Cold Protection of Foliage Plants in Shadehouses and Greenhouses

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Each year winter temperatures are low enough in one or more of the major foliage plant growing regions in Florida to cause chill/cold injury since the majority of the foliage plants grown in Florida are subtropical and tropical in origin and are susceptible to damage at temperatures below about 50 °F [10 °C] (7). This publication is intended to inform ornamental foliage plant growers about various cold protection measures that can be adapted before and during cold events to avoid or minimize losses due to chilling/cold injury. A glossary containing definitions of selected terminology and a list of cited references for further reading are included at the end of this document.

Terminology used to describe cold weather in relation to plants, e.g., freeze, frost and chill, are often confusing and some of the terms are sometimes used interchangeably. For example, frost and freeze, with a vague definition being “an air temperature less than or equal to 32 °F [0 °C].” During a frost event water within the plant may or may not freeze, depending on several factors (including concentration of ice nucleating bacteria and ability of plants to supercool). Freeze injury in plants mainly occurs due to extracellular (outside the cell) ice formation inside the plant tissues, which draws water out of the cells, dehydrating and causing injury to them. Either the entire plant or sometimes plant parts such as buds, leaves, flowers, stems or roots are injured by cold temperatures.

Chilling injury is different from frost and freeze injury and is caused due to exposure of tissue to temperatures above the freezing point and below 46–54 °F [8–12 °C] (18, 26). Chilling injury is primarily due to disruption of cell membranes. Damage due to chilling temperatures differs with plant species and cultivars, temperature, exposure time, type of plant organ and developmental stage; plants can recover from damage if the exposure was very brief, but may have lingering damage that reduces growth. Irreversible damage occurs if the exposure time is prolonged.

In Florida, cold temperature damage to foliage plants is often due to chilling temperatures. The common symptoms of chilling injury are A) rapid wilting of leaves and appearance of water soaked areas; B) appearance of sunken pits due to cell collapse; C) accelerated senescence; D) increased decay, due to leakage of plant metabolites, encouraging bacterial and fungal growth; E) reduced growth or sprouting capability; and F) damaged areas turning brown and necrotic due to warm temperatures followed by chilling temperatures.

COLD PROTECTION

Nursery owners growing various tropical and sub-tropical plants under shadehouses can take several steps to protect plants from chilling injury. For convenience the following cold protection strategies are classified into two categories: Passive protection and Active protection.

PASSIVE PROTECTION

Cold protection methods that are adapted before low temperatures occur to help avoid the need of active protection are referred to as passive protection. These methods are preventive and act for long periods of time and

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become beneficial when chilling events occur. Following are the main passive methods.

- **Site Selection and Management of Cold Air Drainage**
- **Plant Selection and Management**
- **Plant Nutrition and Pruning Management**
- **Irrigation Management**
- **Cryoprotectants**
- **Plant Coverings — Aqueous Foams and Plant/Row Covers**
- **Heat Curtains and Shadehouse Cladding**
- **Monitoring Weather Forecasts**

**Site Selection and Management of Cold Air Drainage**

Most growers are usually aware that some areas of their property are more prone to cold damage than others. Consulting with local growers and extension advisors should be considered as a first step for selecting a new site and to find out about the appropriate plants and varieties to grow in that area. Typically low lying and northwest spots in local topography have colder temperatures and, hence, more damage. Cold air is denser than warm air, so it flows downhill and accumulates in low lying spots much like water. Therefore it is advisable to avoid cold spots unless adequate cost-effective cold protection methods are included in the long-term operation. In addition, segregation of plants/cultivars according to their cold sensitivity and nursery site characteristics can help reduce damage due to cold temperatures. Locating production areas on the south/southeast side of large bodies of water (lakes, reservoirs) can have a moderating effect on temperatures during advective freezes (3, 15).

Managing cold air drainage is another part of site selection and management. It is important to study the down slope flow of cold air at night to prevent cold damage problems. A careful study of topography and/or use of smoke bombs or other smoke generating devices to study the cold air drainage can be informative. This information can be used for proper placement of diversion obstacles to provide protection from cold damage. Avoid building a shadehouse in low areas where cold air settles; instead, growing tender plants in sites with good air drainage can provide a measure of protection. Land leveling can sometimes improve cold air drainage through nursery crops so that incoming cold air continues to pass through crops without settling. Covered structures (shadehouses and greenhouses) under which plants are grown need to be completely sealed to protect plants from cold winds during advective freezes. The number of entryways for regular cultural practices should be minimized during the windy cold events and the rest of the entries should be sealed with heavy duty groundcover or other impermeable material. However, sealing a shadehouse can lead to colder temperatures occurring inside the structure than outside due to the lack of air mixing during radiation freezes and cold events (29). Thus, preventing air infiltration of shadehouses during cold events is a two-edged sword — beneficial under windy conditions, but counter-productive during calm cool weather. However, if the temperatures are expected to go below the critical levels for the tropical foliage plants being grown, the structures must be closed up to retain heat.

**Plant Selection and Management**

Determining the planting dates that minimize potential for chilling temperatures is important. Shipping of the most susceptible plants before the chilling events is a smart thing to do to avoid losses. If chilling temperatures cannot be avoided, then selecting
tolerant cultivars that can withstand low temperatures is wise. For some genera of foliage plants, research (5, 13, 17) has demonstrated that there are significant differences in chill sensitivity among genera and cultivars (Table 1).

**Table 1. Relative chill sensitivity of some foliage plant genera.**

<table>
<thead>
<tr>
<th>Resistant</th>
<th>Aglaonema</th>
<th>Anthurium</th>
<th>Dieffenbachia</th>
<th>Philodendron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emerald Star</td>
<td>Small Talk</td>
<td>Panther</td>
<td>Deja Vu</td>
</tr>
<tr>
<td></td>
<td>Jewel of India Stars</td>
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<td></td>
<td>Hope</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Selloum</td>
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<tr>
<td>Moderately resistant</td>
<td>Black Lance</td>
<td>Bubble Gum</td>
<td>Camouflage</td>
<td>Imperial Green</td>
</tr>
<tr>
<td></td>
<td>Green Lady</td>
<td>Gemini</td>
<td>Star Bright</td>
<td>Imperial Red</td>
</tr>
<tr>
<td></td>
<td>Maria</td>
<td>Misty Rose</td>
<td></td>
<td>Scandens</td>
</tr>
<tr>
<td></td>
<td>Patricia</td>
<td>Pepper Mint</td>
<td></td>
<td>Micans</td>
</tr>
<tr>
<td>Intermediately resistant</td>
<td>Amelia</td>
<td>Cotton Candy</td>
<td>Camille</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mary Ann</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Penny</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately sensitive</td>
<td>Manila Pride</td>
<td>Big and Bold</td>
<td>Carina</td>
<td></td>
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<tr>
<td></td>
<td>Royal Queen</td>
<td>Red Hot</td>
<td>Octopus</td>
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<td></td>
<td></td>
<td>White Gemini</td>
<td></td>
<td>Sterling</td>
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<tr>
<td>Highly sensitive</td>
<td>Jubilee</td>
<td>White Heart</td>
<td>Tropic Honey</td>
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<td></td>
<td>Queen of Siam</td>
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<td>Silver Frost</td>
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<td>Silver Queen</td>
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</tbody>
</table>

Chilling sensitivity can vary depending on the severity of chilling temperature and duration of time that plants are exposed to the chill as well as plant growth stages, pot sizes used for production, and whether or not plants have been acclimated by chilling temperatures.

Knowing the relative chill sensitivity of the foliage plants can help in management decisions regarding which plants to group together and where to put them to minimize the need for heating and potential for chill damage to occur.

**Plant Nutrition and Pruning Management**

Unhealthy plants are more susceptible to cold damage and more often fail to recover from injury than plants grown with balanced nutrition. Although the relationship between specific nutrients and cold damage is not clear (23), in general, applications of nitrogen and phosphorous may stimulate new growth and thereby increase crop susceptibility to cold damage. Avoid nitrogen application, which might interfere with hardening during later summer and early winter. Recent research (12) suggests that supplemental silicon fertilization, at least of one grass, can enhance chilling resistance. Research about the effects of silicon on foliage plant chill sensitivity is needed.
Foliage plants may be pruned for a number of reasons — shaping, removing diseased or damaged branches, inducing branching, etc. Research has shown that, in some cases and for some crops, pruning prior to the occurrence of cold temperatures can lead to increased cold injury (2, 30). However, the effects of pruning of foliage plants on subsequent chilling injury sensitivity has not been studied.

Irrigation Management

Soils and growing media serve as sinks for energy during the day and sources of heat at night. Heat transfer is due to conduction. Dry soils/media have more air spaces, which limit heat retention and inhibit heat transfer (25). In addition, wet soils/media are usually darker, resulting in increased absorption of solar radiation. Therefore, watering plants to field or container capacity before cold events can help protect the plants by increasing heat absorption and storage.

Cryoprotectants

Cryoprotectants typically have been evaluated for protection of plants or plant parts from freezing temperatures, but not the much higher chilling temperatures that can damage tropical foliage plants. The modes of action for many of the products have been to try to prevent ice nucleation from occurring on the plant surface and/or to promote supercooling, strategies inappropriate for chill sensitive tropical foliage plants. Furthermore, many of the products tested have been of little or no benefit, regardless of mode of action (1, 8, 9, 11, 24).

Plant coverings

Covering plants with aqueous (water-based) foams may be effectively used for cold protection (6, 16); however, foams may not be suitable for use in shadehouses and on tall growing crops and may not provide adequate protection for foliage plants. Foams serve as physical barriers to conductive, convective and radiation heat transfer. Advantages of using foams are that they are relatively cheap, non-toxic, easy to use and breakdown easily when exposed to sunlight. Disadvantages include the equipment and labor required for application and the need to reapply the materials each day.

Plants can also be protected, to a limited extent, using fabric crop covers, a.k.a. row covers and frost blankets. These needle-punched, woven or spun-bonded covers are lightweight and porous, allowing them to be laid directly over the crop foliage while still allowing the plants to be watered with overhead irrigation. Crop covers are made mainly of polyethylene, polyester and polypropylene; however, other plastics and fabrics are used. Covers are generally soft and nonabrasive and come in a range of thicknesses and widths. In general, the thicker the cover the greater the protection (14, 27). Again, the taller the crop the less effective the covers, if the only heat source is the soil and/or growing medium.

Heat Curtains and Shadehouse Cladding

Retractable heat/thermal curtains (RHCs) can be used to reduce heat losses through the roof of shadehouses and greenhouses (Fig. 1) (21, 22). This method is expensive initially, but is less labor intensive than applying and removing seasonal shadehouse cladding every year. In addition to the labor savings, the annual costs of the polyethylene sheeting and its potential plant growth reductions due to the additional shading from the polyethylene during the entire winter when radiation levels are already low may make RHCs cost effective in the long run.
Seasonally applied clear polyethylene film cladding of shadehouses is often used to trap heat, warm the soil and increase chill protection. Unfortunately, polyethylene transmits infrared radiation (IR) readily, resulting in heat being lost from polyethylene-covered structures to the outside (20). Films are available that have been designed with reduced IR transmission, but they are more expensive and may not be cost effective for seasonal applications. Air tight cladding is critical for retaining heat in shadehouses.

Weather Forecasts and Warnings

It is important that growers closely monitor weather forecasts. Previous years’ weather data can be obtained from weather station websites; for example, from the Florida Automated Weather Network (FAWN, http://fawn.ifas.ufl.edu). Information can also be obtained by contacting cooperative extension service staff. This information can be used to plan for current and future years’ nursery operations. Understanding the local weather forecast gives time to react and take necessary actions. Some losses can be prevented if growers align planting dates, cold protection measures, cultivation practices, shipping dates, etc. based upon weather forecasts and plant requirements.

ACTIVE PROTECTION

Active protection includes strategies that are adapted during and after the freeze. These are temporary and are labor or energy intensive or both. Several of these are combinations of both passive and active methods and may be adapted as needed. A prerequisite for any active protection plan is having an accurate temperature monitoring system.

- Temperature Monitoring

The following are the main active methods.
- Geothermal Heating
- Combustion Heating
- Combination Methods

Temperature Monitoring

For accurate temperature measurements to be made, not only must the sensor be accurate, but its placement needs to be such that it provides true air temperatures (10). Temperature sensors range from simple, inexpensive liquid-containing glass thermometers to more complex solid state electronic devices such as thermisters. Even a high quality liquid-containing glass thermometer, one with 0.2°F subdivisions, costs less than $30. For automated systems, use of thermostats that have sensors consisting of corrosion resistant coils filled with liquids (or, in some cases, gases) are often used. The coil serves to increase surface area and improve (shorten) response times. Thermostats are typically located near the center of greenhouses/shadehouses and are shielded from direct sunlight. Electronic sensors are also commonly used, especially as components of automated climate control systems.

If temperatures in the greenhouse or shadehouse are not uniform during cold events, then readings should be taken in the typically coldest spots. In addition,
measures should be taken to reduce that non-uniformity and/or plants should be arranged in the structure to take those temperature differences into account. All readings, whether by thermometer or automated thermostat, should be made at plant height so the measurements are of the air temperatures that surround the plants. Aspirated thermometers and thermostats have fans that move air across the sensor and can provide more accurate monitoring and faster response.

**Heating**

It is obvious that any attempts to heat shadehouses and greenhouses effectively and economically require that they be sealed in some way to reduce air movement and heat loss from the structures (see Heat Curtains and Shadehouse Cladding section). In addition, heat must be released inside the structures in adequate amounts, based on the volume of the structures, to maintain the target temperatures. Two primary sources of energy are generally used to supply heat inside of shadehouses and greenhouses in Florida — geothermal and combustion. There are advantages and disadvantages to using either source.

**Geothermal energy.** Water, primarily from underground wells, is the most common “low temperature geothermal” heat source. Surface waters, which are also heated by the earth, can also be used; however, during cold weather, surface waters are typically colder than groundwater. As water cools at temperatures above freezing, sensible heat is released. For example, as 72 °F well water cools to 32 °F, it gives off 83,664 calories of heat per gallon of water. Besides supplying heat inside shadehouses, raising the relative humidity to saturation inside a shadehouse can lead to the formation of fog. Fog can prevent transmission of infra-red radiation from the crop and, thereby, reduce heat loss (19).

The advantages of using water for cold protection compared to using heaters are that A) equipment and installation costs are generally less (conventional irrigation systems could even be used but are not generally recommended except in emergencies), B) operational costs are greatly reduced since the only fuel needed is that used to run the water supply pumps (4), C) maintenance costs are low since the equipment components do not wear out quickly and are inexpensive to replace, and D) less air pollution is created due to the lower fossil fuel consumption.

Disadvantages of using water for heating are that A) leaching of nutrients and pesticides can occur if the water flows through the growing medium, B) reduced crop root-zone aeration and foliar wetting could lead to increases in leaf and root diseases, C) the shadehouse and surrounding areas could become flooded, and D) water, a limited resource, is removed from the aquifer if well water is used. However, the use of various low pressure mist and fog systems that use significantly less water and direct it differently than regular irrigation systems can greatly reduce and/or eliminate some of the listed disadvantages. The following are examples of some systems designed to minimize some of the disadvantages of using water for heating shadehouses4.

a) *Over-the-Roadways Mist Systems.* Water is applied using mist nozzles installed over-the-roadways so that the water does not leach through the plant beds nor directly wet the crop

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4 Please note, these are not the types of systems used to freeze protect subtropical crops in unclad shadehouses; instead these systems are to protect chill sensitive foliage crops in plastic sheeting clad shadehouses.
foliage (Fig. 2). This increases the moisture and heat content of the air and results in the formation of fog inside the shadehouse. In one shadehouse where an over-the-roadways mist system was used, water consumption was reduced by more than 50% compared to using the conventional over-the-bench mist irrigation system.

b) **Under-the-Bench Mist Systems.** In shadehouses where the plants are growing on open benches, heating water can often be applied using mist nozzles installed under the benches. This type of installation eliminates leaching and water logging of the growing medium and allows the heat to rise through the crop. Fog is produced as the air becomes saturated, the same as with the other systems. Under-the-bench systems may or may not save water depending on the operating pressure, orifice size and number of mist nozzles that are used.

c) **Among-the-Plants Fog Systems:** With these relatively new systems, the water is applied using low pressure fog nozzles arranged among the plants (Fig. 3). Fog quickly fills the shadehouse and creates a radiant heat loss barrier. These systems have been shown to greatly reduce water requirements, compared even to the mister-based cold protection systems. It was determined that a low-pressure fog system used 86% less water compared to the over-the-roadway mist system mentioned above (Fig. 4).

Figure 2. Over-the-roadways mist cold protection system.

Figure 3. Among-the-plants low-pressure fog cold protection system.

Figure 4. Comparison of temperatures inside shadehouses heated using either an over-the-roadway mist or an among-the-plants low-pressure fog system. The fog system used 86% less water than the mist system while maintaining equivalent or warmer temperatures.
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Combustion energy. Various kinds of heaters — burning solid, liquid or gaseous fuels — can be used to provide supplemental heat to shadehouses to help replace energy losses during cold events. Fossil fuels such as liquefied petroleum gas, natural gas and fuel oils are the most often used source of energy; however, logs, lumber and other non-fossil fuel sources can also be used in the appropriate heaters. Temperatures inside shadehouses will not drop to damaging levels if sufficient heat is generated inside the shadehouses to replace the energy lost. To achieve best results, shadehouses should be leak proof.

Some advantages of using combustion heaters are that A) water is not removed from the aquifer; B) humidity in the shadehouse can be kept lower than when using water for heat, thereby helping to reduce the chances of foliar disease development; C) it does not impact the growing media; and D) large differentials between outside and inside temperatures can be maintained given adequate numbers, sizes and types of heaters. A big disadvantage of using combustion compared to using geothermal energy sources are the much higher costs — capital, operating and maintenance (4). Additional disadvantages of combustion heating include A) the release of air pollutants, some of which can adversely affect tropical foliage plants inside the shadehouse if the heaters are not properly vented (31), B) the potential for fuel spills/releases that could cause environmental contamination, and C) the use of a limited resource. For detailed information about the selection, installation and use of combustion heaters in greenhouses/enclosed shadehouses see Hanan (10) and Nelson (20).

Combinations of Methods

Crop covers and irrigation. Research has shown that the combination of crop covers and over-the-crop water applications can maintain warmer temperatures under the covers than when covers are used alone (28). Whether or not this combination would be effective and economically feasible for use to cold protect tropical foliage plants is unknown.

Under-the-Bench Mist System and Retractable Heat Curtains: Recent studies (Stamps et al., unpublished) showed that a combination of an under-the-bench mist system combined with the use of retractable heat curtains maintained about a 30 °F [17 °C] temperature differential between inside and outside the shadehouse during an advective freeze. As mentioned previously, this combination would minimize the seasonal use of polyethylene film cladding.

GLOSSARY

Advective freeze. A weather event in which temperatures drop to or below the freezing point (32 °F [0 °C]) because of large-scale mass movements of cold air (windy conditions).

Cladding. A covering over the outside of a building, e.g., polycarbonate panels on a greenhouse.

Combustion. Exothermic (process of releasing energy in the form of heat, light, electricity or sound) chemical reaction between a fuel and an oxidant (e.g., oxygen).

Conduction. The flow of heat through a material or from one body to a cooler body in contact with it.

Convection. Heat transfer caused by the circulation of gases or liquids.
Crop cover. A cold protection device that is draped over a crop to trap heat from the soil.

Cryoprotectant. Any agent added to living tissue that reduces susceptibility to cold injury.

Fossil fuel. A fuel formed from the remains of organic materials and largely comprised of carbon and hydrogen. Coal, oil and natural gas are all fossil fuels.

Geothermal. Pertaining to the heat of the earth.

Heat. Energy transferred from one place to another by virtue of a temperature difference.

Over-the-crop irrigation. Application of water to a crop from above.

Radiation. Energy transferred through space as electromagnetic waves.

Radiation freeze. A weather event in which temperatures drop to or below the freezing point (32 °F [0 °C]) under calm conditions.

Sensible heat. Heat absorbed or transmitted when the temperature of a substance changes but the substance does not change state.

Supercooling. Process whereby the fluids in plants can remain liquid at temperatures below freezing, partly due to the presence of antifreeze proteins that prevent ice nucleation.

Literature Cited


27. Stamps, R. H. 1990. Spunbonded polypropylene covers aid cold
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