots at the outer edge of the container could be lost without affecting top growth. However, the temp difference between the edge and the center of an 8.8 liter container in a polyethylene overwintering structure is not significant (10). Therefore, if the young roots at the edge are killed, those throughout the container are killed. Although the survival of young roots may not be crucial to the survival of the whole plant, loss of the water absorptive and nutrient uptake capacity of young roots may decrease the top growth and may also be a serious problem if rapid growth was desired following overwintering. Therefore, the determination of hardiness for both young and mature roots could provide more useful information. Perhaps the killing temp of young roots would be a better estimate of the point at which some damage occurs and reduces the quality of a plant whereas the killing temp of mature roots indicates the limit of simple survival. However, the extent to which the relatively higher killing temp of young roots limits the survival of the whole plant is still not clear. Consequently, more research is necessary to determine the relative importance of young root damage and the effect of freezing on the root regenerative capacity of surviving roots, in addition to the survival of the whole plant.

Literature Cited

1. Chandler, W. H. 1913. The killing of plant tissue by low temperature. *Mo. Agr. Expt. Sta. Res. Bul.* 8.
2. Havis, J. R. 1976. Root hardiness of woody ornamentals. *HortScience* 11:385-386.
3. ________, R. D. Fitzgerald and D. N. Maynard. 1972. Cold-hardiness response of *Ilex crenata* Thunb. cv. Hetzi roots to nitrogen source and potassium. *HortScience* 7:195-196.
4. Mityga, H. G. and F. O. Lanphear. 1971. Factors influencing the cold hardiness of *Taxus cuspidata* roots. *J. Amer. Soc. Hort. Sci.* 96:83-86.
5. Parker, J. 1959. Seasonal variations in sugars of conifers with some observations on cold resistance. *Forest Sci.* 5:56-63.
6. Pellett, H. 1971. Comparison of cold hardiness levels of root and stem tissues. *Canad. J. Plant Sci.* 51:193-195.
7. Pellett, N. E. 1973. Influence of nitrogen on phosphorous fertility on cold acclimation of roots and stems of two container-grown woody plant species. *J. Amer. Soc. Hort. Sci.* 98:82-86.
8. ________ and D. B. White. 1969. Soil-air temperature relationships and cold acclimation of container grown *Juniperus chinensis* 'Hetzi'. *J. Amer. Soc. Hort. Sci.* 94:453-456.
9. Potter, G. F. 1924. Experiments on resistance of apple roots to low temperatures. *N.H. Agr. Expt. Sta. Tech. Bul.* 27.
10. Wiest, S. C., G. L. Good and P. L. Steponkus. 1976. Analysis of thermal environments in polyethylene overwintering structures. *J. Amer. Soc. Hort. Sci.* 101:687-692.
11. ________, ________ and ________. 1976. Evaluation of root viability following freezing by the release of ninhydrin-reactive compounds. *HortScience* 11:197-199.
12. ________ and P. L. Steponkus. 1976. Acclimation of *Pyracantha* tissues and differential thermal analysis of the freezing process. *J. Amer. Soc. Hort. Sci.* 101:273-277.

HortScience 13(2):174–176. 1978

Induction of Fascicular Bud Development in *Pinus sylvestris* L.[1]

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Additional index words. Pinus sylvestris, pruning, cytokinins, benzylaminopurine, isopentenyladenine, cycloheximide.

Abstract. **Multiple treatments with benzylaminopurine, kinetin, isopentenyladenine and cycloheximide, each at 3 concentrations were applied to *Pinus sylvestris* L. All chemicals reduced shoot extension and needle length. Benzylaminopurine (BA) 225 ppm induced 100% fascicular bud development. Removing new growth of multiple shoots from pruned stems of the previous year's growth induced fascicular buds on the last growth flush. Continued treatment resulted in fascicular bud-break and shoot growth in August.**

Annual pruning and shaping of Scotch pine is necessary to insure a well-formed, dense Christmas tree for market. Removal of the apical bud from the main stem (leader) and lateral shoots results in fascicular (from needle bundles) and interfascicular bud development (Fig. 1A). Thirty to 40 buds may develop on the apical 5 cm of the leader. In the succeeding year many of these buds develop into branches.

Lateral shoots have been induced to growth after cytokinin treatment to apples (11), macadamia (1), tea crabapple (3), roses (4), poinsettia (10), and holly (16). Wider branch angles, which may be an advantage, often result from buds induced to grow by cytokinin treatment (14).

There are two sources of lateral buds in pines: branch buds which arise in the axils of scale leaves, and needle fascicular buds that are anatomically short or dwarf shoots. Cohen and Shanks (1975) were able to induce fascicular buds on 5-year-old *Pinus ponderosa* Laws, using foliar sprays of BA with best results achieved from a combination of pruning plus BA. Whitehall and Schwabe (1975) obtained interfascicular bud outgrowth in *P. sylvestris* with BA plus triiodobenzoic acid with and without succinic acid-2,2-dimethylhydrazide.

The present research was undertaken to determine if successive treatment

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[1] Received for publication May 21, 1977. Published with the approval of the Director of the Arkansas Agricultural Experiment Station.

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