CHAPTER TWENTY-SEVEN

Cold Injury

Frost Damage; Frost Heaving; Winter Desiccation

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Cold injury is the result of plant cells killed by temperatures at or below freezing. The extent and degree of injury depend on many factors, and predicting exactly when frost damage is going to occur is difficult.

Frost damage may be confused with:
Mechanical damage
Pesticide damage
Phomopsis canker
Sirococcus tip blight
Tip blight of pine
Upper stem canker

Symptoms appear:
1+0, 2+0, transplants
Late spring and early fall

A good description of how frost can damage plants is given by McDonald, who says that frosts can be divided into two categories: radiation frosts, and wind and advection frosts. The two types may occur simultaneously, and in some instances a radiation frost may intensify a wind frost.

Radiation frosts occur on cloudless nights with little or no wind, when excessive amounts of heat energy in the soil and plants are lost to the sky as long-wave radiation. Temperatures of leaves, air near the ground, and the soil surface may fall below freezing. Advection frosts occur when cold air flows from a higher location to a lower one, displacing lighter, less dense warm air. Such flows will pool and concentrate if they encounter an obstruction, causing a "frost pocket." Wind in excess of 4 mph from cold regions causes a wind frost, which can occur at any time of the day or night and is not necessarily related to topography.

Two other types of cold-weather damage occur in Pacific Northwest bareroot nurseries: frost heaving and winter desiccation. Frost heaving leaves seedling roots partly or totally uncovered due to alternate freezing and thawing of soils. Winter desiccation is the result of cold or frozen soils inhibiting uptake of moisture by roots so that part or all of the seedling top desiccates and dies.

Figure 27-1. Cold-damaged Douglas-fir seedling; typical needle yellowing later turns brown. Oregon Department of Forestry photo.

Occurrence

Woody plants of the temperate zones undergo a distinct seasonal change in their ability to withstand cold. As a general rule, they are damaged easily by temperatures of 0 degrees C (32 degrees F) or just below during the growing season, but can stand much lower temperatures without damage during dormancy. The hardening and dehardening of plants do not occur on the same dates each year. Frost resistance is influenced by a combination of environmental factors, primarily temperature, day length, and moisture—factors that vary from one year to the next.

Seedlings are most often injured in fall when they have not acquired enough coldhardiness to withstand early frosts, and in spring when a late frost occurs after seedlings deharden. Frost damage can occur in all Pacific Northwest nurseries, although the degree of potential damage varies with the location of the nursery.

Susceptibility of seedlings to frost damage varies among forest tree species commonly grown in nurseries. Frost resistance is high in lodgepole pine, ponderosa pine, incense cedar, Engelmann spruce, and true firs; medium in the coastal variety of Douglas-fir and in western hemlock and western redcedar; and low in Sitka spruce.

However, sensitivity to frost is by no means uniform within a species, particularly in those with a wide geographical distribution. Even seedlings from the same seed source may vary widely in their susceptibility to frost. As a general rule, seed sources from high elevations and higher latitudes are more frost-resistant than those from low elevations and lower latitudes. The date of bud set can be used as general indicator of coldhardiness. Provenances that set winter buds early tend to suffer less from fall and winter frost than those that set winter buds late in the season.

Frost resistance varies also among parts of a seedling. Leaves are generally the most hardy and roots the least hardy organs, with stems and buds occupying an intermediate position. Frost resistance may vary even within the same plant organ. In a stem, cells of the phloem and cambium are more sensitive to frost than cells of the cortex or the xylem.

Winter desiccation may be confused with:
Lower stem canker
Pesticide damage
Phoma blight

Symptoms appear:
2+0, transplants
Spring

To complicate matters further, the annual cycle of hardening and dehardening is not synchronized for all parts of a seedling. In some species, needles reach their peak of frost resistance 4 to 6 weeks later than stems, and 2 to 4 weeks later than buds.

Needles—Frost injury to needles changes their color to a reddish-brown, sometimes preceded by a purplish or dull gray hue (Figures 27-1, 27-2, and 27-3). Newly killed needles, however, cannot be distinguished visually from uninjured needles because this color change takes days—sometimes weeks or even months—to occur. In general, the color of the needles will change sooner if seedlings were injured in spring rather than in fall or winter when temperatures tend to remain low.

It is possible to check for damage immediately after a cold spell, however. Electrical impedance of cell membranes is altered when membranes are damaged. Impedance can be measured with special equipment, and damaged tissue can be thus detected as soon as it has thawed out.

Figure 27-2. Large-scale damage to Douglas-fir seedlings because of freezing temperatures. The seedlot in the foreground was more coldhardy **and is apparently unaffected.**

Figure 27-3. Frost damage to recently flushed foliage of Douglas-fir. Oregon Department of Forestry photo.

Figure 27-4. A slice through the stem of a Douglas-fir seedling shows the browning of the cambium caused by freezing damage.

Stems—Injury to stem tissues can be observed by slicing away strips of bark. Injured stems show various degrees of browning (Figure 27-4). Rarely, stems will show visually recognizable external signs such as shriveled or deep-reddish-brown bark. If the phloem has been killed, bark will feel mushy and can be peeled from the stem easily. If frost occurred without snow cover on nursery beds, the first place to look for freezing injury is close to the ground because that is where temperatures are lowest and thus where frost injury is likely to occur first. If seedlings were covered partially by snow, stems should be examined just above the snow line.

Another indication of damage to the stem is shedding of needles. Needles may be shed even if they themselves were not killed by frost; this appears to be associated with injury to the needle traces and cortical tissues of the stem. If both needle and stem tissue are damaged, needles will begin to drop after 2 to 3 weeks. If only needles are damaged, they tend to remain attached to seedlings for several weeks or even months before they drop.

Winter desiccation can affect both needles and stems. This injury occurs when a low-humidity wind blows across the seedlings at the same time that cold wintertime temperatures freeze the upper soil layer, preventing or restricting moisture uptake by the roots. The needles can literally dry up. Often a snow cover prevents damage by protecting the seedlings from the wind or by preventing the ground from freezing, or both. Still, damage will occur to any portion of the seedling above the snow layer.

Buds—Cold injury to buds is not immediately apparent externally. Four to 6 weeks after they are frozen, injured buds begin to take on a dried-up appearance. However, buds can be checked for injury a few days after exposure to freezing temperatures by cutting them open (Figure 27-5). Tissue inside a frost-damaged bud will show light brown to dark brown discoloration—the darker the tissue, the more severe the injury.

Roots—Roots probably sustain less damage from frost than do the above-ground parts of seedlings because the soil temperature falls much more slowly than the temperature above ground. Soil often remains unfrozen even when above-ground temperatures fall below freezing. Moreover, the limited information available indicates that frost resistance ratings for above-ground parts of seedlings do not necessarily apply to their roots. In addition, tolerance to root damage from frost varies with species. Roots of western hemlock have been shown to be hardier than roots

Frost heaving may be confused with:
Cutworm damage
Damping-off
Seedcorn maggot damage

Symptoms appear:
1+0
Winter through spring

Figure 27-5. Cold-injured and noninjured lateral bud. Note that the center area of the left lateral bud is brown, in contrast to the green center of the bud on the right.

Figure 27-6. Frost heaving in small 1+0 seedlings.

of ponderosa pine and noble fir.

Injured roots show brown or almost black discoloration when bark is stripped away. Injured bark becomes mushy and can simply be pulled off. At this stage, however, freezing injury can easily be mistaken for symptoms of fungal diseases. Caution is necessary to avoid a wrong diagnosis.

Freezing and thawing of the upper soil surface are responsible for frost heaving. This condition, while not actually an injury, leaves seedling roots partially or totally uncovered (Figure 27-6). The expansion and contraction slowly pulls seedlings out of the ground. Larger seedlings with well-developed root systems generally are not affected, though roots can take on a corkscrew appearance in severe cases of repeated freezing and thawing of the soil surface (Figure 27-7).

Predisposing factors

Irrigation schedules that extend active growth of shoots well into the fall predispose seedlings to damage from early frosts. Insufficient irrigation, particularly during the second or third year, limits the accumulation by seedlings of carbohydrate reserves. This contributes to lowered frost resistance and may result in freezing injury during dormancy.

Nutrition can influence the seasonal growth pattern of seedlings and thus alter their susceptibility to freezing injury. Fertilization may result in prolonged growth in fall or earlier bud burst in spring, thus increasing the risk of frost damage. Nutrient stress also reduces frost hardiness.

Loss potential

The potential for loss is considerable but difficult to quantify because of the many variables involved. Seedlings will die if the roots or the cambium and phloem of the lower part of the stem have been killed. Injury to needles is less serious; it will weaken the seedling but not necessarily kill it. Douglas-fir may recover if uninjured buds are left on the stem.

Management

Overhead irrigation is an effective means of protecting seedlings from radiation or advection frosts. Water droplets suspended in the air reduce heat loss by lowering the flow of outgoing long-wave radiation. Irrigation prevents frost by increasing the thermal conductivity and heat capacity of the ground and by making possible the release of latent heat when the water freezes (Figure 27-8). The temperature of seedlings will not fall below the freezing point as long as the freezing process—the changing of water from the liquid to the solid phase—continues to take place. Overhead sprinkling, however, does not protect against freezing injury when temperatures drop below -7 degrees C (20 degrees F). Sprinkler systems usually cannot be kept in operation at such low temperatures anyway.

If applied improperly, however, overhead irrigation may be ineffective or may even increase frost damage. Seedlings sprinkled with insufficient water during a light radiation frost may suffer serious damage. This may be because when the air is dry, the temperature of the wetted needles will approach the wet-bulb temperature, which may be significantly lower than the dry-bulb temperature. Another possible reason is that the small amount of ice that forms on a leaf will prevent the undercooling of the cell solution and also may dilute the solution, thereby raising the freezing temperature.

Selected references

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Figure 27-7. Corkscrew-appearing root system due to repeated soil freezing (expansion) and thawing (contraction).

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Figure 27-8. Frost control in a bareroot nursery. The release of latent heat as the water freezes prevents the temperature of the seedling from falling below 0 degrees C (32 degrees F). Once the air temperature drops below -7 degrees C (20 degrees F), injury can no longer be prevented by this method. Photo courtesy of IFA Nurseries, Inc.