Reduction of Frost Damage

Introduction

Over the last few years there has been renewed interest in reducing frost damage in Australia because of the devastating frosts in vineyards and orchards (pome and stone fruit), particularly in the 2006-2007 season. Besides the damage to high value per hectare crops frost damage was also evident in broad acre crops including cereals and canola.

It should be pointed out that there is no 100% guaranteed method to eliminate frost damage and hard frosts late in the spring are hardest to address. A good strategy will save most of the crop in most frosts of down to -5oC. However, a frost of -10oC will damage most crops at the flowering stage.

There are a number of physical precautions which fruit growers can take to minimise frost damage and any serious grower should be familiar with the common practices, such as spraying with water, removing trash and mulch from the soil surface, mechanical methods for circulating air that mixes inversion layers, keeping the soil moist and avoiding cultivation.

These practices for reducing the potential frost damage are, in general, not possible for cereal or canola crops. Therefore addressing damage to the broad acre crops is somewhat more difficult than for orchards and vineyards.

This article looks at strategies and products which can reduce the amount of frost damage. It is based on laboratory research in Australia and in the UK and trials in Australia and New Zealand with support from anecdotal evidence from the USA. There is also considerable research from the USA which has not been reviewed but the basic conclusions have been mentioned in this article (particularly with respect to hydrophobic dusts and polymer coatings). This article is restricted to frost damage caused by temperature inversion and does not deal with very severe frost (-10oC or less) to dormant trees, pasture and cereals in winter. Some background material, on the degree of frost necessary to cause damage, has been based on the very extensive work reported by workers in the USA. On a world scale the problem of frost damage is enormous and extensive research has been undertaken. An article of this size can only hope to give a general overview- hopefully it will be useful.

Frost damage can be due to "extracellular" or intracellular" freezing. Generally extracellular freezing damage is that which occurs by freezing of water on the surface of the plant and is dominant under very moist overcast conditions. Whereas "intracellular" damage is dominant under clear sky conditions with relatively little moisture on the plant surface. At any one time the damage is generally a mixture of the two types but one type predominates. Extracellular damage is relatively rare in orchards or vineyards but occurs more frequently in cereals (and may be observed in canola).

The low temperature which can be sustained by a plant without damage is referred to as the critical temperature and for many crops the critical temperature is between 0oC and -2oC when the plant is actively growing.
In the dormant period trees often do not sustain any damage at temperatures of -10oC or less.
Species or varieties exhibit different frost damage at the same temperature and physiological stage depending on the recent weather conditions and their adaptation to cold temperatures prior to the frost period (called hardening). Plants tend to harden against frost injury during cold periods but rapidly lose the hardening after a few warm days. Scientists are divided on the primary mechanism of frost hardening but it is probably due to an increase in solute concentration in the plant tissue but a more subtle mechanism involving modification of the cell wall is also thought to be involved.

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Methods of minimising frost damage can be divided into two types, methods that are designed to raise the minimum temperature reached (physical methods) and methods that are designed to stop ice formation (chemical methods). Physical methods are well documented in articles on the web and will be discussed only briefly here. The most successful frost damage preventative measures for high value crops use a combination of both physical and chemical methods.

Physical methods

Location

When setting up a new venture it is important to:

- choose a location which is not susceptible to hard frosts. Frosts are reduced if there is protection from southerly and westerly winds.
- choose a site within the location without gullies and hollows. A two per cent fall along the vines or tree lines with no barrier to airflow is ideal.
- avoid windbreaks that hinder airflow including windbreaks across the bottom of the vineyard or orchard which trap cold air causing it to bank up. Windbreaks even across the top of the vineyard or orchard can severely restrict air movement.

Soil type and moisture

Dark soil absorbs more heat than light soils and gravel soils absorb more heat than clay soils. Soils that absorb more heat are less likely to be frost prone. In some circumstances it may be worthwhile considering applying organic humate (which is very dark) to the soil. Although this is expensive, $500- $1500 per hectare there are added long term advantages such as increased organic matter, better water and nutrient holding capacity and release of locked up nutrients.

Soil with significant moisture will tend to be warmer than the surrounding air so trees or vines with moist bare soil around the trunks will suffer less freezing than dry soil or soil covered with mulch. Dry mulch will attract ground frosts - avoid it at all costs until the frost danger period is over. Compacted soils are less frost prone than cultivated soils.

Overhead Sprinklers

Overhead irrigation is the most commonly used method of frost protection in vineyards.

There are many system designs, but all depend on two factors:

- when water freezes, the formation of ice releases energy and
- irrigation water is usually significantly warmer than the surrounding air.

This method has three disadvantages:

- if significant amounts of ice form on the vines or trees there may be damage caused by the inability to support the additional weight leading to major damage
- the method can waste considerable amounts of water and
- systems relying on sensors activating an alarm and subsequent manual start up require 24 hr attention.

Air Mixing

Mixing the layer of air near the soil surface with the layers a few metres above the soil can reduce the risk of frost. There are two man made methods to mix the layers. The first is to use wind machines. Wind machines can generally create an increase in air temperature of 1 to 1.5oC.

Another way in which inversion layers can be mixed is by the use of helicopters. This method is expensive and subject to considerable regulation. It is more common in New Zealand than in Australia.

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Chemical Methods

Fertilizers
One simple strategy for reducing frost damage is simply to avoid the use of any nitrogenous fertilizer during or before the frost danger period. Excess nitrogen induces susceptible new growth and also restricts the uptake of potassium in a plant.

High levels of potassium in a plant have been shown to induce greater frost tolerance in many crops.
Any solution containing large amounts of potassium salts (or sodium or calcium salts), freezes at temperatures considerably lower than pure water. Liquid fertilizers containing a high level of potassium are available from a number of Australian companies. Whilst these can be used to reduce frost damage the effect is short-term and too heavy or too frequent application can cause foliage and/or bud burn, the net effect being negative.

Oil Sprays
Vegetable oil such as canola oil can be used to reduce frost damage. It is a method worth considering if there is only a short warning of a likely frost and the area to be treated is small.

Copper sprays
The formation of ice on buds and leaves is partially dependant on small particles which act as nuclei for ice formation. Copper sprays have the ability to reduce the numbers of bacteria reducing the number of ice nucleation points and hence giving some frost protection. There is no doubt that some benefit is obtained but it is difficult to quantify.

Sugars
Sugars such as sorbitol and glycol derivatives have been used to achieve a reduction in the freezing temperature of the plant cell contents. In general, these approaches have been unsuccessful because there are toxic effects or the treatment is not economically viable at the application rates needed to give a few degrees of frost tolerance. Application of small amounts of molasses can impart a small increase in frost tolerance.

Hydrophobic dusts
Overseas studies have indicated that hydrophobic (water hating) dusts can reduce frost damage. These appear to work by repelling water condensation on leaves, which is a normal precursor to extracellular frost damage. They do not appear to be commercially available in Australia. In the absence of condensed water on the foliage it is possible for the water in the plant to supercool and not freeze. The effectiveness of hydrophobic dusts depends on a number of factors including the length of the freeze period and the species of plant. Research has shown consistently less damage when hydrophobic dust is used on potatoes, grapevines, citrus and tomatoes.

Anti - transpirants
These cut down the transpiration rate by covering the leaves with a semi-permeable membrane.
This membrane forms a polymer coating on the leaf, but still
allows them to transpire. These products needs to be applied about 24 hrs before adverse weather conditions and reapplied every 2-4 weeks depending on conditions.

Seaweed digests
There is little doubt that these are the most important products currently available in Australia to minimise frost damage. Scientific studies both in Australia and overseas have shown that regular application of seaweed (kelp) digests can increase frost resistance. Low concentration seaweed digest applications at about 10-12 day periods throughout the frost danger period can give 2 to 3 degrees of extra frost tolerance for pome and stone fruit. A suitably chosen seaweed extract can be the grower's best defence against late frost at blossom time.

Choosing a seaweed digest
Several factors need to be considered:

- Seaweed digests are often tailored for use on a particular crop and are fortified with conventional fertilisers or organic sources of nitrogen. Those that have added nitrogen may well reduce rather than increase frost resistance because of the effect of the nitrogen producing sappy growth.

They should be avoided when the aim is to increase frost tolerance. Foliar sprays of Fish / Kelp mixtures should be avoided for this reason.

- Most of the scientific work showing increase frost tolerance by seaweed digest application has been based on alkaline digests but acidic digests also appear to work. It is not clear that fermentation produced extracts work as well. Further, it might be expected fermentation - produced extracts may be counter productive, as the spores present may well be ice nucleators.
- Digests that have a relatively high potassium level may be superior to those with low levels because of the effect of increase potassium uptake by the plant through the foliage.
- For foliar application of a seaweed digest, it needs to be applied as a fine spray. It should have been passed through a fine filter during the manufacturing process.
- The digestion process needs to be carried out carefully as it is desirable that the product once on the buds or foliage is slightly sticky and forms a very thin layer over the leaves.

Seaweed digests increase frost tolerance in several ways.

- They contain a number of plant growth regulators, two of them, (cytokinins and betaines) increasing turgidity of the cell wall.
- They contain sugars, such as mannitol, and also potassium both of which will lower the freezing point of the cell fluid and explain part of the observed effect.
- Extensive work by scientists in the UK seems to indicate that there is something in the digests that triggers a gene responsible for "hardening off" the plants.

Whatever the mechanisms involved numerous studies have shown that liquid seaweeds can reduce frost damage in a wide range of crops. Liquid seaweeds fortified with potash and/or other minerals are more effective than pure liquid seaweed.

Crop Specific Remarks
Pome and stone fruit.
Frost damage can be significantly reduced in these crops by developing a strategy. Liquid seaweed application every 8 to 12 days during the frost danger period should be an important part of that strategy. This would be expected to give an extra 2 to 3 oC extra frost tolerance. The first application should be made at least 36 hrs before the expected frost.
The cost is about between $6 and $12 per acre for each application (based on the cost of Frost Guard, Cosy Wrap or Eco Kelp-see below). The number of applications will depend on the location typically up to four in Victoria and up to six in Tasmania.

Grapes
Physical methods
There are several additional physical methods which can reduce frost damage in grapes.
Variety selection Variety selection is important but obviously spring frost damage is not the only consideration. Earlier bursting varieties are more likely to be affected by frosts than later bursting varieties. The temperature at which damage occurs increases as the vine grows. Typically temperatures of less than -3.5oC are needed to damage vine tissue at the woolly bud stage whereas temperatures of less than -0.6oC will damage shoots of 15 cm or so. Therefore if there is a very late frost early bursting varieties will be damaged more than later bursting varieties.

Dormant vines and trees can often tolerate temperatures as low as -10oC without any damage. The problem arises when dormancy breaks and buds appear. The table below gives values of the air temperature when damage to vine tissue may occur.
(Based on data given by Hedberg, 2000, Australian Viticulture Vol 4. No 4, p18-22).

-3.5oC or less	woolly bud stage (continued periods can kill the primary bud*)
-2.0oC or less	early budburst
-0.60 oC or less	shoots up to 15 cm long
0oC or less	shoots 15 cm and longer

* A grapevine compound bud (winter bud) contains three dormant buds: the primary, secondary and tertiary bud. The primary bud is the one that normally grows. If that shoot is killed the secondary or tertiary bud will usually develop. However, these other buds tend not to be as fruitful as the primary bud.

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Trellis Height Radiation frosts, those that form on clear still nights, have an inversion layer several metres above the ground that contains warmer air than that found at the soil surface. These are the most typically experienced frost in vineyards in Australia. The temperature is lower at ground level than 4 metres above the ground. The difference can be 3 or 4oC. The air temperature difference between buds separated by a height difference of 1 metre could well be 1oC. Consequently there is a greater risk of frost damage the closer the buds or shoots are to the ground.

Timing of Pruning Bud burst can be delayed by late pruning and this can reduce the risk of frost damage.

Chemical methods
The most important chemical method is to use a high potassium liquid seaweed. Early in the growth period it would be expected that the buds will have an additional 2-3oC of frost tolerance if sprayed every 8 to 12 days but once the shoots are about 10 cm or more application needs to be made every 6 to 8 days and the additional frost tolerance drops to 1.5-2 oC.

Canola

The extent of frost damage in canola in Australia in 2006 (and 2008) was enormous; the Weekly Times reported for 2006 "the Victoria crop is expected to be down 70 per cent, NSW down 80 per cent and South Australia about two-third below average." A significant part of this reduction was due to the drought but the crop was also decimated by late frosts. Frost damage in canola and cereals was also significant in north-east Victoria and the Midlands, Tasmania in the 2008 season. Again both of these regions were also drought affected in 2008. Unfortunately frost damage in canola has not been so extensively studied as frost damage in fruit trees, grape vines or cereals.

However, it appears that the pattern of damage is similar to cereals. Initially after emergence the plant has some natural frost hardiness but this is virtually lost after a few warm days. The natural frost tolerance decreases to flowering and further decreases to seed pod set. Canola usually flowers for 3-5 weeks and frost damage is greatest if it occurs towards the end of flowering and through pod filling. After pod filling, the natural frost tolerance then increases slightly. During the period up to seed pod set some natural hardening can occur but this is rapidly lost if there is a warm period.

The selection of an appropriate variety can be crucial, mid season varieties will flower and fill pods later, reducing the risk of frost damage. However, earlier maturing varieties are more suited to drier areas, so the choice of variety is often a compromise.

The use of high potassium liquid seaweeds for increasing frost tolerance on this crop has not be so extensively investigated as with pome and stone fruit. It appears that application rate of about 5L/ha will give some protection between 2 and 12 days after application. The increase in frost tolerance is greater than that obtained in the case of pome and stone fruit and appears to be of the order of 4oC. The difficulty in undertaking scientifically rigorous field trials on canola should not be underestimated but unreplicated trials and small plot trials support the estimate of about 4oC of extra frost tolerance.

Cereal crops

The susceptibility of cereals varies widely. The relative resistance to freezing decreases from rye > bread wheat > triticale > barley > oats > durum wheat. During winter the critical temperature (i.e. the temperature below which damage occurs) changes with the degree of hardening. When fully hardened rye can withstand temperature of -40 to -45oC whereas durum wheat cannot withstand temperatures of less than -10oC.

The critical damage temperature is generally low at the germination stage increasing to between -1 and -2oC at flowering and then decreasing to -2 to -4oC once the head is formed. Hardening can lower these critical damage temperatures. Frost damage in cereals is usually greater in drought years because dry soil cools more quickly than moist soil and crops already under water stress are more susceptible to frost damage.

Range of critical damage temperatures (oC) for cereals, pulses, oil and silage crops
(modified from FAO book on Frost Protection: Fundamentals, Practice and Economics Volume 1, ch4. table 4)
see www.fao.org

Crop	Germination	Flowering	Fruiting
Spring wheat	-9,-10	-1,-2	-2,-4
Oats	-8,-9	-1,-2	-2,-4
Barley	-7,-8	-1,-2	-2,-4
Corn	-2,-3	-1,-2	-2,-3
Beans	-5,-6	-2,-3	-3,-4
Peas	-7,-8	-2,-3	-3,-4
Lupin	-6,-8	-3,-4	-3,-4
Sunflower	-5,-6	-2,-3	-2,-3
Safflower	-4,-6	-2,-3	-3,-4
Soybeans	-3,-4	-2,-3	-2,-3
Sesame	-0.5,-1	-0.5,-1	
Cotton	-1,-2	-1,-2	-2,-3
Cabbage	-5,-7	-2,-3	-6,-9
Sorghum	-2,-3	-1,-2	-2,-3
Buckwheat	-1,-2	-1,-2	-0.5,-2

Because of the relatively low dollar return per acre on broad acre crops it is important to consider all the advantages and all the costs before deciding which option to take if any. The liquid seaweeds recommended for frost damage reduction in broad acre are those which are relatively high in potassium but low in nitrogen and relatively low in phosphorus so the added nutritional value is, at best, moderate. However, liquid seaweeds contain a range of plant growth enhancers and these can give rise to increased tillering, increased yield, an increase in stalk strength and increase in drought tolerance.
Recently there has been extensive research into the efficacy of hydrophobic dusts. Potentially these are cheap enough for use on cereal crops but their use has not been adopted in Australia to date.

Concluding comments
As pointed out by Margaret Chidgey in "the Olive Press" (www.australianolives.com.au) "Frost (damage) prevention requires a management strategy using a number of physical methods, in conjunction with some products" In 2004 the author added "under most Australian conditions, the amount of frost protection afforded by regular application of suitable kelp digests would be sufficient to deal with about 70% of the frost damage to grapes, apples and stone fruit. Combined with physical methods this percentage could be increased to over 85%".
Research is still in progress on frost damage reduction. However, experience with Australian Bull Kelp based products of frost damage reduction to stone fruit orchards in the Murray Goulburn Valley and to grapevines in the South Island of New Zealand support the economic feasibility of using seaweed based products for minimising frost damage.

If the frost pattern of 2006 is repeated the time, effort and cost in developing a strategy for vineyards and orchards, will pay great dividends and even if there is no damaging frosts the other benefits, such as better quality fruit, increased yields and reduced fungal problems will usually amply offset the cost of liquid seaweed application.
For canola, cereals and other broad acre crops the use of liquid seaweeds may be economically viable.
Further research on hydrophobic dusts, work on cheaper liquid seaweed production methods and research on factors which enhance natural frost hardening, offer exciting possibilities for addressing reducing frost damage.

There is a range of locally produced products liquid seaweed products which may be effective but these have not been specifically designed to reduce frost damage. However, there are a few locally produced liquid seaweed products specifically designed to increase frost tolerance - Frost Guard and Cosy Wrap manufactured by Fair Dinkum Fertilizers, (www.fairdinkumfertilizers.com) Eco Kelp marketed by GV Crop Protection, (Shepparton) and Ectol marketed by Farmer Marketing Network (FMN) (www.ectol.com).