Tree Planter's Notes, Vol. 47, No. 2 (1996)

Cold Hardiness Testing to Time Lifting and Packing of Container Stock: A Case History

Richard W. Tinus

Plant physiologist, USDA Forest Service, Flagstaff, Arizona

A model of cold hardening and dehardening was developed for ponderosa pine (Pinus ponderosa *var.* scopulorum *Engelm.) and Douglas-fir* (Pseudotsuga menziesii *var.* glauca *(Beissn.) Franco), and was used in conjunction with cold hardiness testing to decide when to begin lifting and packing container stock into cold storage, and when packing should be completed.* Tree Planters' Notes 47(2):62-67; 1996.

Over the last 15 years, physiological tests have been developed and are coming into widespread use in reforestation programs to measure and track the quality of planting stock (Tanaka and others 1994). One of the most useful characteristics to test for is cold hardiness— not only because trees usually need some degree of hardiness to tolerate cold storage and the conditions they will encounter on the planting site but also because it is a useful indicator of root growth potential (RGP) and bud dormancy (Burr and others 1989; Tinus and others 1986). Furthermore, cold hardiness is quicker to measure than RGP or bud dormancy, and given enough data, lends itself to creation of predictive models. This paper describes the use of cold hardiness testing to

- Aid in deciding whether to accept a contract-grown container seedling crop.
- Produce a predictive model of cold hardiness.
- Determine when lifting and packing into cold storage should begin, and when it should be completed.

In February 1995, there was concern about container seedlings received at the USDA Forest Service Payson Ranger District in Arizona that (1) they may not have been dormant, (2) buds were not present or not well developed, (3) there was too much root growth, (4) they got too warm in transit, and/or (5) the caliper was too small. Although a morphological examination yielded tentative answers to all of the concerns, I tested them to provide additional information in support of a management decision on whether to accept and plant the seedlings.

Samples of ponderosa pine— *Pinus ponderosa* var. *scopulorum* Engelm.— seedlings were tested for cold hardiness by freezeinduced electrolyte leakage (FIEL) and RGP. The test for FIEL can give precise answers and be completed in 3 days. Determination of RGP takes 7 days (Burr and others 1987). Both tests have proven useful for management decisons (Burr and others 1986, 1989). The 50% index of injury from FIEL was -18 /C, which is about half of maximum cold hardiness, and the shape of the cold injury versus temperature curve suggested that although the seedlings were losing hardiness, the RGP was high. On this basis, I recommended that the trees be accepted and planted. However, the cold hardiness tests indicated that packing should have been completed some time earlier.

Because the Forest Service had contracted with the same nursery to produce a crop for 1996, I offered to model cold hardiness as a function of temperature and photoperiod for ponderosa pine and Douglas-fir— *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco— so that, in the fall and winter, cold hardening could be tracked in real time using local weather records. The model could be used in conjunction with FIEL and RGP tests to tell the nursery when to begin lifting and packing into cold storage and when it should be finished.

The model was developed using data from a growth-room study in which ponderosa pine and Douglas-fir were exposed to a simulated fall, winter, and spring over 25 weeks (Tinus and others 1995). Cold hardiness was measured weekly as the trees hardened and dehardened under 5 different combinations of photoperiod lengths and day and night temperatures (figure 1). Rates of hardening and dehardening were calculated by linear regression on segments of the hardening curve (figure 2), and the regressions assembled to yield daily rates of hardening as a function of temperature (figure 3). Other rules governing whether the trees would harden or deharden in response to photoperiod, temperature, and degree of hardiness were factored in based on previous work (Burr and Tinus 1988; Leinonen and others 1995). The complete model is presented on page 67.

Daily maximum, minimum, and average temperatures from the reporting weather station at the New Mexico State University Horticulture Farm for the last 4 years (figure 4A-D), were used to model the cold hardiness of ponderosa pine and Douglas-fir for the months of October through February (figure 5A-D). The lifting and packing window was considered to open when the 50% index of injury fell below -22 /C. Previous work has shown that at this point RGP has doubled or more

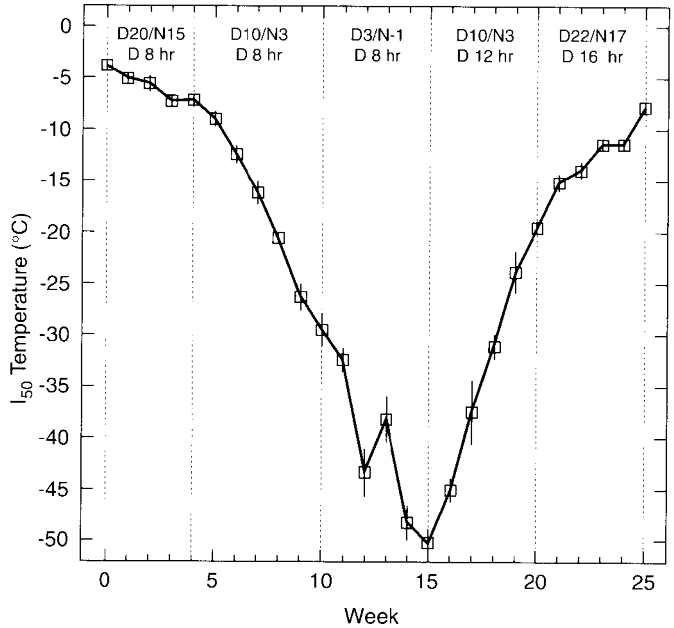

Figure 1—*Douglas-fir cold hardiness measured by freeze-induced electrolyte leakage during a 25- week growth-room experiment. Day/night temperatures and photoperiod are indicated for each segment at the top. Error bars are the 95% confidence intervals.*

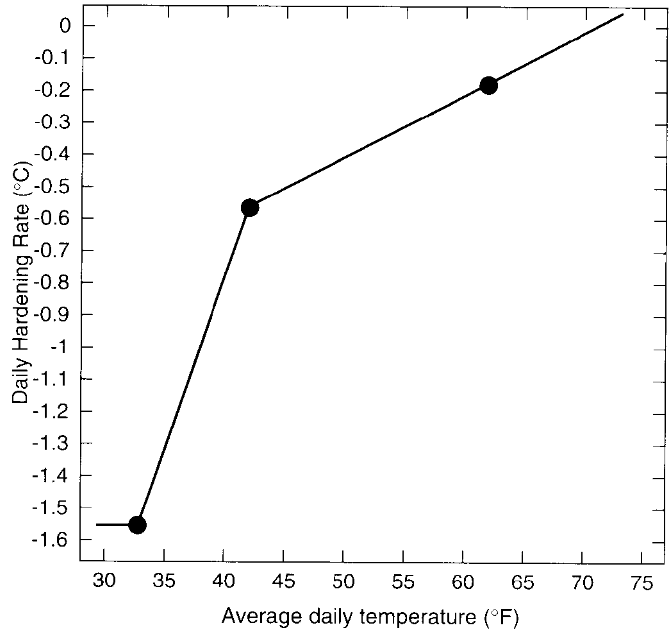

Figure 3—*Cold hardening rates of Douglas-fir as a function of average daily temperature (°F were used to avoid having to convert all the weather records).*

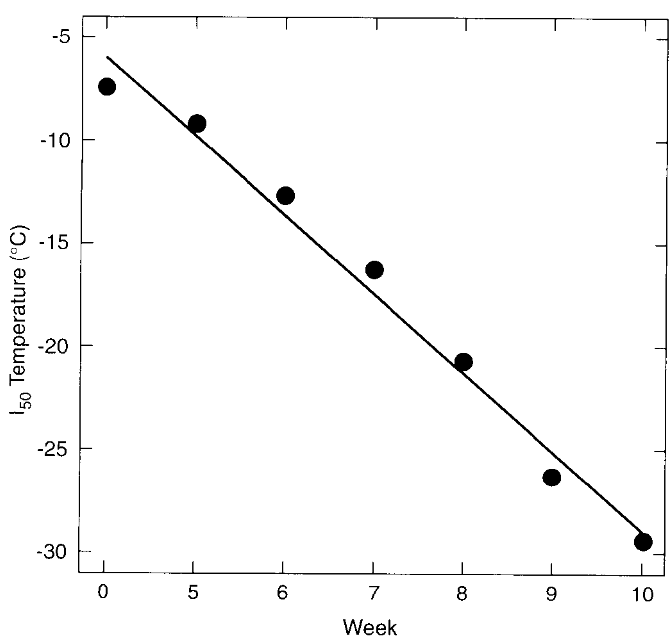

Figure 2—*One of several regression lines calculated from segments of figure 1. The slope of the line is the rate of cold hardening.*

from its late summer low, the chilling requirements for budbreak have been met, and the seedlings will continue to gain cold hardiness when placed in cold storage (Burr and others 1989; Tinus and others 1986). The packing window was considered to close when a significant amount of cold hardiness had been lost, in this case about 5 /C from the maximum.

Examination of figure 4A-D shows that year-to-year temperature patterns are different, causing differences in timing and rate of hardening and dehardening, and the degree of hardiness achieved (figure 5A-D). The 1 measurement taken in February 1995 (figure 50 showed that the model underestimated cold hardiness of ponderosa pine by about 3 /C. A possible reason for this is that the New Mexico State University Horticulture Farm weather station is about 100 to 150 m lower in elevation and on the edge of the heat island created by the city of Las Cruces but the nursery is 16 km away. This means that the seedlings at the nursery probably had been exposed to temperatures a few degrees colder than the temperatures used to drive the model. The model also indicated that packing should have been completed in midJanuary.

I began modelling cold hardiness in early November 1995 so that the Forest Service contracting officer could be notified when the nursery should start lifting and when packing into cold storage should be finished. The NMSU Horticulture Farm's weather data are updated daily and are available on the Internet (http: / /weather.nmsu.edu/sum96/nmsue96.sum gets you the 1996 data, for instance), which allowed weekly updating of the model (figure 5D). This was important, because each year is different, and one cannot predict the weather accurately more than a week in advance.

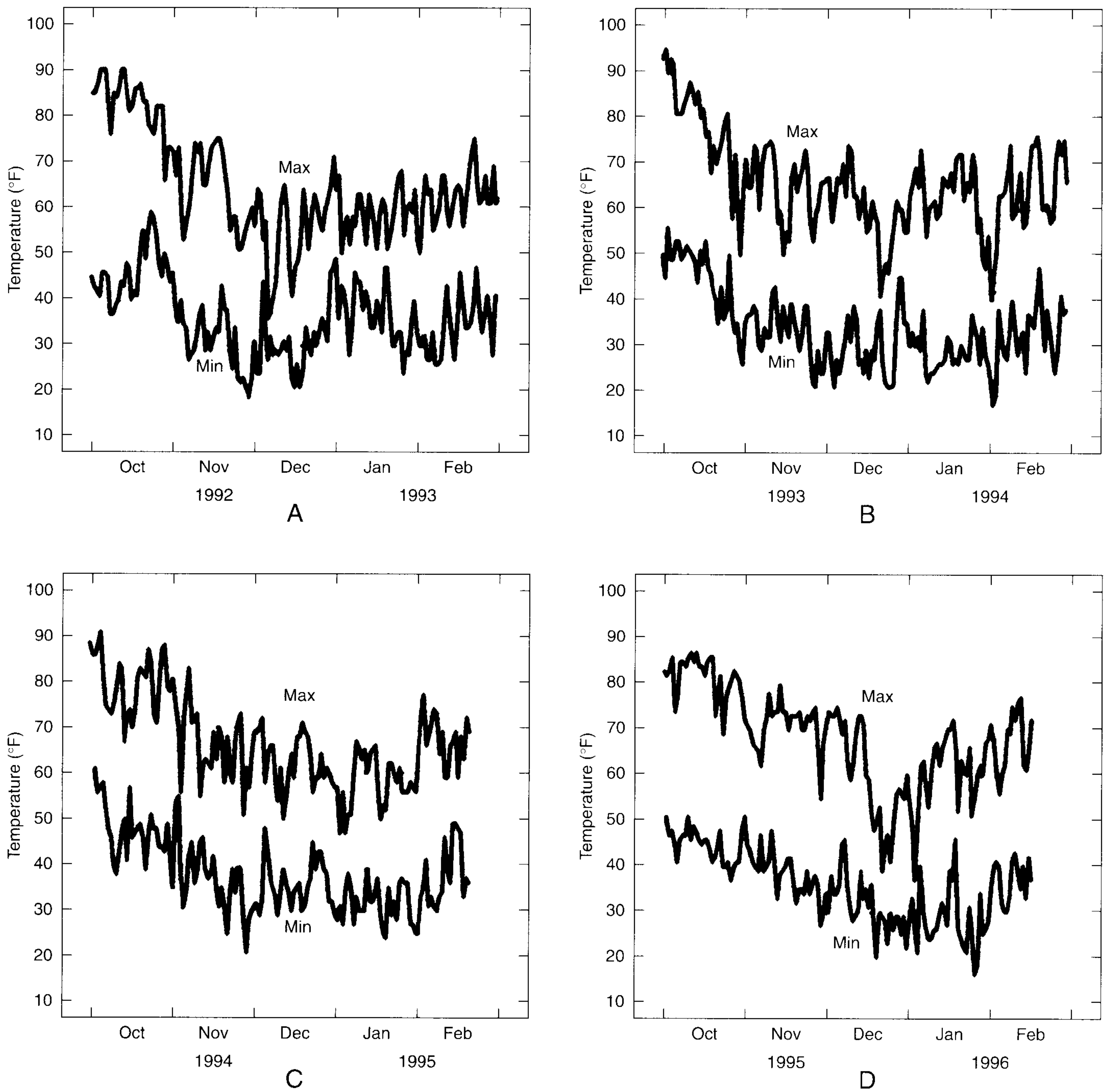

Figure 4—*Daily maximum and minimum temperatures at the New Mexico State University Horticulture Farm, Las Cruces, NM.*

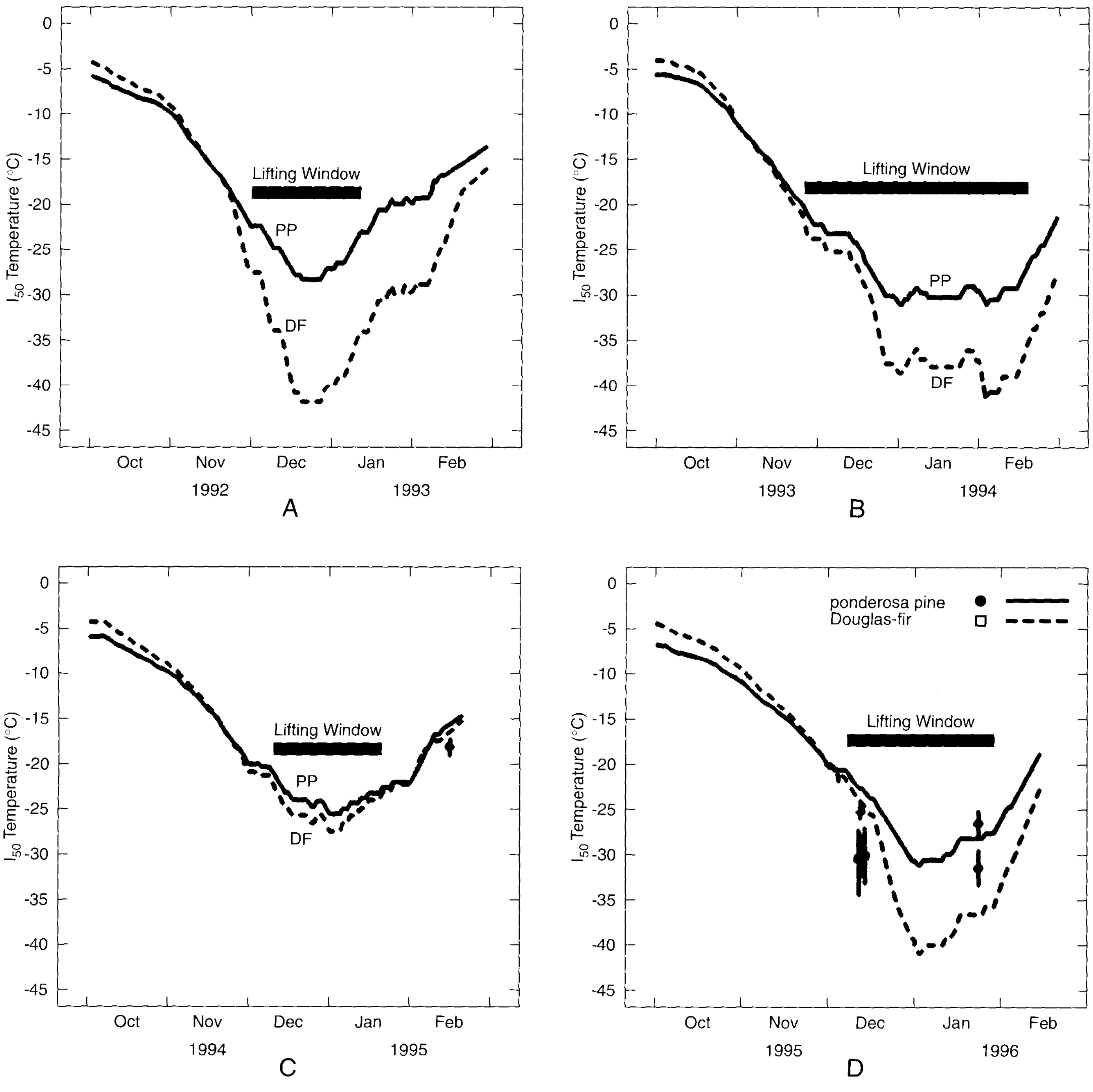

Figure 5—*Cold hardiness of ponderosa pine and Douglas-fir as estimated by the model (solid and dashed lines) and measured by FIEL (data points; error bars are the 95% confidence intervals). The lifting window opens when the 50% index of injury reaches −22 °C and closes when 5 °C of cold hardiness have been lost from the maximum.*

The model indicated that the lifting window opened December 8, because the 50% a index of injury for both ponderosa pine and Douglas-fir had reached -22 /C. The nursery sent samples from 2 lots of each species by overnight mail for FIEL and RGP testing. Once again, the model underestimated cold hardiness, and by December 13, it was clearly time to begin lifting and packing. This was 3 weeks earlier than originally planned (figure 5D). The RGP was very satisfactory, ranging from 23 to 33 roots/seedling after 7 days in a mist chamber at 19 /C.

The model indicated that maximum cold hardiness was reached on January 2 and was being lost thereafter due to rising maximum day temperatures (figure 4D). However, the loss was slow thoughout January because of continued subfreezing night temperatures. By January 18, it looked as though the end of the packing window was about a week away, so another set of samples was tested. Two lots of ponderosa pine and no Douglas-fir were sent, representing only trees that had not yet been packed and from different seedlots than were tested in December. The trees were still quite hardy and close to what the model predicted, but the 2 lots were significantly different (figure 5D). The lot with the greater hardiness had been stored outside, while the less hardy one had been kept in a greenhouse. The RGP was 30 and 39 roots/seedling for the 2 lots. The measurements confirmed that as of January 24, it was still OK to pack, but that packing must end soon, as local temperatures were rising.

Packing was completed January 30, and it is expected that the seedlings in cold storage were fully dormant and in good physiological condition. Had the model not been run in real time and its results made available to the contracting officer weekly and confirmed by 2 sets of FIEL and RGP tests, lifting and packing would have been started after January 1 on a schedule planned months earlier based on guesswork and managerial convenience, and probably would have continued into late February once again, well after the packing window ended.

This case history shows how the use of a cold hardiness model in conjunction with testing can be a valuable and practical strategy for determining lifting and packing windows. However, the information will not be complete until field performance of seedlings lifted and packed within and outside of the modelled windows are compared.

Address correspondence to: Dr. Richard W. Tinus, USDA Forest Service, Southwest Forestry Complex, 2500 South Pine Knoll Drive, Flagstaff, AZ 86001; e-mail: /s=r.tinus/OUl=S28L02A@fswamhs.attmail.com

References

Burr KE, Tinus RW, Wanner SJ, King RM. 1986. Comparison of four cold hardiness tests on three western conifers. In: Landis TD, tech. coord. Proceedings, Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting; 1986 August 12-15; Tumwater, WA. Gen. Tech. Rep. RM-137. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 80-86.

Burr KE, Tinus RW, Wallner SJ, King RM. 1987. Comparison of time and method of mist chamber measurement of root growth potential. In: Landis TD, tech. coord. Meeting the challenge of the nineties; Proceedings, Intermountain Nursery Association; 1987 August 12-14; Oklahoma City, OK. Gen. Tech. Rep. RM-151. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 77-86.

Burr KE, Tinus RW, Wallner SJ, King RM. 1990. Comparison of three cold hardiness tests for conifer seedlings. Tree Physiology 6(4): 351-369.

Burr KE, Tinus RW. 1988. Effect of the timing of cold storage on cold hardiness and root growth potential of Douglas-fir. In: Landis TD, tech. coord. Proceedings, Combined Meeting of the Western Forest Nursery Associations; 1988 August 811; Vernon, BC. Gen. Tech. Rep. RM-167. Fort Collings, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 133-138.

Burr KE, Tinus RW Wallner SJ, King RM. 1989. Relationships among cold hardiness, root growth potential, and bud dormancy in three conifers. Tree Physiology 5: 291-306.

Leinonen I, Repo T, Hanninen H, Burr K. 1995. A second-order dynamic model for the frost hardiness of trees. Annals of Botany 76: 89-95.

Tanaka Y, Brotherton P, Hostetter S, Dyce S, Chapman D, Belanger J, Johnson B, Duke S. 1994. The operational seedling testing program at Weyerhaeuser. In: Landis TD, Dumroese RK, tech. coord. National Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. RM-257. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 256-260.

Tinus RW, Burr KE, Wanner SJ, King RM. 1986. Relation between cold hardiness, root growth capacity, and bud dormancy in three western conifers. In: Landis TD, tech. coord. Proceedings, Combined Meeting of the Western Forest Nursery Council and Intermountain Nursery Associations; 1986 August 12-15; Tumwater, WA. Gen. Tech. Rep. RM-137. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 87-95.

Tinus RW, Greer DH, Robinson LA. 1995. Effect of high C02 on cold acclimation and deacclimation of three conifers. In: Tinus RW, ed. Interior West Global Change Workshop. 1995 April 25-27; Fort Collins CO. Gen. Tech. Rep. RM-257. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 48-50.

Cold Hardiness Model of Rocky Mountain Ponderosa Pine and Douglas-fir

A model was produced to estimate the cold hardiness of ponderosa pine and Douglas-fir being grown at Las Cruces, NM, based on daily maximum, average, and minimum temperatures and the dynamics of cold hardiness that have been learned over the last 10 years, primarily at Fort Valley, AZ, in 1988 and the experiments run in New Zealand in 1993–1994. The model is not very smooth but gives answers that look very reasonable.

General Rules for Both Species

1. No hardening occurs before October 1. Photoperiod is too long and temperatures too warm.
2. Minimum hardiness is assumed on October 1 and hardening proceeds according to the temperature-dependent first stage.
3. Warm temperatures do not deharden until LT_{50} reaches − 22 °C. Then warm temperatures do reverse hardening. This could happen in November.
4. In December below-freezing nights permit hardening with maximum day temperature up to 15.5 °C. No hardening occurs if maximum day temperature is warmer. If minimum night temperature is warmer than +1.5 °C, then no hardening occurs, if day temperature is greater than 10 °C. If maximum day temperature is greater than 15.5 °C and minimum night temperature is greater than 4.5 °C, then dehardening occurs.
5. In January and February, dehardening occurs if maximum day temperature >10 °C, and mimimum night temperature >3 °C. Dehardening occurs if maximum day temperature >15.5 °C and minimum night temperature >0 °C. Hardening occurs when maximum day temperature <5.5 °C and minimum night temperature <0 °C. If none of these conditions prevail, hardiness does not change.

Species-Specific Rules

PONDEROSA PINE:

Minimum cold hardiness: LT_{50} = −6.5 °C

Hardening rates:
When average daily temperature (T) >5.5 °C, then daily change (CH) in LT_{50} is: CH = −0.675 + 0.0318*T
When average daily temp < 5.5 °C, then daily change in LT_{50} is 0.50 °C and does not change with temperature.

Dehardening rates:
When LT_{50} is lower than −16 °C, daily loss of hardiness = 0.59 °C.
When LT_{50} is warmer than −16 °C, daily hardiness loss = 0.19 °C.

DOUGLAS-FIR:

Minimum cold hardiness: LT_{50} = −3.9 °C

Hardening rates:
When average daily temperature (T) >5.5 °C, daily change in LT_{50} is: CH = −0.75 + 0.0345*T
When average daily temperature is 5.5 °C, >T<0.5 °C, daily change in LT_{50} is: CH = −1.649 + 0.198*T
When average daily temp T< 0.5 °C, daily change in LT_{50} is −1.55 °C and does not change with temperature.

Dehardening rates:
When LT_{50} is lower than −18.3 °C, daily loss of hardiness is 0.87 °C.
When LT50 is warmer than −18.3 °C, daily loss of hardiness is 0.27 °C.