UNIVERSITY OF FLORIDA
Florida Cooperative Extension Service

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Cold Protection Methods[1]

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INTRODUCTION TO YOUNG TREE COLD PROTECTION

Protecting young trees from cold damage is a difficult task which has been complicated by several factors in the last decade. These complications include a significant increase in the number of young trees planted over the last several years, increases in cost of fuel, equipment and labor and an increase in the number and severity of freezes. The problems of young tree care, a shortage of trees and increasingly frequent freezes have generated a new interest in protecting young citrus trees from possible damage by cold. Since young trees are small and occupy a relatively small percentage of a planted grove acre, protection by most active means is not particularly effective. This is especially true of heating with fossil fuel sources which are now quite expensive in addition to being inefficient for young tree protection. Wind machines could be considered for protection, but their use is limited to calm nights with temperature inversions and the cost of acquisition and operation of this equipment could not be economically justified for non-bearing groves. Irrigation for cold protection is a possibility and is now widely used in many young groves where properly designed and maintained microsprinkler systems are in place. Such systems require uninteruptible power sources to avoid problems of electrical blackouts. Many young citrus trees are placed in a situation where active cold protection measures are difficult, if not impossible, and growers have to rely upon passive means of cold protection. Some of the more important passive cold protection measures include cultivar and rootstock selection, site selection, clean cultivation, pre-freeze irrigation and the use of banks and wraps.

COMPARISON OF METHODS

High fuel cost has made grove heating during freeze nights prohibitively expensive except for high value crops. Wind machines are effective under some conditions, but they require maintenance and need a strong temperature inversion for optimum effectiveness. Fog can provide protection, but light winds can blow the fog away from the grove and obscure nearby roadways. High volume overhead sprinkler irrigation has been used effectively on limes and avocadoes in south Florida where temperatures do not normally go far below freezing. In central and north Florida, where temperatures are usually colder, overhead sprinklers should not be used on large citrus trees because the weight of the ice formed can break off limbs and cause tree collapse. With overhead systems, all leaves are wetted and susceptible to damaging evaporative cooling during low humidity or windy freezes. Many trees were killed in the windy 1962 freeze when overhead sprinklers were used. Because of the cost of fuel, microsprinkler irrigation

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is rapidly becoming the preferred method for providing cold protection. This type of irrigation works particularly well for resets and the lower trunk and branches of young trees. However, once microsprinkler irrigation has begun, it must be continued until the grove temperature rises above freezing. If irrigation stops before then, the trees will likely be more damaged than if the irrigation continued. Banking very effectively provides cold protection to the trunks of young trees. However, banks are time consuming to erect and can produce some pest and cultural problems. The grower can avoid some of these problems by using tree wraps, which can be left on for an extended period of time once installed. While tree wraps as a whole are effective for cold protection, they are not as effective as banking. Protection varies greatly depending on the type of tree wrap used. Table 1 compares energy requirements for the various methods of cold protection discussed here.

SOIL BANKING

Soil banking (Figure 1) consists of placing a mound of soil around the tree's trunk to protect the bud union and trunk from cold. It is one of the most efficient cold protection methods for young trees and has been used with success for many years.

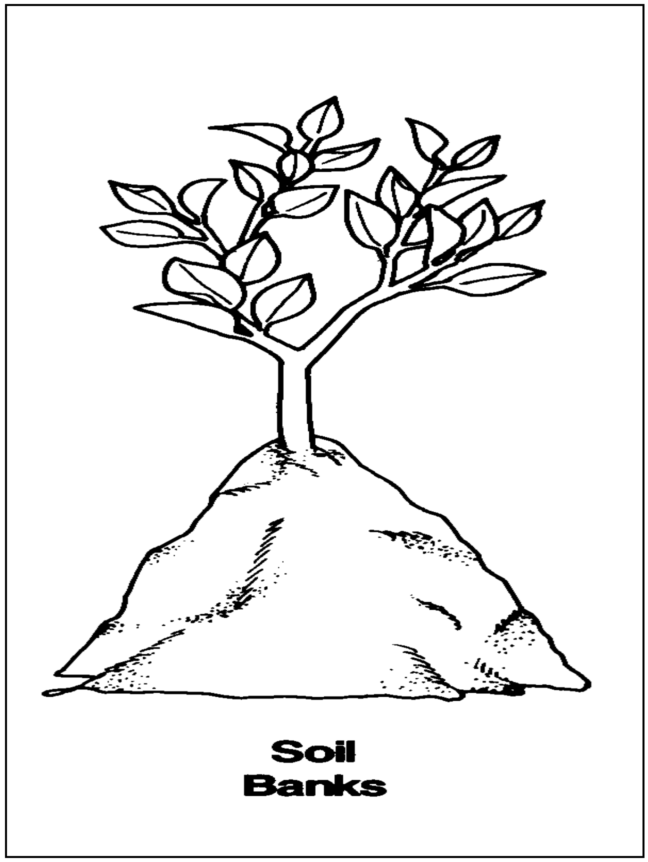

Figure 1. Soil bank

Banking principles

Since the soil stores heat from the sun during the day and releases it at night heat deep in the soil moves up to the surface by conduction and is lost to the air by radiation. By mounding soil around the trunk of a tree (banking), heat is conducted through the soil and into the protected area of the young tree. Thus, banking protects by conduction and insulation as well.

When to bank

A definite answer to the question of when to bank has not been derived. It would be most efficient if trees were banked the day before a freeze, but the state of the art of weather forecasting does not permit this luxury. Growers in much of south Florida do not bank at all since that area has such a low cold damage probability. However, growers in the north and much of central Florida realize the high probability of cold damage and routinely bank young trees in the fall as a regular production practice. A good rule of thumb is to try to have all trees banked by November 15 for the northern areas and no later than mid-December for the rest of the state.

Making the Bank

Banks can be constructed with a shovel or hoe, a blade on a tractor or similar tool, or with a banking machine. Build them as high as reasonable, up into the scaffold limbs whenever possible. Higher banks afford more protection, but they also require more labor and expense to build. Use only soil which is free of weeds, sticks, bags or other trash as these will invite damage from insects and disease. Watch banks carefully during the winter since wind and rain may erode them. Rapid recovery of freeze-damaged trees will be the payoff for a good banking job.

Unbanking

Trees can be safely unbanked as soon as the danger of cold weather has passed. In most areas this will be in mid or late February. If banks remain on the trees too long in warm weather, disease and insect problems increase and there is danger of a physiological bark sloughing disorder (sweating) which can quickly kill the young tree. Unbanking should be supervised just as closely as banking to prevent tree damage from careless equipment operation. Also, care must be taken to ensure the bank is removed completely and the soil carefully leveled around the young tree. Leaving too much soil around the tree trunk may encourage foot rot in the susceptible scion portion of the tree.

Banking Hazards

Tree Damage

Careless operation of equipment may break limbs, skin trunks and even destroy trees. Equipment operators must be conscientious and well-trained if the operation is to be a success. Broken limbs and skinned trunks should be treated with a good water-repellent pruning paint or fungicide before being covered with soil. Some mechanical equipment used for banking removes considerable soil from a relatively small area, resulting in damage to roots near the soil surface. The use of such equipment should be avoided or care should be taken to make sure damage is minimized.

Diseases and Insects

Fungal disease can sometimes be a problem when trees are banked. Placing soil on the susceptible scion portion of the young citrus tree may predispose the plant to foot rot if conditions are optimal for development of the fungus. Application of a suitable fungicide before banking will help reduce the incidence of foot rot. Ants and termites may sometimes become a problem in banks, particularly if there is trash in the soil used to construct the banks. Problems such as these can be dealt with as they occur or a preventive insecticide can be sprayed at the time of banking. Many growers routinely spray trees with a suitable insecticide-fungicide mixture just before banking as an insurance measure. One hundred gallons of spray should treat 400 to 600 trees if properly applied.

Banking Considerations

These factors should be taken into consideration before choosing banking as a cold protection method:

1. Soil banks must be put up before danger of cold and removed as soon as possible after the threat of cold has passed.
2. Labor to build banks is expensive.
3. Hot periods during winter months may necessitate early removal of at least a portion of the bank before the danger of cold is over.
4. Construction of banks is often hindered by weeds or in the case of larger trees, overhanging limbs.

Soil Bank Summary

Advantages

1. Excellent insulating value (12 - 15° above air temperature in most cases)
2. Sprout inhibitor
3. Conforms well to large or irregularly shaped trees
4. No cost for material, only labor

Disadvantages

1. Must be constructed and taken down seasonally
2. Difficult to maintain
3. Occasional problems with bark sloughing and foot rot
4. Moderate insect and disease problems
5. Must be removed after freeze damage to allow regrowth
6. Labor cost is expensive

TREE WRAPS

Theory of Cold Protection

Tree wraps are most useful in protecting young citrus trees during mild to moderate freezes or in traditionally warmer locations within the state. Tree wraps protect only the trunk, and consequently leaf loss can occur during moderate or severe freezes. Wraps work by delaying, but not preventing, heat loss from the tree trunk as air temperatures decrease. Temperatures under tree wraps generally are 0° to 6°F higher than air temperatures, depending on the type of wrap. However, the tree produces and stores very little heat, and during severe freezes of long durations the temperatures under most wraps will approach air temperatures. Wraps are most effective during freezes of short durations where temperatures drop rapidly. They are less effective, however, during freezes where temperatures decrease slowly and remain low for protracted periods. The effectiveness of the wrap is related to the insulating value of the wrap material. Consequently, wrapping trunks with thin-walled materials is ineffective for temperature control, while thicker insulating materials are more effective.

Wrapping

Most tree wraps, unlike soil banks, can be attached anytime during the year and left on the tree throughout the year or even for several years. However, some types of wraps, like those made of poor insulating materials or clear plastic, may damage or even kill the tree due to excessive daytime trunk temperatures during the summer.

When freeze damage occurs, wraps should be removed or pushed down to allow for growth of new shoots. Wraps should be properly positioned and fastened around the trunk for best results. It is important to cover the entire lower trunk, especially at the base.

Heating Effects

Insulating materials are used extensively in most tree wraps to provide cold protection. Since insulation holds heat in, protection is provided by slowing down the loss of heat from young tree trunks, thus making them warmer. However since there is very little heat stored in the trunk of a young citrus tree, wraps utilizing insulation alone have limited effectiveness.

Dormancy Effects

The degree of dormancy of young citrus trees is a function of environment, and measures to slow the growth of trees usually results in dormancy and a better ability to tolerate low temperatures. Insulating materials in some cases may help to keep tree trunks cool during daylight hours resulting in greater dormancy and an increased tolerance to low temperatures. Though not substantiated by research, the principle is confirmed by observation. Possible effects of light on tree dormancy is speculative but observations support the theory. Trees wrapped with opaque materials rarely sprout under such wraps because light is excluded. Sprouting is evidence of growth and lack of dormancy, so materials which block light may help to contribute to tree dormancy.

Use of Liquids

Some wraps utilize pouches of liquid (usually with an ice nucleator in solution) to furnish additional heat inside the wrap, next to the tree trunk. When liquids freeze, heat of fusion is released which can generate considerable heat. When this heat is released within the confines of an insulating material, and next to the tree trunk, it can be quite effective.

Types of Tree Wraps

Selection of the proper tree wrap for a particular grove depends on a number of factors including cost, ease of installation and probability of freeze damage. For example, growers in northern regions of the state should choose wraps with good insulating qualities, while growers in warmer southern locations may opt for less costly, thinner wraps. Tree wraps also inhibit sprouts and protect trunks from herbicide and mechanical damage. Consequently, no one wrap is best for all situations.

Fiberglass Wrap

The advantages and disadvantages of fiberglass wrap (Figure 2) are discussed below.

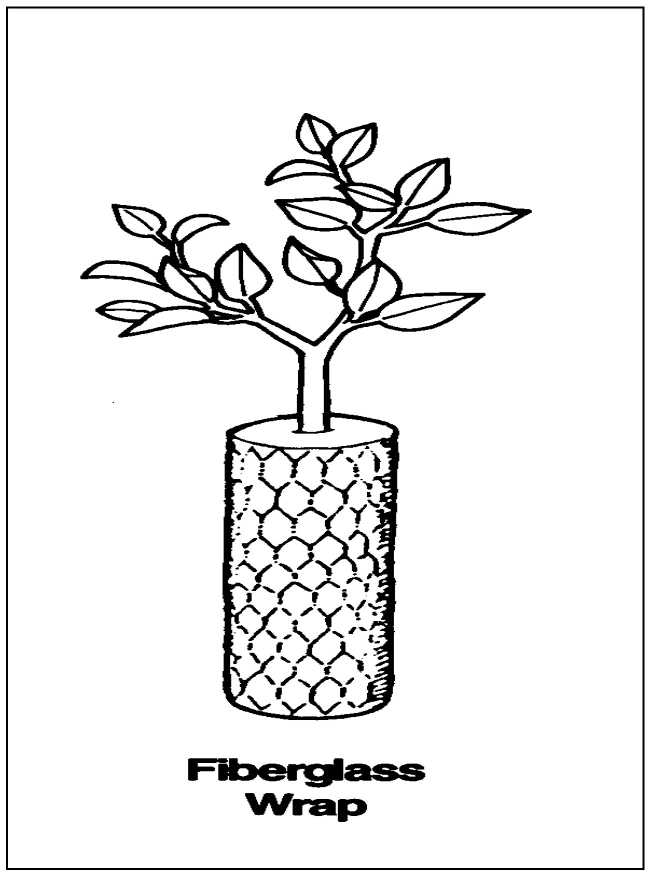

Figure 2. Fiberglass wrap

Advantages

1. High insulating value (3 - 6° above air temperature)
2. Moderately durable
3. Sprout Inhibitor
4. Can be pushed down to allow for regrowth following a freeze
5. Inert, will not hold water for long periods of time, rarely causes foot rot problems
6. Moderately inexpensive
7. Conforms well to large or irregularly shaped trunks

Disadvantages

1. More difficult to install and handle than some other wraps
2. Moderate ant problems

Polyurethane foam

The advantages and disadvantages of polyurethane wrap (Figure 3) are listed below.

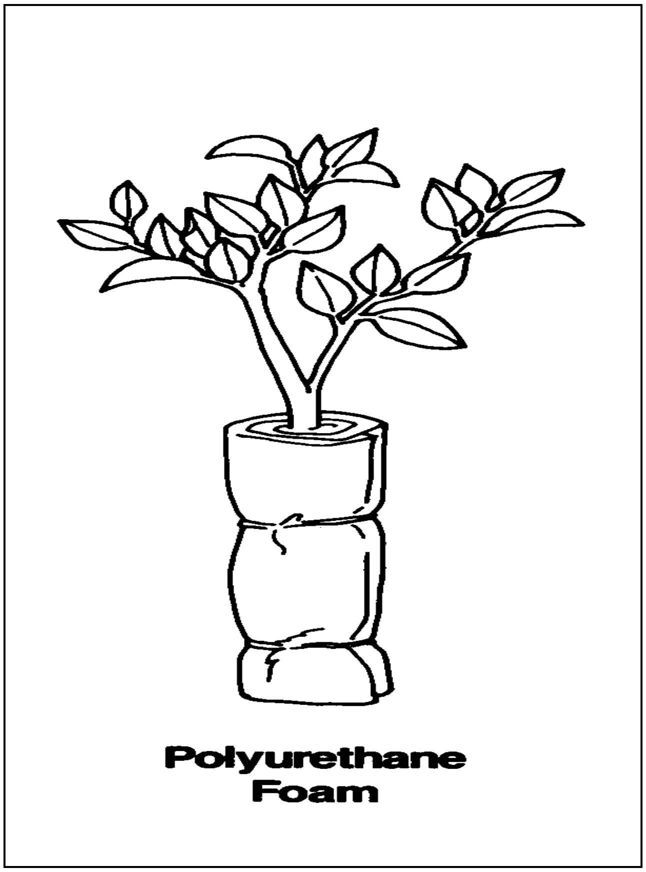

Figure 3. Polyurethane foam wrap

Advantages

1. High insulating value (3 - 6° above air temperature)
2. Moderately durable
3. Sprout Inhibitor
4. Moderately inexpensive
5. Moderately easy to handle and install
6. Conforms well to large or irregularly shaped trunks

Disadvantages

1. May become waterlogged, particularly if used with irrigation
2. Sunlight deteriorates some wraps
3. Foot rot is an occasional problem
4. Must be removed after freeze damage to allow regrowth

Rigid Polystyrene Foam (Thick-Walled)

Listed below are the advantages and disadvantages of thick-walled rigid polystyrene foam (Figure 4).

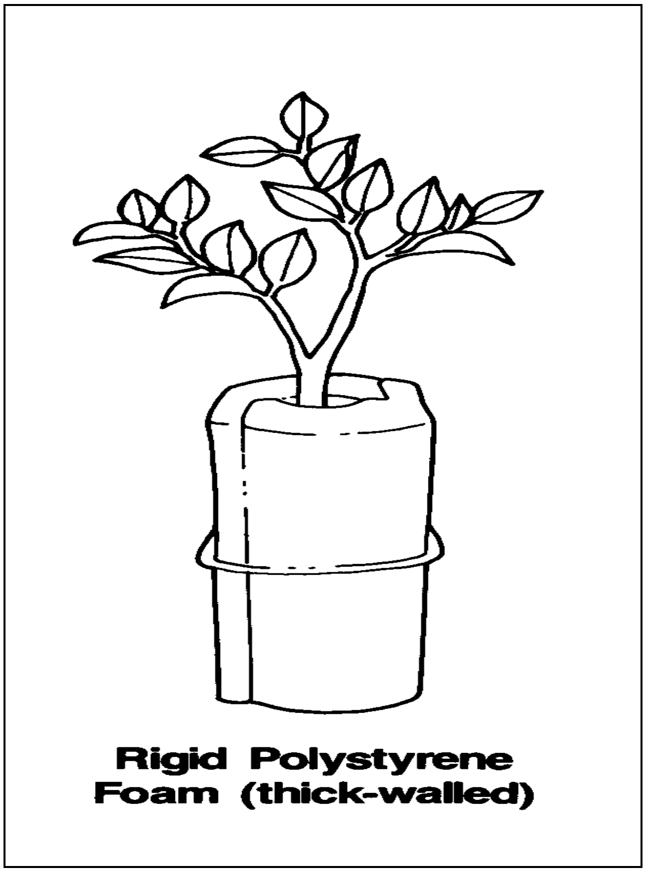

Figure 4. Thick-walled rigid polystyrene foam

Advantages

1. Very high insulating value (4 - 8° above air temperature)
2. Very durable
3. Moderate sprout inhibitor
4. Will not hold water, rarely foot rot problems
5. Easy to handle and install

Disadvantages

1. Expensive
2. Moderate ant problems
3. Must be removed after freeze damage to allow for growth
4. Subject to loosening by animals, may fit poorly on irregularly shaped trunks

Rigid Polystyrene Foam (Thin- Walled)

Below are listed the advantages and disadvantages of thin-walled rigid polystyrene foam wrap (Figure 5).

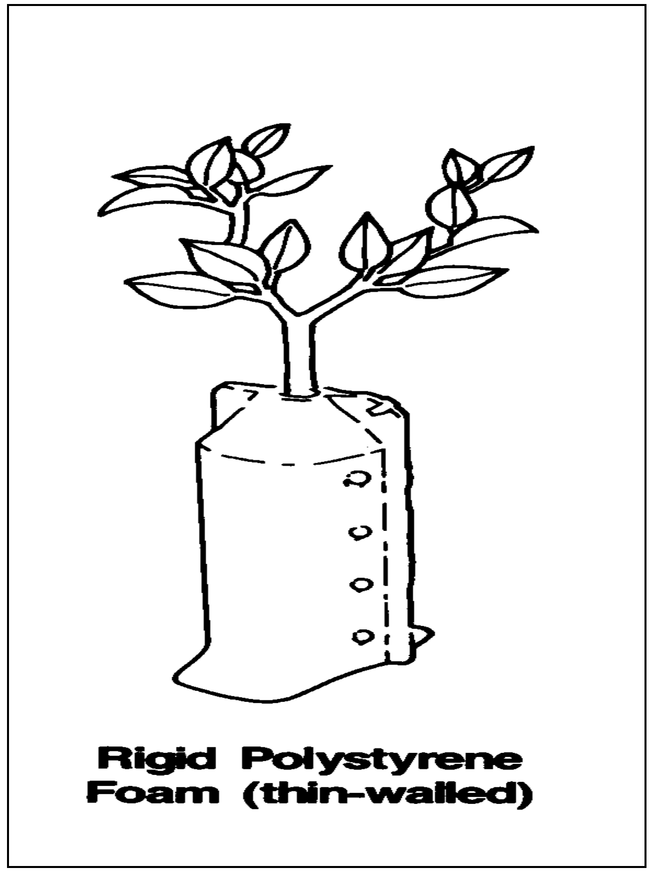

Figure 5. Thin-walled rigid polystyrene foam

Advantages

1. Low to moderate durability
2. Sprout inhibitor
3. Will not hold water, no foot rot problems
4. Inexpensive
5. Moderately easy to handle and install

Disadvantages

1. Low insulating value (0 - 2° above air temperature)
2. Moderate to severe ant problems
3. Must be removed after freeze damage to allow regrowth
4. Not suited for large, rapidly growing trees, may fit poorly on irregularly shaped trunks

Closed Cell Polyethylene Foam

Discussed below are the advantages and disadvantages of closed-cell polyethylene foam (Figure 6).

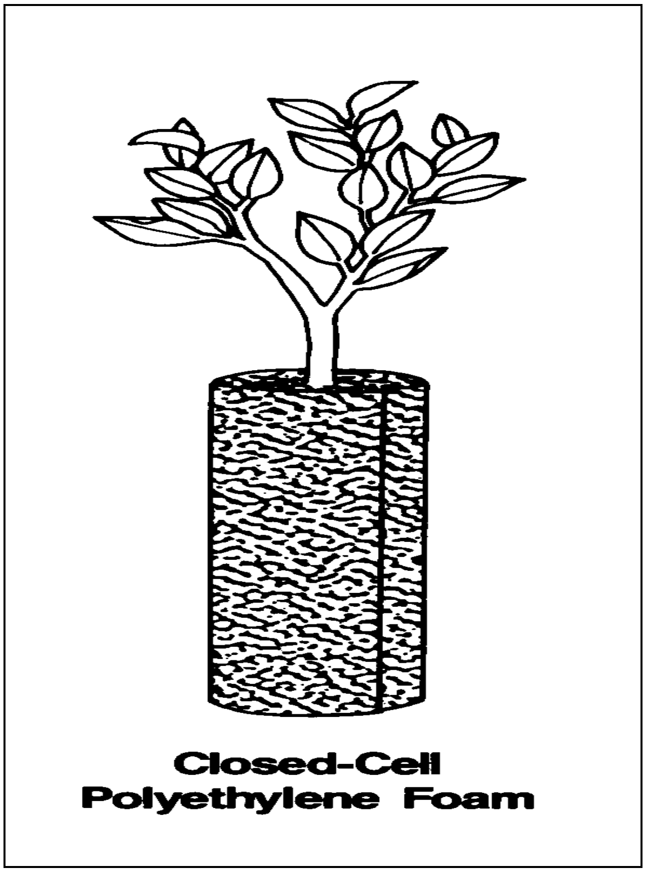

Figure 6. Closed-cell polyethylene foam

Advantages

1. Moderate insulating value (2 - 4° above air temperature)
2. Moderately durable
3. Sprout inhibitor
4. Inert, will not hold water, rarely causes foot rot problems.
5. Easy to handle and install
6. Some models use irrigation water supply tube inside for extra protection.

Disadvantages

1. Moderately expensive
2. Ant problems are severe in some areas
3. Must be removed after freeze damage to allow regrowth
4. May cause bark sloughing and fit poorly on large or irregularly-shaped trunks

MICROSPRINKLER IRRIGATION

Overhead, high-volume sprinklers have been used successfully in citrus nurseries for years as a means of cold protection. Recently, there has been interest in using low-volume microsprinklers to protect young trees in the field; however, success varies with the type of system, application rates, type of freeze (advective vs. radiative), and severity of the freeze.

Theory of Protection

Water protects young trees by transferring heat to the tree and the environment. The heat is provided from two sources, sensible heat and the latent heat of fusion. Most irrigation water comes out of the ground at 68° to 72°F, depending on the depth of the well. In fact, some artesian wells provide water of 80°F or more. As the water is sprayed into the air, it releases this stored (sensible) heat. However, by the time the water reaches the tree it has lost most of its energy, particularly for low volume microsprinkler systems. Consequently, the major source of heat from irrigation is provided when the water changes to ice (latent heat of fusion). As long as water is constantly changing to ice the temperature of the ice-water mixture will remain at 32°F. The higher the rate of water application to a given area, the greater the amount of heat energy that is applied.

The major problems in the use of irrigation for cold protection occur when inadequate amounts of water are applied or under windy (advective) conditions. Evaporative cooling, which removes 7.5 times the energy added by heat of fusion, may cause severe reductions in temperature under windy conditions, particularly when inadequate amounts of water are used. In addition, most irrigation systems will not protect the upper portion of the canopy.

Types of Microsprinkler Systems

A number of low-volume microsprinklers which can be used for cold protection of young citrus trees are currently available. As with tree wraps, no one system is best for a given grove situation. Remember that microsprinkler irrigation is primarily used to irrigate trees, and practical irrigation designs may not necessarily provide optimum cold protection. Again, cost, ease of operation, and especially probability of freeze damage should be considered when selecting an irrigation system. However, the key to successful cold protection using any microsprinkler system is providing a continuous and adequate volume of water directly to the trunk of the tree. This is particularly true during advective freezes where water may be blown away from the trunk.

It is generally advisable to place the emitter northwest of the tree, approximately 1 yard or less from the trunk. Emitters should be attached to risers for greatest tree trunk protection. Improper placement or inadequate spray coverage will greatly lessen the effectiveness of the irrigation. A 90° spray pattern which concentrates the water on the trunk and lower limbs gives cold protection superior to a 360° or 180° pattern. Inverted cone sprinklers positioned above the wrap in the tree also give adequate protection. The volume of water applied depends on the amount of cold protection required. Generally, 10 gallons per hour (gph) applied directly to the trunk in a 90° pattern will provide adequate cold protection during most freezes.

Wraps Plus Irrigation

This combination of cold protection measures provides protection by insulation plus heat of fusion from water freezing on the wrap, and in some cases, water actually being piped through the wrap to provide even more protection. Spraying water on wraps in sufficient volume and without interruption will theoretically not allow temperatures to fall below 32°F. Furthermore, if ground water is piped through the wrap prior to spraying it externally, additional protection could be provided.

When used in combination with adequate irrigation most tree wraps provide cold protection to the trunk. However, only wraps with high insulating characteristics provide protection when irrigation is discontinued due to a power outage or break in the irrigation lines. A combination of tree wraps and microsprinkler irrigation provides low cost insurance against such problems.

COLD PROTECTION USING HEATERS

The greatly increased cost of fuel has practically eliminated heaters from the growers cold protection strategy. However, heaters can still be cost effective when used to protect high-value citrus cultivars.

Using Heaters

Orchard heaters provide heat by direct radiation and convection. Stack heaters give out 25-30 percent radiant heat, which moves along a straight line from the heater to the trees. Air around the immediate area of the heater is heated by convection; some of this heat is lost if it rises above the level of the orchard. Because of the need for fuel-burning efficiency and pollution reduction, orchard heaters have evolved to the upright stack design. Vaporizing pot-type stack heat (for example, jumbo cones and return stacks) have the advantage of low initial cost, maneuverability, and versatility. However, fuel can be lost due to spillage, leakage, and boiling of fuel left in the heaters after they are extinguished. Labor requirements for lighting and refueling heaters are high, and an additional crew is frequently needed to refuel heaters if several nights of freeze protection are required. Compared to individual stack heaters, centralized pressure fuel systems burning diesel fuel and liquid propane are more fuel-efficient and offer considerable labor savings. Fuel storage for any heating system is a big expense and environmental liability.

Energy Saving Tips

1. Maintain heaters in good working order. Periodically clean the stacks for most efficient burning of fuel and to keep emissions within the standards specified by air pollution laws.
2. Have sufficient thermographs or thermometers throughout the grove area.
3. Large groves can generally be heated more efficiently than small groves. To protect grove borders, additional heaters must be placed along the edges of the grove, especially on north and west sides.
4. Calculate temperature drop vs. time throughout the night to better determine when heating should be started.
5. It is important to light heaters one to two degrees above the lethal temperature of leaves or

blossoms and buds. If fruit is to be protected, begin protection one or two hours after the critical freezing temperature of fruit has been reached, since the fruit has more mass than buds and cools more slowly or use a thermometer to determine the internal temperature of the fruit.

6. It is frequently possible to stabilize temperatures during the initial phase of protection by lighting every other row of heaters or by lighting central systems and then turning the pressure down. Additional heaters can then be lit or line pressure can be raised slightly to maintain the temperature in the grove as temperatures drop outside the heated area.
7. Many small heaters generally provide more efficient heat distribution than a few large ones. This point became particularly important with higher fuel costs. The additional capital outlay of a greater number of heaters could be returned through more efficient orchard heating.
8. Be familiar with cold areas in your grove so that heaters in those areas can be lit first.

Minimizing Heating Requirements

Selecting the proper temperature for lighting heaters or starting any system of cold protection can affect fuel savings. For example, using climatic data for Bartow, Florida, protecting a grove nine out of ten years at 28°F. would require at least 26 hours of heating per winter. However, if the crop would tolerate 24°F., the grower would only have to heat five hours, using one-fifth as much fuel. Citrus fruit will withstand temperatures of 28°F for approximately two hours. But leaves and twigs (fruiting surface) will often withstand 24°F or lower. With the uncertain future of fuel supplies, growers may seriously consider only protecting the fruiting surface of the tree and allowing the fruit to freeze. The fruit may still be used for processing if it is harvested within a week to ten days following the freeze. Leaf freezing points are a good estimate of the temperature at which leaves twigs and wood freeze. Often, twigs and leaves will freeze at or near 24°F in the early fall, but may withstand 22°F or slightly lower temperatures during mid-winter.

WIND MACHINES

Wind machines offer some excellent advantages in cold protection because they minimize labor requirements, consume less fuel per acre protected and require less fuel storage than heaters. They are permanently located in the grove and have a low operational cost per acre. Fuel requirements for wind machines are about 10 gal/hr or 1 gal/acre/hr compared to 10-35 gal/acre/hr with heaters. These advantages must be weighed against the disadvantages of rather high capital costs and the failure of the wind machine to provide adequate cold protection under all conditions. Wind machines are dependent on having an inversion--that is, warmer air at approximately 40-50 feet above the orchard. A temperature inversion of at least 5° difference is necessary and an inversion of 10-15°F makes the wind machine very effective. They are most beneficial when located in low pockets where they mix cold, heavy air, which settles there, with warmer air above. In general, one can use the rule of thumb that 10 horsepower is required to protect one acre. Usually, one wind machine is required for each 10 acre block. However, the increase in temperatures are highest nearest the machine and decrease toward the edge of area protection. Heaters can frequently be used near the edge of the area protected to remedy this situation. Start wind machines when temperatures are two to three degrees above the lethal temperature. Because of the low cost of running a wind machine, plus the fact that it can only raise the temperature a few degrees, it is necessary to start the wind machine early. It is very important that wind machines be run at the rpm specified by the manufacturer, since they provide considerably less protection when operated at a lower speed.

Helicopters are sometimes used as a cold-protection device, if they are stationed nearby. Otherwise, they are too expensive. They are utilized as a large, moving wind machine. When helicopters are used effectively, a number of temperature monitors are required in the grove to determine the coldest areas and the frequency of passes the helicopter must make. Monitors should turn on a light when temperatures reach a critical value. Rapid refueling or more than one helicopter may be necessary since protection cannot be halted once temperatures are below the critical point.

Heating in conjunction with wind machines provide better protection at lower cost than heaters alone. For example, an orchard requiring 35 heaters per acre without the use of wind machines would require 15 heaters per acre with wind machines. Heaters plus wind machines and good air temperature inversions would permit heaters to be used less than half the time, which would reduce fuel consumption and increase the heater's life span.

Table 1. Energy requirements of various cold protection methods for young citrus trees

	Fuel Consumption	
Method	gal/hr/acre	BTUs/hr/acre (in thousands)
Heaters	20 - 40	2,800 - 5,600
Wind machines	0.5 - 1.5	70 - 210
High volume sprinklers	0.25 - 0.75	35 - 105
Low volume sprinklers	0.10 - 0.25	14 - 35

Source: T. R. Mee

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Cold Protection for Nursery Crops[1]

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Winter temperatures are frequently low enough to cause cold injury to tropical, subtropical and occasionally temperate plants that are produced in Florida. This publication provides information for ornamental plant producers regarding symptoms of cold injury, plant adaptation to cold, environmental conditions leading to cold injury and methods to alter the environment to avoid or minimize cold injury.

Cold injury includes damage from temperatures above and below freezing. Many tropical and herbaceous plants do not adapt or harden to withstand freezing temperatures and may be injured by temperatures below 10°C (5°F). Injury caused by low temperatures above freezing is chill injury and damage caused by freezing temperatures is freeze injury.

Cold Injury Symptoms

Cold injury symptoms usually occur after exposure to critically low temperatures, not during the cold exposure. Direct injury is inflicted at a cellular level and the response of plant tissues to this injury is revealed through visual or measurable symptoms. The rate at which these symptoms develop depends upon the severity of the exposure and the environmental parameters after the exposure. Continued cool temperatures and high humidity after an exposure to cold may slow the symptom development, while high light intensity and warm temperatures may accelerate symptom development.

Chilling

Many chilling-injury symptoms are common to other stresses such as drought stress, root rot diseases, phytotoxicity to chemicals, heat stress and light stress. General symptoms of chill injury to plant leaves, stems and fruits are listed below:

1. Surface lesions, pitting, large, sunken areas and discoloration. These symptoms have been reported on several orchids.

2. Water-soaking in tissues results from disruption of cell structure and release of cell solutes into spaces between cells, and is commonly followed by wilting and browning.

3. Internal discoloration (browning) of pulp, pith, and seed.

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4. Accelerated rate of senescence (natural death), but with otherwise normal appearance.

5. Increased susceptibility to attack by fungi and bacteria not commonly found on the plant.

6. Slowed growth, or limited growth flush. This symptom may be difficult to detect without non-chilled plants for comparison or a thorough knowledge of normal growth rate.

Freezing

Symptoms of freeze injury could include desiccation or burning of foliage, water-soaked areas that progress to necrotic spots on leaves, stems or fruit and death of sections of the plant or the entire plant. Close examination of woody plants several days or weeks after freezing may reveal a dead or weakened root system or split bark on stems or branches. Obvious symptoms on plant foliage may not be present until after the plant has been stressed by warm temperatures. A hot, bright day could increase transpirational water loss beyond the ability of injured roots or stem conductive tissue to replace. Subsequent symptoms might include wilting and/or desiccation, as caused by direct drought stress.

Plant Response to Freezing Temperatures

When considering new plant material for use in the landscape or as a possible nursery crop, cold hardiness should be determined. Hardiness indicates a plant's resistance or ability to adjust to cold stress in order to tolerate freezing temperatures.

The timing and degree of cold hardiness is determined by environmental conditions and the genetic makeup of a particular plant. Inherent, genetic potential is the first limiting factor in development of hardiness, with plant species and genotypes within species differing in their tolerance to cold. Most tropical plants fail to develop hardiness regardless of preconditioning environmental conditions. Some species are always killed by freezing while others tolerate temperatures as low as –196°C (-320°F) in midwinter.

The geographic source of a plant plays an important role in the timing of hardiness. Northern plants sensitive to daylength start to cold harden sooner in autumn than southern plants when grown on the same site. Therefore, selection of seed or cutting stock of desired plants from cold hardy genotypes is an important consideration.

Plant reaction to environmental conditions leading to increased cold tolerance is called <u>cold acclimation</u>, and plant reaction to environmental conditions resulting in less tolerance to cold is called <u>cold declamation</u>. Although in more northern climates acclimation occurs primarily in the fall and declamation in the spring, rapid changes in plant cold tolerance occur throughout the fall, winter and spring months in Florida as environmental conditions change rapidly.

Environmental factors, such as daylength, temperature, nutrition, water availability, light intensity and physiological maturity of a plant or plant part are known to play a role in cold acclimation. Once the effect of these environmental factors on cold acclimation is understood, sound cultural practices directed toward increasing cold tolerance can be developed.

Generally, plant growth slows or ceases before cold acclimation begins. Decreasing daylength provides the primary stimulus or trigger for cold acclimation in many plants. Phytochrome, a light-receptive sensory pigment in leaves and bark, detects decreasing daylengths of autumn and initiates biochemical and physiological changes that slow vegetative growth and increase cold acclimation. Plants that react primarily to daylength slow growth at approximately the same time each year, regardless of temperatures. Temperature is the primary stimulus for cold acclimation in some subtropical plants such as citrus. However, in most plants there is an interaction between photoperiod and temperature on plant growth and development, and the most rapid cold acclimation is produced by short photoperiods and low temperatures.

Plants should withstand cold best if fertilized with a balanced ratio of plant nutrients that produce optimum growth (Pellet and Carter), but the rate of fertilization should be reduced slightly in fall and winter to reflect the lower nutrient requirement during the cold months. Plants under severe nutrient deficiencies or plants receiving nutrients at near toxic levels do not withstand cold or recover from cold injury as well as plants with properly balanced nutrition.

Moderate drought stress can result in increased cold tolerance in some plants by slowing growth and initiating dormancy. Many plants native to the dry plains respond to this treatment because in nature the plants are commonly subjected to dry conditions before the onset of winter. Although water stress may increase cold tolerance in some plants, such stress may result in an unacceptable decrease in quality of plants such as azaleas.

The maximum cold tolerance level is seldom reached in Florida, even with temperate plants, because of the loss of hardiness during extended warm periods in winter months. Plant metabolic activity slows during extended cold periods, but a period of warm temperatures can stimulate rapid declamation. Temperature seems to be the primary environmental factor controlling declamation and plants can reacclimate if a subsequent slow temperature drop occurs. A rapid temperature drop following a warm period, a common event in Florida, may produce injury and death to plants.

Evaluation of cold hardiness is further complicated because different tissues and organs of the same plant may display varying degrees of hardiness. Flower buds are often damaged by freezes while vegetative buds or stem tissues are uninjured. Plants grown for their floral display may be hardy, but if their flower buds are killed every year, they will be unsatisfactory for landscape use. Leaves of broad-leaved evergreens may be injured by cold yet the stems remain unharmed. Root tissues are less resistant to freezing injury than stem tissues, with young roots being more sensitive to cold than mature roots. Stems and leaves of <u>Pyracantha</u> <u>coccinea</u> 'Lalandii' acclimated to –26°C (-15°F), and mature roots to –17°C (1°F), while young roots failed to survive below -50C (23°F) (Waist and Steponkus). Lack of old resistance in roots is not usually a problem in field production or in the Florida landscape, however, it may be the limiting factor to winter survival of containerized plants when prolonged freezing temperatures occur.

Plants that survive freezing temperatures must either avoid or tolerate the formation of ice in their tissues. The primary mechanism by which plants avoid freezing is supercooling. Supercooling occurs when the plant's temperature drops below its freezing point without ice formation. Even pure water will supercool. The lowest subfreezing temperature recorded before ice formation is the supercooling point. Unfortunately this point is not a constant value but varies for repeated tests on the same solution. Under field conditions supercooling generally allows nonacclimated plants to avoid freezing when temperatures in the -1 to –3°C (31 to 26°F) range occur.

Cold-resistant plants tolerate water freezing in their tissues as long as the ice crystals form between cells (extracellular freezing) and not inside them (intracellular freezing). Extracellular ice formation is the type of freezing encountered in nature and is tolerated by hardy plants in their cold-acclimated state. Intracellular freezing disrupts the cell and is always fatal. Generally, freezing rates in nature are too slow to allow intracellular freezing. Cooling rates of 2°C per minute or faster are required for intracellular freezing, and slower cooling allows sufficient time for water to move through the surrounding membrane and form ice crystals in extracellular spaces. Thus at the cellular level, the requirements for freezing resistance in any hardy plant are the avoidance of intracellular freezing and the tolerance of extracellular freezing.

Principles of Heat Transfer

Heat loss by plants involves heat transfer which should be understood before formulating and evaluating cold protection methods. Heat may be transferred by conduction, convection or radiation.

Convection

<u>Convection</u> is the process of heat transfer within a fluid or air that results in mass motion of molecules in that fluid or air. Heat is transferred from air at the soil surface to air above the earth by convection. Air becomes lighter when heated and rises to be replaced

by heavier, cooler air. This mass motion of air is called convective mixing and explains why air just above the earth's surface does not become extremely hot on a sunny, summer day.

Radiation

Radiation is the process of heat transfer from one object to another without the aid of a transfer medium. The sun's rays heat the earth's surface and can burn human skin by radiant heat transfer. The surfaces in a greenhouse are warmed by absorption of short wave solar radiation. These surfaces reradiate heat to the air above them as long wave or infrared radiation.

Environmental Conditions Leading to Cold Injury

Cold conditions in Florida are a result of cold air masses moving down through more northern states and pushing into Florida. Temperatures associated with these fronts depend upon where the pressure systems originate and the rate at which they move into Florida. Environmental conditions created by these cold fronts can be categorized into one of two general types: moist air with considerable cloud cover or dry air and clear skies. Windy conditions can accompany either of these conditions, and wind is an important consideration in developing plant-protection strategies. Daily temperature fluctuations are greatest when clear skies exist. Solar radiation warms the earth's surface during the day and air temperatures of 16 to 21°C (60 to 70°F) are common even though the minimum temperatures at night may be less than –1°C (30°F). This large fluctuation is primarily due to radiation cooling.

Radiational cooling occurs primarily at night when the heat absorbed by the earth's surface during the day is reradiated into the atmosphere. Air at or near the soil surface is warmest during day and coldest during night under such conditions. Heat lost from surfaces by radiational cooling moves away from the earth's surface by convective mixing. The soil continues to lose heat until it is colder than the air just above it; then the soil absorbs heat from the air. The existing condition is a cold air layer near the earth's surface with a rapidly cooling soil surface. The warmest air may be from a few feet to one hundred feet above the soil surface. Plant leaves close to the ground may sustain freeze injury even through the temperature a few feet above the leaves is above their freezing point. This condition is called a “temperature inversion" because it is an inversion of normal daytime conditions where the warmer air is near the ground.

Moist air and cloud cover reduce the fluctuation of daily air temperatures. Cloud cover reduces the amount of solar radiation reaching the earth's surface during the day, and heat radiating from surfaces on a calm night is absorbed by clouds and reradiated back to the earth's surface. The primary cooling process of plants and other objects during cloudy, calm, cold weather is conduction of heat from the leaf to the colder air surrounding it. Leaf temperature generally is not lower than the air temperature in these conditions.

Wind increases the rate of temperature drop. A 5- to 10-mph wind on a cold, cloudy night constantly replaces the warmer air on leaf surfaces with cold air, and this accelerates the rate of heat loss from the leaf. A temperature gradient will develop between the leaf and the air if the air is calm and the rate of heat loss from the leaf would be reduced slightly. Wind on a clear night prevents or reduces the formation of an inversion layer by mixing the warmer air above the crop with colder air at the crop surface, thus slowing the rate of leaf temperature drop.

The lowest temperatures occur in Florida when cold, dry (clear skies) air masses move rapidly across the United States and into Florida. Generally, as such a cold front moves from north Florida to south Florida, the temperature of the air mass increases, but the amount of temperature increase depends upon how fast the front is moving. Clear skies at night greatly increase the chance of crop injury by allowing considerable radiational heat loss from the crop environment.

The terms frost injury and freeze injury are often confused. The injury mechanism in both is the freezing of cellular water, but freeze injury can take place even if frost is not present. Frost occurs when the dewpoint of the air (the temperature at which air is saturated with water) is reached at freezing temperatures. Air can hold less water vapor as it gets colder. When the dew point occurs at freezing temperatures, the water vapor in the air changes to ice crystals on exposed surfaces. When the air contains a lot of moisture, the dew point may be reached before freezing temperatures occur and water vapor will condense as a liquid on exposed surfaces. Dew may freeze after it has condensed on leaf surfaces if the air temperature drops below freezing, but this type of ice formation is less damaging to plants.

When the humidity is very low, freeze injury can occur without frost. Freezes without frost are often called "black frosts."

Measuring Environmental Conditions

Proper measurement of environmental conditions is essential for predicting or assessing plant response and for optimum management of plant protection systems. Temperature is the most important environmental parameter to be measured by the nursery manager. However, temperature measurements related to relative humidity and wind speed and direction can provide the manager with more insight into current and expected conditions.

Relative humidity is the quantity of water vapor present in the atmosphere, expressed as a percentage of the quantity which would saturate the air at the same temperature. Relative humidity helps to determine how rapidly temperatures drop. It also affects plant response to cold temperatures and influences how well specific protection systems work. Air with a high relative humidity will resist temperature change more than dry air, and plant water lost to desiccating winds will be lessened by high relative humidity. Relative humidity sensors and recorders are available in a wide range of prices and accuracies. One practical way of measuring relative humidity at a given temperature is with a wet-bulb thermometer. A wet-bulb thermometer has a bulb covered with a moist muslin bag, thus lowering the measured temperature by loss of latent heat through evaporation. The lower the wet bulb temperature compared to the dry bulb temperature, the lower the relative humidity.

Care should be taken to purchase high quality thermometers which should be routinely calibrated in an ice water bath. Electronic sensors such as thermocouples and thermisters can be purchased or made to sense a temperature at a particular point. Microprocessors are available that can be programmed to scan a large number of temperature sensors at predetermined time intervals and record the temperatures.

Methods Used for Cold Protection

Water Used for Cold Protection

The unique physical properties of water as a vapor, liquid or solid make it a primary factor in plant protection from freezing or chilling temperatures. As water cools at temperatures above freezing, "sensible" heat is released. Actually, 1000 calories of heat energy are released as 1 liter of water is cooled from 3°C to 2°C (8.3 BTUs /gallon/°F). A BTU, British Thermal Unit, is defined as the heat required to raise the temperature of 1 pound of water 1°F or to raise 816 grams of water 1°C. As water cools from 16°C (60°F) to a liquid at 0°C (32°F) 16 kcal per liter (232 BTU's per gallon) of water are released into the surrounding environment. Fogging, flooding and sprinkling (at temperatures above freezing) use the sensible heat in water to moderate temperature drop in the nursery.

When water changes from a liquid to solid state (ice), a tremendous amount of energy is released. This energy is called the "heat of fusion" and is equal to 80 kcal per liter or 1200 BTU's per gallon. Sprinkling when air temperatures are below or approaching 0°C (32F) is sometimes called icing and uses the heat of fusion to provide cold protection for plants.

Sprinkling

Sprinkling for cold protection is becoming increasingly popular in Florida nurseries. It can be used to moderate temperatures above freezing because of sensible heat in water and can maintain plant leaf temperature at 1 to 2°C degrees or more. Sprinkling should continue until after thawing or the wet bulb temperature rises above freezing especially if windy, dry conditions prevail. Evaporative cooling occurs because heat energy is lost to the atmosphere as water changes from a liquid to a vapor. Do not rely on a household window thermometer to monitor leaf and air temperatures.

The water must be delivered uniformly with allowances for changes in wind velocities and direction. Wind adversely affects the sprinkler distribution pattern and causes the heat from the heat of fusion to be lost by evaporation. This means that up to seven times the amount of water used for a freeze on a calm night must be applied to compensate for heat loss due to evaporation and conduction when a 5- to 10-mph wind exists.

The greatest disadvantage of sprinkling is breakage of plant limbs due to ice weight. Easily broken container plants may be placed on their sides and iced to prevent breakage, but should be placed upright as soon as possible after the freeze.

Sprinkling for freeze protection can be used effectively in Florida. Plants do not have to be repositioned, and there are no structures to erect, therefore the reduced labor requirements for sprinkling is an advantage. However, frequent sprinkling may leach nutrients and/or cause waterlogged soils or container media which may result in plant stunting or death. The large amount of water required for this practice could be a limiting factor in some areas of Florida.

Water applied to aisles of shade structures or greenhouses increases the moisture content of the air and soil surrounding the plants (increases wet-bulb temperatures), thus slowing the rate of temperature drop. The water absorbs heat during the day which is released slowly at night. The water should be applied in late afternoon of a warm day. Sides of adequately constructed shade houses can be covered with ice by sprinkling on freezing nights to reduce the effect of wind.

Fog

Fog also retards the loss of heat from soil and plant surfaces to the atmosphere. Natural fogs create a barrier to radiant heat loss much like clouds, although their effectiveness varies with the size of the suspended water particles. Fog can provide up to 4°C (8°F) of protection outdoors during radiational cooling. Applying ground water with an average temperature of 21°C (70°F) to a shade house or greenhouse can create a ground fog if the ground surface is several degrees cooler than the water. This applied water adds heat to the plant environment and/or buffers temperature change by increased humidity. Fogging is most effective in an enclosed structure such as a greenhouse or partially enclosed structure such as a saran house but must be uniformly distributed. Temperatures can be elevated as much as 5°C (9°F) in these unheated structures. High pressure, low volume systems are the best means available to create a uniform fog. A low volume system dramatically reduces water requirements compared to sprinkling.

Air Movement for Cold Protection

Wind machines have been used for many years in citrus and vegetable industries and recently in the ornamental industry as a means of cold protection. Wind machines are only effective in the advent of radiational freezes characterized by winds less than 5 miles per hour.

Denser cold air settles in low areas resulting in temperature strata with warm air above the cold. Wind movement can disturb this inversion existing on calm nights. This forced air movement will mix the cold and warm air resulting in warmer air surrounding the plant. Air movement also helps distribute and circulate heat added by orchard heaters or other sources.

Cold Protection Structures

Structures for cold protection are used to prevent plant desiccation caused by winds associated with severe freezes, to trap heat present and to contain supplied heat energy. They should be constructed to withstand high winds and minimize heat loss. These structures are expensive because of construction materials and required labor for movement of plants in and out as the conditions or seasons change.

Florida nursery operators should analyze nursery production systems for each plant species, the risk of cold damage and the projected dollar return before investing in structures for cold protection. Certain high value crops warrant structures specifically for cod protection, but in other cases, dual purpose structures should be considered. A structure used for shading in summer often can be used for cold protection during winter.

Structures can be constructed of wood, galvanized pipe, conduit, PVC pipe, or concrete reinforcing rods and cost will be the overriding factor in determining which to use. Sizes of structures depend on size of plants to be protected, growing bed width and length, and the production system used. Detailed plans for various greenhouses and cold frame structures can be obtained from the Extension Agricultural Engineer through your local cooperative extension agent.

A common winter protection structure is the quonset type constructed of bent galvanized pipe. Half-inch pipe joints are used for bows which are placed inside larger pipe studs that protrude 15 cm (6 inches) from the ground. This results in a house 4.3 meters (14 feet) wide and 1.8 meters (6 feet) tall. The bows are usually 61 cm (2 feet) apart and the house is usually long enough to accommodate common-size polyethylene. One purlin down the center is adequate for support. Similar construction with PVC pipe bows also has become popular due to reduced costs of PVC pipe. The house should be oriented in a north-south direction to distribute the light uniformly within the structure. A clear polyethylene covering (4 to 6 mil) is usually pulled over the ends and secured along the sides. A door at one or both ends facilitates entry. Venting may be done by raising the plastic on the side opposite prevailing winds and closing during cold weather.

Frames for such permanent structures are usually built on a portion of the container production area and plants from areas adjacent to the quonsets are crowded into these structures to reduce the number of houses needed. The irrigation system for the container production area is usually not flexible enough to use to irrigate plants enclosed in these quonsets and expensive hand watering may be required.

One may elect to construct small, lightweight, portable structures which can be placed over beds of cold-sensitive plants during cold weather and removed during warm weather. Such portable structures may be small quonsets constructed of conduit, PVC pipe or concrete reinforcing rods covered with concrete reinforcing wire for support. They should be wide enough to span a bed 1.8 to 3.0 meters (6 to 10 feet) long. Quonsets made to stack on top of each other will facilitate storage. Polyethylene coverings can be attached to wooden strips at the bottom of each side. A small piece of plastic may be secured over ends of the structures and opened during the day for ventilation. Portable quonsets have definite advantages to the nonportable galvanized pipe structures since plants are not repositioned and the structure may be removed for watering.

Winter temperatures in Florida are not consistently low enough to warrant placing plants on their sides in structures and covering with Styrofoam™ or polyethylene material for the entire season. Nursery operators might consider placing high-value container plants on their sides in the event of a severe freeze. The plants may then be covered with 1 or 2 mil of polyethylene, Styrofoam™ or other insulating material supported just above the plants so the cover is not in direct contact with the foliage. The insulating material should be removed and the plants placed upright after the freeze.

Shade structures are most effective in providing protection during cold weather with little air movement. Saran structures may raise the ambient temperature under them 1 to 2°C (2 to 4°F) by reradiated heat radiating from the ground and objects within the structure. Lath houses are less efficient than saran structures at reradiating heat, but both provide some cold protection. Sides of shade structures may be covered with water during freezing conditions since the ice forms a windbreak. Care should be taken that ice loads do not crush the structure. Some shade structures are designed so they can be covered with polyethylene film during winter months or when cold weather is expected.

Plants may be placed in cold frames for protection from rapid temperature fluctuations. Small plants, such as liners, can be set upright in the frame while larger plants (1 gal. etc.) may be placed on their side. Placing larger plants in the frame is an expensive operation, and one should contemplate placing the plants on their sides and covering in the field rather than transporting to a cold frame. In either case, the plants should be placed upright as soon as cold weather passes. Frames may be economical for protection of liners which were propagated and/or held in the frame through the winter. Cold frames may be covered with polyethylene, Styrofoam™ or other insulating materials placed over the plants to trap radiant heat. Polyethylene or other light transmitting covers with a southern exposure permit solar radiation to warm the structure. The frame covering should be removed on warm days to prevent excessive heat build up.

Supplementary Heat

Air temperatures inside unheated quonsets made of a single layer of plastic are usually about 3°C (5°F) warmer than outside air on a cold night. This small temperature differential can be critical to the survival of many plants, however, supplemental heat ensures that plant environment temperatures are above critical levels. Adding heat to an enclosed structure is more feasible than heating an outside growing area with orchard heaters, but energy costs may prohibit the heating of any woody ornamental growing area. If outside heating is used, it should be combined in combination with other protection techniques such as wind movement, fog or some barrier created to reduce radiant heat loss. The decision to add supplemental heat must be based on crop value and rate of return on investment.

Heat sources for structures include solar radiation, well water and boilers fired by oil, gas or wood. Solar heating systems, warm water units and unheated well water circulation offer the greatest potential for Florida woody ornamental growers. Nursery operators should consult their Water Management District personnel before installing unheated well water circulators. Several passive solar heating designs are available that collect the sun's rays and store this heat energy in some medium like stone or water. The heat collected during the day is then circulated in the structure at night.

Circulation of warm water (43 to 54°C, 110 to 130°F), not hot water, in enclosed growing and/or storage areas has gained popularity in recent years. Warm water is more economical than forced-air heat to keep plant environments above a critical minimum temperature. This water often is circulated through PVC pipe installed in some material like sand or concrete under plant containers.

Well water temperatures in Florida during winter months range from 20 to 24°C (68 to 75°F). A system has been designed and tested at the Agricultural Research Center in Monticello, Florida that circulates unheated well water through PVC pipe in a propagation cold frame. This system kept the minimum cold frame soil temperature above 12°C (54°F) and the minimum air temperature above 8°C (46°F) while outside temperatures were below –7°C (20°F) for several hours. Minimum soil and air temperatures in cold frames without this water circulation system were 4°C (40°F) for the same time period.

The decision to add heat to the plant growing environment must be based on economics. Costs and returns for a given heating system, structure and crop plant must be known or estimated before a system is constructed or an existing system is used.

Treatment of Plants After Cold Stress

The environment to which plants are subjected after cold stress 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 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 can be frozen for several consecutive hours. Clear skies are common when extremely low temperatures occur in Florida. 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 manifest 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.

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