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Jump to page
1 2 3 4

Mitigating Frost Damage in Nursery Production

Frost damage to nursery crops across Australia is a continuing issue with recent frosting events occurring in previously believed 'frost free' areas. In 2007 coastal areas of southern Queensland experienced severe frosts, some less than 500m from the ocean, which resulted in tens of thousands of dollars worth of damage. In this Nursery Paper Queensland Industry Development Manager John McDonald explains how to anticipate a frosting event and mitigate the damage to your crop.

Eucalyptus buds after a frost event (Palmwood Tropicals)

Mitigating Frost Damage in Nursery Production

What is frost?

A frost event is the result of a drop in temperature at or below 0˚C with wind speeds under 10/15km/h. Temperatures below 0˚C with wind speeds **above** 10/15km/h cause freezing, this is a different phenomenon to frost. It is very difficult to modify the unprotected environment in an attempt to reduce crop damage during freezing conditions, whereas frost mitigation through environment modification can be effective. The chance of a 'freezing' event occurring in Australia's nursery production areas is most likely to occur in higher altitude areas.

Frosts are caused when air temperatures at ground level drops below 0˚C, with low air movement and a clear night sky resulting in heat transfer from plants to the atmosphere. The decrease in temperature causes water in plant cells and within intercellular spaces to freeze into ice. This, in due course, ruptures cell walls and plant tissue. The management of frost and the limitation of damage to nursery crops need to be understood to be effective in both protected and unprotected cropping systems in frost sensitive areas.

Eucalyptus buds protected by ice (Palmwood Tropicals)

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Heat Transfer

During a normal day the air temperature profile in the atmosphere decreases with height. The sun warms the ground and crops via radiant heat transfer and this heat warms the surrounding air, in-turn becoming less dense and rising to be replaced with cooler air from above. At night the soil and plants are initially warmer than the ambient air temperature and the heat begins to move from these to the cooler air (radiant heat transfer) and will continue until the air is warmer than the soil and crops. Plant tissue will lose heat faster than the ground; therefore measuring the crop temperature at crop height is required to get a clear guide.

In a frosting event an inversion layer typically forms at approximately 8 - 9m above the ground surface and traps the colder air beneath it. An inversion layer is a band of less dense warm air (temperature increasing with height) that can be a few meters thick to upwards of 100m in height and occurs at night with wind speed below 10 – 15 km/h.

Based on the above it is important to note that the air temperature is usually warmer than the plant temperature. Therefore, if measuring the air and basing mitigation action on a 0˚C figure it is likely that the plants have been at or below -6˚C for some time. Ground temperature on calm nights can be between 1 and 6˚C colder than air temperature recorded at shoulder height (approximately 1.5m) at the same location. This means crop damage may already have occurred or could occur more readily if conditions remain unfavourable for an extended time period.

Many producers protecting crops from frost will add a "safety factor" to their minimum temperature threshold (e.g. frost protection measures triggered at 3˚C at standard 1.5m thermometer reading). Be aware that cold air is dense air and will flow, due to gravity, to the lowest areas in the nursery and collect in what are termed frost pockets or cold spots. Cold air can also be dammed against fences, vegetative areas such as hedges and dense shrub plantings as well as permanent structures such as buildings. Use a number of thermometers around the nursery to record the temperature differences that occur over the entire site which will allow you to identify potential problem areas.

Eucalyptus buds damaged (Palmwood Tropicals)

Mitigation Measures

The most obvious mitigation measure is site selection and ensuring the crops are grown in areas that are less likely to offer cold air traps. Ensure that the site has good air drainage and in frost prone areas this typically means growing the most frost sensitive plants upslope and the hardier stock closer to the flat ground. Avoid artificial air traps such as structures, earth works and vegetation including hedges and windbreaks that are placed down slope or in the prevailing wind direction. Research has also shown crops grown close to large bodies of water (farm dam) are less likely to be frost damaged due to the heat transfer keeping the surrounding air temperature higher.

Frost damage (Denby Cycads Townsville)

Sound crop nutrition can be a useful measure in mitigating crop damage due to frost however, avoid nitrogen induced soft growth as this material is more susceptible to damage. Solutions higher in salts (nutritional elements) have a lower freezing point and increased levels of potassium can increase cell wall strength reducing frost damage. Plant anti-transpirants have shown to be effective across some crop lines at various temperatures and are based on the application of a polymer that allows the plant to continue to respire (gas exchange) and minimise plant water loss (transpiration) maintaining plant turgidity. These products must be applied prior to a frost event and have a specific period of efficacy requiring re-application after this period.

Generally production nurseries choose irrigation water to manage/limit frost damage due to the ease of linking automatic temperature sensors to irrigation controllers that trigger sprinkler application. Also, as most nursery production in Australia is irrigated by overhead sprinkler systems this is also cost effective as no further capital investment is required. For this system to be at its most effective the irrigation design must meet the bare minimum industry best management practice guidelines of a Coefficient of Uniformity (CU) of > 85% and a Scheduling Coefficient (SC) of < 1.5 to ensure a complete and even coverage across the crop (Rolfe, C. et al. 2000, 'Managing Water in Plant Nurseries').

Irrigating during a frost event (Palmwood Tropicals)

The latent heat produced from water freezing and forming ice (fusion) on the foliage surface is enough to keep plant temperatures above freezing point, as long as the application rate and longevity of operation are appropriate to the temperature and frost duration. This latent heat transfers to the plant material and keeps the plant sap from dropping below 0˚C and freezing. Irrigation water is generally accepted as an effective management for frost incidences down to approximately -7˚C. The ice formation can also act as a film of insulation on the foliage and protect plant parts from air temperatures below freezing.

Eucalyptus crop protected by irrigation (Palmwood Tropicals)

The irrigation must be matched to the temperature drop and it must be continued until the temperature returns to above freezing (ice begins to melt). It is generally accepted that irrigation continue until the sun shines on the foliage. Too much irrigation water can cause problems with breakage of foliage and branches (ice formation) as well as water logging of growing media. Shutting off the water too early can cause the plant temperature to drop back to the danger point. An approximate irrigation water application rate of 15 – 20mm per hour during a frost event is a good point for most production nurseries that need to cycle through irrigation stations across multiple growing areas. Initial evaporative cooling can drop leaf temperature by 1 – 2˚C therefore irrigation should commence prior to the temperature reaching 0˚C e.g. 3˚C which can also help avoid irrigation pipes and solenoids from freezing closed.

Vireya crop protected by ice (Palmwood Tropicals)

When the temperature sensor, or manual operation, triggers the irrigation system to begin operating, the cycling of the 'run times' per station needs to be considered. As a general rule each station is run for approximately 3 - 5 minutes (application rate of 15 – 20mm/h) and as long as the temperature remains below the trigger threshold, each station should cycle through at approximately 15 - 20 minute intervals. The irrigation continues until the ice on the plants begins to melt. Lower mean application rates require shorter intervals, such as 3mm/h, will need to be on a 1 minute cycle. The higher the application rate, the thicker the ice formation therefore, the longer that latent heat is produced. For sprinklers spaced at distances over 7m the application rate is generally lower than 15mm/h and the rotation is slower than short spaced sprinklers. When such a design is used, it is important to ensure that a sprinkler rotation is completed under 1 minute, particularly if the system is delivering around 3 – 5 mm/h.

An **inadequate** irrigation system delivering too little water for ice formation can result in more significant plant damage than if no water was applied at all during a frost event. This is because the water fails to freeze into ice and it evaporates into the surrounding air. This evaporative process is increased with higher wind speeds. The process "evaporative cooling" of water evaporating in fact draws 7½ times more heat calories from the environment (plants) than that in ice formation. This means that 7½ times more water must be freezing rather than evaporating. The evaporation process of an iced-over plant can cause the plant temperature to drop significantly below that of a non-iced-over plant and result in greater damage. The general cause of the evaporation is wind and this usually occurs closer to sunrise and can trap the unwary.

Other methods of frost mitigation include the use of heat and air movement. Heating systems such as gas/oil/electric heaters, electric heat mats and hot water heating as under bench or in-floor systems are commonly used throughout the world. These approaches are generally only viable for use in fully protected structures (poly, glass, etc) due to the cost of generating the heat and the ability to retain heat for effective and efficient operation. An alternative that has been used for heating outdoor areas (effective down to 0˚C air temperature) is the use of fire drums (e.g. half 44 Gallon drums) in a grid pattern spaced approximately 30m by 30m across the growing area. The drums burn waste timber and are ignited manually when the temperature threshold is reached. This form of frost mitigation acts by increasing temperature across the area as well as encouraging air movement aimed at displacing the cold still air around the plants.

Air movement through the use of large fans can be useful in minimising frost incidence in both indoor and outdoor production systems. The fans are usually in a bank across the area and are triggered by a temperature sensor calibrated to the threshold level. The air movement can 'move' the trapped pocket(s) of cold air away from the crop and in some cases can drag in warm air if the inversion layer is close enough to the ground and fans. It is important to know the amount of air that these systems will displace to ensure the correct fan size is used. That is, over a given area the fan(s) need to have the capacity to move the air at 10 – 15km/h and no more than this rate. Greater air speed will create the potential for 'evaporative cooling' to occur.

A final point of interest; information from researchers in Tasmania suggests there is evidence to show plant species are susceptible to phyto-burning (sunscald). This is the result of intense sunlight burning the plant foliage due to the clear atmosphere that is present after a frosting event. This can be alleviated through various covers placed over crops believed to be susceptible.

Frost mitigation fans (Woodlea Nursery)

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