PLANT COLD HARDINESS AND WINTER PROTECTION

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The natural distribution of plant materials as well as the survival of introduced plants is determined to a large extent by minimum winter temperatures (Figure 1). Acclimation to low temperatures, therefore, is a process critical to the survival of woody plants and herbaceous perennials in northern climates. Since plant cold hardiness is so basic to plant performance, an understanding of plant cold hardiness physiology is important not only to the plant physiologist, but also to growers and consumers of nursery field and container plant material.

Types of Winter Injury
Some common types of winter injury associated with above ground portions of plants include sunscald, frost cracks, foliar browning, blackheart, die-back, flower bud damage, dehydration damage, heaving damage, and late spring and early fall frost damage. Winter injury to nursery and landscape plants may also result from breakage caused by the weight of snow and ice accumulation. Ice storms can result in tremendous losses. Landscape plants may also be damaged by snow removal equipment and deicing salts. Many herbaceous perennials require well aerated soil and may be injured or killed in poorly drained soils over the winter.

Root cold hardiness is critically important. Roots are always less cold hardy than top growth and root cold hardiness may be the critical factor which determines plant survival under certain conditions. Increased container production and use of above ground landscape planters makes root cold hardiness an even more important consideration. Under such conditions plant roots are exposed to lower temperatures than they would be if grown under natural conditions. Roots are also exposed to greater temperature fluctuations under container growing conditions. During years with very severe winters or when winter protection from snow is lacking, root cold hardiness also becomes an important factor in landscape survival. Poor growth of trees and shrubs following a severe winter is often attributed to other causes such as drought or disease, since symptoms of the injury do not become apparent until midsummer when the previous winter and its conditions have been forgotten. Trees and shrubs exhibiting root injury may resume growth normally in the spring, sending out vegetative shoots and blossoms and they may even set fruit. Later, when the tree is stressed by warmer, drier conditions, the effects of previous winter's root injury become apparent. Portions of the crown, and in severe cases the entire plant, may wilt and die.

The temperatures to which roots are subjected are determined by soil temperature which in turn are influenced by many factors including soil texture, specific heat, heat conductivity, radiation, water content, organic matter content, evaporation, soil solution concentration, topographic position, surface condition, air temperature, sunshine, wind velocity, barometric pressure, precipitation, and soil or media composition. A difference of only a degree or two can make a significant difference in root survival. Younger roots are generally less cold hardy than older roots. Structure and distribution of the root system can also affect root survival. Roots located near the soil surface as a result of shallow rooted species, high water table or shallow irrigation, are less protected and more likely to be damaged by low temperatures than more deeply rooted materials.

Frost damage may not result in the direct loss of the plant. Many plants are vegetatively hardy while flower buds are subject to injury, such as Forsythia. These plants may exhibit reduced flowering and fruiting following severe winters. Although plants may not be killed, winter injury often results in subsequent infection by wood decay fungi. Frost injured tissue can also provide an entrance for pathogenic fungi and bacteria. Trees stressed by low temperature injury are also often more susceptible to attack by insects and foliar diseases.

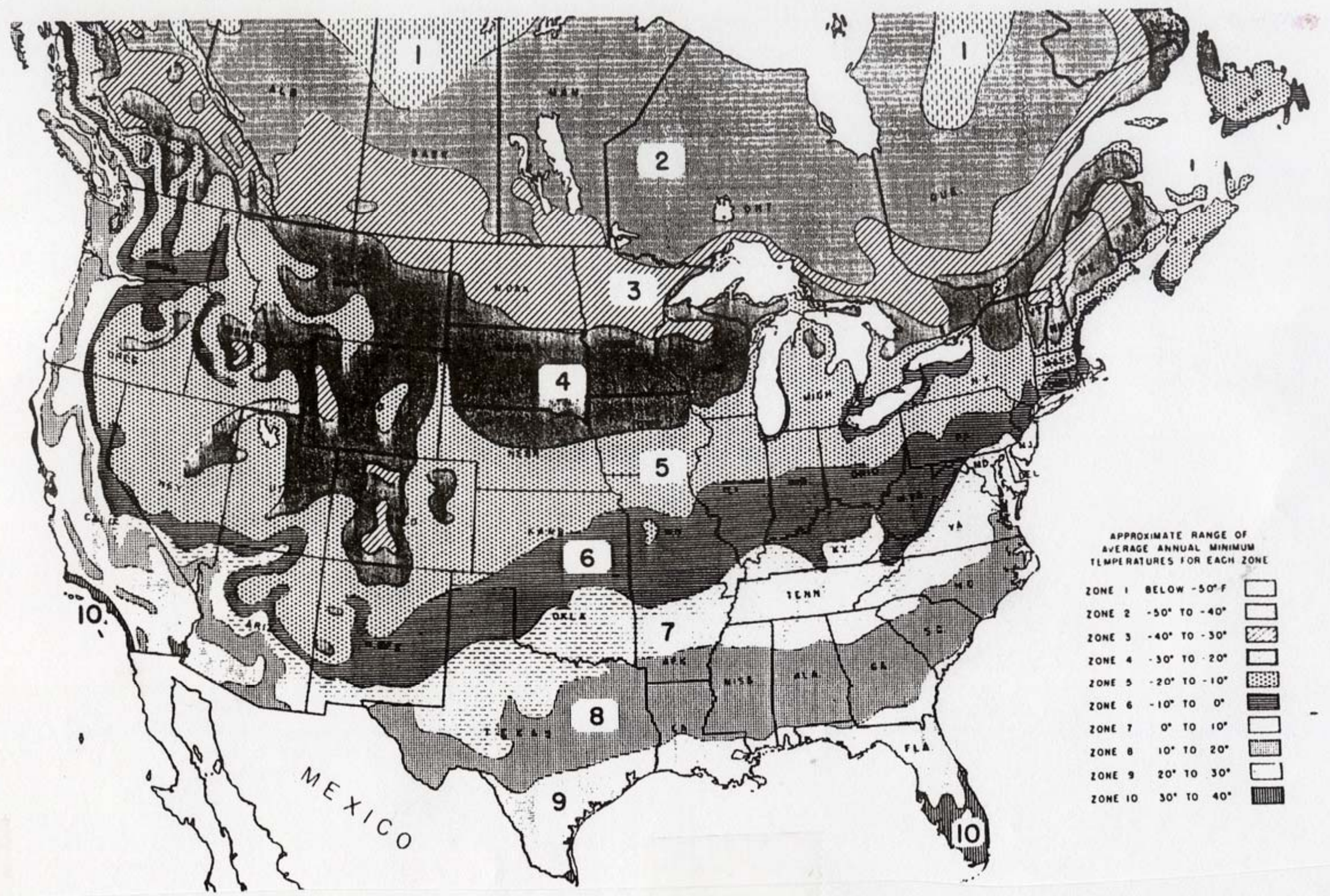

Figure 1. USDA Cold Hardiness Zone Map.

Cold Acclimation

The development and maintenance of cold hardiness is a dynamic process called cold acclimation. The degree of cold hardiness developed during acclimation varies considerably between species, between members of the same species adapted to different geographical locations, and according to environmental conditions. Cold hardiness results from a delicate balancing act between a plant's genetic capacity to harden and a wide variety of environmental factors. The steps involved in the process of cold acclimation are outlined in Figure 2. **Any environmental factor which slows the growth rate of plants will generally increase freezing tolerance**. Such factors include: low temperature, reduced soil moisture, shortened photoperiod, and reduced nitrogen availability. The opposite is also true wherein relatively high levels of nitrogen and/or moisture lead to reduced acclimation during the fall. Prolonged warm weather in the fall can also delay the development of cold hardiness resulting in increased winter injury. Plant hormones called gibberellins also increase growth and reduce hardiness development. **Slight** stress from drought, fertility and heat will often increase plant cold hardiness, however, severe levels of moisture, nutrient or environmental stress interfere with hardiness development and result in increased injury.

Decreasing photoperiod or shortening days, and low temperatures are the two main factors involved in the initiation and development of plant cold hardiness. The cessation of growth and induction of dormancy or rest caused by shortened photoperiods account for the central role of light in the initial phase of plant cold hardiness development. Temperature is the most critical factor involved in the second developmental phase of plant cold hardiness. If environmental, cultural and physiological factors have been, and continue to be favorable, cold acclimation progresses further in response to decreasing temperatures in late fall and early winter.

Many changes in plant metabolism, physiology, and morphology are associated with cold hardiness development. Some changes which have been documented by research include: reduced water content from changes in root hydraulic conductivity and transpiration; increased membrane permeability; increased binding of water to cellular constituents; replacement of intracellular structural water with protective molecules including sugars; production and translocation of hardiness promoting factors; decreased stored starch; reorientation of macromolecules into stable forms; changes in protein synthesis from enzyme activity; protein content; protein associations; changes in amino acid content, synthesis, degradation and availability; changes in carbohydrate content, synthesis, degradation and protective functions; changes in lipid saturation levels, synthesis, degradation and membrane involvement; changes in nucleic acids including DNA and RNA; changes in membrane structure; and changes in phosphorus levels. The exact relationships among all of these changes and cold hardiness development have not been fully elucidated; however, the end results of cold acclimation are changes in plant morphology, physiology, and metabolism which enable plants to either **avoid** or **tolerate** the formation of ice within plant tissues.

The first line of defense against the formation of ice is called **freezing point depression**. The freezing point of cellular water is determined by the soluble solute content of sugars, organic acids, amino acids, and proteins in the cell sap. Even before complete hardening, plants can survive exposure to temperatures a few degrees below 32°F (0°C) without the formation of ice. Further hardiness development requires the cessation of growth, initiation of dormancy, and exposure to low temperature.

Freezing of plant tissue can also be avoided through the process of **supercooling**. Supercooled water is water whose temperature has been lowered below 32°F (0°C) without the formation of ice crystals. Supercooled water does not freeze because of compartmentalization of cellular water and the absence of either external or internal ice nucleators. Under the right conditions, a plant’s water can be supercooled until the homogeneous nucleation point of water is reached, which is -38ºF (-38°C). Supercooling can often be detrimental rather than beneficial since when nucleation does occur, ice formation is rapid and can cause extensive mechanical damage caused by intracellular, or inside the cell, ice formation. For this reason supercooling rarely occurs under natural conditions in woody plants except in a few cases such as in the flower buds of some plants including azalea, which survives low temperatures by supercooling. A brief outline of the methods by which hardened plants survive exposure to freezing temperatures is provided in Figure 3.

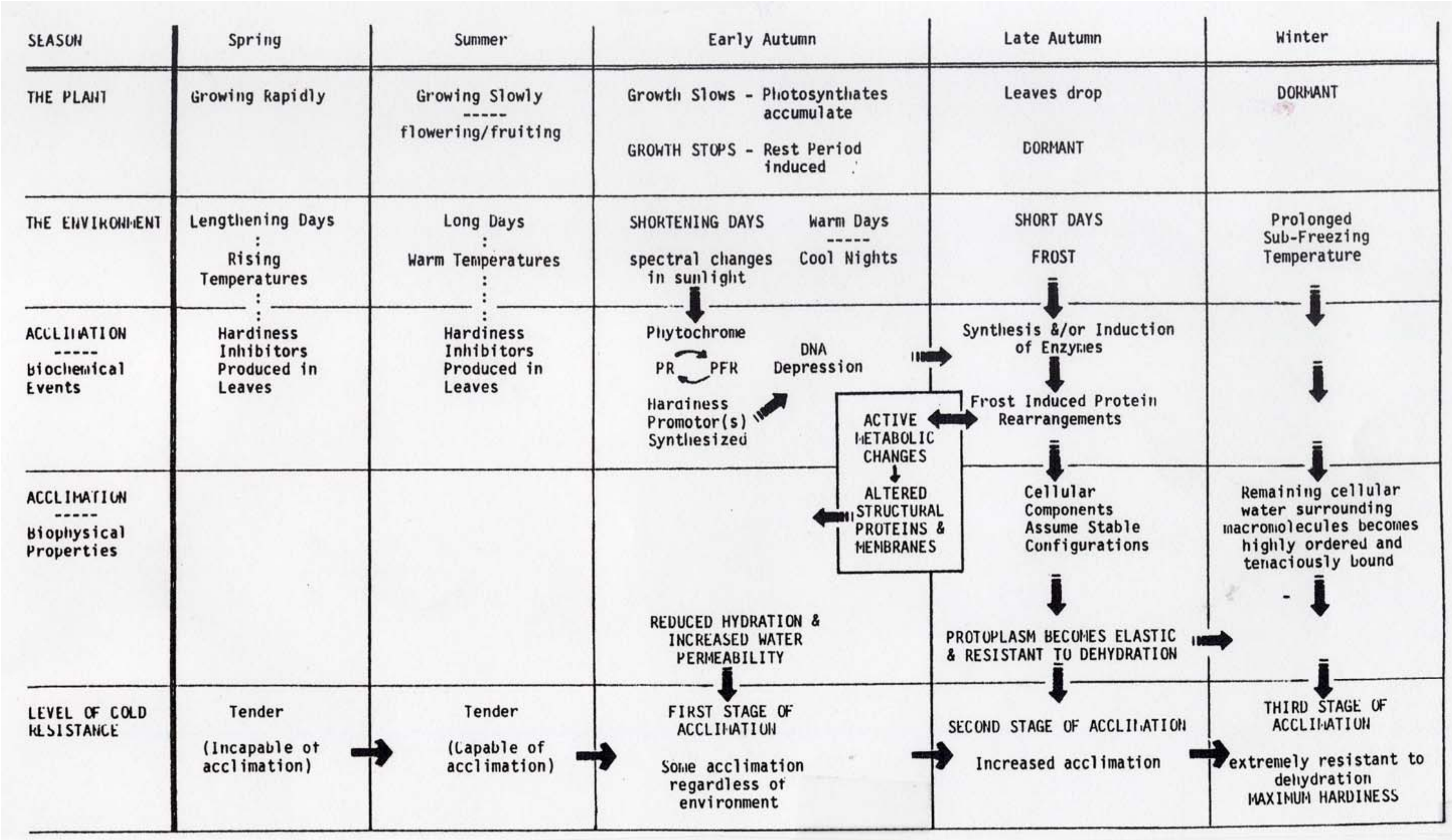

Figure 2. Cold acclimation in woody plants. Adapted from: C.J. Weiser. 1970. Cold Resistance and Injury in Woody Plants. Science 169:1269-1278.

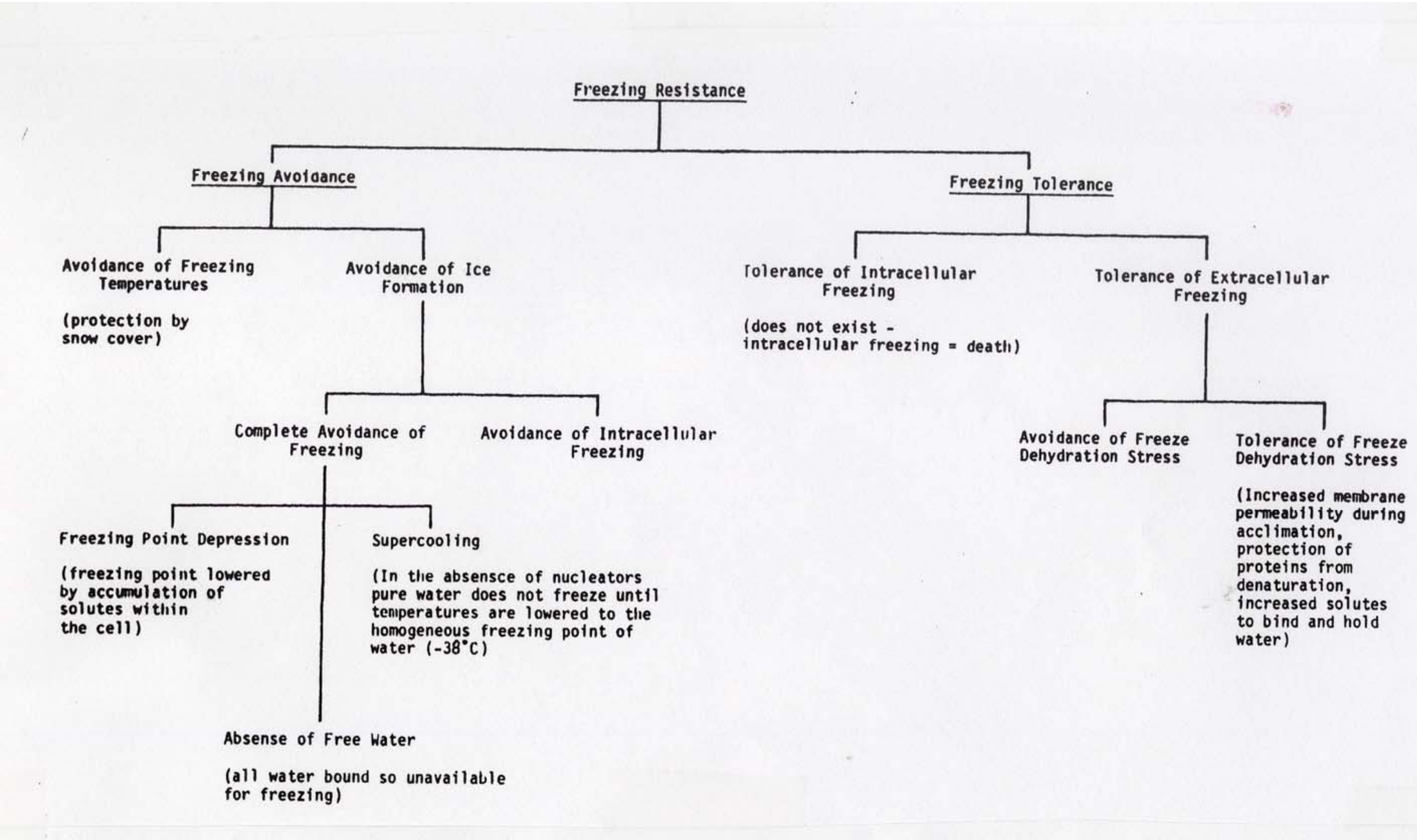

Figure 3. How plants survive freezing temperatures. Adapted from: J. Leavitt. 1971. Responses of Plants to Environmental Stress.

Plants which are able to tolerate very low temperatures must be able to accommodate ice within the plant without disruption of their tissues. They must also be capable of surviving severe desiccation of the cytoplasm or cell contents, and subsequent mechanical and biochemical stresses on cellular constituents. Hardening results in an increase in cytoplasmic viscosity making the cytoplasm more resistant to mechanical disruption. Hardening may also involve increased binding of water to macromolecules and membranes. Thus, frost resistance is essentially the ability to tolerate intercellular or outside the cell ice and cell dehydration without injury.

Under natural conditions, temperatures generally fall at relatively slow rates. Under such conditions, water in plants begins to freeze. This occurs first in water located outside and between the living cells. These locations are called intercellular spaces. The freezing in the intercellular spaces is called extracellular freezing. Under natural conditions, as freezing progresses, water continues to move out of the cell and continues to freeze extracellularly. If temperatures drop very quickly, ice may form within the living cell, which is called intracellular freezing, resulting in death of the cell. Examples of this occurring in nature include injury to evergreen foliage and sunscald damage on the south and southwest exposures of plant materials. During a short sunny period in the winter, tissues can thaw and become active. If the sun should become blocked by a building or a cloud, tissue temperatures can drop quickly, resulting in intracellular freezing and death.

Once developed, the continued internal maintenance of cold hardiness depends on the same environmental factors responsible for the inhibition of growth, induction of dormancy, and initiation of cold hardiness development. If temperatures remain low after internal dormancy has been broken, plant material will retain cold hardiness levels. If periods of warm temperatures occur after the internal genetically-based and physiologically-based dormancy requirements have been satisfied, cold hardiness may be reduced or lost. This will result in injury if temperatures fall again rapidly. Again, the site where the plant is naturally adapted plays a role in the relationship between frost hardiness and dehardening during the spring.

Other factors such as supercooling, cyclic freezing and thawing, and prolonged exposure to freezing temperatures can affect plant survival. Further understanding of the complex biochemical and physiological responses to environmental stimuli resulting in cold hardiness development and maintenance is needed to completely understand this critical factor in plant survival.

Winter Protection

The most important factors that enhance winter survival are:

1. **Selection of plant materials which have been proven to be cold hardy.**

2. **Locating plant materials on sites to which they are adapted**.

3. **Providing proper production cultural practices throughout the growing season to ensure optimal plant health and vigor**.

Selecting plant materials that are genetically hardy and locating them on sites where they are adapted and will grow well, is the best insurance against winter injury. **Always determine the geographical source of the plant material, whether it is seed, cuttings or other forms of transplants, since cold hardiness is genetically determined.** The timing of acclimation and deacclimation is also genetically controlled and is crucial to survival.

A good example of the importance of site to plant cold hardiness and survival would be the location of plants on north facing slopes. One of the characteristics of north slopes is greater frost penetration which one might think would result in greater root injury. However, snow is less likely to melt on northern slopes and subsequent snow accumulation insulates the soil and roots from injurious temperatures. In addition, snow cover remains on northern slopes longer in the spring which delays deacclimation and growth. This prevents injury from late spring freezes.

Adequate fertility and moisture is necessary to promote strong, balanced and healthy growth and development. Pruning should be timed properly so as not to promote succulent growth late into the fall. Avoid excessive nitrogen fertilization in late summer and fall to reduce succulent growth and to promote hardiness. A gradual reduction in watering will also help to harden plants in preparation for winter. Avoidance of herbicide injury, and stress due to insects and diseases, which may weaken the plant and reduce its ability to acclimate adequately, will also help insure proper hardiness development.

Ensure that plant material enters the winter with adequate soil moisture by watering thoroughly **after** plants have hardened off, but prior to freeze-up. A moist soil also acts as a buffer against rapid changes in soil temperature due to the specific heat of water as compared to that of air.

Planting a cover crop such as oats or rye in field situations will facilitate hardening-off of plant materials through competition for moisture and nutrients. Competition with a cover or companion crop will also promote the development of a deeper root system resulting in less injury to surface roots. Cover crops will also catch snow which provides moisture and insulation. Cover crops can also reduce damage caused by windblown snow and soil particles especially on evergreens, young plants, and field-stuck cuttings.

Mulching will help moderate soil temperature and reduce cyclic freezing and thawing. Mulching also conserves soil moisture. Winter mulching with straw or hay is critical to the survival of many herbaceous perennials, and it reduces soil heaving of newly transplanted stock, particularly in open winters.

Shading of sensitive plant materials from winter sun and wind with burlap, wrapping, or through proper landscape plant placement relative to buildings, other plant material and topography, will decrease injury from sunscald, desiccation, and temperature extremes.

The potential for winter injury to plants produced in containers is especially high because plant roots in containers are exposed to much lower temperatures than when roots are insulated by soil in the field. Container grown plants require special attention to insulate roots from injurious winter temperatures. At the very least, containers should be consolidated and tipped with the plant tops pointing west or south using the tops of the plants to cover the row of containers ahead of them. This arrangement increases the potential for collection of snow resulting in increased protection. It also reduces temperature fluctuations in the container by shading the containers from winter sun. Although snow is an excellent insulator, reliable snow cover throughout the winter is not consistent. Therefore, additional protection for tipped container stock is required. Plants may be covered with an insulating layer of straw or specifically designed insulating blankets such as microfoam. A layer of plastic, followed by an eight to 12-inch layer of straw and a second layer of plastic to keep the straw dry, provides excellent winter protection for container stock. Refer to the chapter on Container Production for more detailed information on winter protection of container stock.

Although not a low temperature problem, salt damage and rodent damage are also usually associated with the winter season. The use of salt for deicing purposes during the winter can cause problems for plant materials growing adjacent to streets, driveways, and sidewalks. Plants can be injured by salt carried in runoff or by salt spray from passing vehicles. The best solution to this problem is to avoid the use of such materials. If this is not possible, only plants which are tolerant of high salts should be used in these areas (Tables 1 and 2). Thorough and deep irrigation of areas prone to salt accumulation in early spring may reduce salt injury by leaching salts below the root zone.

To protect container stock from winter rodent damage, place rodent bait in and around the parameters of the area. Start placing the bait in the parameters in early September and continue until the plants are covered. For planted trees, tree wrap is somewhat effective, but a one-quarter inch wire mesh may be required in heavy infestations. It should be inserted two inches into the soil and extended up to the lowest branch or beyond the average snow level. Properly applied barrier techniques are necessary to prevent damage from rabbits, voles, mice, deer feeding, and deer rubbing.

The best way to a avoid winter cold injury and physical damage to nursery and landscape plants is to select reasonably hardy plants and to employ proper production and cultural practices.

Table 1. Relative salt tolerance of trees and shrubs.

High Salt Tolerance

Acer platanoides (Norway Maple)
Aesculus hippocastanum (Horse Chestnut)
Betula alleghaniensis (Yellow Birch)
B. lenta (Cherry Birch)
B. papyrifera (Paper Birch)
B. populifolia (Gray Birch)
Caragana arborescens (Siberian Pea Shrub)
Crataegus species (Hawthorn)
Elaeagnus angustifolia (Russian Olive)
Fraxinus americana (White Ash)
Gleditsia triacanthos (Honeylocust)
Larix decidua (European Larch)
L. leptolepis (Japanese Larch)
Lonicera xylosteum (European Fly Honeysuckle)
Lycium (Matrimony Vine)
Morus sp. (Mulberry)
Parthenocissus quinquefolia (Virginia Creeper)
Picea glauca (White Spruce)
P. pungens (Colorado Blue Spruce)
Pinus mugo (Mugo Pine)
P. nigra (Austrian Pine)
Populus acuminata (Lanceleaf Poplar)
P. alba (White Poplar)
P. balsamifera (Balsam Poplar)
P. deltoides (Cottonwood)
P. grandidentata (Big Tooth Aspen)
P. nigra (Black Poplar)
P. nigra `Italica' (Lombardy Poplar)
P. tremuloides (Trembling Aspen)
Potentilla fruticosa `Jackmanii'(Jackman's Potentilla)
Prunus armenica (Apricot)
Quercus alba (White Oak)
Q. macrocarpa (Bur Oak)
Q. rubra (Red Oak)
Q. robur (English Oak)
Ribes alpinum (Alpine Current)
Robinia pseudoacacia (Black Locust)
Rosa rugosa (Rugosa Rose)
Salix fragilis (Crack Willow)
S. viminalis (Common Osier)
Shepherdia argentea (Buffaloberry)
Spiraea X vanhouttei (Vanhoutte's Spirea)
Symphoricarpus albus var. Laevigatus (Garden Snowberry)
Tamarix pentandra (Fivestamen Tamarisk)
Ulmus glabra (Scotch Elm)

Moderate Salt Tolerance

Acer ginnala (Amur Maple)
A. negundo (Boxelder)
A. saccharinum (Silver Maple)
Alnus glutinosa (Black Alder)
Betula sp. (Birch)
Fagus sp. (Beech)
Fraxinus pennsylvanica (Green Ash)
Juniperus sp. (Juniper)
Juniperus virginiana (Red Cedar)
Pinus ponderosa (Ponderosa Pine)
P. sylvestris (Scotch Pine)
Prunus serotina (Black Cherry)
Pseudotsuga menziessii (Douglas Fir)
Pyracantha sp. (Firethorn)
Rhus glabra (Smooth Sumac)
Salix alba (White Willow)
S. pentandra (Laurel-Leaf Willow)
SpiraeaXbumalda `Froebelii' (Froebel's Spirea)
Syringa vulgaris (Common Lilac)
Thuja sp. (Arborvitae)
T. occidentalis (Eastern White Cedar)
Ulmus americana (American Elm)

Low Salt Tolerance

Acer pseudoplatanus (Sycamore Maple)
A. rubrum (Red Maple)
A. saccharum (Sugar Maple)
Alnus rugosa (Smooth Alder)
Abies balsamea (Balsam Fir)
Berberis sp. (Barberry)
Carpinus caroliniana (American Hornbeam)
Carya ovata (Shagbark Hickory)
Celtis occidentalis (Hackberry)
Cornus stolonifera (Red Osier Dogwood)
C. stolonifera `Flaviramea' (Yellow-twig Dogwood)
Euonymus alatus (Winged Euonymus)
Fagus sylvatica sp. (European Beech)
Juglans nigra (Black Walnut)
Larix sp. (Larch)
Ligustrum vulgare (Common Privet)
Malus `Hopa' (Hopa Crabapple)
Picea abies (Norway Spruce)
Pinus resinosa (Red Pine)
P. strobus (White Pine)
Rosa sp. (Rose)
Sambucus racemosa (European Red Elder)
Spiraea sp. (Spirea)
Tilia americana (American Linden)
T. cordata mill. (Little-Leaved Linden)
Tsuga canadensis (Eastern Hemlock)
Viburnum sp. (Viburnum)
Viburnum trilobum (American Highbush Cranberry)

Table 2. Relative salt tolerance of grasses and grass-like species.

High Salt Tolerance

Agropyron elongatum (Tall Wheatgrass) - CS, RRPL, B, CH
Agropyron trachycaulum (Slender Wheatgrass) - CS, RRPL, B, CH
Agrostis stolonifera/A. stonolifera var. palustris (Creeping Bentgrass) - CS, T, R, CH
Alopecurus arundinaceus (Creeping Foxtail) - CS, RRPL, B, CH
Amophila breviligulata (American Beachgrass) - CS, RRPL, R, CH
Chasmanthium latifolium formerly Uniola latifolia (Northern Sea Oats) - WS, RRPL, R, CH
Cynodon spp. (Bermuda Grass) - WS, RRPL, T, R
Distichus stricta (Inland Saltgrass) - WS, RRPL, R, CH
Festuca arundinacea (Tall Fescue) - CS, RRPL, T, B, CH
Leymus angustus formerly Elymus angustus (Alkali Wildrye) - CS, RRPL, B, CH
Leymus triticoides formerly Elymus triticoides (Creeping Wildrye) - CS, RRPL, R, CH
Panicum amarum (Sea Panicgrass) - WS, RRPL, R
Paspalum vaginatum (Seashore Paspalyum) - WS, RRPL, T, R
Puccinellia aircoides (Nutall Alkaligrass) - CS, RRPL, T?, R, CH
Puccinellia distans (Weeping Alkaligrass) - CS, RRPL, T (cv. Fults), R, CH
Puccinellia lemmonii (Lemon Alkaligrass) - CS, RRPL, T?, R, CH
Scirpus maritima (Alkali Bulrush) - RRPL, R, CH
Spartina patens (Salt Meadow Cordgrass) - WS, RRPL, R, CH?
Sporobolus airoides (Alkali Sacaton) - WS, RRPL, B, CH
Stenotaphrum secundatum (St. Augustinegrass) - WS, RRPL, T, R
Unicola paniculata (Sea Oats) - WS, RRPL, R
Zoysia japonica (Zoysiagrass, Japanese Lawngrass) - WS, RRPL, T, R, CH
Zoysia matrella (Manilagrass) - WS, RRPL, T, R
Zoysia tenuifolia (Mascarenegrass) - WS, RRPL, T, R

Moderate Salt Tolerance

Andropogon gerardii (Big Bluestem) - WS, RRPL, B/R, CH
Aristida purpurea (Purple Three - awn) - WS, RRPL, B, CH
Axonopus affinis (Common Carpetgrass) - WS, RRPL, T, R
Buchloe dactyloides (Buffalograss) - WS, RRPL, T, R, CH
Calamagrostis acutiflora (Feather Reed Grass) - CS, RRPL, B, CH
Carex nebraskensis (Nebraska Sedge) - RRPL, R, CH
Carex nostrata (Bearded Sedge) - RRPL, R, CH
Elymus glaucus (Blue Wildrye) - CS, RRPL, B, CH
Eremochloa ophiuroides (Centipedegrass) - WS, T, R
Lolium perenne (Perennial Ryegrass) - CS, RRPL, T, B, CH
Miscanthus spp. (Miscanthus, Maidengrass) - WS, RRPL, R, CH
Paspalum notatum (Bahiagrass) - WS, RRPL, T, R
Phalaris arundinacea (Reed Canarygrass) - CS, RRPL, T, B, CH
Schizachyrium scoparium formerly Andropogon scoparius (Little Bluestem) - WS, RRPL, B, CH
Scirpus acutus (Hardstem Bulrush) - RRPL, R, CH
Spartina pectinata (Prairie Cordgrass) - WS, RRPL, R, CH
Sporobolus cryptandrus (Sand Dropseed) - WS, RRPL, B, CH
Stipa viridula (Green Needlegrass) - CS, RRPL, B, CH
Typha latifolia (Common Cattail) - RRPL, R, CH

Table 2 Continued. Relative salt tolerance of grasses and grass-like species.

Low Salt Tolerance

Agrostis capillaris (Colonial Bentgrass) - CS, T, R, CH
Agrostis tenuis (Colonial Bentgrass) - CS, RRPL, T, R, CH
Beckmannia syzigachne (American Sloughgrass) - CS, RRPL, B, CH
Bouteloua curtipendula (Sideoats Grama) - WS, RRPL, R, CH
Bouteloua gracilis (Blue Grama) - WS, RRPL, R, CH
Bromus ssp. (Brome Grasses) - CS, RRPL, B/R, CH
Carex aquatilis (Water Sedge) - RRPL, R, CH
Dactylis glomerata (Orchardgrass) - CS, RRPL, B, CH
Deschampsia caespitosa (Tufted Hairgrass) - CS, RRPL, B, CH
Festuca longifolia (Hard Fescue) - CS, RRPL, T, B, CH
Festuca ovina (Sheep Fescue) - CS, RRPL, T, B, CH
Festuca rubra ssp. commutata (Chewings Fescue) - CS, RRPL, T, R, CH
Panicum virgatum (Switchgrass) - WS, RRPL, B/R, CH
Phragmites communis (Common Reedgrass) - CS, RRPL, R, CH
Poa pratensis (Kentucky Bluegrass) - CS, RRPL, T, R, CH
Sorghastrum avenaceum formerly S. nutans (Indiangrass) - WS, RRPL, B/R, CH
Zizania aquatica (Wild Rice) - CS, RRPL, B, CH-annual

CS	=	Cool season
WS	=	Warm season
RRPL	=	Reclamation, range, prairie and landscape use
T	=	Turfgrass species
B	=	Bunchgrass = non-spreading
R	=	Rhizomatious/Stoloniferous = spreading
CH	=	Cold hardy or selections exist that are cold hardy in the upper Midwest