PLANTS IN COLD CLIMATES

By NORMAN E. PELLETT

University of Vermont, Burlington, Vermont 05401, USA

Cold temperature is perhaps the most limiting factor to widespread growth of plants (4). Man often insists on growing plants which are not quite adapted to his winter climate. Therefore, winter injury is a common problem from Mexico to Alaska and from Italy to Norway.

North American garden writers often recommend plants by cold hardiness zone, assuming that low temperature is the most limiting factor for plant survival (5). Plants are assigned to one of ten hardiness zones, each zone representing a 10 degree Fahrenheit range of average annual minimum temperatures. Each plant is assigned to the coldest zone where the author judges the plant will survive. This system fails to account for cold hardiness differences among climatic races of the same species, but has proven quite useful for providing information on adaptation of woody plant cultivars.

Winter causes plant injury in many ways (4, 16); low freezing temperatures often kill flower buds, late-to-mature stems and the roots. Late spring frost may injure dehardened flowers and shoots that have started growth. Rapidly decreasing temperatures in the afternoon on late winter days may injure the bark or foliage on the south side of woody plants after these tissues were warmed by bright sun (16). Desiccation of evergreen foliage may result when cold or frozen roots and stems are slow to replace evaporated moisture from the plant tops (9, 11, 12). In young trees, frost may injure the stem base near the ground (1, 9, 12).

Woody plants differ in their ability to prepare for winter (Table 1). Most trees and shrubs cannot tolerate ÷ 5° C when they are actively growing. Some have the ability during autumn to develop a cold tolerance to temperatures as low as ÷ 196° (8) while others don't develop any cold hardiness.

The mechanism by which some plants, but not others can develop cold hardiness seems to be complicated. Scientists after 75 years of research cannot yet explain the mechanism by which plants develop tolerance to very low temperatures. However, much is known about certain events in the plant during cold acclimation (4, 16).

Flower buds are often less hardy than stems. Peaches are a poor crop in much of the northern U.S. because flower buds are killed in winter. Many native trees could spread beyond their northern limits if flower buds were not injured by low temperatures (13).

Roots are less resistant to freezing injury than stems. Cold acclimation of roots is probably related to soil temperatures since stems below ground were no more resistant than roots (16). Apple roots above ground were as cold hardy as stems (15). The roots of a variety of container-grown shrubs and trees were not able to tolerate temperatures below ÷ 8 to ÷ 15° C during winter (2). The roots of unprotected container-grown nursery plants are often injured in the northern U.S. The practice of growing trees and shrubs in above-ground containers along streets, in parks, in shopping centers or in gardens is limited by root injury during winter in cold climates.

Tissues in the plant vary in cold hardiness. In *Malus,* living xylem cells are hardier than other tissues in early fall, but less hardy by as much as 30° C in mid-winter (7). Blackheart is an injury sometimes observed in apple wood after a severe winter (6). In many cold-hardy deciduous trees, cortical tissues, cambium and buds resist injury in

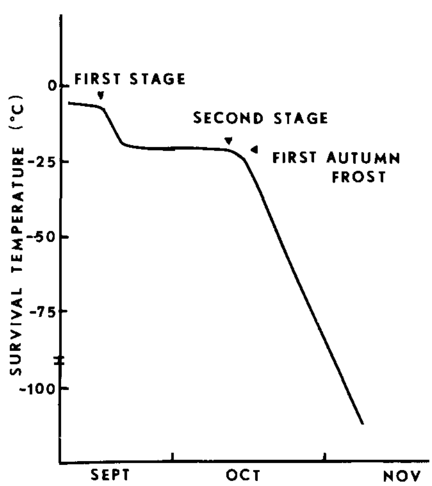

Fig. 1. Stages of cold acclimation of woody plants. After Weiser (16).
Fig. 1. Stadier i kuldetilpasningen hos vedplanter. Efter Weiser (16).

mid-winter to ÷ 70° C while living xylem tissues may be injured at ÷ 30° (10).

Denmark's plants are generally protected from extremely low mid-winter temperatures in a climate moderated by the sea. But freezing injury to introduced species by early autumn and late spring frosts is a common problem in Scandinavia. It is important to select plants which mature their growth in late summer and start growth rather late in the spring.

Hardy, woody plants undergo a series of changes during autumn as they prepare for winter. Cold acclimation of many woody plants appear to proceed in two stages (Fig. 1).

When several ecotypes of a single species are grown in the same location, they may have great differences in the timing of growth cessation (terminal bud-set), leaf drop, onset of rest, and cold acclimation. These differences reflect the plant's evolution in adapting to the environment of their native sites.

Figure 2 shows the cold acclimation of 3 ecotypes of *Cornus stolonifera* collected from 3 different climates between 45° and 47° latitude, but grown in Minnesota in the USA (16). More than 25 races were collected from wide-spread locations in North America and

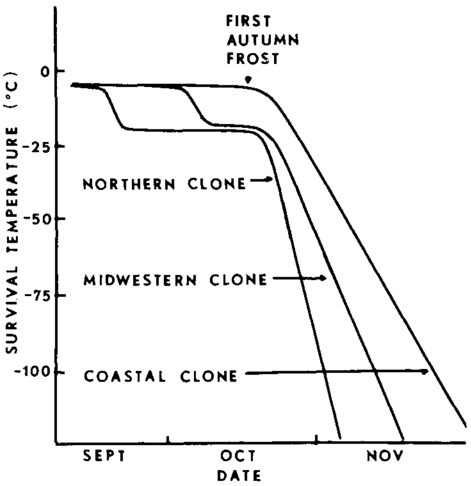

Fig. 2. Cold acclimation of 3 ecotypes of *Cornus stolonifera* growing in Minnesota. Northern clone from Dickinson, N. Dak., the midwestern clone from Excelsior, Minn. and the coastal clone from Seattle, Wash. After Weiser (16).

Fig. 2. Kuldetilpasning hos 3 økotyper af *Cornus stolonifera* fra North Dakota, Minnesota og Washington.

they all became very hardy (÷196°C) by mid-winter in Minnesota (14). In spite of this, plants from the west coast (mild climate, long growing season) were partially killed back by autumn frosts in Minnesota because they did not acclimate soon enough.

The first stage of cold hardiness is important in Denmark because it may prevent injury by early autumn frosts. The first stage appears to be induced by short days.

In a research study at the University of Vermont in the USA (17), short days (SD) of 8 hrs increased the cold hardiness of *Cornus stolonifera* and *Weigela florida* (Fig. 3). Long days (LD) inhibited development of cold hardiness. Plants in the SD treatment exposed to 15 minutes of red light (R) at 660 nm in the middle of the long night, acted similar to plants receiving the LD treatment. However, plants in the SD treatment exposed first to 15 minutes of R in the middle of the night followed by 15 minutes of far red (FR) at 730 nm acclimated to cold as did SD plants. This is proof that the first stage of cold hardiness is a response to photoperiod rather than a photosynthetic response or due to some other process.

However, not all plants develop the first stage of cold hardiness as was seen for the coastal ecotype of *Cornus* (Fig. 2). *Pyracantha coccinea* »Kasan« did not respond to the day length treatments described for *Cornus* and *Weigela* (17). *Pyracantha* apparently has the ability to survive low temperatures in mid-winter, but lacks the mechanism for early hardiness development in response to day length. It is important in plant breeding and selection programs to recognize and select plants which develop early hardiness. Smithberg and Weiser observed that hardiness development is more closely related to the length of the growing season than to latitude (14). The 3 ecotypes of *Cornus* in Figure 2 are from regions with approximately the same latitude, but with quite different growing season. The coastal clone came from an area with the longest growing period.

The second stage of cold acclimation is a low temperature response and usually begins about the time of the first frost in autumm (Fig. 2). Lower temperatures increase the rate of cold acclimation. Therefore, a cultivar growing in a colder climate will generally develop more cold tolerance.

Plants from regions with short growing seasons but moderate winter temperatures usually start their cold hardiness development early and may become as hardy in mid-winter as ecotypes of the same species in areas with the coldest winter temperatures (14). Some, but not all tree species in the southern U.S. attain a much greater cold hardiness than necessary to survive the winter in their native climate (13).

Plants from more southerly latitudes growing at high elevation may be better adapted to survive late spring frosts in coastal regions of Scandinavia than northern plants from continental climates. The southern, high elevation plants have a short growing season, mature their tissues early, perhaps in response to decreasing temperatures at high elevation. These plants may also start growth later in the spring than northern continental plants, thus avoiding injury by late spring frost.

Løfting observed that the type of winter injury of several North American provenances of *Pinus contorta* varied in three Denmark sites (3). Following prolonged cold and sunny weather in March of 1962, provenances from the east coast of Vancouver Islands in British Columbia (B.C.), in Canada and inland B.C. developed discolored needles on Jutland heath and dunes regions, but not on the inland

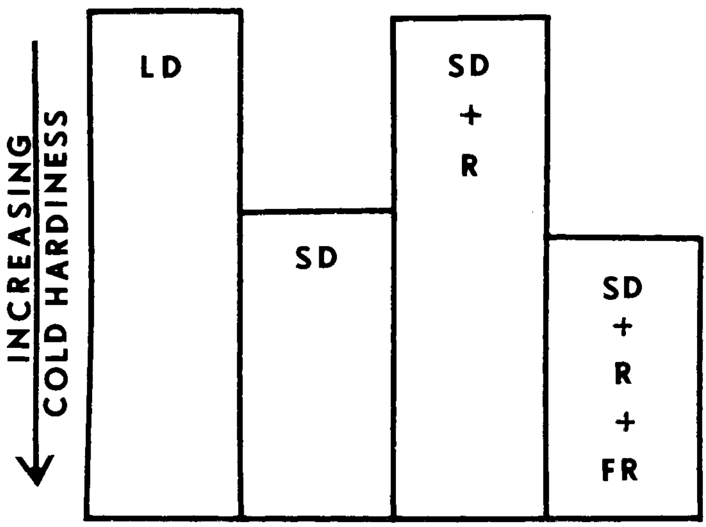

Fig. 3. Effect of photoperiod treatments on cold acclimation of *Cornus stolonifera* (northern clone). Adapted from Williams, Pellett and Klein (17).

Fig. 3. Figuren viser, at forsøg med langdagsbehandling af en nordlig klon af *Cornus stolonifera* hæmmer udviklingen af kulderesistens, mens forsøg med kortdagsbehandling virker modsat. Imiterede langdagsbetingelser, hvor kort dag kombineres med et kvarters afbrydelse af mørkeperioden ved belysning med rødt lys, nedsætter kulderesistensen; ophæves afbrydelsens virkning ved efterfølgende belysning med langrødt, opnås samme effekt som ved kortdagsbehandling.

sand and diluvial sand regions. Severe cold, early frost and low precipitation during the 1962-63 winter in all three Denmark sites caused needle discoloration and frost injury to cambium in the Washington-Oregon coastal provenances, but not more northerly provenances. Løfting suggested use of provenances from a central zone to lessen chances of both problems.

It appears difficult to predict the adaptation of provenances and species when they are moved to a new climate, but it seems that plants which mature early in the autumn in the new climate will have a good chance to survive the winter temperatures if other climatic factors don't render the plants more sensitive. Studies on timing of growth cessation and hardiness development are useful tools in introducing new plants.

Table 1.
Midwinter low temperature tolerance (°C) of several North American tree species. Adapted from Sakai and Weiser, (13).

	Bud	Leaf	Twig	Source
Populus tremuloides	÷196[a]		÷196[a]	Canada
Picea glauca	÷50	÷80	÷80	Canada
Tsuga heterophylla	÷20	÷20	÷20	Oregon (Corvallis)
Tsuga heterophylla	÷35	÷40	÷35	Alaska (Juneau)
Pinus ponderosa	÷35	÷40	÷50	Idaho (1200 m)
Quercus garryana	÷15		÷20	Oregon coast
Quercus virginiana	÷8	÷8	÷7	Mississippi (Greenville)

[a]Twigs survived immersion in liquid nitrogen (÷ 196° C) after prefreezing to ÷ 15°.

Resume

Vinteren kan være den faktor, der mere end andre begrænser udbredelse og dyrkning af planter; det er ofte forbundet med vanskelighed at dyrke planter, der ikke er tilpasset det lokale vinterklima. Vinteren kan på mange måder skade planterne: Streng frost kan for eksempel dræbe blomsterknopper og skud og rødder på planter dyrket i potter eller containere. Vårfrost kan ødelægge blomster og skud i begyndende udvikling. Udtørring af stedsegrønne blade kan forekomme, når kolde eller frosne rødder og grene for langsomt erstatter den fugtighed, der fordamper fra plantens øvre dele. Især skader de lave midvinter-temperaturer planter, der ikke er tilpasset klimaet. De fleste træer og buske kan ikke overleve minus 5°, når de er i vækst. Nogle er i stand til i løbet af efteråret at opnå resistens mod så lav temperatur som minus 196° i flydende kvælstof (*Populus tremuloides*), mens andre overhovedet ikke opnår frostresistens.

Planterne gennemgår en række forandringer, når de forbereder sig til vinteren. Kuldetilpasningen forløber hos nogle planter i 2 stadier: det første er en reaktion på kortere daglængde, det andet på faldende temperaturer. Det første stadium kan være vigtigt for beskyttelse mod tidligt indtrædende efterårsfrost, som kan være et problem i Danmark. Planter fra områder med lang vækstperiode kan blive dræbt, når de flyttes til områder med tidlig frost. Graden af vinterhårdførhed er afhængig af temperaturforholdene i tilpasningsperioden om efteråret. En klon kan være mere hårdfør i et nordligt klima, hvor temperaturerne er lavere, end i et sydligere og mildere. Generelt opnår nordligt forekommende planter større vinterhårdførhed end de sydligere, uanset om det nordlige område har kystklima, men det er dog ikke alle sydlige planter, der er mindre hårdføre end nordlige. Nogle er i stand til at overleve vinteren, når de flyttes langt mod nord, hvilket tyder på, at andre faktorer har begrænset deres naturlige udbredelse.

Det er vanskeligt at forudsige tilpasningsmuligheden hos planter, der flyttes til et andet klima, men øjensynlig er det de planter, der afmodner tidligst på efteråret i et nyt klimaområde, der har bedst chance for at overleve vinteren. Undersøgelser af tidspunkt for vækstafslutning og af udviklingen af vinterhårdførhed er derfor nyttige ved indførsel af nye planter.

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