Cold Hardiness of Climatic Zone 9 Plants at 53° North Latitude

David Robinson, Ph.D.

This article is based on a talk Dr. Robinson gave at the Annual Meeting of the Magnolia Society in Ireland, March 2001.

Although my garden at Earlscliffe, Baily, Co Dublin is situated at 53° 3' north latitude, it has a favorable microclimate and contains many climatic zone 9 (USDA) plants. The harsh 2000/2001 winter, the most severe since I started taking records in 1969, provided a good opportunity to record the effect of low temperatures on many marginally hardy plants.

The 2000/01 Winter

Autumn 2000 was mild and wet with temperatures well above average in early December. However, on the night of December 26/27, 2000, the air temperature fell to –6 °C (21.2 °F) and to –4 °C (24.8 °F), –7 °C (19.4 °F), –5.5 °C (22.1 °F) and –4.5 °C (23.9 °F) on the following four nights. For the three days between the 28th and 30th of December the temperature never rose above –3 or –4 °C (26.5 or 25 °F) during the day. At the end of the cold spell (December 30th), the temperature rose 7.5 °C (13 °F) during the night and was 3 °C (37 °F) by morning, so the speed of thaw was rapid.

After a relatively mild January, another cold spell began on February 23/24, 2001 and the minimum air temperatures recorded on this, and the following nine days, were: –2 °C (28.4 °F), –2 °C (28,4 F°), –1.5 C° (29.3 F°), –2.5 °C (27.5 °F) –2.5 °C (27.5 °F), –5.5 °C (22.1 °F), –5 °C (23 °F), –5 °C (23 °F), –5 °C (23 °F) and –1 °C (30.2 °F). A severe northerly gale blew up on the night of February 25/26 and the snow that fell that night persisted in shaded places for a full week. In an area that had seen little snow in the last 30 years, these conditions were exceptional.

Apart from temperature records, the response of many plants confirms the severity of the winter. Young plants of the banana *Musa basjoo* were killed back to ground level although, since first planted in 1973, they had survived all previous winters with stems intact. *Erica canaliculata,* the most vigorous and one of the most hardy of the South African heaths growing at Earlscliffe, survives most winters unscathed. However, the 2000/01 winter killed back previous year's growth on some plants by over 50cm (19.7in).

David Robinson

David Robinson

Photograph 1 (top). *Sonchus arboreus* was killed to the ground in December 2000 but resprouted strongly from the base in April.

Photograph 2 (bottom). *Tetrapanax papyrifer,* in foreground, dropped all its leaves cleanly at the start of the cold spell in December but recovered well in April. The Chusan palm *(Trachycarpus fortunei),* in background, from central and southern China is the hardiest palm that can be grown in Ireland.

As one of my interests is growing trees and shrubs that are close to their climatic limit, it is inevitable that a cold winter will kill many of the more tender plants. I do not regard plants killed in this way a disappointing loss but rather as an educational experience, an opportunity to gather fresh information and a chance to plant up again with more frost-tender plants.

To obtain an accurate picture of plant hardiness, no fleece or other artificial means of protecting plants is used, no matter how severe the frost, and no plants are overwintered under cover.

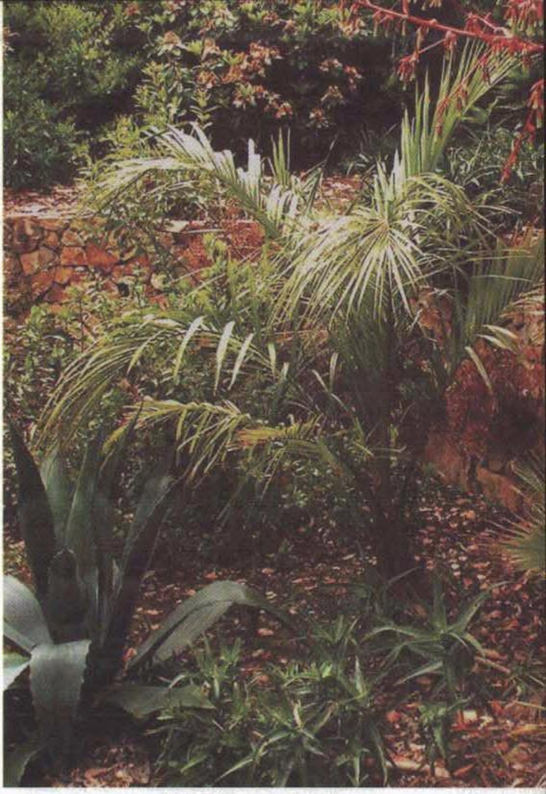
Factors Influencing Plant Hardiness

Plant hardiness is mainly influenced by the absolute minimum temperature, but this is only one of many factors involved. Other factors include the duration of freezing temperatures, the speed of drop, the hardening up process, the speed of thaw, the moisture content of the plant, soil and air, and the soil type.

Healthy, well-grown plants are better able to cope with cold than plants in a debilitated condition. A correlation between the development of frost hardiness and an increase in sugar content has been demonstrated for a large number but not for all plants. The exact role of sugar is still debated but it has been suggested that high sugar decreases the freezing point by accumulating in the vacuoles and decreasing the amount of ice formed. Others believe that both sugars and amino acids can protect specific sensitive proteins and enzymes from the effect of freezing.

Because of the link between plant well-being and tolerance of low temperature, a wide range of cultural factors are relevant, including nutrition, freedom from pests and diseases, and general husbandry. The morphology of the plants also plays a part with some plants having especially susceptible stem, buds, or roots. In addition, other climatic factors such as wind chill and depth of snow cover may play a negative or positive role.

Previously it has been suggested that high fertility predisposes plants to low temperature injury. With food crops this has been shown to be false. Plants fertilized for optimum growth, or yield, are not unduly susceptible to low temperatures; in contrast, nutrient deficient plants and those over-fertilized so that yield is depressed are susceptible. It seems likely that these results are also linked to sugar levels within the plant.



David Robinson

David Robinson

Photograph 3 (top). *Juania australis* is rather rare in cultivation but it survived the 2000/01 winter with no sign of injury.

Photograph 4 (bottom). The graceful Rimu from New Zealand (*Dacrydium cupressinum*) is suitable only for the milder areas of Britain and Ireland but so far has escaped damage at Earlscliffe.

Photograph 5. *Protea lacticolor* suffered only slight damage to unripened tips during the winter and should flower well in late summer 2001.

Hardening Up Process

With the approach of winter, important differences are evident between many climatic zone 8 plants and those in zone 9. Zone 8 plants undergo a hardening up process under the influence of photoperiod and falling temperatures. With temperatures in the range of 1 and 5 °C (33.8 and 41 °F), plant growth gradually ceases, metabolic changes take place in plant proteins, and soft growing tips lose moisture and become more lignified. In contrast, many zone 9 plants harden up only slowly or not at all and many, including a large number of *Eucalyptus* species, continue to grow slowly during a mild winter. Consequently they are susceptible to damage by periods of subzero temperatures.

Low Temperature and Plant Injury

Low temperatures can kill plants in different ways. In highly susceptible plants, cell contents may freeze and death occurs rapidly due to disruption of protoplasm. In other plants, however, ice crystals are first formed outside the cells in the walls and intercellular space as a result of the antifreeze effect of the cell contents. Further cooling leads to the growth of these crystals with the water being drawn from the cells. When this occurs, the plant may die slowly as a result of desiccation. This is now believed to be a more common cause of plant death than cell disruption by ice crystals.

Contrary to previous widely held beliefs, it is now thought that the formation of ice in the intercellular spaces of itself is not responsible for plant death. The view that plants tolerate low temperatures because the freezing point of protoplasm is lowered as water moves out of the cell has also now been largely discredited.

Evergreen plants that are damaged by low temperatures may absciss their leaves cleanly or, in cases of more severe injury, may hold onto the dead foliage for many months. In general, plants that absciss their damaged leaves appear to have a better chance of survival than those that hold onto them in a dead condition.

Leaf abscission is controlled by plant hormones and it is generally believed that auxins prevent abscission as long as the leaf blade is healthy and growing. In the case of deciduous species in the autumn and evergreen plants with damaged leaves, auxin flow diminishes and the plants produce ethylene, which triggers leaf fall. Where death or severe injury occurs suddenly, the plant's hormonal control mechanism is destroyed and so foliage dies but does not fall. In these cases, the chances of recovery by re-sprouting from the above ground part of the plant are remote. However many plants affected in this way can re-sprout strongly from below soil level. The likelihood of regrowth from adventitious buds on stems and branches of many injured plants appears to be greater where leaf abscission has occurred.

Effect of 2000/2001 Winter on Zone 9 and Other Tender Plants at Earlscliffe

Zone 9 plants at Earlscliffe reacted in many different ways to the 2000/01 winter (see the tables at the end of this article for a list of plant successes and failures). Many fleshy succulents, which contain much water, were especially susceptible to freezing conditions and collapsed quickly during the cold spell in December. Plants in this group were: *Aeonium tabuliforme, A. arboreum* 'Atropurpureum' and many other *Aeonium* species. *A. balsamiferum,* although damaged, appeared to be the most hardy of the species tested and many plants survived. Another Canary Island succulent, *Greenovia aurea,* was more tolerant of freezing conditions than *Aeonium* spp., although its response varied from no discernible effect to severe blackening of foliage and death in different parts of the garden. *Solanum laciniatum,* the soft subshrub *Solanum quitoense* (zone 10) and young plants of *Musa sikkimensis* and *M. basjoo* were killed back to ground level. When succulents are killed immediately due to intracellular freezing they collapse quickly as mushy pulp. Within a few weeks the remains of many non-lignified plants killed in this way virtually disappear.

However, not all plants with a high moisture content were sensitive to low temperature damage. A number of plants with fleshy leaves, including some *Agave* species, *Aloe striatula, A. aristata* and *Beschorneria yuccoides,* all survived completely unharmed. Among the agaves, *A parryi, A. ferox* and *A. americana* were uninjured but all the outside leaves of *A. sisalana* were desiccated, although the youngest leaves in the heart of the plant remained green. *Furcraea longaeva,* another succulent related to *Agave,* reacted differently; the older leaves were undamaged but some of the younger leaves turned temporarily chlorotic with a few dead patches but the plant quickly recovered when temperatures rose in the spring.

The foliage of a 4m (13ft) high plant of *Brugmansia sanguinea* collapsed immediately after the first severe frost on December 26/27, 2000. However, although the entire top growth was killed, much of the root system remained alive during the winter and, as after previous hard winters when the plant was killed back, it began to resprout strongly from the base about six months afterwards.

In contrast, plants that are killed by cell desiccation do not show the effects of this type of injury for many weeks. Many tender plants with small to medium sized, firm leaves are affected in this way, including *Metrosideros excelsa, Psoralea pinnata* and *Eucalyptus ficifolia,* Their leaves gradually wilt and turn brown and the plants show typical symptoms of drought.

The link between frost hardiness and sugar content was demonstrated by the variable response of seedlings of *Echium pininana,* the Giant Borage from the Canary Islands, naturalized in a *Betula* woodland. This plant is hardy here in a normal winter but in 2000/01 many plants were killed in the middle the woodland but survived in the open and in the woodland fringe. It seems likely that sugar levels were low in plants in shade inside the wood and so they died, even though the canopy of branches would have given some degree of protection from frost. The higher sugar levels of plants growing in more open situations probably accounts for their greater tolerance.

Echium pininana has large fleshy leaves that, at sub-lethal temperatures, wilt when the temperature drops at night below approximately –3 °C (26.6 °F) and regain turgidity when the temperature rises again during the day, presumably as water moves out of cells into intercellular space and back again. With experience it is possible to gauge approximately the temperature between –2 °C (28.4 °F) and –8 °C (17.6 °F) by the extent of the flaccidity of the leaves.

Differences Within Genera

As a result of their evolutionary history, big differences often occur in the susceptibility of species within a genus. *Euryops virgineus* started flowering in December, showed no sign of low temperature injury and is still in flower in July 2001. Some plants of *E. pectinatus* suffered moderate leaf scorching and die back but survived while *E. chrysanthemoides* died quickly. *Metrosideros robusta* was not affected in any way by low temperatures but plants of *M. excelsa* were killed back to ground level. Among the tree ferns, *Dicksonia antarctica, D. squarrosa* and *Cyathea dealbata* showed only slight signs of damage but *C. cooperi* still shows no signs of life in July 2001 and may be dead.

As would be expected from a genus covering a vast geographical area, different species of *Eucalyptus* responded differently to the low temperatures. All *Eucalyptus ficifolia* saplings raised from seed collected from the wild in Western Australia in January 1996, were killed back to ground level. Several hundred plants survived the mild winters between 1996/97 and 1999/2000 in good condition but were unable to withstand temperatures of –6° (21.2 F°) and –7° (19.4 °F) after Christmas 2000. About 6% of these saplings showed some regrowth from their base in June 2001 although their survival is far from assured. A few plants raised from seed collected from higher elevations have been severely damaged but appear to be somewhat less susceptible to low temperature injury than the progeny of seed collected in the plant's areas of natural distribution. *E. curtisii* from the Brisbane area of Queensland was also severely scorched and is unlikely to live. Approximately 70 other species of *Eucalyptus,* mainly from New South Wales, Victoria and Tasmania, survived in good condition. These include *Eucalyptus crenulata* from Victoria which continued to grow throughout the winter without any significant injury to the expanding young foliage.

Leaf Abscission and Plant Recovery

With few exceptions, no regrowth from branches occurred on evergreen plants that held onto their dead foliage after the cold spells in December and February. Plants in this group included: *Erica x hiemalis, Erica versicolor, Agathosma ciliata, Cineraria* 'Purple Picotee,' and *Psoralea pinnata.* However, many plants that had their top growth killed resprouted strongly from the base, such as *Pelargonium papilionaceum* and *Sonchus arboreus* (see Photograph 1). *Nerium oleander* was an exception insofar as epicormic growth occurred in June although most of the dead foliage was still attached to the plant.

Other normally evergreen plants which abscissed all their foliage cleanly after low temperature injury included *Itoa orientalis, Tetrapanax papyrifer* (see Photograph 2) and *Grevillea robusta.* Plants in this group have produced leaves from adventitious buds on branches although those of *Grevillea robusta* are still weak in late June.

Root Systems

The location of roots in the soil is important both with regard to plant health and freezing injury. Examination of the root system of plants at Earlscliffe shows that many have most of their roots in the top 5cm (2in) of soil. This is due to the absence of severe drought, relatively shallow soil and the routine use of herbicides to control weeds so that the soil surface is not disturbed.

Stem tissue is usually less sensitive to low temperature injury than root tissue, but roots of trees and shrubs are injured less in winter because the soil cover protects them to some extent from exposure to freezing temperatures. In theory plants with their roots close to the soil surface, should be especially susceptible but there was no evidence of this under conditions at Earlscliffe. Nevertheless when soil freezes, roots are often damaged, especially the small physiologically important ones.

A large number of roots were examined on February 18, 2001 and as far as could be ascertained root damage on many plants was minimal compared with the severe injury evident on top growth at that date. Despite extensive damage to foliage, stems and branches, the roots of many plants appeared to be turgid, moist and fresh. Plants in this category that eventually recovered included: *Brugmansia sanguineum, Tetrapanax papyrifer, Sonchus arboreus, Strobilanthes penstemonoides, Metrosideros excelsus* and a small number of saplings of *Eucalyptus ficifolia*. Plants with apparently healthy roots in February which failed to recover included: *Cyathea cooperi, Psoralea pinnata, Solanum laciniatum* and many saplings of *Eucalyptus ficifolia*. With some plants it was clear that both top and root were severely damaged, e.g. *Solanum quitoense, Europys chrysanthemoides* and *Aeonium* spp, and that recovery was unlikely. However, many plants resprouted from the base, many months after the entire top growth has been killed, indicating that the root system is less susceptible to low temperature injury in many species than the above ground part of the plant.

The fact that a large part of the root system of most plants at Earlscliffe is close to the soil surface may be an overall advantage rather than a disadvantage. Roots growing in the surface soil layers seem to be especially important to plants, due partly to the fact that this region is richer in nutrients and oxygen than deeper layers. It has also been shown that young roots are the main production sites in plants for some essential growth hormones such as gibberellins and cytokinins. Gibberellins promote stem elongation by stimulating cell division and cytokinins stimulate cell enlargement as well as cell division and so promote leaf expansion. On balance, the horticultural advantages of allowing roots to exploit the soil surface under conditions at Earlscliffe seem to outweigh any possible disadvantage due to increased risk of low temperature injury.

Survivors

Although many zone 9 plants were killed or severely injured during the 2000/01 winter, even larger numbers have apparently survived un-harmed or with slight damage only. All palm trees appear to have come through the winter well. These include *Trachycarpus fortunei, Chamaerops* *humilis, Phoenix canariensis, Jubaea chilensis* and young plants of *Washingtonia robusta, W. filifera, Brahea armata* and *Butia capitata.* The rare palm from the Juan Fernandez Islands *Juania australis* showed no signs of low temperature injury and continues to grow strongly (see Photograph 3).

Many tender conifers have also survived in good condition, such as the Rimu, *Dacrydium cupressinum,* (see Photograph 4) *Lagarostrobus franklinii, Callitris rhomboidea, C. oblonga* and *Podocarpus totara.* Other nonconiferous survivors included: *Pseudopanax arboreus, P. ferox, P. laetus, Lomatia ferruginea* and *Telopea speciosissima.* Bromeliads including *Ochagavea carnea, Fascicularia bicolor* and many species of *Puya* survived uninjured. The aromatic tree *Doryophora sassifras* is also in good condition. This plant has assumed a special interest in recent years as, in its native New South Wales, it grows alongside the soon to be released "fossil tree" the Wollemy pine, *Wollemia nobilis.*

Protea lacticolor showed slight scorching only of unripened shoot tips and the King Protea, *P. cynaroides* has also survived although with some leaf damage (see Photograph 5). *Banksia spinulosa* flowered in November 2000 and was little affected by winter cold but the combination of a wet blanket of snow and gale force winds on the night of February 26/27, split off several main branches. The grass tree, *Xanthorrhoea preissii* appeared to be in as good condition in spring as it was when it entered the winter. It was planted in August 1995 and has been slow to recover from transplanting shock.

Increase in Hardiness of *Echium pininana* by Natural Selection

Although *Echium pininana* is an endangered species in its native Canary Islands, it self seeds freely in many coastal areas of Ireland. Plants can grow from over 1m (3.3ft) to a height of 6m (19.7ft) between February and early June. The plant flowers in its second or third year and being monocarpic, dies after flowering. *E. pininana* is cross pollinated and produces seeds prolifically (in excess of 200,000/plant), which germinate readily and dense carpets of *Echium* seedlings are commonplace. Plants developing from these seedlings survive most winters but in hard winters many are killed by cold. On two occasions (1978/79 and 1986/87) during the last 24 years all plants were killed by low temperatures of –6° C (21.2 °F) in January. After these severe winters new seedlings develop from the seed bank in the soil.

It seems possible that natural selection is producing a more cold hardy strain of *E. pininana,* as in two recent cold winters (1995/6 and 2000/01) when temperatures fell to –7 °C (19.4 °F), many seedlings survived.

Conclusion

It is obvious that a large number of climatic, physiological, genetic and cultural factors are involved in plant tolerance to low temperatures. In addition, marked differences in microclimates can occur in a small area, even on a garden scale. Plants that appear to be killed can resprout up to a year after the initial damage occurred. Consequently, rapid removal of apparently dead plants is inadvisable. It would also appear that the only way to ascertain if a zone 9 plant is hardy in a marginal area is to plant it and see what happens.

The following lists describe the effect of 2000/2001 winter on some tender plants at Earlscliffe, Baily, Co. Dublin, Ireland

Killed

Aeonium tabuliforme
Agathosma ciliata
Aloe arborescens
Cordyline rubra
Cyathea cooperi
Echium candicans
Echium nervosum
Echium wildpretii (many plants, but some survivors)
Erica versicolor
Erica x hiemalis
Eucalyptus ficifolia (some may recover)
Euryops chrysanthemoides
Kunzea baxteri
Lampranthus radiatus
Leucodendron argentea
Nolina recurvata
Psoralea pinnata
Rhododendron vireya 'Tuba'
Ruschia frutescens
Solanum laciniatum
Solanum quitoense

Injured to varying degrees but likely to recover

Agave pravissima
Agave sisalana
Araucaria bidwillii
Banksia spinulosa
Brugmansia sanguinea
Casuarina equisetifolia
Correa backhouseana
Corynicarpus laevigatus
Cyathea dealbata
Cyperus alternifolius
Dicksonia squarrosa
Dodonea viscosa 'Purpurea'
Doryanthes excelsa
Erica canaliculata
Erica glandulosa
Eriobotrya deflexa
Euryops pectinatus
Furcraea longaeva
Hedychium greenei
Itoa orientalis
Melianthus major
Metrosideros excelsa
Musa basjoo
Musa sikimensis
Nerium oleander
Pelargonium papillionaceum
Protea cynaroides
Protea lacticolor
Roldana petasites
Sonchus arboreus
Strobilanthes penstemonoides
Tetraclinus articulatus
Tetrapanax papyrifer

Uninjured

Agave americana
Agave ferox
Agave parryi
Aloe aristata