Passive Frost Protection of Trees and Vines

Summary of Recommendations

Several management practices can reduce the potential for frost damage in an orchard or vineyard. The practices include:

1. **Site selection** or choosing a location for an orchard or vineyard less prone to frost damage. Frost-sensitive crops should not be grown in low areas where cold air is trapped by natural topography, vegetation, or by manufactured obstacles that inhibit drainage of cold air.

2. **Soil and ground cover management** to maximize the storage and later release of heat from the soil within and upwind of a crop. To reduce the chances of frost damage, make sure that the ground is firm, moist, and exposed to sunlight inside and upwind (upslope) from a crop by (a) eliminating or cutting ground cover, (b) keeping the top 1 foot of soil moist, and (c) not cultivating.

3. **Delay bloom and crop development** through planting on north-facing slopes and by selecting crops or varieties that develop later in the spring is beneficial for avoiding frost damage.

These passive management practices are less expensive than active frost protection with sprinkler irrigation, and wind machines, and can be more cost effective in some cases. Even when active protection methods are used, employing these passive practices can minimize the need for active protection and reduce expenses.

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Introduction

Freezing temperatures can have a devastating effect on tree and vine crop production, if they occur during critical developmental periods. During dormancy, most crops are relatively insensitive to all but extremely low temperatures. The sensitivity of crops to frost increases rapidly, however, from the onset of flowering to small nut or fruit stages when crops are generally the most sensitive. Fortunately, the probability of damaging temperatures occurring decreases rapidly during these early developmental stages. Frost damage can also occur before a fall harvest in some crops, and the probability of damage increases if harvest is delayed.

Proper management of your orchard or vineyard before a frost night can minimize potential damage. These management practices, before a frost night, are called "passive protection." During a frost night, such protection practices as sprinklers and wind machines are categorized as "active protection." This leaflet discusses passive protection methods that can improve effectiveness or eliminate the need for active frost protection.

Advection and Radiation Frosts

Two types of frost situations can occur. One is called an "advection frost," which occurs when freezing air blowing into the area displaces warmer air that was present before the frost occurrence. Moderate-to-strong winds, no inversion, cloudy or clear skies, and freezing temperatures even during daylight typically characterize advection frosts. In some cases, the temperature can remain below freezing for several successive days. Advection frosts are difficult to protect against. The other type of situation, "radiation frost," is characterized by light winds, temperature inversions, clear skies, and daytime temperatures above 32°F (0°C). Fortunately, radiation frosts are much more common than advection frosts in California.

Mechanisms of Heat Transfer

Radiant heat is what you feel when you stand near a burning fireplace or when you are exposed to sunlight. Everything that has a measurable temperature emits radiant heat. The warmer the source of radiation, the greater the amount of heat radiated.

Radiant heat is important in passive frost protection because more nighttime heat is radiated from the soil to the crop if the soil surface temperature can be maintained higher. The sky also has an effective temperature and downward radiation that contributes to protection. Clouds, fog, and high humidity help to maintain a higher effective sky temperature, which provides more protection than during clear skies.

In convection, heat is transferred by moving air. For example, heat is convectively transferred from a furnace that warms the air and then moves it by a fan to different rooms in a house. When wind moves air over an object with a different temperature, heat is transferred to or from the object, depending on which is warmer. This process occurs as cold air moves over the ground and through a crop during a frost night.

In conduction, heat is transferred without movement of the transfer medium. An example would be to place the end of a fireplace poker into a fire. Eventually, heat will be conducted up the poker from the end in the fire to your hand and the temperature of the poker in your hand will increase. Conduction is very important in soil heat transfer and it can be affected by cultural management. A primary objective of passive frost protection is to maximize heat conduction into the soil during the day so that more heat can be released to the crop at night.

Another mechanism of heat transfer is the movement of water that carries latent heat and releases it to the surroundings when condensing, cooling, or freezing. Similarly, water removes heat from the surroundings when it melts, warms, or evaporates. Freezing, melting, and evaporation are the main processes that transfer heat to or from water on a frost night. Approximately four times as much heat is released to the surroundings during freezing than in cooling water from 68°F (20°C) to 32°F (0°C) and four times as much heat must be transferred from the surroundings to melt water as it takes to raise the temperature from 32°F to 68°F. Approximately 166 BTUs of heat are released when a pound of water changes from a liquid at 32°F to ice at 32°F. Evaporation can also be an important factor because it removes approximately 7-1/2 times as much heat from the surroundings as freezing an equal quantity of water. Fortunately, evaporation rates are low during frost nights.

Fog, Clouds, and Wind

Fog, clouds, and wind tend to protect crops from radiation frost. Fog and clouds slow dropping temperatures because radiation from the sky downward is increased relative to that emitted upward from the ground. Under these conditions, there is usually little or no net loss of heat from the crop and the temperature will drop slowly or can even increase (fig. 1). Surprisingly, even very high thin clouds or light fog can greatly slow temperature drop.

Light wind can markedly affect slowing temperature drop. Temperatures will decline most rapidly when there is no wind and will drop less slowly as wind speeds increase during a radiation frost. The beneficial effects of light winds are less when cold air has settled and an inversion has formed. Therefore, light wind early in the evening will slow temperature drop more than the same wind speed later during a frost night. A hanging plastic ribbon on the edge of an orchard or in an open area can be used as an indicator of light winds. The ribbon should be about 3 feet long and should be tied so that the bottom hangs about 3 feet above the ground. If the bottom of the ribbon is obviously fluttering and displaced from vertical by a foot or more,

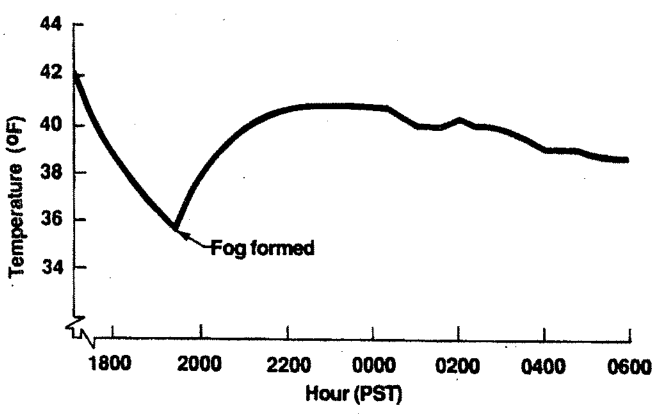

Fig. 1. Air temperature measured over citrus during fog formation on the nights of January 8-9, 1981.

the wind speed is probably great enough to slow temperature drop. If it is hanging straight down, there is no wind and temperatures will decline more rapidly.

Humidity

Humidity is very important during a radiation frost night because the minimum temperature will usually not drop much after reaching the dew-point temperature. If you have a low dew-point near 32^{o}F or below, then the danger of frost damage is greater. High humidity reduces the danger because downward radiant heat tends to be greater. Also, fog, dew, or white frost (ice) are more likely to form, releasing latent heat (heat stored in the water) to the soil, air, and crop when the humidity is high. In most cases, formation of dew or white frost is beneficial, except in citrus where research has shown that white frost forming on the fruit early in a frost night can lead to more damage than when no frost is present.

Soil, Water Content, Cultivation, and Ground Cover

Soils can affect temperature drop because heat capacity (heat storage capability) and conductivity vary, depending partly on soil texture. Generally, when they are dry, sandy and peat soils do not store or conduct heat as readily as loam and clay soils. The result is that there is a greater daily temperature range at the surface for light soils than for heavier soils, and the minimum surface temperature is lower. Soils with a darker color often absorb more sunlight than a light colored soil and store more heat. Consequently, areas within an orchard with lighter colored soil (and no ground cover) are prone to frost damage.

Conductivity and heat storage in soils are greatly affected by water content because water stores considerable heat, and moist soil conducts heat more readily than a dry soil. Figure 2 shows a sample daily temperature profile change of a moist and a dry soil. The critical factor to frost protection is that the surface minimum temperature is higher for a moist soil. Most of the daily change in temperature occurs in the upper 1 foot, so it is important to maintain water content in the upper 1 foot of soil near field capacity to keep the soil surface temperature as high as possible. Many

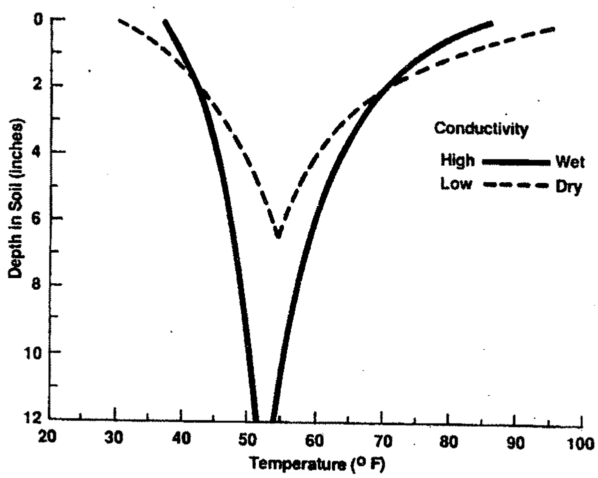

Fig. 2. Daily range of soil temperature at various depths for soils with high and low conductivity.

growers have had nearly total yield losses when frost occurred and the orchard or vineyard soil was dry. They have reduced or avoided damage when the soil was moist. It is not necessary to wet the soil below 1 foot deep in the soil for frost protection.

Cultivation is detrimental to frost protection and should not be practiced during frost season. Turning the soil reduces heat capacity and conductivity, and it removes heat from the soil because water brought to the surface evaporates and takes heat away in the process. Often cultivation before a frost night can result in severe yield loss where none would have occurred otherwise. Cultivation becomes less of a problem as leaves develop and the floor of the orchard or vineyard becomes more shaded during daylight.

Ground cover inhibits solar radiation (sunlight) from reaching the ground surface and reduces the amount of heat stored in the soil. This results in a lower minimum soil surface temperature and less radiation from the ground surface to warm the air and crop during a frost. Ground cover also slows transfer of heat from the soil to the crop at night. Ideally, there would be no ground cover to optimize passive frost protection. Because ground covers are beneficial for other purposes, it is best to keep the ground cover short, either by mowing or through use of chemicals, but not by cultivation.

Soil and ground cover management has varying effects on minimum temperatures within orchards and vineyards. The effects are most important under clear, calm conditions when there are no leaves on the trees. If there are clouds, fog, or significant wind, the beneficial effects of these other factors on temperature will often dominate over benefits or detriments resulting from soil and ground cover management.

When there are no leaves on the trees and an inversion forms, temperatures will generally be lowest near the soil surface and will increase with height from there (fig. 3). With extensive foliage on the trees, the effects of floor management are less important because the radiating surface has moved to the tops of the trees or vines and the temperature varies little with height within the orchard (fig. 4). Above the orchard temperatures will

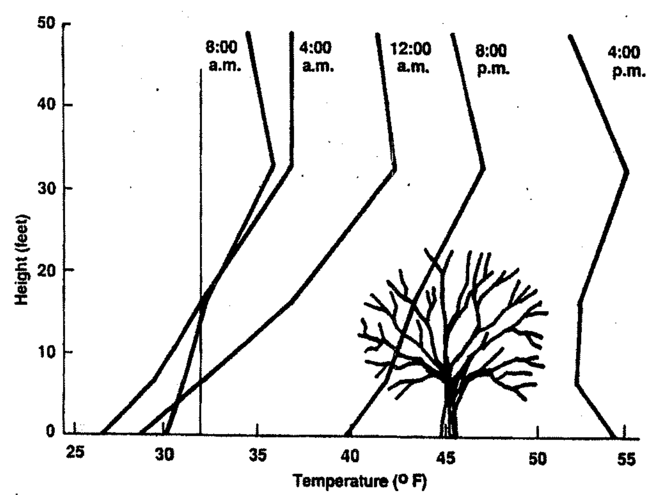

Fig. 3. An example of temperature changes up to 50 feet (15 m) height over bare ground at Davis, California on February 4-5, 1985. A similar temperature profile is common for leafless orchards with minimal or no ground cover.

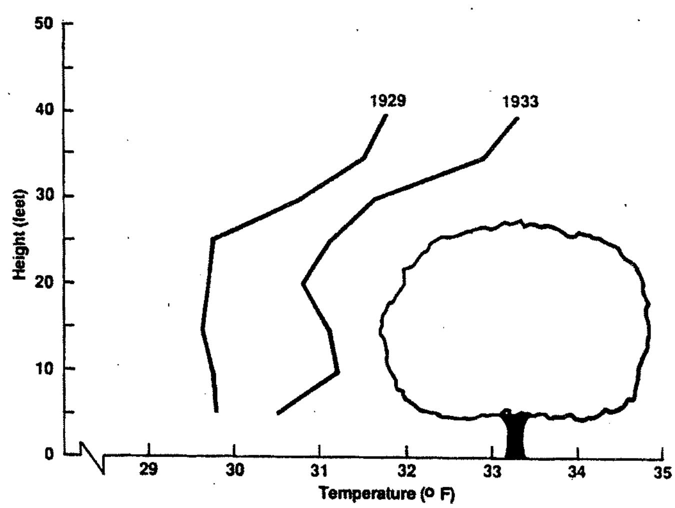

Fig. 4. Mean minimum temperatures averaged over all frost nights (1929, 1933) in a walnut orchard near West Covina, California. Referenced by H. B. Hanson (1956) after C. Cole.

increase with height. Thus, good floor management is most important at the beginning of the frost season for deciduous trees and vines; it becomes less important as the ground is shaded by crop leaves. Air temperature differences of only 0.5°F between orchards with and without ground covers at 5-foot height have been reported when orchard foliage is fully developed (H. B. Hanson 1956). Floor management is always important for frost protection of citrus and young deciduous trees and vines where wide plant spacing always leaves the ground exposed during daylight.

Ice-nucleating bacteria are present on most tree and vine crops, and some evidence indicates that the potential for frost damage is greater when the concentration of ice-nucleating bacteria is high. Ground covers are probably contributors to the spread of these bacteria. Therefore, it is prudent to minimize ground covers even after appreciable crop foliage has developed in the spring.

When applying water to a soil for passive frost protection, cover as much of the surface area exposed to sunlight as possible. Energy is transferred to or from the soil on a per-unit area basis, and hence a larger area of moist soil will conduct and store more heat. Thus, using sprinklers or flooding that wets the entire soil surface is best. Furrows should be as wide as possible to maximize the surface area to be wetted. The amount of water to apply depends on dryness of the soil relative to the maximum it can hold (field capacity). Generally, it is unusual to need greater than 1 inch to 1 1/2 inches application depth to refill a relatively dry, clay loam soil. Lighter soils require less water with an application of 1/2-inch to 1-inch depth for a dry, sandy soil. Note that if water is applied uniformly, a 1-inch depth is approximately 27,000 gallons per acre (0.62 gallons per square foot).

Another consideration is the condition of the area surrounding your orchard or vineyard. Crops that are downwind from pasture or low-growing crops are in more danger of frost damage than those downwind or downslope from other tree or vine crops where passive or active protection is practiced. Cultivation upslope can also lower the minimum temperature within an orchard or vineyard. Minimum soil surface temperatures measured over turfgrass or over a cultivated field are as much as 7°F lower than over a firm bare ground (H. B. Hanson 1956). The air temperature differences measured at shelter height (5 feet) and above are less than 7°F, but colder air will develop over a colder surface and will increase the likelihood of frost damage downslope. This situation can be avoided by practicing the same management used in the orchard or vineyard.

Site Selection

Selecting a good location to grow your crop is often the best method of passive frost protection. Because cold air is more dense than warm air, it flows downhill much like water. Thus, low spots where cold air will collect should be avoided. The tops of hills are also often cold and generally it is best to plant on a slope. One procedure that might help in locating potentially hazardous sites is to identify locations where fog develops on nights when fog is spotty. The fog will tend to develop in the cold spots first because the cold air will settle there and the low spot reaches the dew-point temperature before less hazardous areas. On frost nights when the dew-point is low, these spots will be coldest. This method does not work for coastal fogs that move in from the ocean.

One important factor to consider is that the risk of damage is greater if bloom comes early. Warm temperatures tend to bring on bloom, so planting on a north-facing slope can delay bloom and reduce the probability of frost damage. It also is beneficial to be downslope or downwind from a lake. Avoid growing crops in cold spots caused by obstacles such as raised road beds, buildings, or vegetation that inhibit natural cold air drainage.

Delaying Bloom and Leafout

Any management practices that delay bud break will reduce the chances of frost damage because the probability of damaging low temperatures decreases rapidly in the spring. Thus, late or double pruning to delay leafout or bloom is beneficial for crops grown in frost-prone areas. Also sprinkler irrigating or fogging during warm winter or spring days can delay bud break and reduce chances of frost damage. Research has shown that frost damage normally occurs when the ice first forms on leaves and then propagates into the buds, blossoms, fruit, or nuts. Consequently, delaying the development of leaves will reduce the risk of frost damage. Selecting crops or varieties that bloom later in spring can reduce the likelihood of frost damage.

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