# SUCCESSFUL OVERWINTERING OF CONTAINER-GROWN SEEDLINGS

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## ABSTRACT

Ponderosa pine, Scots pine, bur oak, green ash, and seven other hardwood species were successfully overwintered at Bottineau, N.D., buried under snow or moderately dry peat in unheated white plastic or snow-fence covered structures. Several other environments were intermittently successful or failed. Measurements of temperature and water stress to determine cause of success or failure were inconclusive.

In cold climates, container nurserymen have frequently raised beautiful seedlings only to have them ruined during overwinter storage (Zalasky 1977). The principles of overwinter storage are well known in outline (Sakai 1970, Williams 1974, Blackler 1974, Burke *et al.* 1976, Havis and Fitzgerald 1976, Fretz and Smith 1978), but there is little specific information on economical environments in which to overwinter container-grown forest tree seedlings in cold climates (Owston and Stein 1977, Carlson 1979).

There are three causes of overwinter damage, the most obvious of which is low temperature (Havis 1976, Sakai 1978, Studer *et al.* 1978, Desjardins and Chong 1980, Gouin 1980). Container seedlings are more susceptible to damage caused by low temperature than are bare-root seedlings in nursery beds, because the roots, the most sensitive part of the seedling, are above ground. To avoid damage, seedlings must have had adequate time under proper conditions to harden sufficiently, and they must not be exposed to lethal temperatures.

Another cause of overwinter damage is desiccation. When the root ball is frozen, seedlings may not be able to replace moisture as fast as it is lost (Davidson and Mecklenburg 1974, Wiest 1980). Preventing freezing of the root ball to avoid desiccation may be very expensive. Alternatively, loss of water can be retarded by using moisture barriers and minimizing temperature fluctuation or perhaps by supplying moisture to the tops as well as the roots (Havis 1976, Wiest *et al.* 1976, Smith and Mitchell 1977, Smith *et al.* 1977, Smith *et al.* 1978, Gouin and Link 1979).

Finally, rodents and disease may attack. Mouse damage may be eliminated by preventing their entry. The second best approach is to minimize suitable pest habitat and to trap or bait. Foliage molds are more likely to develop if the trees are in the dark or are too wet, and root rots occur if the trees have saturated, unfrozen root balls.

The purpose of this study was to (1) find suitable, inexpensive environments in which to overwinter container seedlings, (2) develop a uniform and reliable procedure to assess overwintering success, and (3) determine the cause of success or failure.

## MATERIALS AND METHODS

Tree seedlings of several species of conifers and hardwoods were grown in Colorado State Styroblocks[1] in greenhouses and hardened by standard methods (Tinus and McDonald 1979) either in the greenhouse or in a lathhouse. Transfer from the greenhouse to the lathhouse was done early enough in the fall to avoid any damage to the seedlings. Seedlings to be stored in the dark over the winter were not moved into a dark location until fully hardened (Van den Driessche 1969; Johnson and Havis 1977; Tinus and McDonald 1979). For the first two winters (1977-78 and 1978-79), the seedlings were left in place until spring; then they were brought into a warm greenhouse, allowed to flush, and rated according to survival, new growth, and dieback.

During the third year (1979-80), samples of each species from each environment were brought into a warm greenhouse at monthly intervals, allowed to flush, and rated after about 6 weeks. At monthly intervals during the fourth year, samples of each species from each environment were brought into a greenhouse held just above freezing; here they were kept dormant in a non damaging environment until the last sample was taken in mid-March. All seedlings were then allowed to flush together and were rated 6 weeks later.

Survival was recorded, although it is a very minimal index of success. The index commonly used in the horticultural industry is an ocular estimate of seedling vigor. Such estimation is satisfactory if one has a single diligent, well-trained observer to make all the observations. We did not. Instead we used a "recovery index" based on measurements that were reproducible with a variety of observers with a moderate amount of instruction. Original stem height minus overwinter dieback, plus new height added during flushing in the greenhouse, divided by original height, yields a dimensionless number. Zero usually means death; one means no net gain in height after one flush; numbers larger than one generally indicate satisfactory survival and growth.

For the last 2 years, thermometers were installed in the outdoor treatments to measure air temperature in the structure and root-ball temperature under the various protective covers. These were read at 8 a.m. and 3 p.m. on the same day each week from November 1 to April 1.

Each month when samples of seedlings were brought into the greenhouse, four stems of each treatment and species were cut while frozen, thawed in plastic bags, and tested for moisture stress with a pressure chamber.

Three different storage structures were used for the tests. A Quonset greenhouse covered with two layers of clear polyethylene was maintained at 1-3$^{0}$C by forced air heating and cooling. Air was circulated under the benches. The seedlings were not covered in any way; they were watered as needed with a low-nitrogen nutrient solution. A second Quonset greenhouse was covered with one layer of clear plastic and one layer of milky white plastic with a light transmittance of about 25%. The containers were set on the ground. The greenhouse was completely closed, with no forced air circulation and no added heat. The third environment was a lathhouse with walls and top of snow-fence (42% barrier); the containers were set on the ground, and there was no other control of temperature or air movement.

[1] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

Within the white plastic covered greenhouse (referred to hereafter as the white plastic house) and lathhouse, the seedlings were grouped, and each group was given one of several additional protective coverings. Each year a control group was not covered. The first year a second group was completely covered with hay, and a third group was covered with moderately dry peat. In the second year the peat covering was repeated and hay was deleted. Another group was enclosed in white plastic, and a fourth group was enclosed in white plastic suspended above the seedlings and then covered with peat. In the third year the peat covering was repeated in the white plastic house, but it was replaced by snow in the lathhouse. A third treatment at each location was not covered but was sprayed with Wiltpruf, a film-forming antitranspirant. In the fourth year the lathhouse treatments were peat cover and white plastic cover. During fall and winter, seedlings accessible to watering were kept watered as needed whenever the root balls were not frozen.

## RESULTS AND DISCUSSION

Table 1 summarizes overwintering success in 1977-78 for the 11 species tested. The best environment was the greenhouse maintained above freezing where there was no opportunity for damage to be caused by low temperature or desiccation. For most species, the white plastic house was a better environment than the lathhouse. A complete covering of peat was very good, but only 4 of the 11 species were tested under peat. Peat cover was much better than hay for two reasons: hay created a favorable habitat for mice, and in spite of poisoned bait the mice heavily damaged the bur oak, crab apple, buffalo berry, and hackberry; there was no mouse damage in any other treatment. Hay also promoted molds that destroyed much of the foliage on ponderosa and Scots pine.

Species differed widely in their performance. Green ash and American elm wintered well in all environments, while ponderosa pine, Scots pine, and hackberry were very sensitive to different coverings (Table 1).

The winter of 1978-79 was very much like that of 1977-78 in terms of minimum temperatures, duration of subzero weather, and date when cold weather first came (Fig. 1). Overall, the tree species tested (Table 2) responded much the same as did those tested the first year. Peat covering in either the lathhouse or white plastic house was best, but the greenhouse was a close second. Scots pine overwintered well in all environments, but did least well with no cover or with peat plus plastic cover. Lack of cover produced poor results in both structures for all species except American plum, which did best in the lathhouse with no cover.

The four species tested appeared to be quite different in their requirements. Scots pine overwintered adequately in all environments but did best in the greenhouse or in the lathhouse covered with peat or plastic. Second best was peat or plastic covering in the white plastic house. The addition of peat over the plastic covering was detrimental, as was no cover. The same pattern occurred with green ash, but covering the plastic with peat was not detrimental; in fact, peat plus plastic covering in the white plastic house was not different from peat alone. Bur oak overwintered best under peat cover or under plastic in the white plastic house. The greenhouse was second best, on a par with peat plus plastic in the white plastic house. The oak was a total loss without cover and with plastic or peat plus plastic cover in the lathhouse. The poor performance with no cover was similar to that of the previous year. Temperature fluctuation was probably greater under the plastic cover; this negated the benefits of the higher humidity it would have created. American plum performed best in the lathhouse with no cover and second best under peat or peat plus plastic. Performance was almost as good under plastic in the

Table 1. Recovery index* ** of stock overwintered in 1977-78, based on 20 measured seedlings per species per treatment

| Location/cover | Species: Ponderosa pine | Scots pine | Siberian larch | Green ash | Bur oak | American elm | Cotone-aster | Siberian crab apple | Russian olive | Buffalo berry | Hackberry | Mean of: 11 species | 4 (or 3) species† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Greenhouse | 1.80 a | 2.40 a | 1.10 a | 1.61 a | 1.65 a | 1.65 a | 1.33 a | 1.85 a | 1.87 a | 1.35 a | 1.11 a | 1.61 a | 1.74 a |
| Lathhouse | | | | | | | | | | | | | |
| None | 0.19 d | 1.13 c | 1.01 a | 1.15 c | 0.66 d | 1.51 ab | 0.77 c | 0.78 c | 1.18 b | 0.71 c | 0.46 b | 0.87 c | 0.75 d |
| Hay | 0.21 d | 1.14 c | 0.66 c | 1.37 b | †† | 1.03 c | 1.01 b | †† | 0.53 d | †† | †† | - | (0.67) |
| Peat | 0.75 c | 1.89 b | 1.05 a | - | 1.05 c | - | - | - | - | - | - | - | 1.19 b |
| White plastic house | | | | | | | | | | | | | |
| None | 0.68 c | 1.03 c | 0.78 b | 1.51 a | 1.09 c | 1.51 ab | 1.29 a | 2.01 a | 0.78 c | 0.95 b | 0.42 b | 1.10 b | 0.89 c |
| Hay | 1.37 b | 0.39 d | 0.73 bc | 1.56 a | 1.33 b | 1.42 b | 1.27 a | 1.47 b | 1.10 b | 1.26 a | 0.49 b | 1.13 b | 0.96 c |
| Peat | 1.63 ab | 1.74 b | 1.08 a | - | 1.73 a | - | - | - | - | - | - | - | 1.55 a |

* Recovery index = (original stem height + new growth - dieback) ÷ original height: 0 = death; 1 = no net growth after 1 flush; >1 = satisfactory survival and growth.

** Within columns, numbers followed by different letters are significantly different at the 5% level by the Duncan multiple range test.

† Included ponderosa pine, Scots pine, Siberian larch, and if available, bur oak.

†† Mouse damage prevented measuring original height and dieback.

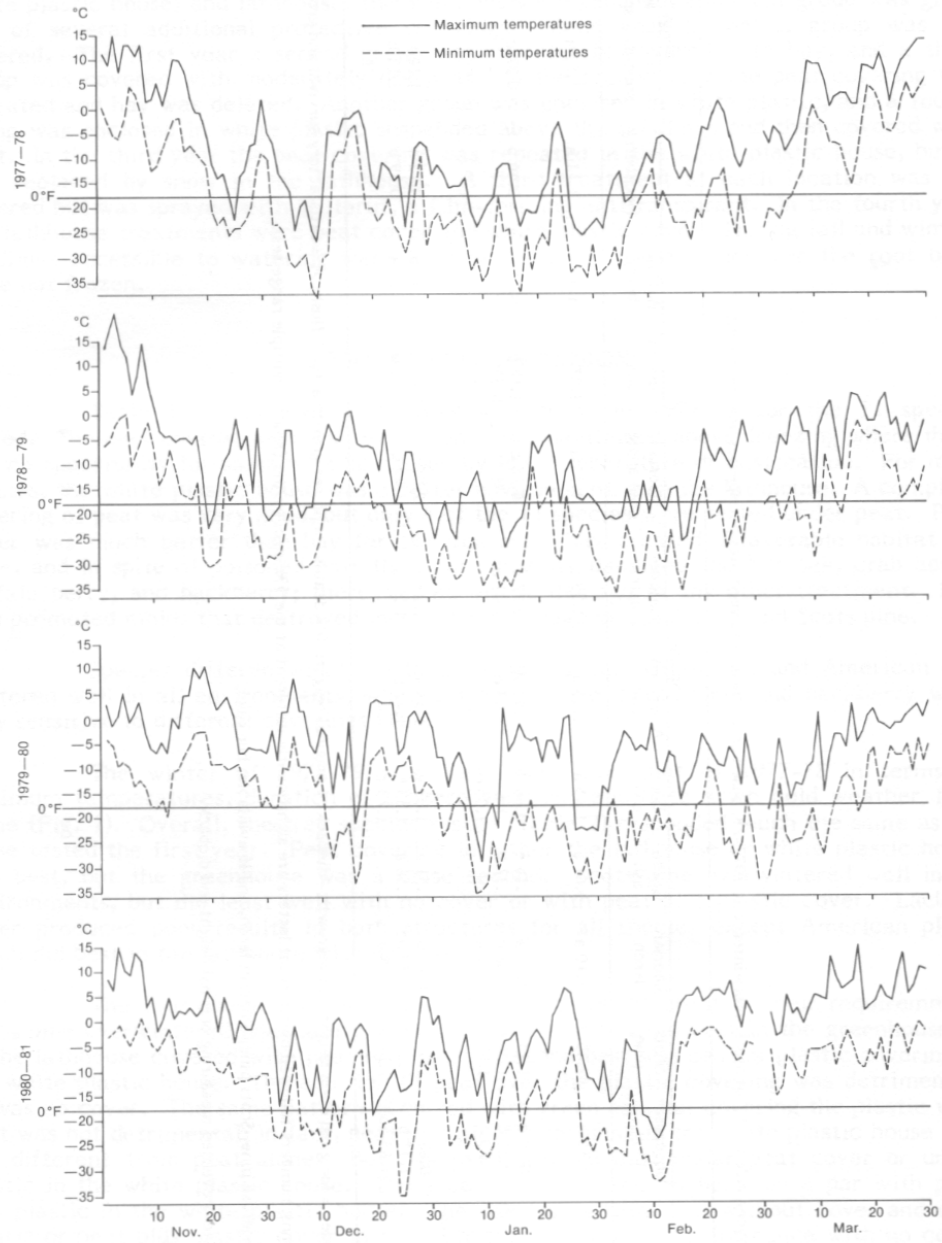


Figure 1. Daily air temperature ranges, November through March, at Bottineau, North Dakota. (A) 1977-78, (B) 1978-79, (C) 1979-80, (D) 1980-81.

Table 2. Recovery index* of stock overwintered in 1978-79, based on 30 measured seedlings per species per treatment

| Location/cover | Species: Scots pine | Green ash | Bur oak | American plum | Mean |
|---|---|---|---|---|---|
| Greenhouse | 2.71 a | 1.73 cd | 1.58 ab | 1.08 d | 1.78 |
| Lathhouse | | | | | |
| None | 1.94 c | 1.63 de | 0** | 1.74 a | 1.33 |
| Peat | 2.68 a | 2.14 ab | 1.76 a | 1.48 b | 2.02 |
| White plastic | 2.54 ab | 1.48 e | 0** | 0.93 e | 1.24 |
| White plastic + peat | 1.68 d | 1.65 de | 0** | 1.43 bc | 1.19 |
| White plastic house | | | | | |
| None | 1.40 e | 1.51 e | 0** | 0.72† | 0.91 |
| Peat | 2.29 b | 2.17 a | 1.70 a | 1.53 b | 1.92 |
| White plastic | 2.27 b | 1.91 bc | 1.73 a | 1.32 c | 1.81 |
| White plastic + peat | 1.63 d | 2.32 a | 1.46 b | 1.56 ab | 1.74 |

* Within columns, numbers followed by the same letter are not significantly different at the 5% level by the Duncan multiple range test.

** No survivors.

† One seedling survived.

white plastic house, but poor under plastic in the lathhouse. Performance in the greenhouse was also mediocre.

The winter of 1979-80 was milder than the previous two (Fig. 1). Minimum temperature went below -18°C (0°F) on November 21 in 1977, and on November 19 in 1978, but not until December 11 in 1979. Man more temperatures during December, January, and February of 1978-79 were above -18 C, and they went below -34°C (-30°F) only twice compared with five and six times the previous 2 years.

For ponderosa and Scots pines, the only treatments that were successful for the entire winter were snow cover in the lathhouse and peat cover in the white plastic house (Table 3). Bur oak overwintered satisfactorily in the white plastic house with peat cover or no cover, but Wiltpruf was apparently detrimental (Smith et al. 1977). Bur oak overwintered well in the lathhouse only when snow covered.

Unsuccessful treatments show a progressive decline in recovery index during the winter (Table 3). Large differences may indicate when the damage was done. Small differences, although statistically significant, are probably not meaningful because each month's sampling was allowed to flush at a different time in the greenhouse.

Inadvertently, another experiment was performed on Scots gine in the green-house. For years this species had been successfully overwintered at 1-3 C. This time the

Table 3. Recovery index* of stock overwintered in 1979-80, based on 15 measured seedlings per species per treatment per month

| Location: | Lathhouse | | | White plastic house | | |
|---|---|---|---|---|---|---|
| Cover: | None | Snow | Wiltpruf | None | Peat | Wiltpruf |
| Month | | | Ponderosa pine | | | |
| Dec. | 0 | 1.87 c | 2.17 b | 1.91 c | 2.54 a | 2.54 a |
| Jan. | 0.13 c | 1.39 b | 0.11 c | 1.70 a | 1.90 a | 1.78 a |
| Feb. | 0 | 1.66 a | 0 | 1.63 a | 1.62 a | 1.39 b |
| Mar. | 0 | 1.32 b | 0 | 1.37 b | 1.93 a | 0 |
| Apr. | 0 | 1.65 b | 0 | 0 | 3.11 a | 0 |
| | | | Scots pine | | | |
| Dec. | 1.68 bc | 1.26 d | 1.77 b | 1.31 d | 2.48 a | 1.52 c |
| Jan. | 1.41 b | 1.12 c | 0 | 1.36 b | 1.98 a | 1.27 bc |
| Feb. | 0 | 1.27 a | 0 | 0 | 1.26 a | 1.28 a |
| Mar. | 0 | - | 0 | 0 | 1.42 a | 1.31 a |
| Apr. | 0 | 1.35 b | 0 | 0 | 3.09 a | 0 |
| | | | Bur oak | | | |
| Dec. | 1.44 ab | 1.59 a | 1.27 c | 1.39 bc | 1.48 a | 1.37 bc |
| Jan. | 1.01 c | 1.50 a | 1.17 b | 1.02 c | 1.11 bc | 1.06 c |
| Feb. | 0 | 1.17 b | 1.14 bc | 1.04 c | 1.11 bc | 1.40 a |
| Mar. | 0 | 1.21 a | 0 | 1.10 a | 1.15 a | 0 |
| Apr. | 0 | 1.18 b | 0 | 1.30 ab | 1.44 a | 0.32 c |

* Within rows, numbers followed by the same letter are not significantly different at the 5% level by the Duncan multiple range test. Zeros indicate no survivors and were not included in the test.

greenhouse was held at -2°C, still far above the low temperature killing point of any of the tissues. The crop looked fine when it was removed from the greenhouse in the spring, but in a matter of days after field planting all of the trees turned brown and died. Inability of a frozen root ball to supply sufficient water to the shoot was undoubtedly the cause.

Temperatures in the white plastic house were generally higher, and the diurnal range greater, than in the lathhouse (Figs. 2, 3). Snow or peat cover were highly effective in raising mean root-ball temperatures and reducing root-ball temperature fluctuations. Snow or peat cover were also the most effective overwintering environments.

Moisture stress in green ash and bur oak was much higher than in ponderosa or Scots pine, but stress was not judged high enough to be lethal in any of them (Table 4). Empty xylem vessels in oak and ash may account for the high stress readings, unlike in the

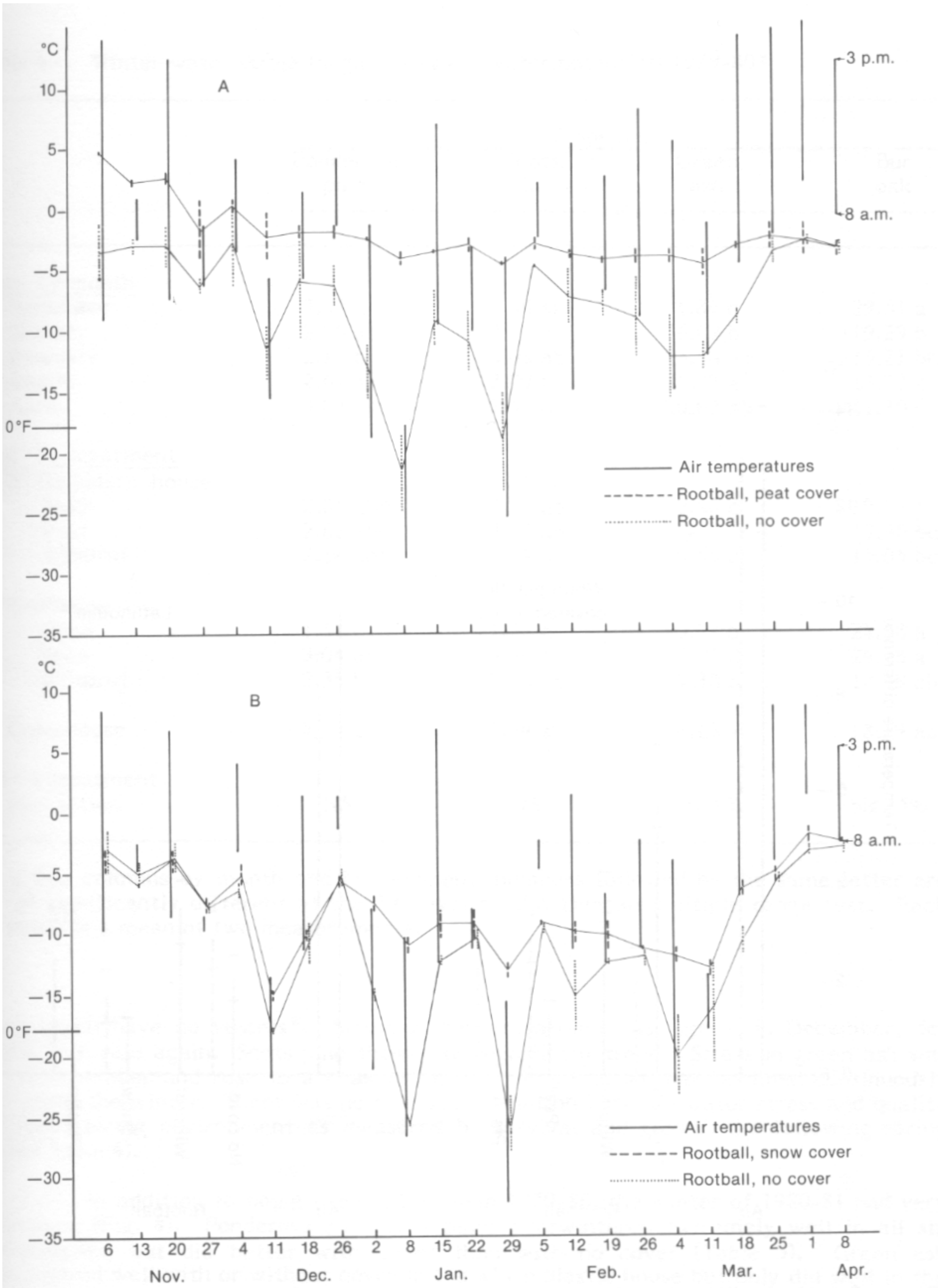


Figure 2. Daily air and root-ball temperature ranges (8 a.m. to 3 p.m.) measured at weekly intervals, November 1979 through March 1980, in the (A) white plastic house and (B) lathhouse.

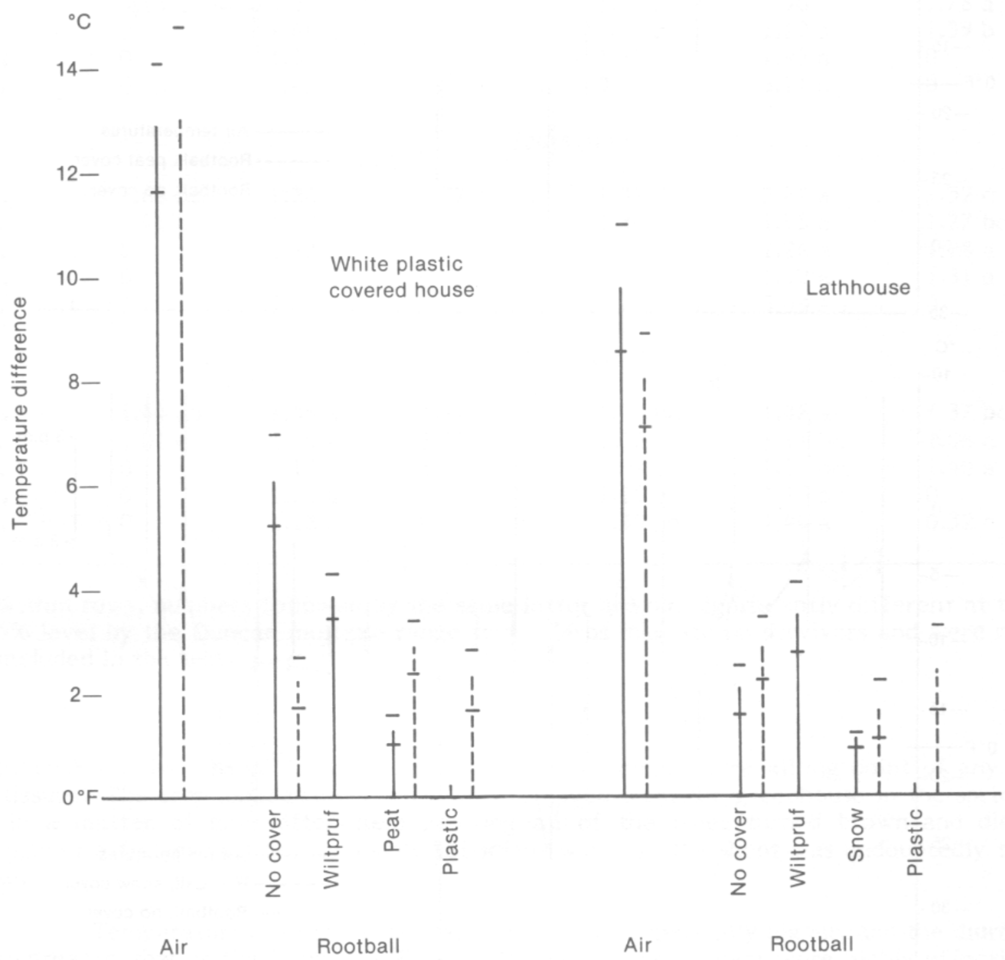


Figure 3. Mean difference between 3 p.m. and 8 a.m. air and root-ball temperatures, November through March, for the (A) white plastic house, (B) lathhouse. Solid lines are for 1979-80; dashed lines are for 1980-81. Horizontal lines represent plus and minus one standard error.

*Table 4. Winter water stress (negative xylem water potential) 1979-80**

| | Species | | | |
|---|---|---|---|---|
| | Ponderosa pine | Scots pine | Green ash | Bur oak |
| | bars | | | |
| Mean by month | | | | |
| December | 3.52 a | 3.40 ab | 1.84 c | 29.51 a |
| January | 2.54 ab | 3.94 a | 16.42 b | 19.29 b |
| February | 2.11 b | 3.08 ab | 23.38 ab | 15.21 bc |
| March | 2.62 ab | 2.29 b | 25.27 a | 13.72 c |
| April | 3.04 ab | 2.51 b | 20.03 ab | 11.70 c |
| Mean by treatment | | | | |
| White plastic house | | | | |
| None | 2.85 abc | 3.27 ab | 10.46 c | 10.74 c |
| Peat | 2.68 abc | 3.76 ab | - | 13.90 bc |
| Wiltpruf | 2.86 abc | 2.84 b | 10.54 c | 15.05 bc |
| Lathhouse | | | | |
| None | 1.51 c | 1.56 c | 20.97 b | 24.38 a |
| Snow | 3.04 ab | 3.96 a | 3.81 d | 24.48 a |
| Wiltpruf | 2.34 bc | 2.38 bc | 24.38 b | 18.49 ab |
| Greenhouse | 4.13 a | 3.54 a | 34.15 a | 18.19 ab |
| Date x treatment interaction | NS | NS | Sig. 5% | Sig. 5% |

* Within columns by month and by teatment, numbers followed by the same letter are not significantly different at the 5% level by the Duncan multiple range test. Each figure is a mean of two measurements.

*pines, which have no vessels*[2]. *Stress in ponderosa pine was highest in December, de-*clined, then rose again. Scots pine showed no significant trend. Stress in green ash was low in November and rose to a peak in March. Stress in bur oak declined continuously throughout the winter. There was no consistent relation between water stress and quality of overwintering environment as measured by survival and growth the following spring (Tables 3 and 4).

*In addition to being even milder than 1979-80, the winter of 1980-81 had very* little snow (Fig. 4). Ponderosa and Scots pines overwintered extremely well in all six environments, but did better with cover than with no cover (Table 5). Green ash overwintered well with or without cover in the white plastic house but only did well in the lathhouse without cover. Bur oak overwintered best under cover in the white

2 *Personal communication from Merrill Kaufmann, plant physiologist, Rocky Mountain* Forest and Range Experiment Station, Fort Collins, Colorado.

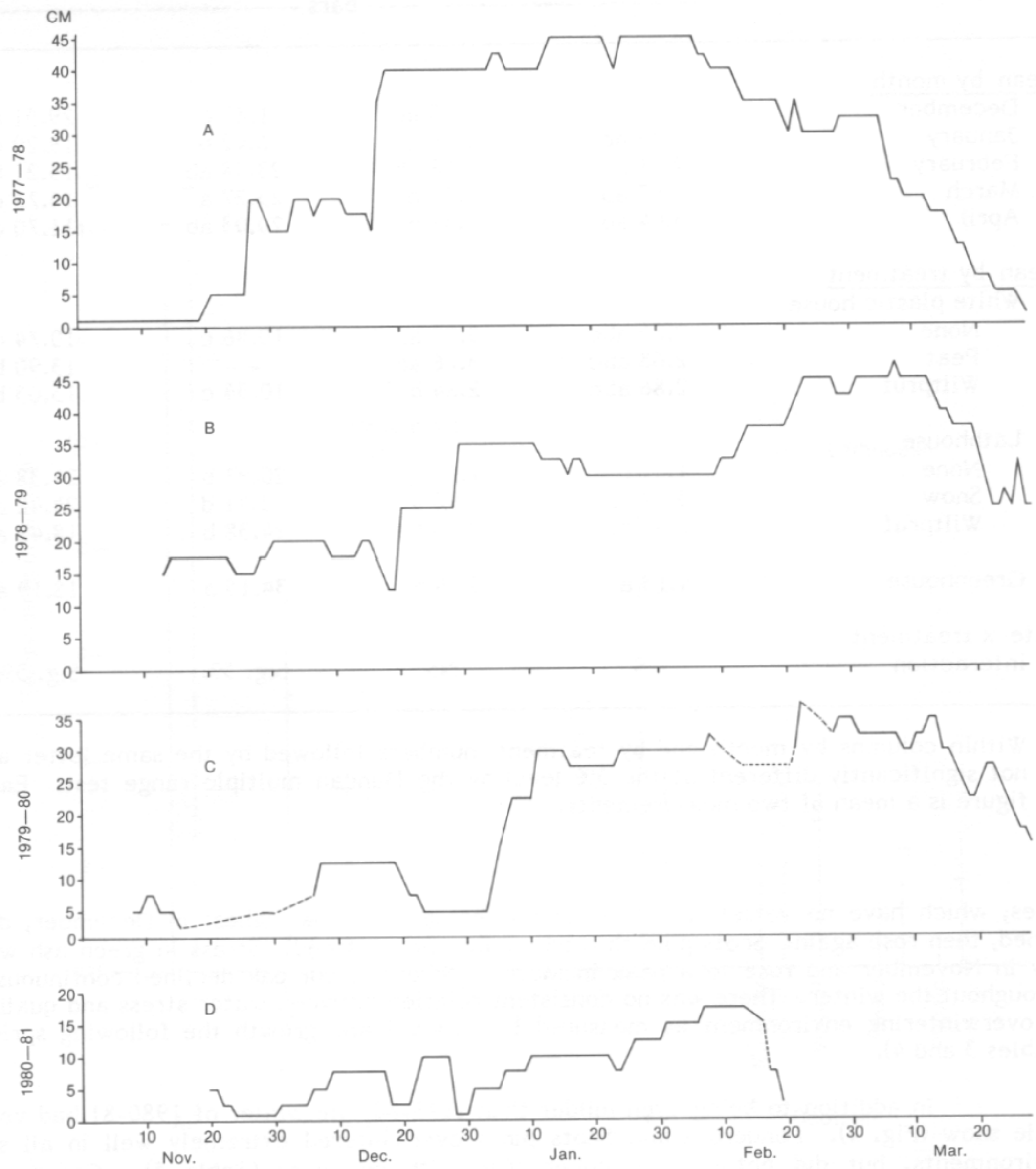


Figure 4. Daily snow cover at Bottineau, North Dakota, November through March. (A) 1977-78, (B) 1978-79, (C) 1979-80, (D) 1980-81. Dashes indicate no data available.

Table 5. Recovery index* of stock overwintered in 1980-81, based on 8 measured seedlings per species per treatment per month

| Location/cover | Ponderosa pine | Scots pine | Green ash | Bur oak |
|---|---|---|---|---|
| Mean by month | | | | |
| November | 2.73 b | 3.08 a | 1.71 a | - |
| December | 2.78 b | 3.44 a | - | 1.05 ab |
| January | 3.14 a | 3.41 a | 1.55 a | 0.94 bc |
| February | 2.92 ab | 3.45 a | - | 0.87 c |
| March | 2.48 c | 3.49 a | 1.52 a | 1.17 a |
| Mean by treatment | | | | |
| Lathhouse | | | | |
| None | 2.46 d | 3.08 c | 1.47 a | 1.09 a |
| Snow | 2.94 ab | 3.95 a | - | 0.89 c |
| White plastic | 3.05 a | 3.26 bc | 0.13 b | 0.77 c |
| White plastic house | | | | |
| None | 2.64 cd | 3.06 c | 1.45 a | 0.98 bc |
| Peat | 3.05 a | 3.26 bc | 1.53 a | 1.11 ab |
| White plastic | 2.76 bc | 3.61 ab | 1.63 a | 1.20 a |
| Date x treatment interaction | NS | NS | NS | NS |

* Numbers within columns followed by the same letter are not significantly different at the 5% level by the Duncan multiple range test.

plastic house and without cover in the lathhouse. The pattern of minimum temperatures and diurnal temperature fluctuation was much the same as in the previous year (Table 6, Fig. 3). Pressure bomb measurements were more consistent than in the previous year (Table 7). For each species, water stress declined from November to a low in December or January and was followed by an increase to the November level (oak and ash) or higher (ponderosa and Scots pines). Lowest stress was under white plastic or peat in the white plastic house. Stress under other environments was somewhat higher. Although absolute stress levels varied, all four species behaved similarly with respect to environment and date. As before, the water stresses measured were not great enough to be lethal.

## CONCLUSIONS AND SUMMARY

For most of the species tested, the most reliable overwintering environment is a greenhouse held just above freezing by appropriate heating and cooling. The disadvantages of this method are (1) it is more expensive than necessary and (2) in late winter, as the days lengthen and the sun's angle rises, it may become difficult to hold daytime ternperatures down and the seedlings may have to be moved to another environment to prevent breaking of dormancy (Litzow and Pellett 1980).

Table 6. Minimum temperatures recorded during overwintering

| Location/cover | °C 1979-80 | 1980-81 |
|---|---|---|
| Lathhouse | | |
| Air | -32 | -36 |
| Root ball/none | -28 | -22 |
| Root ball/peat | -15 | -22 |
| Root ball/plastic | - | -21 |
| White plastic house | | |
| Air | -29 | -24 |
| Root ball/none | -25 | -14 |
| Root ball/peat | -6 | -12 |
| Root ball/plastic | - | -18 |

Table 7. Winter water stress* (negative xylem water potential) 1980-81

| | Species: Ponderosa pine | Scots pine | Bur oak | Green ash |
|---|---|---|---|---|
| | bars | | | |
| Mean by month | | | | |
| November | 2.9 b | 3.2 bc | 10.7 b | 7.3 a |
| December | 2.3 b | 2.0 c | 4.4 c | - |
| January | 2.5 b | 1.4 c | 11.0 b | 2.9 b |
| February | 3.8 ab | 4.5 b | 15.8 a | - |
| March | 5.7 a | 8.3 a | 10.8 b | 7.6 a |
| Mean by treatment | | | | |
| White plastic house | | | | |
| None | 2.9 b | 3.6 a | 9.4 bc | 3.1 b |
| White plastic | 3.0 b | 3.4 a | 7.7 c | 3.8 b |
| Peat | 4.1 a | 3.9 a | 10.2 b | 6.0 a |
| Lathhouse | | | | |
| None | 3.2 ab | 4.2 a | 13.4 a | 6.1 a |
| White plastic | 3.2 ab | 4.2 a | 11.8 ab | 5.3 ab |
| Snow | 4.1 a | 4.0 a | 10.8 b | 7.3 a |
| Date x treatment interaction | NS | NS | NS | NS |

* Within columns by month and treatment, numbers followed by the same letter are not significantly different at the 5% level by the Duncan multiple range test. Each figure is a mean of four measurements.

At Bottineau, however, it is quite possible to overwinter stock successfully in unheated and even open structures. Burial under snow or slightly moist peat provides an excellent and reliable environment for Scots and ponderosa pines and many of the hardwood species tested. Snow has the advantage that it leaves no residue that must be removed prior to shipment, but it is not always available when needed. If melting occurs, snow cover may result in saturated root balls and exposed tops, which are detrimental. Other covers were intermittently successful, and sometimes with hardwoods the best results were obtained with no cover.

Why this is so is still not clear. Snow and peat coverings raised minimum rootball temperatures substantially; however, temperatures measured over the winters of 1979-80 and 1980-81 were never below the expected killing points of the species tested (Havis 1976; Studer et al. 1978), although the killing points of the seedlings in this experiment were not actually measured.

There was not much difference between environments in measured water stresses, none of which was high enough to be lethal (Cleary and Zaerr 1980; Heth 1980). Because there is no demonstrated correlation between water stress and subsequent survival and growth, water stress measurements would not provide the nurseryman with useful information on overwintering success.

The recovery index as defined here appears to be sensitive to the important variables in the overwintering environment, but its absolute magnitude varies with species, the degree of bud development before overwintering, and the conditions of flushing afterwards. In other words, it is a relative index of overwintering success.

**LITERATURE CITED**

Blackler, M.H. 1974. Winter hardiness in woody perennials. Commonwealth Bureau of Horticulture and Plantation Crops, East Mailing, Kent, England. Rep. 41/74.

Burke, M.J., L.V. Gusta, H.A. Quamme, C.J. Weiser, and P.H. Li. 1976. Freezing and injury in plants. Annu. Rev. Plant Physiol. 27:507-528.

Carlson, L.W. 1979. Guidelines for rearing containerized conifer seedlings in the prairie provinces. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-214.

Cleary, B. and J. Zaerr. 1980. Pressure chamber techniques for monitoring and evaluating seedling water status. N.Z. J. For. Sci. 10:133-141.

Desjardins, R.L. and C. Chong. 1980. Unheated environments for overwintering nursery plants in containers. Can. J. Plant Sci. 60:895-902.

Davidson, H. and R. Mecklenburg. 1974. Overwintering of evergreens in plastic structures. HortScience 9(5):479-480.

Fretz, T.A. and E.M. Smith. 1978. Woody ornamental winter storage. HortScience 13(2):139-140.

Gouin, F.R. 1980. Overwintering container-grown ornamentals under thermo-blankets with and without clear, white, or black polyethylene. HortScience 15(4):491492.

Gouin, F.R. and C.B. Link. 1979. Temperature measurements, survival, and growth of container-grown ornamentals, overwintered unprotected, in nursery shelters and under microfoam thermo-blankets. J. Am. Soc. Hortic. Sci. 104(5):655658.

Havis, J.R. 1976. Root hardiness of woody ornamentals. HortScience 11(4):385-386.

Havis, J.R. and R.D. Fitzgerald. 1976. Winter storage of nursery plants. University of Massachusetts, Amherst, Mass. Coop. Ext. Serv. Publ. 125.

Heth, D. 1980. Root and shoot water potential of stressed pine seedlings. N.Z. J. For. Res. 10(1):142-147.

Johnson, J.R. and J.R. Havis. 1977. Photoperiod and temperature effects on root cold acclimation. J. Am. Soc. Hortic. Sci. 102(3):306-308.

Litzow, M. and H. Pellett. 1980. Relationship of rest to dehardening in red-osier dogwood. HortScience 15(1):92-93.

Owston, P.W. and W.I. Stein. 1977. Production and use of container seedlings in the west. Pages 117-125 *in* W. Loucks (ed.). Proceedings of the Intermountain Nurserymen's Association Annual Meeting, Manhattan, Kansas.

Sakai, A. 1970. Mechanism of desiccation damage of conifers wintering in soil-frozen areas. Ecology 51(4):657-664.

1978. Low temperature exotherms of winter buds of hardy conifers. Plant Cell Physiol. 19(8):1439-1446.

Smith, E.M. and C.D. Mitchell. 1977. An evaluation of structures in overwintering woody ornamentals. Pages 31-33 *in* Ornamental plants--1976. A summary of research. Ohio Agric. Res. Dev. Cent., Wooster. Res. Circ. 226.

Smith, E.M., G.A. Theil, and C.D. Mitchell. 1978. An investigation into the cause of conifer damage in nursery storage. Ohio Agric. Res. Dev. Cent., Wooster. Res. Circ. 236:21-23. Wooster.

Smith, E.M., C.D. Mitchell, J. Aylsworth, and R. 12aker. 1977. Evaluation of polyfilm coverings in overwintering woody ornamentals: Part III. Protecting plants within structures. Pages 11-12 in Ornamental plants--1976. A summary of research. Ohio Agric. Res. Dev. Cent., Wooster. Res. Circ. 226.

Studer, E.J., P.L. Steponkus, G.L. Good, and S.C. Wiest. 1978. Root hardiness of container-grown ornamentals. HortScience 13(2):172-174.

Tinus, R.W. and S.E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colorado. Gen. Tech. Rep. RM-60.

Van den Driessche, R. 1969. Influence of moisture supply, temperature, and light on frost-hardiness changes in Douglas fir seedlings. Can. J. Bot. 47(11):17651772.

Wiest, S.C. 1980. The three-dimensional redistribution of water and solutes in a frozen container medium. J. Am. Soc. Hortic. Sci. 105(4):620-624.

Wiest, S.C., G.L. Good, and P.L. Steponkus. 1976. Analysis of thermal environments in polyethylene overwintering structures. J. Am. Soc. Hortic. Sci. 101(6):687692.

Williams, R.J. 1974. A unified model of plant hardiness based on osmotic stress. Cyrobiol. Abstr. 11(6):555.

Zalasky, H. 1977. Bibliography of frost damage in tree nurseries. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-190.