The Best Practice Guide for UK Plum Production
Orchard Management to Reduce Frost Damage

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Introduction

The vast majority of plum varieties is frost hardy but their early to mid-spring flowering period makes plums particularly prone to frost damage. Flowering time is mainly driven by spring temperature which has seen an increase by a degree centigrade in the last two decades and 4 days decrease in the average number of spring ground frost days, reaching 33 days for the 207-2016 period (Source: Met office). Climatic models predict a further 3 degree increase in spring temperature (UKCP), which will result in an earlier bloom, exposing flowers to a longer risky period for frost.

Frost is divided in two types: radiation frost occurs when, with a clear sky and calm winds, the temperature near the surface of the earth drops to below freezing point. As temperature drops, the cold air flows downward to lower topographic areas and a warm air layer forms, preventing air movement and resulting in a rapid decrease in ground air temperature. Advective frost is the most difficult to prevent as it consists in the movement of a dry and cold (subzero) air mass with winds usually exceeding 8 km.h-1.

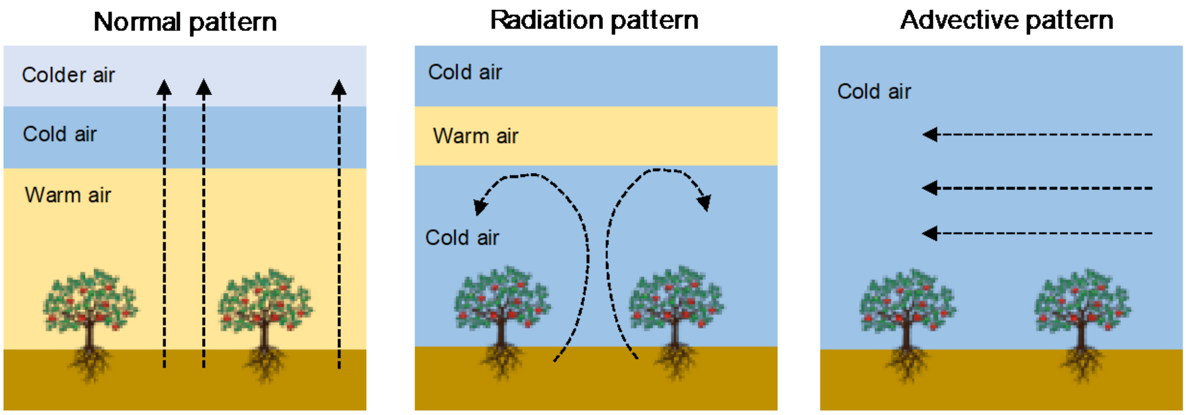

Figure 1. Types of frost and their associated air layers patterns. Arrows represent air movement and energy transfer

Frost damage can be explained by the rapid transformation of a fraction of the extracellular water into ice. Frost can spread from the tissue surface at a speed reaching 40 mm.s-1, leading to damage of the cell membranes. Frost damage can also be the result of tissues dehydration via supercooling. Tissues supercooling mechanism is not fully understood but consists in the formation of extracellular ice and a concomitant loss of intracellular water resulting in the collapse of the cells. Sensitive tissues, such as xylem and primary tissue of plants are very susceptible to cold temperatures because of the large proportion of water in the cell. Lignified and suberised tissues are more resistant, the cuticle inhibiting ice nucleators and force water into the supercooled tissue.

A combination of these and other factors determine the temperature at which ice forms inside the plant tissue and when damage occurs. The amount of frost injury increases as the temperature falls and the temperature corresponding to a specific level of damage is called a "critical damage temperature" (Figure 1). These critical values are likely to differ from air temperature as bud, flower and small-fruit temperature tend to be colder than air temperature.

	First swelling BBCH01	Side white BBCH03	Green tip BBCH09	Tight cluster BBCH55	First white BBCH59	First bloom BBCH60	Full bloom BBCH65	Post bloom
Old temp	--	--	--	--	-5.0	-2.8	-2.8	-1.1
10% kill	-10.0	-8.1	-6.6	-4.4	-3.3	-2.8	-2.2	-2.2
90% kill	-17.8	-16.1	-13.8	-8.9	-5.6	-5.0	-5.0	-5.0

Figure 2. Source: Mark Longstroth, Michigan State University Extension Educator, all photos by Mark Longstroth (MSUE)

Passive protection

Site selection

Protection against frost starts with a good site selection for planting. Low topographic spots accumulate local cold air and should not be planted with plums unless adequate cost-effective active protection methods are included in the long-term management strategy. Soil types differ in their ability to store heat (sand > clay) and higher water content improves heat storage and transfer. Fences, windbreaks, woodland and field hedges can be used to divert cold air flow around the field boundaries and are effective methods to reduce frost damage. Any obstacles to down-slope air movement should be removed to allow cold air drainage. When possible, orchard rows should be oriented in the direction favouring cold air drainage through the field.

Soil management

Inter-row cover crops reduce the solar energy received by the soil and reduces the heat released from the soil during the night. Removing cover crop improves energy transfer and heat storage. Generally, mowing, cultivation and spraying with herbicides are methods to remove floor vegetation. If possible, the cover crop should be mowed sufficiently early to allow the residue to decompose or the cut vegetation should be removed. For grass taller than about 5 cm, there is little difference in orchard floor surface temperature, but the surface temperature increases as the canopy gets shorter, to the highest minimum surface temperature for bare soil. Orchard floor minimum surface temperature differences as high as 2 °C have been reported between bare soil and 5-cm high grass. Soil cultivation creates air spaces in the soil and it should be avoided during frost-prone periods as the larger air spaces will tend to transfer and store less heat. Cultivation should be done well before the frost season and the orchards can be irrigated before 2-3 days prior to frost to improve heat transfer and storage. Mulches and compost reduce heat transfer into the soil and hence make orchard crops more frost prone after bud break.

Active protection

Heaters

Heaters provide supplemental heat to help replace energy losses. Generally, heaters either raise the temperature of metal objects (e.g. stack heaters) or operate as open fires. If sufficient heat is added to the crop volume so that all of the energy losses are replaced (140 to 280 W m-2), the temperature will not fall to damaging levels. However, the systems are generally inefficient (i.e. a large portion of the energy output is lost to the sky), so proper design and management is necessary. By designing a system to use more and smaller heaters that are properly managed, one can improve efficiency to the level where the crop is protected under most radiation frost conditions. However, when there is little or no inversion and there is a wind blowing, the heaters may not provide adequate protection. Heater distribution should be relatively uniform with more heaters in the borders, especially upwind, and in low cold spots. Borders should have a minimum of one heater per two trees on the outside edge and inside the first row.

Wind machines

Figure 3: Wind machine (Source: Good Fruit Grower).

Wind machines alone generally use only 5 percent to 10 percent of the fuel consumed by a fuel-oil heater protection system. However, the initial investment is high (e.g. about £20,000 per machine). Wind machines generally have lower labour requirements and operational costs than other methods; especially electric wind machines.

Most wind machines (or fans) blow air almost horizontally to mix warmer air aloft in a temperature inversion with cooler air near the surface. They also break up microscale boundary layers over plant surfaces, which improves sensible heat transfer from the air to the plants. However, before investing in wind machines, be sure to investigate if inversions between 2.0 and 10 m height are at least 1.5 °C or greater on most frost nights.

Figure 4: Wind machine

Wind machine noise is a big problem for growers with crops near cities and towns, and this should be considered when selecting a frost protection method. Generally, one large wind machine with a 65 to 75 kW power source is needed for each 4.0 to 4.5 ha. The effect on temperature decreases approximately as the inverse square of the distance from the tower, so some overlap of protection areas will enhance protection.

Fans that vertically pull down warm air from aloft have generally been ineffective and they can damage plants near the tower. Wind machines that blow vertically upwards are commercially available and there has been some testing of the machines. However, there were no published research reports found when preparing this guidebook.

Over-plant sprinklers

Over-plant sprinkler irrigation is used to protect low-growing crops and deciduous fruit trees with strong scaffold branches that do not break under the weight of ice loading. Even during advection frosts, over-plant sprinkling provides excellent frost protection down to near -7 °C if the application rates are sufficient and the application is uniform. Under windy conditions or when the air temperature falls so low that the application rate is inadequate to supply more heat than is lost to evaporation, the method can cause more damage than experienced by an unprotected crop. Drawbacks of this method are that severe damage can occur if the sprinkler system fails, the method has large water requirements, ice loading can cause branch damage, and root disease can be a problem in poorly drained soils.


Figure 5: Over-plant sprinkler

Application rate requirements for over-plant sprinklers differ for conventional rotating, variable rate, or low-volume targeted sprinklers. As long as there is a liquid-ice mixture on the plants, with water dripping off the icicles, the coated plant parts will be protected. However, if an inadequate precipitation rate is used or if the rotation rate of the sprinklers is too slow, all of the water can freeze and the temperature of the ice-coated plants can fall to lower temperatures than unprotected plants. Sprinklers should be started and set at the rate as recommended by the manufacturer.

Over-plant sprinklers should be started when the wet-bulb temperature is higher than the critical (Tc) temperature. Starting when the wet-bulb temperature reaches 0 °C is less risky and it may be prudent if there are no problems with water shortage, waterlogging or ice loading. Even if the sun is shining on the plants and the air temperature is above 0 °C, sprinklers should not be turned off unless the wet-bulb temperature measured upwind from the crop is above the critical damage temperature. If soil waterlogging or water shortages are not problems, permitting the wet-bulb temperature to slightly exceed 0 °C before turning off the sprinklers adds an extra measure of safety.

Surface irrigation

In this method, water is applied to a field and heat from the water is released to the air as it cools. However, effectiveness decreases as the water cools over time. Partial or total submersion of tolerant plants is possible; however, disease and root asphyxiation are sometimes a problem. The method works best for low-growing tree and vine crops during radiation frosts.

Because of the relatively low cost of flood irrigation, the economic benefits resulting from its use are high and the method is commonly used in many countries. As much as 3-4 °C of protection can be achieved with this method if irrigation is done prior to the frost event. The depth of water to apply depends on the night-time energy balance and the water temperature. Table 2.3 provides an estimate of the depth to apply as a function of the maximum water temperature on the day preceding the frost event.

Disclaimer

The information contained within this Best Practice Guide is correct to the best of the authors' knowledge at the time of compilation but it must be understood that the biological material/systems and the regulatory framework referred to within these guides are subject to change over time. Anyone looking to make use of the information should check it against prevailing local conditions.

All pesticide recommendations and approvals are subject to change over time and the user of this Guide is reminded that it is his/her responsibility to ensure that any chemical intended for use by them is approved for use at the time of the intended application. The user is reminded that they must carefully read and follow the label on each chemical before applying any treatments.