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SPECIAL ... OVERWINTERING CONTAINER-GROWN PLANTS:

I. PRINCIPLES: PROTECTING CONTAINER-GROWN PLANTS DURING THE WINTER MONTHS

The primary causes of winter damage to container-grown nursery plants during the winter months are: 1) Desiccation, and 2) Freeze damage (mostly to the root system). The purpose of this article is to describe the theory of desiccation and freeze damage, describe how plants cold acclimate, and discuss ways of preventing plant desiccation and winter damage to container-grown nursery plants.

Why container-grown nursery plants desiccate during the winter

Plant species differ in their ability to resist and survive desiccation stress. Generally, plants with waxy surfaces and deciduous plants that lose their foliage in the fall and become dormant are more resistant to desiccation stress.

Although plants vary in sensitivity to desiccation stress, they are all subject to desiccation winter injury. The problem results from faster loss of water from the top portion of plants (transpiration) than water uptake through the roots. This situation can occur in the following manner: **1) Changes in the roots: Roots do not acquire dormancy, but during the winter their growth is inhibited due to low temperatures.** When this occurs, the ability of the roots to absorb water at the root tips decreases as the root tissues mature and become suberized. In some plants, water uptake is impaired at low temperatures due to changes in the cell membranes. In both situations, water uptake is reduced drastically, thereby, reducing the plants ability to compensate for rapid transpirational losses**. 2) Change in viscosity of water**: As temperature decreases the viscosity of the water increases. And, as the viscosity increases, the rate of water uptake through the root system decreases. Therefore, as the temperature of the soil decreases the plants become less efficient at compensating for the transpirational loss. 3) **Ice:** Eventually, as the temperature continues to decrease, the water in the container freezes. When this occurs water uptake is completely shut down while transpiration continues**. 4) Environment above ground**: The rate of transpirational loss is related to the environment of the above ground portion of the plant. Transpiration increases with decreasing humidity, increasing light intensity, increasing wind speed and increasing temperature. Some plants are well adapted to regulating transpiration by closing the pores (lenticels, stomata) and/or producing cuticular waxy surfaces.

Plant desiccation increases when a combination of the above conditions occur. For example, if the water in the container is frozen, the light intensity and wind velocity are high, and the humidity is low this will result in no root absorption of water, a rapid rate of transpiration, and shoot-leaf desiccation.

How plants cold acclimate and deacclimate

1) Development of Cold Tolerance in Shoots:

The development of cold hardiness (acclimation) and loss of hardiness (deacclimation) is dependent on the genetic potential and physiological condition of the plants. Some plants cannot cold acclimate while others can acclimate to extremely low temperatures (-196°C). Those plants that can acclimate, acclimate in response to changes in the environment. There are times when these plants cannot tolerate freezing temperatures (e.g. spring and early fall) and times when they are able to resist very low temperatures (e.g. during winter). The difference in hardiness of some plants at their two extreme growth stages may be as much as 190°C. An important principle to remember is that the degree of hardiness changes in response to the environment, and responsiveness of the plant to the environmental changes depends on the growth stage of the plant.

A relatively simple way to explain the annual physiological condition of a typical temperate plant is by a numerical system, called **the ºGS (Degree Growth Stage) Model** (Fuchigami, et.al. 1982, Kobayashi, et.al. 1983). The main purpose of this system is to illustrate the dynamic nature of the plant, which changes daily, and to quantitatively know the plant's stage of development. It also serves a useful purpose of explaining when plants acclimate and how they respond to environmental conditions.

According to the °GS Model, temperate plants go from 0°GS to 360 GS in any given year (Figure 1). It should be emphasized that each °GS is not equated to days in a year or a specific calendar date, but is related to the condition of the plant (Growth Stage of the plant).

The °GS model states that the plants are not hardy between O°GS to 180°GS (spring budbreak to vegetative maturity). Plants are able to cold acclimate at 180°GS (vegetative maturity, Nissila, 1978) and are capable of maintaining some degree of hardiness through 360°GS.

90-180ºGS: The beginning of hardiness induction actually occurs before any increases in hardiness are evident. Between 90º - 180°GS, the leaves of plants receive a signal when the daylength shortens below a critical level **- the critical short daylength is the main controlling factor which determines when plants go dormant**. This signal produces a dormancy inducing hormone within the leaves which is then translocated throughout the plant (Fuchigami, 1971) eventually terminating the growth of the buds, producing dormant buds. **The production of the dormancy inducing hormone is favored by warm temperatures**. At this stage the plants are vegetatively mature (dormant) and are no longer dependent on light and/or leaves for overwinter survival.

180°-270°GS: The rates of acclimation and deacclimation are based on the growth stage and temperature. The rate of acclimation increases with lowering temperatures. Freezing temperatures are not required for acclimation, however, non-killing frosts can hasten the rate of acclimation, however, non-killing frosts can hasten the rate of acclimation (Weiser, 1970). Basically, the rate of acclimation at a given temperature increases between 180º - 270°GS. Plants generally do not deacclimate or lose hardiness during this period (fall and early winter), even at relatively high temperatures (20°C).

270º - 315º GS: At this stage the plant is generally at its hardiest level (mid-winter), and the degree of hardiness is maintained by low temperatures. However, at high temperatures (above 20°C), they can deacclimate.

Between 315° - 360°GS, only very low temperatures (e.g. less than 5°C) can promote acclimation, while any temperatures above this will cause deacclimation. The rate of deacclimation increases at later stages and with increasing temperatures. (fall and early winter), even at relatively high temperatures (20°C).

Table 1 explains the relationship of the °GS to the growth status of the vegetative buds of temperate zone woody plants.

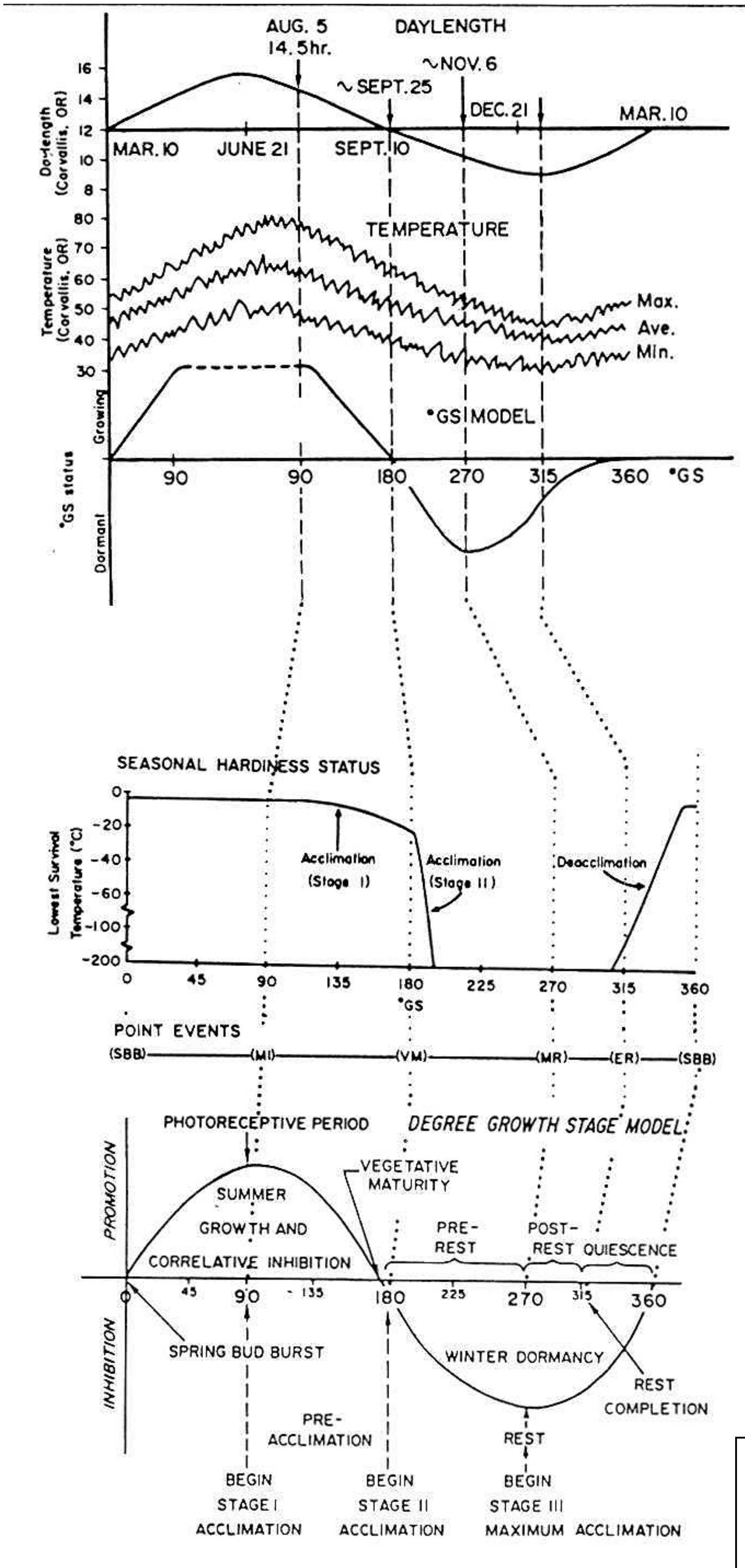

Figure 1: Degree Growth Stage model for identifying developmental stages of terminal vegetative buds of temperate zone woody plants.

TABLE 1: Growth and dormancy timing and terminology for growth stages and phases during the annual development cycle of terminal vegetative buds of temperate zone woody plants (from Kobayashi et al., 1982)

Developmental status	Growth stage	Degree growth stage (°GS)[1]	Growth phase
Growing	**Spring Bud** Break **(SBB)**	0	
Growing		0-90	Rapid growth
Growing	**Maturity Induction (MI)**	**90**	
Growing inhibited		90-180	Decreased growth and correlative inhibition
Dormant	**Vegetative Maturity (VM)**	**180**	
Dormant		180-270	Deepening rest
Dormant	**Maximum Rest (MR)**	**270**	
Dormant		270-315	Decreasing rest
Dormant	**End of Rest (ER)**	**315**	
Dormant		315-360	Quiescence

[1] Degree growth stage (°GS) is a numerical representation of bud development. Annual growth cycle is represented by 360 GS.

What does this mean to the grower?

To the grower, the most important concepts to remember are:

a) Plants can develop cold tolerance (acclimate) during dormancy (180 - 360°GS).

b) Development and loss of cold tolerance (acclimation and deacclimation) is temperature and growth stage dependent.

Between 180 - 270°GS, the rate of acclimation increases with lowering temperatures and deacclimation is not a problem. Potential for cold damage occurs in years when warm fall seasons that delayed the start of acclimation are followed immediately by rapid freezing temperatures that fall below the level of plant hardiness. It is important that the plants be conditioned to low temperatures early in the fall to hasten their acquisition of hardiness before rapid onset of low temperatures.

After 270°GS as plant development approaches 360°GS, the major problem is deacclimation. Deacclimation rates increase in this later growth stage, and deacclimation rate is more rapid at higher temperatures. Protective structures used during this time should be used mainly to insulate the plant and prevent extremes in temperatures (high or low temperatures). Structures that cause wide daily fluctuations in temperature (e.g. closed, polyethylene structures) are especially detrimental during this period.

2) Development of Cold Tolerance in Roots:

A major problem in overwintering container-grown plants is that the roots are significantly less cold-tolerant than the shoots of the plant. In some plants the difference in hardiness between the roots and shoots can be as much as 50°F: e.g. in *Pyracantha coccinea* Roen. Lalandei , stems can survive -15°F when fully acclimated; older, woody roots are killed at 2°F; and young roots are killed at 22°F (Stepkonkus, et.al., 1976).

Why are roots less hardy than shoots? As stated previously, the acclimation of the shoots and buds of temperate plants is dependent on environmental signals which regulate the development of growth stages in the tops of plants. Short daylengths and warm temperature promote vegetative maturity development (180º - GS) and low temperatures promote hardiness following 180°GS. In roots, however, photoperiod has no effect on root growth. In fact**, roots do not acquire dormancy**. Root growth is strictly a function of temperature - e.g. above a threshold temperature roots grow; below this temperature root growth stops. This physiological difference between roots and shoots is believed to be one of the major reasons for their differences in hardiness. In general, to harden, a tissue or organ must cease growth before it is capable of hardening. Therefore, the hardiness of roots is strictly a function of temperature and possibly closely associated with its threshold temperature for growth. Low temperatures promote root hardiness, whereas high (warm) temperatures cause deacclimation at any time during the winter months.

What does this mean to the grower?

To the grower the most important principles to remember are:

a**) Roots do not go dormant**, in fact, they do not have the stages of development that shoots do.

b) **Root hardiness is a function of temperature** - low temperatures promote hardiness, and warm temperatures promote deacclimation. Therefore, in practice an important consideration in the production of container plants is to insulate the root system from extremes in temperatures. Typically the root systems of container plants are poorly buffered from temperature extremes because of their exposure to the environment and the small quantity of media that surrounds the roots. Consequently, the temperatures of the roots of container plants fluctuate greatly in response to environmental changes. Since roots do not go dormant, and development of cold tolerance in the root is strictly related to root growth activity (temperature dependent), cold damage might occur at any time during the year. The rate of deacclimation in tissues that do not acquire dormancy (i.e. roots) is rapid -- the entire hardiness level can be lost within 24 hours. Once deacclimation occurs and growth begins, reacquisition of cold tolerance may require days. The roots of plants exposed to warm temperatures are thus quite susceptible to freezing temperatures.

II. PRACTICES: OVERWINTERING CONTAINER-GROWN, WOODY PLANTS UNDER STRUCTURELESS COVERS

The primary objectives when protecting container-grown nursery plants during the winter months are: 1) ENVELOPE the plant to prevent foliage desiccation, and 2) INSULATE the plant, especially the root system, from temperature extremes. The optimum protection

system would provide a moisture barrier to prevent severe plant desiccation and evaporative chilling by winter winds and insulation that would maintain plants during the winter continuously at a temperature slightly above that which would cause cold damage.

A. Factors causing fluctuations in plant temperature (heat balance) -

Solar radiation when absorbed is converted to heat energy. During the daytime, the solar radiation gained by an exposed plant exceeds the thermal radiation lost and there is a net gain in heat energy in the plant's environment. Part of the energy heats the plant, soil and air (raises their sensible temperatures) and part goes into evapotranspiration (conversion of sensible heat energy into latent heat energy). In addition to transfer of sensible heat energy from the plants immediate environment by **thermal radiation** to cooler surfaces and by **conversion into latent heat energy** through evapotranspiration, the heat energy may be conducted or convected away. **Conduction** is the transfer of heat energy between particles in direct contact, for example conduction through the plant from a warmer to a cooler region or through water in the soil. In **convection** a flowing medium is necessary. Heat travels between two places via a fluid, such as a gas (air) or a liquid (water).

As air movement (wind) increases, large quantities of heat energy may be removed from the plant through convection and evapotranspiration (evaporative cooling or wind-chill factor). Wind increases the rate of evaporation and removal of heat energy from the leaf. Evaporation of water can lower the leaf surface temperature below the sensible temperature of the surrounding air. The leaf temperature may fall below freezing even though air temperatures remain above freezing.

At night with no solar radiation gain, all outdoor exposed surfaces lose heat by radiation. The clearer the night, the greater the loss due to deep-space radiation. Clouds, or covers that do not transmit thermal radiation, act as a blanket inhibiting this radiant loss, absorbing some radiation and reflecting some back. In addition, at night heat could be lost from the exposed plant and soil by conduction to the surrounding, cooler night air and could be transferred from the plant's immediate environment by wind convection.

B. Selecting a winter protection system to insulate against temperature extremes and fluctuations and to prevent plant desiccation

In selecting an appropriate winter protection system, two questions must be answered: 1) Amount of protection needed, and 2) Months when protection is needed (when to apply, when to remove). The amount of protection needed depends upon the root-killing temperature for the species being grown (Appendix 1) and the climate of the specific production area: Climatic records of monthly minimum temperatures and wind chill factors indicate when to apply protection and degree of protection needed to protect against low temperatures that would be root-killing and shoot-damaging.

Monthly high temperatures and solar radiation indicate amount of sunlight blocking (degree of opaqueness or shading) and insulation the cover must provide to prevent occurrence of high plant temperatures.

Structureless covers provide greater protection than do structure-supported covers:

Quonset structures, hoop houses, etc covered with two layers of poly (air-separated) with at least one layer being opaque white poly and, often, with an additional structureless sheet of poly inside that can be pulled directly over the enclosed plant materials during short periods of cold weather are frequently used with or without forced air heaters in cold climates, i.e. climatic zone 4 (Havis, 1984). However**, plant survival in unheated hoop houses (either single or double layer poly) in zone 7 was not as good as that under structureless protective covers (Table 1, McNeil and Duncan, 1983).** Because of this as well as the greater efficiency and economy associated with application of structureless covers, this report will focus on STRUCTURELESS PROTECTIVE COVERS.

Table 1. The survival of four species of container-grown plants that had been overwintered with five types of protection illustrates differences among plant species in cold tolerance and different degrees of protection provided by different systems (McNeil and Duncan, 1983).

		Species (# survived/total # plts)		
Protection	Holly	Juniper	Cotoneaster	Sweet gum
NO PROTECTION	0/7	0/7	0/7	0/7
STRUCTURES:				
Single-layer poly[1]	0/7	**6/7**	0/7	1/7
Double-layer poly[2]	0/7	**4/7**	1/7	0/7
Lath-sawdust[3]	0/7	7/7	5/7	1/7
STRUCTURELESS:				
Microfoam [4]	0/7	7/7	**6/7**	**4/7**
Plant-foam[4]	0/7	7/7	7/7	5/7

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[1] Hoop house covered with opaque poly, 4 meters wide and unheated.
[2] Hoop house with an outer layer of 6-mil opaque poly, an inner layer of 4 mil clear poly, 4 meters wide, air-inflated and unheated.
[3] Lath frame for roof, 2.5 meters high. Sawdust mulch around the 4 containers.
[4]Commercial foam-blanket covers.

C. Different types of structureless covering materials provide different types and degrees of protection

1. Enveloping but transmitting radiant energy - A clear polyethylene cover is impermeable to moisture and shields the plant from winds thereby reducing both loss of heat and moisture through evapotranspiration as well as convective heat loss from the plant. However, large temperature fluctuations can occur under clear polyethylene. During the daytime, it transmits solar radiation to the enveloped plant which when absorbed by the plant is converted to heat with a consequent rise in plant temperature. Pellett (1984) reported that when the outside air temperature on a sunny day in April was 48°F, air temperature under a single layer translucent polyethylene cover was 104°F. Davidson and Mecklenburg (1981) stated that on clear, sunny days in winter when the outside air temperature is in the low 30s, it is not uncommon for air temperatures to reach 60-70°F and for leaf temperatures to attain levels of 100°F or more.

At night, particularly on clear cold nights, radiant heat from the plant is transmitted through the clear polyethylene with a consequent lowering of the plant temperature: Under radiation cooling, the plant temperature may fall below the outside air temperature. Because daily temperature fluctuations can be extreme under clear polyethylene**, clear polyethylene should be used only as a temporary cover (a few hours to at most a few days) to protect plants from wind chill and excessive moisture loss.**

2. Enveloping structureless covers with low transmission of thermal radiation, i.e. white polyethylene - Airtight enveloping materials (i.e. plastic films, etc) are a barrier-protection from winds and associated convective heat and moisture losses. In addition, when plants are enveloped with white polyethylene, temperature fluctuations are dampened: less light is transmitted through the plant envelope during the daylight hours and less radiant heat is transmitted out at night). **White polyethylene structureless covering is useful in climatic zones and during months when differences between outside and desired enclosed air temperatures are not great. Hicklenton (1982) suggests this method may be used in areas with an annual minimum temperature which is not below 5°F for plants with roots hardy down to 18°F and for more hardy species. It is applied to dormant plants in the fall and removed in early spring before warmer temperatures stimulate renewed plant growth.**

3. Enveloping-insulating materials reduce plant temperature fluctuation and minimize plant moisture loss. Enveloping-insulating covers reduce radiant energy transfer (opaque covering materials), prevent convective transfer of energy (a continuous barrier), and have a low rate of heat conduction. They effectively envelop and insulate the plant from changes in the outside environment thereby preventing temperature extremes (high and low) and maintaining uniform temperature within the plant zone. Microfoam, Guilbond, and fluffed straw between two layers of white poly are examples of enveloping-insulating covers that reduce fluctuations in plant temperature caused by minimizing radiant, conductive and convective heat transfer.

Microfoam, a white styrofoamlike material, is available in 1/8" thick by 72" wide by 450' long or 1/4" thick by 72" wide by 225' long rolls. Microfoam covered by an external layer of white polyethylene is both insulating and enveloping.

Gilbond polyfoam (Guilbond Insulating Blanket, Guilford Packaging and Fiber Inc., P.O. Box 2643, Highpoint, NC 27261), a translucent, expanded plastic foam material with 1 mil white polyethylene film bonded to the surface, is available in 1/4" thick by 80" wide by 250' long rolls. Guilbond insulating blanket with the white poly bonded to the surface is stronger than microfoam and doesn't easily tear in handling (Pellett, 1984). The white poly bonded to the surface will reflect much of the sunlight and prevent undesirable rapid temperature fluctuation and undesirably high temperatures.

Layered materials where the enclosed air gap between the layers is less than 4 inches (convective currents may become established between the two layers if they are separated by a distance greater than 4 inches) reduce heat lost by conduction (air is a poor heat conductor) and convection. Convective heat transfer from the plants to the structure then conduction to the outside environment is greater in an enclosed structure, such as an arch house, than from plants in structureless covering systems where the enclosed air space rarely exceeds four-inch-thickness.

Grass straw is readily available in the Willamette Valley. An enveloping-insulating blanket of 12" of fluffed straw between two layers of white poly placed over container-grown plants, according to Pellett (1984) provided the best protection against low as well as high outside air temperatures and maintained stock in the most dormant condition of any covering tested. It does involve more labor than either the Microfoam or Guilbond Insulating Blanket in application, removal and storage.

Microfoam, Guilbond Insulating Blankets, and white polyethylene film are decomposed by sunlight. At the end of the winter season, these materials should be stored in a dry, dark location to extend their useful lifetime. Such storage care can result in two year usage for Microfoam and 3 to 4 years usage for Guilbond.

D. Plant preparation, application and removal of structureless covers -

When to Cover - When to Uncover? Climatic records indicate earliest date in the fall when protective cover can be safely applied (when plant will have received sufficient cooling to develop cold tolerance), and earliest date in the spring when protective cover can be removed. According to Gouin (1985), it doesn't seem to matter how early plants are placed under the protective coverings once they have gone dormant in the fall. Gouin (1985) stressed, however, that "it is of utmost importance that the plants be uncovered as early in the spring as possible ... Plants must be uncovered as soon as minimum temperatures stop dropping to root killing temperatures of the species being protected...once dormancy requirements have been satisfied, plant shoots exposed to temperatures above freezing rapidly lose their cold tolerance...My recommendations are to uncover as early in February as possible. This spring, those growers who uncovered by February 25 had no problems, those growers who delayed uncovering until March 12, suffered considerable damage."

Dr. Bob Ticknor (personal communication) suggests that in the Pacific Northwest (west of the Cascades), structureless covers should be applied mid-November and removed at the end of February.

1. Develop Cold Tolerance in Plants Before Applying Structureless Cover:

A period of short days and warm temperatures followed by exposure to a period of low temperatures is required for development of cold tolerance in both shoots and roots.

Plants should not be covered until they have developed cold tolerance. It is, however, necessary to protect the root systems of a specific species of container-grown plants when forecasts predict temperatures below the root killing temperature for that specific plant species.

A major problem in overwintering container-grown plants is that the roots are significantly less cold-tolerant than the shoots of the plant: Within a single plant, the cold tolerance of the roots and shoots can differ as much as 50°F: in *Pyracantha coccinea* Roem. 'Lalandei', stems can survive -15°F when fully acclimated. Older, woody roots are killed at 2°F. Young roots are killed at 22°F (Steponkus, etal., 1976). Cold tolerance of shoot tissues (leaf, leaf bud, flower bud, twig) of many woody ornamental species from both the Northern and Southern Hemispheres has been determined and reported by Sakai (1982). Cold tolerance of roots of woody ornamental plants is presented in Appendix 1.

In the fall, cold tolerance develops in the above-ground portion of the plant from the apical buds downward. The portion of the plant stem near the ground is the last portion of the shoots to become cold-tolerant in the fall. Prolonging shoot growth (and retention of foliage on deciduous plants) should be avoided by reduction of irrigation late in the growing season (Green and Weiser, 1982), and, if fertilizing in late summer, nitrate forms of nitrogen, not ammonium forms, should be used (Raker and Dirr, 1979).

Because reduced growth rate or cessation of growth is associated with development of cold tolerance, several researchers have investigated the influence of applied chemical growth retardants on development of cold tolerance (Harrington, et al. 1977; Irving, 1969; Mityga and Lanphear, 1971). Use of growth regulators to promote cold tolerance is not a common practice in commercial production of nursery plants. Irving (1969) stated that when strong growth inhibition and chemical damage occurred, the tissues were more susceptible to low temperatures. Concentration of growth regulator and time of application are apparently critical.

Development of cold tolerance in shoots - The rate and degree of cold tolerance developed is determined by the environment interacting with the genetic potential of the plant. When several clones of *Cornus stolonifera* from different geographical locations (but similar latitudes) were grown at one location, **marked differences occurred in the timing of acclimation**. A clone from Dickinson, North Dakota, acclimated more rapidly than a midwestern clone from Excelsior, Minnesota. And, both of acclimated more rapidly than did a coastal clone from Seattle, Washington. The first two clones had greater winter survivability in a cold winter climate because of earlier development of cold tolerance: The North Dakota clone became tolerant of -25°C temperatures early in September. The Minnesota became tolerant of -25°C in late September, but the Seattle clone did not develop tolerance to -25°C temperatures until late October-early November (Figure 1).

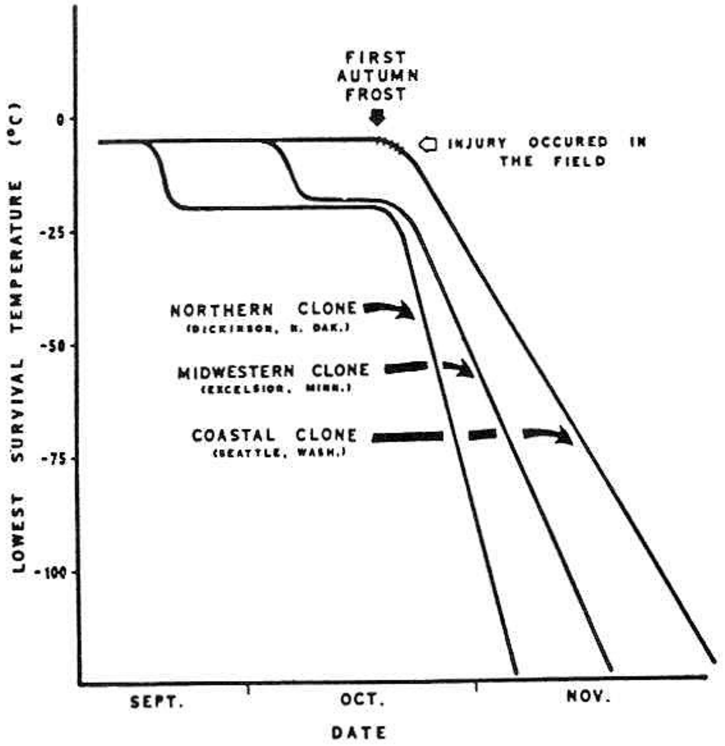

FIGURE 1: A comparison of the seasonal patterns of cold resistance in the living bark of three climatic races of *Cornus stolonifera*. Races from regions with mild climates and long growing seasons acclimate later and more slowly than clones from regions with severe climates and short growing seasons.

DEVELOPMENT OF COLD TOLERANCE IN ROOTS: Root growth slows and cold tolerance develops in response to the short day stimulus received from the leaves and cool root temperatures. However, roots do not become hardier in response to freezing temperatures (root killing temperatures for some woody ornamentals are presented in Appendix 1). If root growth is prolonged by cultural and environmental factors into the fall, development of cold tolerance of lower stems in some plants is delayed and bark splitting occurs.

Mityga and Lanphear (1971) reported that the root system of *Taxus cuspidata* exhibited zones of varying cold tolerance: naturally developed cold tolerance was greatest in root sections closest to the stem while the root tips were least cold tolerant. The light-colored young roots did not develop hardiness under any of the environmental treatments of Mityga and Lanphear.

LOSS OF COLD TOLERANCE MAY OCCUR - SHOOTS: After cold requirements for breaking dormancy have been met, if aerial temperatures rise, the plant may renew growth while in "winter protection" and be susceptible to frosts. The shoot apical buds are first to lose their cold tolerance in the spring and to renew growth. The more active the growth of a tissue, the more susceptible it is to cold damage. ROOTS: Roots do not have dormancy and can renew growth rise above freezing. This new growth is then susceptible freeze damage. It is important to keep the root temperature uniformly low, or to protect the roots from freezing temperatures.

2. **Group, Irrigate and Apply Pesticides:** After container-grown plants have achieved cold hardiness, but prior to covering, plants are grouped close together at a site that is well-drained and free of standing water during wet periods. The plants are irrigated to container capacity, and a protective fungicide is applied. Botrytis susceptible species should be sprayed just prior to covering. Gouin (1985) states that because the relative humidity remains near 100% under the structureless cover, it is important that a good sticker such as "Vapor Gard" or "Wilt Pruf" be used

with "Daconil". Rodent problems may occur: A bait with rodenticide should be spread at several locations in the grouped plants.

3. Lay Upright Plants Down & Cover: Upright plants are tipped over and laid pot-to-pot with foliage overlapping shingle-like. Placement of 3-gallon plants on their sides before covering "...did not appear to affect the foliage of any of the plants, including pine" (Smith, 1984). The structureless cover is placed directly over the plants, and the edges of the cover are sealed to the ground to create a closed-system which should not be opened or disturbed until warm days begin in the spring. The system must be kept closed to conserve ground heat and prevent desiccation of the containergrown plants.

E. CASE REPORTS -

1. The case for structureless, white polyethylene in climatic zones 7b - 8b (Georgia) where temperature seldom drops below 0°f or exceeds 65°F during winter months.

Simply covering beds of container-grown nursery plants with white plastic film that rests directly on top of the plants and is sealed down on all sides of the beds for approximately 3 months (December-March) is widely used in Georgia, climatic zones 7B, 8A, and 8B (Smith, 1984). According to Smith (1984), the night of December 24, 1983, when the temperature dropped to 1 degree in Georgia, there was 80% loss of uncovered *Ilex crenata* and *cornuta* cultivars and 95% loss of uncovered *Ilex vomitoria* 'nana' in one gallon containers. The same species under 4 mil white plastic (Visqueen 1505) held down with 73% shade cloth experienced only about 2% mortality -which occurred only on the margin of the plant groupings. When the covers were removed in mid-March, the plants were in excellent condition with the exception of some minor leaf drop. A successful method for sealing the edges of the plastic to the ground so it will not be blown off involves placing 1 x 4" treated boards around the margins. These are secured to the ground by driving 12" long sections of pipe with a 6" long welded arm on top into the ground every 6 feet. A final step is to secure the plastic-shade cloth covering down by running light nylon cord down the beds every 25 feet. The cord is pulled tightly and anchored to the pipe stakes.

2. The case for structureless, enveloping-insulating covers in climatic zones 5 - 7 (Nova Scotia, Kentucky and Vermont) where winter temperatures may drop below 0°f.

Foam-type, structureless coverings have provided greater protection over a wide-range of temperatures and geographical locations than have poly houses (Hicklenton, 1982). In USDA Hardiness Zones 5-6(Nova Scotia), Hicklenton reported marked differences between air and media temperatures related to the type of protective covering. Air temperatures were highest under clear poly (frequently in excess of 50°F during the day) while the root zone remained frozen - a condition that can result in severe desiccation injury. Least fluctuation of air temperature occurred under microfoam covering. Hicklenton (1982) summarized his research findings and observations by stating, "The high cost of microfoam has induced some nurserymen to use only copolymer-covered storages for containerized plants in northern areas. Providing that white material is used, this method may be satisfactory in areas with an annual minimum temperature which is not below 5ºF for plants with roots hardy down to 18°F and for other more hardy species**. However, in more**

severe climates, microfoam or other material capable of maintaining the root zone temperature above the specific lethal point is necessary for effective winter protection."

Results in Table 1 evaluating overwintering systems in Kentucky also show that the foam-type structureless covers are superior to structureless polyethylene film, poly-covered frames, and healing-in areas for protection of container-grown nursery plants (McNeil and Duncan, 1983). In their study, night air temperatures on January 16th dropped to -24 degrees F. Temperatures in the six temperature modification treatments were: 1) No protection of container-grown plants - root zone temperature reached a low of 3°F. 2) Overhead lath roof with containers bedded in sawdust mulch - container root zone temperature of 9°F. 3) Single-layer, white poly house - minimum air temperature of -8°F and a root zone temperature within the container of -2°. 4) Double-layer poly house (outer layer white, inner layer clear poly) - minimum air temperature of -2° and root zone temperature of 3°F. 4) Structureless Microfoam with additional clear plastic cover - maintained a constant 27 to 25°F air and root temperature. Structureless PlantFoam without additional plastic cover allowed a slight decrease of air and root temperatures to 18-19°F. According to McNeil and Duncan (1983**), "The foam-type covers were superior to poly houses for overwinter protection of container nursery stock, as the foam modified the temperature by 42° to 49°F."** Plant survival ranged from none to 100 percent, depending on species and protection (Table 1). Unprotected plants of all species were killed. Greatest survival of plants, except Japanese holly, occurred with the foam-type covers. Japanese holly plants were killed in all protection treatments. Japanese holly was the most susceptible of the four test species (Japanese holly, cotoneaster, juniper, sweet gum). Grouping and mulching with sawdust gave more protection than placement in poly houses, but was not as effective as foam-type structureless covers.

Several different structureless insulating coverings were also evaluated in Vermont by Pellett (1984). Covers were applied in late November and removed the first week of April. One layer of white poly cover alone gave less temperature moderation than the insulating blankets tested. When container temperatures under 1 layer of microfoam dropped to 23°F, container temperatures under 1 layer of white poly dropped to 10°F. During periods of high sunlight, high temperatures under transparent or translucent covers caused plants to lose cold hardiness and begin growth. When the outside air temperature on a sunny day in April was 48°F, air temperature under a single layer translucent cover was 104°F. At the same time, air temperature under 1 layer of white poly alone was 70°F. Under one layer of microfoam covered with one layer of white poly, the air temperature was 64°F. Air temperatures under an insulating blanket of 12" of straw fluff between 2 layers of white poly were lower than outside air temperatures, and plants were the least advanced with only slight evidence of bud swell. Pellett concluded that "The best protection was given by three layers of microfoam covered by one layer of 4 mil white polyethylene film plastic or by twelve inches of fluffed straw between 2 layers of white poly.

III. COSTS FOR OVER WINTERING PROTECTION

- Costs and materials required for 11 overwintering systems for nursery plants in USDA Climatic Zone 5 & 6 and for six systems in Zones 7 & 8 have been determined by members of the S-103 Cooperative Regional Project studying regional advantages in producing and marketing woody ornamental plants.

For Zones 5 and 6, annual costs per square foot ranged from $0.30 for a structureless system in which plants were simply consolidated and covered with a single layer of polyethylene to $0.93 for a double-layer polyethylene house with a heating system (Table 1, Taylor, et al, 1985). For Zones 7 and 8, costs ranged from $0.21 for a structureless system in which plants were consolidated and covered with a single layer of polyethylene to $0.47 for a polyhouse covered with one layer of polyethylene film. Overwintering costs for protecting similar crops ranged from 18 to 30 percent less in Zones 7 and 8 compared to Zones 5 and 6.

This study on overwintering practices and costs is in manuscript form and will be published by the S103 Cooperative Regional Research Project in 1985. Its availability will be announced in the Ornamentals NorthWest Newsletter.

TABLE 1. - Summary of Annual Fixed, Variable and Total Costs (Cents) of Overwintering Nursery Plants Differentiated by System, Square Foot, and Container Size in USDA Climatic Zones 5 and 6, 1984. (Taylor, etal. 1985)

	Costs (¢) per Square Foot	**Total Costs per Container**		
		¢/1-Gallon*	**¢/2-Gallon***	**¢/3-Gallon***
Structureless (14 x 9 6)				
1. Plants Covered with One Layer of Polyethylene Film	30	10	18	27
2. Plants Covered with a Thermal Blanket** Plus One Layer of Polyethylene Film	33	11	20	30
3. Plants Surrounded by Bales of Straw	40	14	24	35
Structured				
Polyhut Structure Covered with One Layer of Polyethylene Film (6 x 96)				
4. No Structureless Cover Within	44	15	26	40
Polyhouse Covered with One Layer of Polyethylene Film (14 x 96)				
5. No Structureless Cover Within	56	22	38	57
6. Plants covered with One Layer of Structureless Polyethylene Film	58	22	39	58
7. Plants Covered with a Structureless Thermal Blanket Plus One Layer of Polyethylene Film	61	24	41	61
Polyhouse Covered with Two Layers of Polyethylene Film with Air Blown Between the Films (14 x 96)				
8. No Structureless Cover Within	61	24	41	62

9. Plants Covered with One Layer of Structureless Polyethylene Film	63	24	42	63
10. Plants Covered with a Structureless Thermal Blanket Plus One Layer of Polyethylene Film	66	26	44	67
Polyhouse Covered with Two Layers of Polyethylene Film with Air Blown Between the Films Plus Heat (14 x 96)				
11. No Structureless Cover Within	93	36	62	94

*Placed container to container except for a 2-foot aisle down the middle of the polyhouses.
** Thermoblanket was a less expensive type with no polyethylene bonded directly to the thermoblanket.

IV. SYMPTOMS AND TREATMENT OF COLD-DAMAGED PLANTS

"The environment to which plants are subjected after chill exposure affects the degree of injury and rate of symptom development. Importance of post exposure environment varies with the severity of cold stress. Plants exposed to temperatures below their cold tolerance level will not recover. However, damage to plants exposed to near critical temperatures may be influenced by post stress handling. Intense light, low humidity and high temperatures following chilling (45 to 32°F) of some tropical plants result in increased water loss through transpiration. Extreme water stress can develop if the chill exposure has disrupted water absorption, temporarily or permanently.

Root systems of plants in field production are seldom frozen in Florida, but roots of container-grown plants may be frozen for several consecutive hours. Clear skies are common when extremely low temperatures occur. Sunny conditions on mornings after night freezes can result in rapid transpiration (water vapor loss) as leaves are warmed, but the soil/root mass may be frozen and unable to provide ample water to leaves, resulting in excessive water stress and leaf desiccation. Symptoms may not occur for several days and may be manifested as marginal leaf scorch or overall browning. **Watering container-grown plants can thaw the growing medium/root mass and allow water absorption and transport to the leaves**. Excessive water, however, can leach nutrients and cause root injury by waterlogging the growing medium.

Cold injury to roots may not be evident until spring when plants are stressed by high temperatures. Failure to initiate a spring growth flush may be the only visual symptom of winter injury and little can be done to minimize the effect of winter injury at this time. Weakened or injured plants are more susceptible to disease attack, so growers should increase frequency of inspection and implement a preventative fungicide program if justified. Increased shade may also reduce heat or water stress during recovery periods. Justification of such efforts should be determined on an economic basis.

Pruning damaged branches should be delayed until new growth appears or the degree of wood damage can be determined. This ensures that an excessive amount of live wood is not removed. Cold-injured wood can be identified by examining the cambium layer (tissue just under the bark) for black or brown discoloration. Pruning these branches 1 inch behind the point of discoloration reduces the potential for disease development and maintains aesthetically pleasing plants."

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APPENDIX 1: ROOT-DAMAGING TEMPERATURES

"The actual killing temperature will vary with the degree of plant dormancy at the time of exposure to the low-temperature. When plants are preconditioned for low-temperature storage and the temperature remains uniformly low prior to exposure to cold-temperature, the roots will generally survive provided that the temperature does not go below the average killing temperature for the species. However, if the low-temperature follows a period of fluctuating temperatures, especially temperatures that are conducive to growth, the roots could be injured at temperatures significantly higher than the average killing temperature. Also, the roots of newly rooted cuttings have a tendency to be less tolerant of cold-temperature stress than plants with a year or more of growth. To minimize root injury, plants should be stored at a temperature at least 3-5°F above the average killing temperature." - Harold Davidson and Roy Mecklenburg. 1981. NURSERY MANAGE MENT - ADMINISTRATION AND CULTURE. 450 pages. Prentice-Hall, Inc.

Non-notated temperatures were reported by: Bruce Briggs (1980 Ornamentals Northwest Seminars - based on observations at the Briggs Nursery in Olympia, WA) and data reported by John R. Havis (1976, HortScience 11(4):385-386), and Peter L. Steponkus, George L. Good, and Steven C. Wiest (1976, American Nurseryman 144(6):16, 76-79).

(G) = Reported by Francis R. Gouin, American Nurseryman, October 1, 1977, pp 56-57. These are the temperatures that will injure primary and possibly secondary roots, but will not result in 100 percent kill of the root systems in moist soils.

APPENDIX 1: ROOT-DAMAGING TEMPERATURES

DECIDUOUS PLANTS	**ºF**
Acer circinatum	
Vine Maple	0
Acer ginnala	
Amur Maple	0
Acer macrophyllum	
Bigleaf Maple	0
Acer negundo 'Variegatum'	
Variegated Box Elder	10
Acer palmatum	15
Japanese Maple	
'Atropurpureum'	15(g)
Acer rubrum	
Red Maple	0
Acer saccharum	
Sugar Maple	0
Aesculus hippocastanum	
Common Horsechestnut	0
Berberis thunbergii	
Japanese Barberry	10-15
Betula papyrifera	
Paper birch	0
Betula pendula	
European White Birch	0
Betula pendula 'Darlecarlica'	
Cutleaf Weeping Birch	0
Carpinus betulus fastigiata	
Narrow European Hornbeam	0
Catalpa speciosa	
Western Catalpa	0
Chaenomeles speciosa	
Flowering Quince	5
Cornus florida	
Eastern Dogwood	20, 22 (G)
Cornus mas	
Cornelian Cherry	18
Cornus nuttallii	
Pacific Dogwood	22
Cornus stolonifera	
Red Osier Dogwood	18
Cotinus coggygria	
Smoketree	18
Cotoneaster adpressus	
praecox	12 (G)
Cotoneaster congestus	25 (G)
Cotoneaster dammeri	23 (G)
'Skogholmen'	20 (G)

Cotoneaster horizontalis Rock Cotoneaster	17 (G)
Deutzia gracilis Slender Deutzia	15
Fagus sylvatica 'Purpurea' Purple Beech	15
Ginkgo biloba Ginkgo, Maidenhair Tree	15
Gleditsia triacanthos 'Sunburst' Sunburst Honey Locust	10
Koelreuteria paniculata Goldenrain-tree	16(G)
Liquidambar styraciflua American Sweetgum	15
Liqustrum vulgare Common or English Privet	5
Liriodendron tulipifera Tulip Tree	18
Magnolia x 'Ricki'	20
Magnolia x Soulangeana Saucer Magnolia	23(G)
Magnolia stellata Star Magnolia	17, 22 (G)
Oxydendrum arboreum Sourwood	10
Philadelphus cultivars Mock Orange cultivars	15
Potentilla fruticosa Pontentilla Cinquefoil	-9 (G)
Prunus blireana (blireiana) Blireana Flowering Plum	10
Prunus serrulata 'Shirotae' Mt. Fuji Flowering Cherry	10
Rhododendron	
Deciduous Azalea	12
Exbury hybrid	17 (G)
R. prunifolium	20 (G)
R. schlippenbachi	15 (G)
Rhus typhina Staghorn Sumac	0
Stephanandra incisa	18 (G)

EVERGREEN PLANTS	**°F**
Abelia Grandiflora Glossy Abelia	18
Abies amabilis Silver Fir	0
Abies concolor White Fir	0
Abies grandis Grand Fir	5
Abies lasiocarpa Alpine Fir	0
Abies procera Noble Fir	0
Arbutus menziesii Madrona	20
Arbutus unedo Strawberry Tree	20
Aucuba japonica Aucuba, Japanese Aucuba	24
Berberis julianae Wintergreen Barberry	15
Berberis verruculosa Warty Barberry	5
Buxus sempervirens English Boxwood	15
Calluna vulgaris Scotch Heather	15
Calocedrus decurrens Incense Cedar	0
Camellia japonica Common Camellia varieties	24
Camellia sasanqua Sasanqua Camellia varieties	24

Cedrus atlantica 'Glauca'	
Blue Atlas Cedar	10
Cedrus deodara	
Deodar Cedar	10
Chamaecyparis lawsoniana	
'Allumii', Allumi Cypress	
Blue Lawson Cypress	12
'Ellwoodii', Ellwood Cypress	12
Chamaecyparis obtusa	
Hinoki Cypress	0
Chamaecyparis pisifera'Filifera'	
Thread or Threadbranch Cypress	0
Choisya ternata	
Mexican Orange	20
Cistus corbariensis	
White Rockrose	20
Cortaderia selloana	
Pampas Grass	24
Cryptomeria japonica	17 (G)
'Elegans'	15
Cytisus praecox	16 (G)
Moonlight Broom	12
Daphne eneorum	23 (G)
Rock Daphne, Garland Daphne	18
Daphne odora	
Winter Daphne	22
Erica carnea	
Heath	18
Escallonia rubra	
Escallonia	18
Euonymus alata	19 (G)
Euonymus fortunei	
'Argenteo-marginatus'	15 (G)
'Carrieri'	15 (G)
'Colorata'	5 (G)
'vegetus'	23 (G)
Euonymus kiautschovicus (patens)	22 (G)

Fatsia japonica	
Fatsia, Aralia	22
Gaultheria shallon	
Salal	12
Hedera helix	
'Baltica'	15 (G)
Hypericum species	23 (G)
Ilex aquifolium	
English Holly	20
Ilex 'Blue Holly Ilex X meserveae (I. aquifoliurn x I. rugosa)	5
Ilex cornuta	
'Burfordii', Burford Holly	20
'Dazzler'	25 (G)
'Nellie Stevens'	23 (G)
Ilex crenata	
'Convexa	18, 23 (G)
'Helleri', 'Hetzi'	23 (G)
'Stokes'	23 (G)
Ilex glabra	16 (G)
Ilex meserveae	23(G)
Ilex opaca	23 (G)
Ilex hybrid, 'San Jose' (I. X altaclarense 'Wilsonii' & I. sikkimensis)	22 (G)
Juniperus chinensis	
'Kaizuka' ('Torulosa')	20
'Old Gold'	5
'Pfitzerana, 'Pfitzer Juniper	0
Juniperus conferta	
Shore Juniper	
	120
Juniperus horizontalis	
'Douglasi	O (G)
'Plumosa'	12 (G)
Juniperus squamata	12(G)
Kalmia latifolia	
Kalmia, Mountain Laurel	0,15(G)

Leucothoe fontanesiana (catesbaei)	
Drooping Leucothoe	5(G)
Ligustrum japonicum	
Waxleaf Privet, Japanese Privet	20
Magnolia grandiflora	20
Southern Magnolia	
Mahonia aquifolium	10(G)
Oregon Grape	15
Mahonia bealei	23(G)
Mahonia nervosa, Cascades Mahonia	
Low Oregon Grape	15
Nandina domestica	
Nandina, Heavenly Bamboo	20
Osmanthus delavayi	
Delavay Osmanthus	24
Osmanthus heterophyllus	
Hollyleaf Osmanthus	20
Pachysandra terminalis	15 (G)
Pernettya mucronata	
Chilean Pernettya	18
Photinia fraseria	
Fraser Photinia	12
Phyllostachys aurea	
Golden Bamboo	20
Picea abies 'Nidiformis'	
Nest Spruce, Birds' Nest Spruce	0
Picea glauca	-9 (G)
albertiana 'Conica, Dwarf Alberta Spruce, Albertina Spruce	0
Picea omorika	-9 (G)
Picea pungens ‘Glauca’	
Colorado Blue Spruce	9
Pieris formosa forrestii	
Chinese Pieris	20
Pieris floribunda	5 (G)
Pieris japonica	
Japanese Pieris	10-12, 15 (G)

Pinus contorta	
Shore Pine	5
Pinus densiflora'Umbraculifera'	
Tanyosho Pine	15
Pinus mugo mughus	
Dwarf Mugo Pine	0
Pinus thunbergii	
Japanese Black Pine	5
Prunus subhirtella 'Autumnalis'	
Autumn Flowering Cherry	10
Pyrus Calleryana 'Bradford'	
Bradford Pear	15
Prunus laurocerasus	
English Laurel	15
Prunus laurocerasus 'Otto Luykens'	
Otto Luykens Laurel	15
Pseudotsuga menziesii	
Douglas Fir	0
Pyracantha coccinea 'Lalandei'	
Lalandei Pyracantha	
Lalandei Firethorn	12, 23 (G)
Raphiolepis indica 'Rosea'	
Pink India Hawthorn	20
Rhododendron	
Carolinianum	O (G)
catawbiense	0 (G)
Evergreen Rhododendrons	10-18
Hino Crimson'	19(G)
Hinodegiri'	10 (G)
PJM hybrids	- 9 (G)
Rosmarinus officinalis	
Rosemary	20
Sarcococca ruscifolia	
Fragrant Sarcococca	20
Sciadopitys verticillata	
Umbrella Pine	5
Sequoia sempervirens	
Coast Redwood	15

Sequoiadendron giganteum	
Giant Sequoia	5
Skimmia japonica	
Japanese Skimmia	8
Stewartia pseudo-camellia	
Japanese Stewartia	15
Stranvaesia davidiana undulata	
Low Stranvaesia	10
Styrax japonica	
Japanese Snowbell	15
Taxus baccata 'Repandens'	
Spreading English Yew	12
Taxus media	
'Hicksii', Hick's Yew	17(G)
'Nigra'	12 (G)
Thuja occidentalis	10(G)
'Fastigiata' (Pyrdamidalis)	0
Thuja plicata	
Western Red Cedar	0
Trachycarpus fortunei	
Windmill Palm	24

Umbellularia californica	24
Oregon Myrtle	
Vaccinium ovatum, Evergreen	
Huckleberry, Box Blueberry	15
Viburnum burkwoodii	
Burkwood Viburnum	18
Viburnum carlesi	15 (G)
Viburnum davidii	
Davidi Viburnum	18
Viburnum plicatum	
'tomentosum'	20 (G)
Vinca minor	15 (G)
Yucca filamentosa	
Adam's Needle Yucca	15