Managing Heat Stress in Apple Orchards

Defining and Understanding Heat Stress

In apple orchards, heat stress can be problematic and cause severe damage to trees and fruit. Symptoms associated with heat stress include leaf wilting, scorched leaf edges, dead leaves or leaf drop, premature blossom or fruit drop, direct damage to fruit, and more (Figure 1). Tree branches and stems may also sunburn, and shoot growth is inhibited (Coder 2012).

Climate projections suggest more frequent extreme weather events, including the occurrence of high temperatures. This emphasizes the importance of understanding heat stress in orchards and how to reduce crop loss associated with heat stress. Across the entire northwestern United States, temperature averages have warmed about 1.3°F between 1895 and 2011, with significant warming occurring in all seasons except spring (Kunkel et al. 2013).

Heat stress occurs during exposure to high temperatures and can affect plant function and growth. Heat stress is especially problematic during fruit growth and development. Heat stress can be exacerbated when insufficient water is available (drought stress) or when the tree cannot absorb water fast enough to replace what is lost through transpiration. Under these conditions, stomata on leaves close, and the tree can no longer cool itself through transpiration. Stomata are minute pores on the epidermis of the leaf underside that assist in gas exchange with the surrounding atmosphere. Transpiration is the release of water by plants from the soil into the atmosphere and occurs through stomata. Unfortunately, heat stress symptoms can still occur under well-watered conditions. Extremely high ambient air temperatures cause stomata to close, stopping the tree from cooling down through transpiration and causing heat stress, regardless of the tree's water status.

Heat stress is most dangerous for young trees that do not have established canopies; smaller canopies mean reduced capacity for microclimate cooling. Larger trees take up more water from the soil, allowing for better temperature regulation through transpiration and greater shading provided by their established canopies.

Although heat stress will likely become more prevalent in the coming decades, management strategies are available. This publication will highlight the underlying mechanisms of heat stress and management strategies that can be used in Pacific Northwest orchards. Whether through active management strategies, like netting or evaporative cooling, or passive management strategies, like cultivar selection and orchard location, there are a number of ways to mitigate heat stress in apple orchards.

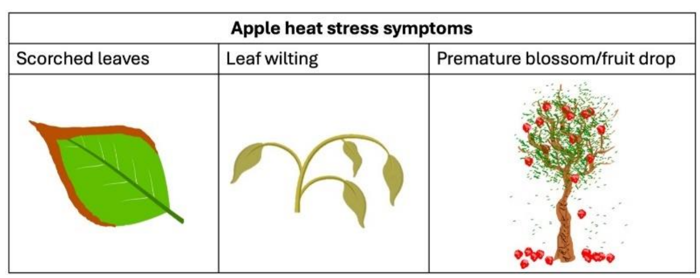

Figure 1. The symptoms of heat stress in apples include scorched leaf margins (left), leaf and shoot tip wilting (middle), and premature blossom or fruit drop (right). Images by Thiago Campbell, Washington State University.

Fruit Damage Caused by Heat Stress

When coupled with drought stress, leaves can surpass the permanent wilting point when under heat stress, resulting in leaf death and, in extreme cases, shoot dieback.

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Symptoms of heat stress are typically seen between June and August in the Pacific Northwest, when daytime temperatures are at their highest, but can persist through harvest and postharvest. Early season heat is commonly associated with premature leaf or fruit drop, and sunburn is most associated with late-season heat stress.

Heat stress can upregulate ethylene (hormone production), resulting in *premature fruit drop* as fruit abscises from the tree. However, other factors, such as fruit load, tree nutrition, summer pruning, water, and pest pressure, can also impact preharvest fruit drop (Irish-Brown et al. 2011). Additionally, some cultivars have a higher tendency to drop fruit than others.

Sunburn can result in over 10% crop loss unless the fruit is protected (DuPont and Taylor 2023). Sunburn can be classified into three categories (Barber and Sharpe 1971; Figure 2):

- *Sunburn browning* is caused by a combination of high fruit surface temperatures and UV radiation. It occurs when fruit surface temperatures reach anywhere from 113°F to 120°F at any stage of development. However, there are cases where there is no sunburn browning after high temperatures and high incidence and severity of sunburn browning at lower temperatures (Willsea et al. 2023). This may occur due to variable water availability within the tree, UV radiation or sun exposure, crop load, or climatic conditions. While not all growers may measure fruit surface temperatures, the ambient air temperature threshold for sunburn is not clearly defined and varies, mainly from the degree of sun exposure fruits are presented with. Given identical ambient air temperature, fruits with higher sun exposure will experience a greater fruit surface temperature than those within the canopy. Sunburn browning appears as yellow, brown, or dark-tan spots on the sun-exposed side of the apple (Schrader et al. 2001), which downgrades fruit on the packing line.

- *Sunburn necrosis* occurs when fruit surface temperatures exceed 126°F and results in cell death (Schrader et al. 2008). It does not require high light intensity. This condition is manifested as dark-brown or black necrotic spots and sometimes causes the fruit to crack.

- *Photooxidative sunburn* develops from sudden light exposure (Felicetti and Schrader 2008) and is not temperature dependent. It is most seen when previously shaded fruits are suddenly exposed to sunlight. It is characterized by whitening or bleaching of the fruit skin (Felicetti and Schrader 2008).

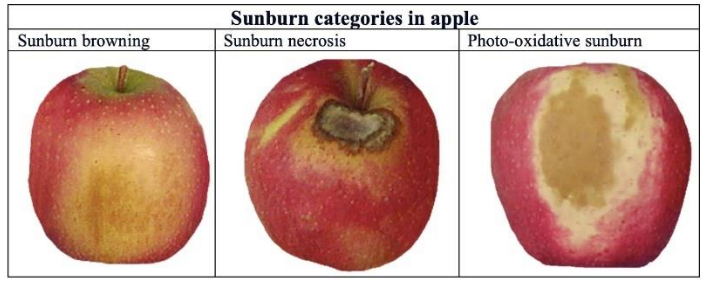

Figure 2. Sunburn in apples falls under three categories: sunburn browning (left), sunburn necrosis (middle), and photo-oxidative sunburn (right). Image credit: Larry Schrader.

Fruits that undergo heat stress in the field are prone to developing physiological disorders during storage, such as lenticel blotching and sunscald (McTavish et al. 2020). Sunscald is characterized by an external darkening of the peel, causing fruit loss (Morales-Quintana et al. 2020). Fruits harvested at higher temperatures have higher metabolic rates, causing firmness to progressively decrease while in storage (DeEll et al. 2001). By rapidly cooling or treating heat-stressed fruit at the time of harvest, metabolic rates can be slowed, and fruit firmness can be maintained.

Mitigating Heat Stress

The shift to higher-density apple orchards with dwarfing rootstocks has had substantial success in the industry by allowing for greater per-acre returns for growers and more efficient sunlight capture on a per-acre basis (Robinson et al. 1991; Tukey 1964). However, these higher-density apple orchards allow for greater interception and distribution of sunlight within the tree canopy (Wagenmakers and Callesen 1995), increasing sunburn risk. Aside from planting considerations, such as climatic conditions, orchard location or slope, and cultivar or rootstock selection, other sun and heat-mitigation strategies that orchardists can adopt are described below and in Figure 3. Table 1 provides a simplified breakdown of each mitigation strategy's relative cost, efficacy, and timing.

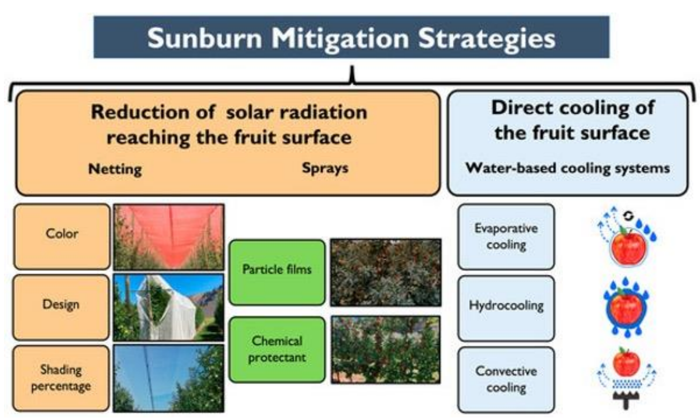

Figure 3. Sunburn mitigation strategies. *Source*: Willsea et al. (2023).

Netting

Netting has become popular as a control method for managing heat stress in apple orchards of high-value cultivars (Kalcsits et al. 2017). Netting filters incoming radiation and keeps fruit surface temperatures about 4.7°F–7.7°F cooler compared to full sun exposure (Kalcsits et al. 2017). However, when air temperatures approach 105°F, the efficacy of netting is reduced.

Netting has multiple benefits, such as hail protection, bird protection, and cooler canopy temperatures. But there are also challenges. Netting can exacerbate the lack of color development in years when fruit color development is poor (Gindaba and Wand 2008). Fruit coloring is a process that is intertwined with temperature and sun exposure. Red coloring is produced by anthocyanin pigments formed before harvest and requires cool nighttime temperatures coupled with solar radiation for optimal development (Arakawa 1990; Saure 1990; Xue et al. 2021). The timing of net deployment in the spring is often determined by the level of risk due to hail events. Once deployed, they can stay in place until harvest. As such, to mitigate a reduction in fruit color development, netting retraction approximately ten days before harvest could be beneficial (Willsea et al. 2023).

Netting can differ in weave pattern and density which alters the percentage of shade and differs in the color of the fabric used. Netting can be purchased in different shade percentages and different colors, although the commercial standard is white netting with 20% shading when draped over the top of the trees (Figure 4). White nets at 20% shading provide the optimal amount of radiation interception while also having a reduced negative impact on fruit color development in bicolor cultivars (Mupambi et al. 2019).

Figure 4. Photo of drape netting being applied in a commercial apple orchard. Image credit: Shannon Dininny and T.J. Mullinax via *Good Fruit Grower*.

Protectant Sprays

Protectant sprays are used for sunburn mitigation in apples, although their efficacy is limited. These sprays reduce radiation stress and sunburn damage by reflecting ultraviolet radiation. Protectant sprays do not consistently reduce fruit surface temperatures, potentially resulting in sunburn. Kaolin clay is commonly used and works by reflecting incoming solar radiation (Glenn and Puterka 2010). Raynox consists of carnauba wax and emulsifiers. These products should be applied before fruit surface temperatures reach thresholds for sunburn development (113°F and above). Since Raynox application is not recommended when air temperatures are above 85°F, it should be applied when temperatures are expected to be near the threshold listed above. These products are low-cost alternatives and can be easily applied, although they may not be as effective when air temperatures exceed the sunburn development threshold and solar radiation is not the main contributor to heat stress.

Cooling: Evaporative Cooling, Hydrocooling, and Convective Cooling (Fogging)

There are three main methods of cooling available with irrigation (Wünsche et al. 2004): *evaporative cooling*, *hydrocooling*, and *convective cooling* (fogging) (Figure 5). The three cooling methods operate differently, although all depend on a certain temperature threshold for activation. While this is not clearly defined, 85°F–90°F is typically used as a threshold.

Evaporative cooling through overhead irrigation involves applying water to the leaves and fruits of trees (Evans et al. 1995). Evaporative cooling operates on a cycle that is often activated at a temperature threshold, typically when temperatures reach above 85°F to 90°F, although this also varies based on irrigation systems and water availability. Orchard location or climate may also influence the temperature threshold for activating cooling methods. Evaporative cooling reduces the temperature within an orchard, although there is a risk of heat stress or sunburn if the water evaporates too quickly and fruit temperature increases. Evaporative cooling often operates in addition to the irrigation system for the orchard. For example, overhead irrigation is cycled in pulses at 30 gallons per minute per acre during heat stress events, usually on for 20 minutes and off for 40 minutes when temperatures reach above 85°F to 90°F (Bolivar-Medina and Kalcsits 2022). Timing, frequency, and volume of overhead irrigation cycling will vary in orchards based on conditions, time of day, wind, fruit temperature, tree canopy size, and other factors; this is only one example of evaporative cooling timing and frequency.

Hydrocooling is the same as evaporative cooling, except it continuously operates during the hottest parts of the day. An average constant water supply of 40 gallons per minute per acre is required during operation, although this depends on tree canopy size. This system is more effective than evaporative cooling in reducing orchard temperatures and can replace irrigation systems. However, excessive water can exacerbate bitter pit and should be applied with caution (Fahalli and Mahdavi 2020; Reid and Kalcsits 2020).

Convective cooling, or fogging, involves applying water as a fine mist that evaporates before reaching leaves and fruit (Bolivar-Medina and Kalcsits 2022). This cooling method is applied continuously, like hydrocooling. Foggers may be placed above tree canopies or within the canopy. Convective cooling uses less water (less than 30 gallons per minute per acre, and sometimes as low as 5 gallons per minute per acre) (Evans et al. 1995; Bolivar-Medina and Kalcsits 2022). Emitter flow varies from company to company. This system requires a parallel irrigation system, and emitters can get clogged if filtration is not sufficient or water quality is poor.

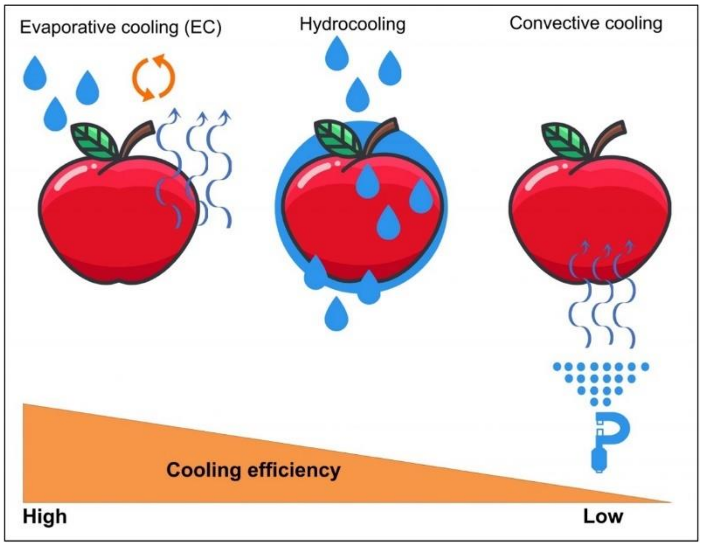

Figure 5. Cooling efficiency comparison of evaporative cooling (left), hydrocooling (middle), and convective cooling (right). *Source*: Extension blog post Cooling Mechanisms for a Tree Fruit Orchard (Jenny Bolivar-Medina and Lee Kalcsits).

Table 1. Comparison of the cost, efficacy, and timing of common heat stress mitigation methods in apple orchards.

Control Method	**Relative Cost**	**Efficacy**	**Timing**
Netting	• Highest cost • High labor demand	• Reduces incoming solar radiation • Reduces air temperature within netting, although efficacy is reduced above 105°F	• Deployed following pollination • Can be retracted/removed prior to harvest to promote color development
Protectant sprays	• Lowest cost	• Reflects incoming radiation • Do not protect against high air temperatures	• Applied prior to heat event
Evaporative cooling	• Medium cost • Installation and labor costs required at planting • Maintenance required	• Cools fruit surface • Effective against high temperatures • Does not protect against UV radiation • Risk of heat stress/sunburn when failures occur	• Activated at the threshold operation temperature (depends on orchard; 85–90°F, 95°F, etc.) (Evans et al. 1995; Bolivar-Medina and Kalcsits 2022) • 10–20 minutes on followed by 15–45 minutes off cycles
Hydrocooling	• Medium cost • Installation and labor required at planting • Maintenance needed • Requires large volumes of water	• Cools fruit surface and orchard air temperatures • Effective against high temperatures • Does not protect against UV radiation	• Activated at the threshold operation temperature (depends on orchard; 85–90°F, 95°F, etc.) (Evans et al. 1995; Bolivar-Medina and Kalcsits 2022) • Runs continuously once turned on
Convective cooling	• Medium cost • Installation and labor required at the beginning of the season • Maintenance needed	• Cools air temperatures in the orchard • Effective against high temperatures • Does not protect against UV radiation • Might use less water than other cooling systems	• Activated at the threshold operation temperature (depends on orchard; 85–90°F, 95°F, etc.) (Evans et al. 1995; Bolivar-Medina and Kalcsits 2022) • Runs continuously once turned on

Are All Heat Stress Management Strategies Created Equal?

While each heat stress management method has its benefits and drawbacks, it is not practical to use all these methods together in an orchard. The following considerations should be made to adopt the approach(es) that best fit your operation:

1. Capital—Do you have enough to establish and manage the deployment and retraction of a netting system? Do you have funding to install and maintain a single, double, or triple system if using water?
2. Water supply—How much acreage can you cover at any given time? What is the quality of the water being sourced? For convective cooling, this is especially important. Do you have enough water for the entire season? For crop protection to be effective, it has to be continued until harvest. If you do not have enough water to protect your crop until harvest, significant crop damage can occur.
3. Variety mix—Do you need to protect all varieties, only high-value ones, or those with high susceptibility to heat stress?

While not all methods can be used in a single orchard, success can be achieved by using a combination of the above-mentioned mitigation methods. For example, there have been successes with combinations of netting and evaporative cooling (Willsea et al. 2023). Since netting reduces incoming radiation and cooling reduces air temperatures within canopies, combining both may provide complete protection. This may not be economically viable in many cases, but it is worth considering when establishing a management method for heat stress for high-value cultivars. Convective cooling might be the only viable option if a farm has limited access to water and capital for heat stress mitigation. In an orchard with capital and water availability beyond irrigation needs, evaporative cooling and netting could be combined to handle prolonged periods of heat stress.

The cultivar grown in an orchard might also limit the applicability of different management strategies. Bicolor, early cultivars like Honeycrisp pose issues with red color development, while late cultivars like Cripps Pink have more time to develop red color, especially after the danger of high temperatures has passed. If you are planting Honeycrisp trees, any of the overhead cooling technologies could help reduce temperatures and improve fruit coloring early season. Netting could also be used, but the overhead cooling systems could benefit red color development in a poor coloring year. Early season coloring might not be as important if you are planting Cripps Pink trees. Cultivars that are easier to color, like Red Delicious and Fuji, are more forgiving of netting for heat stress management, but there is still a chance of impacting red fruit color development.

Handling Heat Stress with the Future in Mind

Farms and orchards are inevitably influenced by climate extremes. In the Pacific Northwest, the climate has changed over the last 100 years and is poised to continue the change for the next 100 years. Future projections point toward extreme weather events becoming more common and average in-season temperatures increasing (Mote et al. 2013; Kunkel et al. 2013; Pruett et al. 2021). Considerations on infrastructure adaptations for heat stress management need to be made early in the orchard establishment process. Whether you are planting a new orchard or acquiring an existing one, managing or avoiding heat stress in Pacific Northwest orchards will be crucial to producing quality fruit in the face of annual weather variation.

Acknowledgments

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