

# OVERTREE EVAPORATIVE COOLING

## SYSTEM DESIGN AND OPERATION FOR APPLES IN THE PNW<sup>1</sup>

by

*Robert G. Evans*  
*Supervisory Agricultural Engineer*  
*USDA-ARS-Northern Plains Agricultural Research Laboratory*  
*Sidney, MT 59270*

Many growers in affected areas are utilizing overcrop sprinkling systems for evaporative cooling (EC) as a feasible, chemical-free technique to reduce sun burn of exposed fruit and/or to enhance color development on "red" or "red-striped" fruit. Much of this interest is due to the emergence of new varieties, new training systems that open canopies to greater light intensities, and the loss of some growth regulators (i.e., daminozide [Alar]) to delay fruit maturity. However, significant problems have been observed in apples with long-term orchard health, increases in foliar diseases, general orchard management including irrigation scheduling and spray programs, and mineral depositions on fruit. In general, there are significant problems in the design and operation of current systems, primarily due to the large amounts of water required.

Overtree EC applies water above the crop. As this water evaporates, it directly cools the leaves, fruit and the orchard air depending on local climatic conditions and the rate water is applied. Avoiding excessive leaf and fruit temperatures during the hottest part of the day can greatly reduce the incidence of sun burn on directly exposed fruit. Orchardists have also found use of EC just prior to sundown and sometimes around sunrise has improved color development on red apples (especially early varieties) before harvest. If done properly, EC may generally increase harvested fruit size due to reduced water stress levels and improved management of soil water status throughout the season.

Almost every type of commercially available sprinkler and microsprinkler is being utilized in the PNW for EC with applications ranging from 8 gpm/ac ( $1.25 \text{ L s}^{-1} \text{ ha}^{-1}$ ) to over 80 gpm/ac ( $12.5 \text{ L s}^{-1} \text{ ha}^{-1}$ ) with varying degrees of effectiveness. Problems occur as a result of one or a combination of the following: a) existing irrigation systems are used which were not designed to meet hydraulic and operational requirements of EC; b) there is an inadequate supply of water for both irrigation and cooling, EC water application rates are too low and soils may become too dry; c) the water applications cannot be cycled to maximize evaporative efficiency and avoid excessive water use; and d) poor water quality causing deposits on fruit and/or leaf burn from salt accumulations.

In some areas and years, orchardists may use EC for 35-75 days and even more per season. Consequently, EC potentially impacts several major areas of total orchard management including pest and disease control, fruit maturity, fruit storage characteristics, fruit color development, seasonal irrigation water requirements and irrigation scheduling. In addition, expensive investments in treatment facilities in the orchards and packing sheds due to poor water quality (primarily calcium carbonates) are often necessary to remove surface deposits on fruit. Scientifically-based irrigation scheduling programs with actual measurements of soil and/or plant parameters are desirable. All

---

<sup>1</sup> Articles printed in *The Good Fruit Grower*, Yakima, WA. 1993. Vol 44(11):23-27 and Vol 44(12):29-32 were extracted from earlier versions of this draft manuscript. This paper is intended as a discussion of the state-of-the-art of OT evaporative cooling. There is much that we do not yet know about sun burn and its control, mostly dealing with horticultural and fruit physiological aspects. This article represents the author's thoughts and knowledge on OT EC of *apples* as of July 1999.

of these factors increase system installation and operating costs which must be recovered through better prices from improved fruit grade.

Limited past research on EC of apples has been associated only with improving red color development ranging from about  $3.9 \text{ L s}^{-1} \text{ ha}^{-1}$  (25 gpm/ac, continuous applications) to around  $10.9 \text{ L s}^{-1} \text{ ha}^{-1}$  (70 gpm/ac) pulsed on 15 minute cycles (Unrath, 1972a, 1972b; Unrath and Sneed, 1974; Griffin, 1974). The studies were successful at improving red color development on 'Red Delicious' apples.

Sun scald (discoloration or burning of fruit surface exposed to direct sun, often referred to as "sunburn") can discolor the skin and negatively affect the appearance of several important crops including fresh apples, pears, grapes and other fruits as well as many vegetables such as peppers and tomatoes. It is a serious economic problem in many apple growing areas in the Pacific Northwest and around the world. The surface blemished fruit cannot be sold for fresh market consumption which receives the highest prices.

Almost all apples can burn regardless of color. Some red varieties may color over burned areas so the damage may not be visually evident, but these apples often have storage problems due to the internal damage. The mechanisms and the causes of sun burn are not well understood and much work remains to be done by plant physiologists on this subject. Data on the threshold conditions where burn begins to occur are not available for any variety, however, it is well known that there are big differences between varieties in their susceptibility to sun burn. Some of the more sun scald susceptible varieties are 'Jonagold', 'Braeburn', 'Golden Supreme', 'Ginger Gold' and 'Fuji'. Satisfactory criteria for evaluating these conditions and the long-term horticultural impacts of EC techniques are not known

Available information on the design, management and operation of overtree EC systems for sun burn reduction is mostly anecdotal grower experiences. Innovative orchardists are learning by trial-and-error about EC under the low humidity and hot summer temperatures typical of many PNW fruit growing districts. Consequently, a research project was initiated by WSU and the Washington State Tree Fruit Research Commission in 1991 to develop knowledge on design and operation of EC systems for apples where the primary emphasis is on reducing the temperature of exposed fruit tissue (skin) to reduce sun burn.

### **Damage Mechanisms for Sun Burn**

A narrow range of ultraviolet (UV) light contributes to red color development in apples (Arakawa, 1988). However, experiments with UV-inhibiting plastic films have indicated that radiant heating in conjunction with certain bands of ultraviolet light are the major causes of sun scald damage (Andrews, 1993). The contributions of heat and UV light are probably interdependent. Evaporative cooling is unquestionably affecting the sun burn process by reducing radiant and advective heating of exposed fruit. Certain anti-oxidants (e.g., ascorbate) applied to the fruit surface have also been somewhat effective in reducing sun burn by UV radiation (Patterson and Moore, 1983)

Some data indicate that sun burn is a progressive phenomenon and accumulates over time. Some varieties may become more susceptible as they begin to approach maturity. Darker (eg. red) fruit also tend to absorb heat faster than green fruit which may be tied to the perceived increase in varietal sensitivity to sun burn as season progresses. There is also some evidence that exposed fruit may be "conditioned" early in the season to withstand some burn damage later in the season.

### **Cooling Mechanisms**

There are basically three ways water reduces crop temperatures. In order of increasing effectiveness, they are:

- 1.) evaporate water in air (undertree or overtree) and use the circulation (convection) of the cooled air to reduce fruit temperatures (convective cooling);

- 2.) apply water to the leaves and fruit, using the "cool" water to extract the sensible heat from the plant organs and carry it away via liquid "runoff" (hydro-cooling);
- 3.) apply water to the leaves and fruit and directly extract heat by sensible to latent heat transfer (evaporative cooling).

All water-based orchard cooling techniques will use one or more of the mechanisms. The relative contribution of each will depend on climatic conditions, water application rates, application uniformity and system operation. It can be shown that the most effective of these cooling modes will be evaporation of water from the fruit surface followed by removal of the water vapor by mass air movement (Merva, et al. 1979; Barfield et al., 1974; Barfield et al, 1990; Chesness, et al., 1979; Hamer, 1986).

Evaporation of water requires large amounts of heat (910 BTU/lb of water at 86°F [2.43 MJ/kg of water @ 30°C]). The heat for evaporation comes directly from solar radiation and/or any other heat source that is in contact with the evaporating water including air and vegetation..

For sun burn protection, it is desirable to reduce fruit temperature during the warmest parts of the day. To cool fruit, we must first counteract the all sources of incoming heat energy "loads" that cause the exposed fruits' temperatures to rise. *Evaporative cooling relies on the fact that the evaporation of water takes heat and it will take the energy it needs from the air and fruit.* If the amount of heat extracted is greater than the total incoming heat energy, the temperature of the fruit will decrease. Conversely, if the amount of heat extracted is less than the incoming energy, fruit temperature must increase. Research has shown that the most effective fruit temperature reductions occur when the water directly evaporates from the surface of the fruit.

This heat "load" on fruit that is exposed to the sun has two principal components: 1) direct radiative heating from the sun; and, 2) advective heating from hot air originating from outside the block moving through the orchard. Taking a simple physical chemistry approach, we can make some calculations to give us the relative magnitude of the amount of water required for effective overtree evaporative cooling of exposed fruit. Assuming that we want to cool apples under conditions where the incoming solar radiation has an intensity of  $800 \text{ W m}^{-2}$  and that we have an air temperature of 95°F (reasonable numbers for the middle of a summer day). To equal (neutralize) the energy from the incoming solar radiation would require the complete evaporation of about 21 US gal/min/ac above the tree canopy (assuming: 8.36 lb<sub>m</sub>/US gallon of water, 1040 Btu/lb<sub>m</sub> is the latent heat of vaporization, 8695 Btu to evaporate 1 US gallon of water, and  $1 \text{ W/m}^2 = 0.3170 \text{ Btu/hr/ft}^2$ ). However, there is also an advective (wind) component that is typically at least equal to the solar radiative heating during periods of high air temperatures, low humidities and low wind speeds. This means that *at least 40 gpm/ac* would have to be continuously applied over the tree during this period to just equal the incoming both radiative and advective heat energy and maintain the exposed fruit surface at ambient temperatures (in this case 95°F) under these assumed conditions. Cooling the exposed fruit below ambient temperature would require the application of additional water. These calculations are supported by field data measuring actual exposed fruit temperatures on hot summer days in south central Washington of cooled and uncooled fruit. Higher wind speeds and/or higher air temperatures would increase the amount of water required for effective evaporative cooling.

Overtree sprinkle/microsprinkle systems that apply water in very fine droplets (fogging or misting) and/or at low application rates (<30 gpm/ac) tend to evaporate most if not all the applied water before it reaches the fruit. The tree/fruit temperatures are essentially reduced by convection of cooled air. These systems are generally not cycled, but are on continuously for several hours. Cooling is usually initiated and turned-off based on arbitrary threshold air or fruit temperatures. These systems usually require a duplicate water application system for irrigation due to the low application rates, poor uniformities and lack of adequate water reaching the soil surface. Soil water management is a major concern. There is a much greater risk of problems with deposition of minerals on fruit and leaves than with higher application rate systems. Low pH water should always be used with these systems.

Undertree sprinkle systems cool the air below the plant canopy and must also rely on convection to cool the fruit. Use of this process for heat transfer is inefficient. Undertree sprinkling for cooling often results in excessive amounts of water applied to the orchard floor due to typically long on-times and daily use over extended periods. Cycling of these systems is possible but may not be feasible due to low cooling benefits.

Systems that primarily rely on hydro-cooling generally apply substantially greater than 40 gpm/ac on a continuous basis over the total area being cooled once the "critical" air or fruit temperatures (as determined by the grower) are reached. Some evaporation occurs, but much of the heat transfer is by constant runoff of free water from the plant. This technique is quite effective in reducing fruit temperature but it is also extremely inefficient in its use of water and often results in seriously waterlogged soils. These conditions can seriously affect the long-term health of the orchard, blister spot, bitterpit and scab may increase, trees may have less physical stability, soil-borne diseases may increase, runoff from the field may occur, and nutrients / chemicals may be leached from the soil profile into the groundwater. Fruit may be softer at harvest. Consequently, heavy reliance on this practice is not recommended for orchard cooling even on very sandy soils without drainage problems.

Direct evaporative cooling has its primary emphasis on operating the system to maximize "evaporative efficiency" while minimizing the total application of water. These systems apply water at average rates at least equal to 30 gpm/ac. The management of these systems requires pulsing the water on and off so that free water is continually evaporating. Much of the following discussion is directed towards this type of EC for the PNW.

#### EC for Color.

Some orchardists are utilizing EC primarily for earlier color development on early red and red-striped apples. There is probably limited benefit using EC for improved color on late apples (eg. harvested towards the end of September and later) in most years in the PNW.

Threshold temperatures and color responses vary widely between different varieties of apple. Color pigment development (ie., idaein) generally occurs in the temperature range from 41°F to about 86°F (optimum approaches 70°F) and the amount of coloring will be in direct proportion to the amount of time that fruit is in this range. Consequently, midday EC will have minor coloring benefits.

To try for improved early color, these growers are applying water over the fruit and canopy starting 4 to 6 weeks before expected harvest date. Depending on application rate and uniformity, it is believed that optimum benefits will occur by starting EC about 30 minutes before and continuing about 20 to 40 minutes after sundown or until fruit and ambient air temperatures are similar. Some of these growers are also applying water again at sunup for about a 1 hour period to extend the lower fruit temperature periods. However, there are no data from controlled experiments to support the benefits of early morning sprinkling.

Because of the need to cool fruit rapidly at dusk for color enhancement, basically all overtree water application systems will have some benefit regardless of the application rate. Even very low volume systems will be able to rapidly cool orchard temperatures once the incoming radiative loads (eg. daily peak of 600-800 Watts/m<sup>2</sup>) from the sun are absent (solar radiation is only a part of energy balance). This type of operation will probably have little effect on either delaying or enhancing fruit maturity levels.

No firm recommendations can be made on the timing or the temperature thresholds for most effective EC for color. However, EC for color should probably be discontinued in the morning when average fruit flesh temperatures rise above the 70°F range due to considerations of water conservation and general orchard health.

### EC for Sun Burn Reduction.

Sun burn will be reduced by EC during the hottest parts of the day. EC will often be required from mid-morning until sundown (at which time some color benefits may accrue). The purpose is to maintain the temperature of the cells just under the skin of exposed fruit below heat burn damage levels by evaporating applied water. However, it should be noted that some burn may occur on hot days even under high application rates. Fruit maturity may be delayed with daytime EC. It should be pointed out that in south central Washington that at least 0.5 LPs/ha (20 gpm/ac) is required to meet radiation loads and at least another 0.5 LPs/ha (20 gpm/ac) is required to meet advective energy inputs in order to control fruit temperatures when the water is applied directly to the fruit.

The requirements of EC for reducing sun burn are the most restrictive in terms of water application rates, system design and orchard management. The systems must be able to meet requirements dictated by the extreme PNW climatic conditions. Application rates should at least equal peak evaporative demands of about 40-45 gpm/ac for minimal sun burn damage (total area actually covered; eg., tree canopy and cover crop) on a continuous basis. If EC is cycled based on time (eg. 20 minutes on, 20-40 minutes off), applications should be in the range of 60-70 gpm/ac. At lower rates fruit temperatures can continue to increase during periods with high solar radiation loads. "Targeted" EC which wets only the canopy could potentially apply less on a total area basis. Cycles should not have less than 15 minute on-times.

Overtree irrigation of susceptible varieties (eg., Jonagold, Fuji, etc) during daytime hours are not recommended until you want to start EC for the rest of the season. Since daytime irrigations also cool, it apparently predisposes fruit for burning, much like late season branch shifts that expose new fruit that quickly burn. Once you start cooling--you have to continue for the rest of the season. EC for sun burn is usually not required before mid-July on most varieties.

Cooling at night for sun burn reduction with either overtree or undertree systems is not effective. Fruit temperatures are usually below damaging levels and there is no solar radiation load to counteract. Night applications of water should be limited to irrigations and/or at dawn and dusk for some possible color development.

### EC for Larger Fruit Size.

Growers using EC must do an exceptional job of managing the soil water (irrigation scheduling) to maintain optimal growing conditions. Most increases in fruit size under EC will be primarily due to improved water management and, to a lesser degree, to reduced heat stresses. Fruit sizes will frequently vary across any block. However, improved water management under high frequency water applications may reduce many effects of soil type, depth and nutrient status variability on sizing.

Theoretically, fruit size may be increased by utilizing EC to reduce plant water stress due to high temperatures and maintain plant organs closer to their optimum photosynthesis range (60°F to about 80°F). Photosynthesis will begin to decrease above and below this range. However, the actual number of hours that photosynthesis would be greatly reduced are relatively small and water management is likely the most dominant factor.

Fruit sizes may be reduced if growers are not adequately monitoring soil water status. EC (vs hydro-cooling) cannot provide crop irrigation requirements and soils can become quite dry at increasing soil depths causing excessive moisture stress in the tree. Waterlogged conditions under "hydro-cooled" systems may also reduce fruit size. It is remotely possible that fruit size could also be reduced due to: a.) disease/pest pressures due to potentially reduced efficacy of spray programs; and, b.) poor water quality reducing photosynthetic efficiency due to mineral precipitates and/or specific ion toxicities.

### Other Considerations.

EC for sun burn reduction has been shown to delay maturity. This tends to result in firmer fruit with lower sugars which may be a benefit for controlled atmosphere (CA) storage. It may also be used to lengthen harvest intervals by manipulating fruit maturity. Another potential side benefit is that fruit in wetted bins, which were watered in the field prior to harvest, tend to have less desiccation in storage.

### Specific Concerns (not inclusive).

Growers must prevent primary apple scab infections prior to initiation of any EC for the season. The same is true for Fireblight where infections must be prevented and/or removed from the orchard before use of EC. Control of codling moth in the first generation may be critical because of the risk of washing off pesticides by EC during the second codling moth generation.

## **SYSTEM SELECTION AND DESIGN CRITERIA**

Systems for EC should be engineered from the very beginning of orchard planning. It is often expensive and very difficult to retrofit existing irrigation systems for EC. Many growers are installing two systems: 1.) overtree sprinkle for cooling; and 2.) undertree sprinkle for irrigation and frost protection. The average application rates for EC are usually much too low for overtree frost protection. This dual system approach is preferable, but is more expensive. There is no perfect EC-irrigation system.

### **General Considerations**

The most dominant considerations will be the overall economics (cost, available capital, anticipated returns, etc.), water supply (quantity, quality and seasonal availability) and personal preference. Other general factors will include: available labor (cost/quantity/quality); soils (depths, types, variations, saline/sodic); field size, shape and topography; and climatic factors. Cultural considerations will include: variety and spacing; trellising/training systems; specific spray programs; pruning programs/practices; fertilizer requirements; tillage practices; cover crop / soil erosion problems; soil compaction; harvesting; existing pressure from fire blight and apple scab. Crop factors that should be specifically considered with respect to EC are fruit quality, mineral deposition and disease control.

Design factors will include: desired uniformity of application; potential average application rates; level of automation (control systems); chemigation and fertigation; larger pipe sizes and pressure controls; pump selections (efficiency, power costs, etc.); soil or crop limitations; and reuse of any runoff water.

### Water Quantity

Reliable and adequate long-term water supplies are critical for EC programs. There will generally be a 25% to 40% or more increase in seasonal water requirements through a properly designed and operated EC system. EC for sun burn reduction is not a water conservation measure.

By intent, EC is specifically designed to have very high water losses to evaporation. There may be a slight reduction in actual total crop water use compared to a non-cooled block, but the use of EC will definitely require more total water over the season. Published estimates of seasonal irrigation requirements for non-cooled mature apple trees in Central Washington with a cover crop (EB 1513) are about 39 to 48 inches. EC may add another 12 to 18 inches of water to this total depending on operational criteria. At the same air temperatures, evaporation rates will be higher under windy conditions than in more protected areas which will further increase total water deliveries.

Most growers do not have adequate water supplies for both cooling and irrigation under typical canal delivery systems. Consequently, many are buying "extra" water, drilling wells and/or building large ponds for holding supplemental water and/or unused allocations. Storage ponds can also be used to supply water for overtree or undertree sprinkling for frost protection in the spring. Ponds should be lined to reduce the potential for contamination of ground water.

#### Water Quality

Water quality is one of the most significant problems facing successful EC. High evaporation rates with overtree EC can leave excessive surface deposits of calcium carbonates, silicates and other salts on the fruit depending on the chemical composition of the applied water. Mineral deposition tends to be *more significant at lower application rates* (<30 gpm/ac) because less is washed from the fruit during EC. Even with acid treatment, growers may still need to operate low application rate systems 1-2 nights each week to try to wash off deposits for 4-6 hours using with low pH water.

The problem of mineral deposition must be considered from two perspectives: 1) the amount and types of salts present; and 2) the potential for mineral precipitation and the solubility of the compounds. If the amount of total salts in the water is too high (ie., conductivity > 2 dS/m<sup>2</sup>) it is not economical to treat the water (ie., reverse osmosis) and the water should not be used for overtree applications. However, the only exception is that if the vast majority of the salt is sodium bicarbonate (high pH water) it is sometimes possible to treat the water by reducing pH and use it for overtree cooling. *Water for overtree applications should be treated anytime bicarbonates and carbonates are present.* Water from deep wells in central Washington should always be acidified whether for irrigation or cooling.

Water sources in arid areas commonly have pH values of 7.0 or greater. When ground and surface waters have a pH of 7.5 or higher, the potential for calcium carbonate precipitation is high. The treatment and use of chemicals requires an in-depth understanding of water and soil chemistry and an idea of what is desired. The first step in determining treatment needs is to have a chemical analyses made of the water supply (pH, electrical conductivity, Ca<sup>++</sup>, Mg<sup>++</sup>, Na<sup>+</sup>, CO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>). These analyses can be used to determine, among other needed information, the "lime deposition potential" (LDP). The LDP is estimated as the least concentration of either (CO<sub>3</sub><sup>-</sup> milli-equivalents per liter [meq/L] + HCO<sub>3</sub><sup>-</sup> meq/L) or Ca<sup>++</sup> meq/L. Halverson and Dow (1975) suggested that a LDP below 2.0 was not a problem for over crop irrigation (but it is for EC). However, LDPs above 2 ( $\approx$ 100 ppm CaCO<sub>3</sub>) should be cause for concern and probable treatment. An LDP above 4 ( $\approx$ 200 ppm CaCO<sub>3</sub>) should be used for over crop irrigation with caution and only with pH reducing treatments. However, experience has shown that LDPs as low as 1.0 have caused serious mineral deposition problems with evaporative cooling applications.

If combined levels of calcium and magnesium are higher than 50 ppm, calcium phosphates could precipitate and magnesium could form with ammonium to create a magnesium-ammonium phosphate precipitate. The key to prevent such phenomenon is lowering the pH level of the water.

Calcium carbonate (lime) precipitates can be readily controlled by maintaining the pH of the applied water at about 6.5-6.6 (a swimming pool pH tester can be used to monitor) by the careful injection of an acidifying agent (eg., technical grade sulfuric acid or N-pHuric) or a sulfur burner. The use of "spent acids" from smelting or other industrial applications is not recommended. Acidification only addresses the carbonate/bicarbonate problem, it may do very little for problems due to other salts and precipitates.

---

**The general recommendation for central Washington and other arid areas in the western US is that all water that contains Calcium carbonates applied for evaporative cooling should have a pH between 6.0 and 6.6 every time water is applied. This must be accompanied by adequate application rates to ensure proper washing of the fruit and foliage to remove deposits on a frequent basis.**

---

Yet, one has to watch the soil buffering capacity and crop sensitivity to toxicity of various elements if pH is lowered too far. Sulfuric acid is commonly used and is the least expensive, but this is a dangerous compound to handle. Another compound that some use is N-pHuric® which is a mixture of urea and sulfuric acid that is easy to handle, but may apply nitrogen in excess of plant needs over the season. Likewise, the amount of acidity required to lower pH of water to acceptable levels from phosphoric acid alone usually exceeds the crop's requirement for P.

However, with any acidifying agent, it is necessary to develop a water buffering curve to predict how much acid to inject. This can also be established by trial-and-error through direct measurement of the pH of the water and slightly incrementing acid injection rates upward (*wait 30-45 minutes then measure*) until a pH of about 6.6 or less is reached. Use a simple, inexpensive portable pH meter to monitor pH of the applied water throughout the season since the chemical characteristics of the water can vary over the year, and adjust injection rates accordingly.

Acids are congruent or incongruent depending upon whether or not they disassociate completely in water or form other compounds. Sulfuric acid ( $H_2SO_4$ ) is a congruent acid that disassociates in water ( $H_2O$ ), Phosphoric is incongruent meaning it does not donate all its protons to water at the same time, therefore it has to be injected on a quantitative basis not qualitative, such as pH.

Certain chelating agents are often used to reduce calcium deposits on fruit because of safety concerns over strong acids, but they are considerably more expensive and less effective than acids. Polymers such as polyphosphates, organo-phosphates, polymalaic acids and others are also being investigated for carbonate solubility effectiveness. They are less expensive than sulfur burners, do not persist in the environment, approved by the EPA, and are safer to handle than an acid. Dosages as low as 1 - 2 ppm may increase carbonate solubility. Chelates or polymers do not affect water pH, do not reduce the amount of deposits and require frequent washing to remove deposits and avoid possible "salt burning" of leaves. Some believe that the high electrical charge of the polymer molecule keeps potential precipitates in solution and if a compound such as carbonate crystallizes in a polymer environment, the crystal shape does not have sharp corners to give rise to stacking and combining. Rather, the crystals have rounded corners and do stack together at all and wash off easily. These materials are not needed when acidifying agents are used to lower water pH to acceptable levels.

Finally, chlorination may be required for iron and sulfide problems or to eliminate microbial problems. This requires a measured value of least 1.0 ppm of free residual chlorine at the ends of the lines. The free residual is the amount of chlorine that is left after the injected chlorine has reacted with all the sulfides, iron, algae or bacteria. Sufficient quantities must be injected into the system to meet the required reactions to still leave 1.0 ppm residual chlorine. Constant, automated, chlorination is often recommended. Chlorination is most effective when water pH is less than 6.5.

Injection equipment (pumps, tubing, etc) must be able to withstand the specific chemicals being injected (eg., PVC pipe cannot be used with concentrated sulfuric acid). The injection pump supplier should have the necessary information for you to purchase and install the correct materials. Positive displacement chemical injection pumps are recommended.

All chemicals and/or chemical mixtures should also be checked to avoid phytotoxic effects as well as for compatibility to prevent precipitations and maximize efficacy. Except for acids, chemicals should usually be injected upstream of any filters or screens. Injection locations should always provide for adequate mixing. With the exception of chlorine treatments for microirrigation, the hydraulic systems must be flushed of the chemicals before turning off the water.

Special chemigation safety devices are required for all chemical injection systems under federal/state laws and regulations. There can be no reverse flows, system drainage or back siphoning.



### Irrigation Scheduling

EC is not a one-for-one substitute for irrigation. EC reduces the actual water use of the tree on the order of only 15%-20% depending on climatic conditions. Irrigations must be in addition to EC, usually at night. Improved water management including some form of scientific irrigation scheduling is absolutely required.

Under all forms of high-frequency irrigation, the real questions concerning irrigation management are not only when to irrigate but also how much to apply and how to accurately evaluate the water status of the tree. Extensive and frequent soil water measurements should be made across the block with appropriate soil water monitoring equipment. These readings should be used to schedule directly and/or to make adjustments to available reference evapotranspiration (crop water use) estimates from WSU Public Agricultural Weather System (PAWS) and other sources.

An irrigation scheduling program becomes absolutely essential when a grower is attempting to minimize seasonal water use while maximizing EC. This goal requires cycling applications based on plant measurements. Implementation of a "cycled" EC or continuous applications below about 30 gpm/ac should always include a scientifically-based irrigation scheduling program.

Continuous applications above 30-40 gpm/ac may have excessive soil water for extended periods (hydro-cooling) and proper water management can be very difficult if not impossible when EC water applications exceed plant water use requirements.

Substantial and detrimental soil water deficits may develop under EC systems, but may not be readily evident because of the luxurious appearance of cover crops, particularly at higher application rates under pulsed systems. Estimating actual irrigation needs by traditional methods under these conditions can be difficult. Past irrigation scheduling practices such as calendar scheduling or fixed rotations (eg. every 10 days) will usually not be appropriate under EC due to variable effects on plant water use.

Daily records on flow rates, pressures and total water applications across the system should be kept for maintenance as well as evaluation of system operation for future improvement. Information on proper irrigation scheduling techniques and use of PAWS data can be obtained from the county offices of WSU Cooperative Extension.

### Application Rates

There is a compromise between relative levels of sun burn protection and water application rates. Average application rates below about 40 gpm/ac may not minimize sun burn on extremely hot days. Consequently, at lower rates, the decision must be made to either accept increased burn damage over the entire block on extreme days or to cool smaller blocks of more valuable fruit at higher application rates. If the decision is to use EC on a smaller area, the piping and pumping system must be designed to handle the increased local flows at required pressures.

Recent research at WSU-Prosser shows that higher application rates ( $\geq 40$  gpm/ac) work better than lower rates in reducing fruit temperatures. Rapid wetting of the fruit and then letting the water evaporate directly from the surface is effective in reducing fruit temperatures and for water conservation.

---

***Recommendation: Greater than 40 gpm/ac for automatic cycling based on fruit temperature, water quantity not limiting on a continuous basis for the entire block. Application rates should be 60-70 gpm/ac if cycling based on time clocks with at least one 20 minute cycle per hour. All EC should be started and stopped based on fruit temperatures and low pH water used every time. Frequent night time applications with low pH water may be required to wash off inorganic deposits (e.g., 2-4X/wk).***

---

Droplet sizes should be large enough to penetrate the canopy and wet all crop surfaces. Some type of control system is required to pulse or "cycle" the water applications based either on time sequences (eg. 15 minutes on, 30 off as water cycles between three blocks) or on fruit temperatures (core or skin).

Systems in windy areas need to be designed for higher application rates and shorter intervals between pulses. Droplet sizes need to be larger and sprinkler spacing must be closer to provide the necessary application uniformity and penetration of the canopy.

Cycling based on temperature measurements from exposed fruit will require higher flow rates and/or water storage capacities in the event that all blocks turn on at the same time because of timing and/or when evaporation rates exceed the average application rate (system operates continuously) across the orchard. As a general rule for sun burn reduction, it is better to divide a block into two 40 gpm/ac (or 3 at 60 gpm) cooling sets (cycled) than to have one 20 gpm block that would be on continuously. Hydro-cooling should always be minimized.

### MECHANICS OF COOLING

Resolution of the above considerations will determine the hydraulic design. This will be dictated by the proposed use of the system which requires the greatest amounts of water at any one time (usually EC for sun burn reduction in windy areas and/or frost protection). There is little question that proper design of a EC system will be more expensive than a straight irrigation system because of increased pipe sizes, pressure control measures, larger pumps, expanded valving needs, control/automation costs, and possible storage ponds. The entire system should be designed by a competent hydraulic engineer familiar with irrigation systems.

It may be necessary that mainlines, submains, pumps and motors be sized so that entire blocks can be sprinkled at one time, depending on the control criteria. Sizing of sprinkler laterals is usually not different for cooling or irrigation unless different heads are used for each use. Looped hydraulic systems where water feeds into laterals from both ends may have large hydraulic benefits, but can be costly.

Separate undertree sprinkle or trickle systems are often installed for irrigation, or, if the same system is to be used for both cooling and irrigation, a smaller pump is often installed for irrigation purposes and the block watered in smaller sets at night. Low application rate EC systems may have to be operated at night in order to maintain the cover crop. Daytime EC application rates greater than 30 gpm/ac would probably be sufficient for cover crops during most of the season. Drip/trickle systems could be utilized for irrigation with some potential water supply savings, but would have no frost protection benefits.

Pulsed (cycled) systems at higher flow rates ( $\geq 30$  gpm/ac) are preferred for their cooling efficiency in reducing sun burn. However, pulsed systems at any flow rate generally present numerous design challenges, particularly with respect to pipe sizing and pressure controls. These systems will operate for short periods (eg. 10 to 45 minutes) several times each day. Water will drain from the highest elevations in the block through the lowest sprinkler heads every time the system is turned off causing severe waterlogging of soils in low areas. In addition, the shorter the pulse time, the more rapidly the piping system must fill in order to have a uniform application of water over the block. Thus, two major design objectives with these systems are: a) to avoid excessive drainage from the sprinkler heads at lower elevations; and, b) to rapidly fill a system (block) with water.

Most of these concerns can be generally solved by following the design considerations below:

- 1.) Break the blocks under each solenoid valve into several smaller, equal elevation subblocks with individual, spring-loaded check valves to prevent drainage from higher elevations. This also provides for more rapid filling since the entire system does not have to be recharged for each pulse.

- 2.) After the initial fill, the entire system for a block should be designed to fill in 5% or less of the total pulse on-time (eg. a 15 min pulse should fill in less than 40 seconds), usually by the use of mechanical check valves and/or other water elevation controls.
- 3.) The application of water to the canopy must be much more uniform than required for irrigation so that no area receives less than the designated amount and to maximize the evaporative surface. A sprinkler water application uniformity coefficient (UCC) of not less than 80% is often specified and a design UCC of 90% is recommended for windy areas. Generally, this requires that sprinkler radius of throw equal sprinkler spacing along the lateral and not less than about 70% of the spacing between laterals.
- 4.) Solenoid valves should have manual over-rides and should be of the highest quality as they must dependably open and close several thousand times over their useful life. Solenoid and other control valves should be slow closing to avoid water hammer problems.
- 5.) Each solenoid and each subblock under a solenoid valve should have manual isolation valving so that the entire system does not have to shut down to fix local problems in small blocks.
- 6.) Pressure control valving may be required for fully automated systems. They will also be necessary if the same system is used for both irrigation and cooling because piping is oversized for irrigation and elevation effects are often significant. Zone pressure control valves such as pressure regulation valves (downstream pressure is controlled depending on flow) or pressure sustaining valves (upstream pressure is constant regardless of flow; some valves may do both) should be considered under these conditions.
- 7.) Numerous pressure taps should be placed throughout the entire pipe system for maintenance and trouble shooting particularly on low volume and/or low pressure microsprinkle and misting systems.
- 8.) Flow variations from individual sprinkler heads should not vary more than 10% due to pressure. Constant flow nozzles may reduce flow variations, but may have substantial variations in droplet sizes affecting their susceptibility to wind.
- 9.) Continuous bleed air relief, vacuum relief (to prevent syphoning), and pressure relief valves should be installed in appropriate locations (eg. ends of mains and submains, high points, etc). Gate valves should be installed to isolate them for maintenance.
- 10.) Totalizing and rate-of-flow measurement should be installed for the entire system to make sure the entire system is operating correctly and to assist in irrigation scheduling efforts. It is advantageous to have a flow meter on each block being cooled.
- 11.) Foggers, misters and many microsprinklers require good filtration and additional water treatment (eg. chlorine) to reduce the incidence of plugging.
- 12.) Flush valves and drains should be installed for winter maintenance. Provisions should also be made to drain lines above each check valve, solenoid valves (and bonnets), and any low points.
- 13.) Chemical injection for pH control (eg. acid, sulfur burners, etc.) is generally required for groundwater supplies and is often needed with canal (river) water. All chemicals should be injected before the filters for microsprinkle systems. Backflow prevention devices are required under Washington state laws and regulations for all chemical injection systems.

Selection of a particular sprinkler/microsprinkler head should be dictated by the design requirements for uniformity, spacing, application rates and costs. Equipment selection is often a matter of personal preference, but a competent designer should be able to accommodate any operational quirks of a particular device.

### Controls

Evaporative cooling will necessitate good control. Automation is usually required to pulse or "cycle" the water applications based either on time sequences or on fruit temperatures. New advances in irrigation equipment and microprocessor controls make it possible to specifically manage each area of an orchard.

Microprocessor controls can potentially reduce labor, monitor climatic conditions and initiate some action such as frost protection or cycled cooling. When properly designed and used, automation will lead to more efficient cooling, improved soil water management and reduced leaching of nutrients and chemicals to groundwater.

Some EC systems are cycled based on air temperatures, fruit temperatures and/or time while others are operated on a continuous basis (usually based on air temperatures) during the hot parts of the day. Available information shows that starting EC based on air temperatures is a very poor procedure. Research has shown that fruit can warm much more quickly (eg., 15°F to 20°F warmer) and cool off more slowly than ambient air temperatures. It is recommended that initiation and cycling of all EC should be based on fruit core, skin temperatures, or other alternative measurements (eg. "simulated" fruit) that reflect actual fruit conditions.

Sensors to measure fruit core or skin temperatures can be used to either manually control a system or by automated controls. These devices are usually inexpensive thermocouples (TC) or infrared sensors. Thermocouples are easy to make and a simple meter to manually read the TCs can be purchased for \$80-150. Thermocouples may be used about 2 weeks in a fruit and then switched to another fruit. The TCs should be sanitized between fruit by soaking them in household bleach (clorox) for about 2 minutes to kill potential "rot" pathogens.

The simplest control systems will utilize clocks to initiate preset sequences of timed cycles. They can be started either manually or automatically, but should be based on fruit temperature rather than air. This type of control is often used where water supplies are limited. It is recommended that minimum on times should be about 10-15 minutes and each block should have water applied at least once an hour.

Fixed time control sequences are, in effect, designed from some maximum evaporative condition. Above this rate the grower is willing to accept some sun burn damage (average application rate is too low), and below which there may be excess water applied.

Computer automated systems are required for fruit temperature based control of EC. Each block should be able to operate independently and apply water whenever the fruit temperatures rise above target levels.

Temperature probes can be inserted into exposed fruit or into "plaster-of-Paris" (fake) fruit that have almost the same thermal characteristics as real fruit. The exposed fruit (or fake fruit) may be on the tree or picked (replaced weekly) and placed in a fully exposed position above the canopy for control. Control sensors above the canopy will tend to have slightly higher temperatures than those within the canopy. The microprocessor monitors the temperatures and initiates a cycle for a given block when a pre-specified target is reached. The computer would turn the cycle off when the turn-off target is achieved. As evaporative demand increases and fruit temperatures rise, computer controls based on fruit temperatures will result in a decrease between the time interval between cycles until, depending on the average application rate, the system may be on continuously in an attempt to maintain targeted fruit temperatures.

Typical core temperatures for control are: 91°-92°F turn on, turn-off at about 90°F or just as the core temperatures start to decrease. Research indicates that continuous applications around 40-45 gpm/ac are sufficient to hold core temperatures in this range during extremely hot, clear sky, sunny radiative conditions.

Currently, the most significant problem with computerized control systems is that even though the controls, feedback and communications technology are commercially available, they are not currently "user-friendly". There is a real need for simple control systems that start and stop EC cycles by monitoring current fruit conditions allowing control set-points to be easily changed.

### SUMMARY

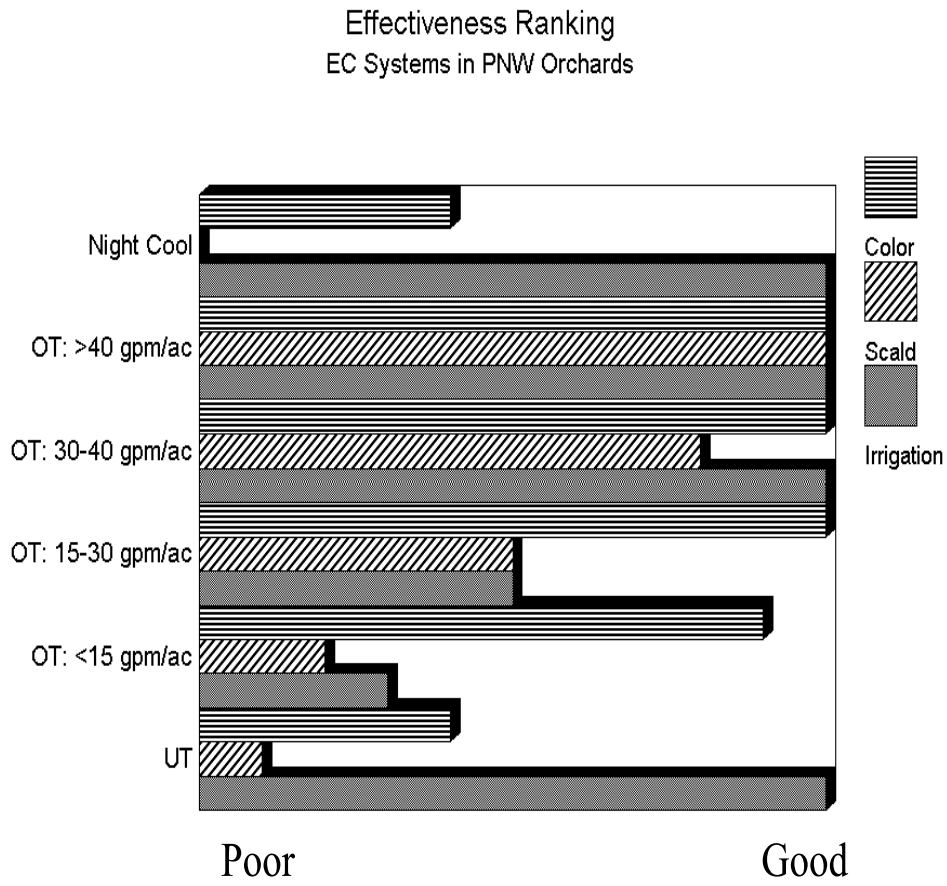
The configuration that presents the least design and operational problems is to have two systems: one for irrigation, one for cooling. The design and operation of an overtree EC system should be aimed at maximizing the direct evaporation of the applied water to the fruit and leaves. These conditions are met by pulsing water applications based on plant measurements. Some form of computerized automation is usually required. Figure 1 presents an estimation of the relative effectiveness of the various water application systems used for EC in the PNW. Application rates should generally be in excess of 30 gpm/ac for reducing sun burn. Color development may be enhanced with all overtree water applications at dusk and perhaps dawn, but minimal color benefits will be achieved by daytime EC.

Evaporation of water takes very large amounts of heat, and, for EC in orchards, this heat can come from the absorption of incoming radiation from the sun, from the air and directly from the fruit and leaves. Therefore, cycling or intermittent water applications to maximize evaporation directly from the fruit and leaves is greatly preferred in reducing sun burn. The EC process can be optimized in areas with low humidities and high daytime temperatures common to many fruit growing regions in the PNW by the use of fruit temperature-based control of pulse initiation and duration. Hydro cooling should be minimized, not only because it is less efficient but also because orchard soils may become saturated over extended periods leading to disease, excessive deep percolation and other problems.

Management of EC systems by pulsing water applications on and off so free water is continually evaporating reduces hydro-cooling and conserves water. Rapid wetting followed by water evaporation directly from the fruit surface was effective in controlling fruit temperatures at the higher application rates. Droplet sizes should be large enough to penetrate the canopy and wet all crop surfaces for effective evaporative cooling. Whenever lime precipitates (calcium carbonates) are in the water, acidifying agents should be injected every time that the overtree EC systems is used.

Scientific irrigation scheduling is required to manage EC and irrigations. Higher levels of control that irrigate each zone according to individual, specific requirements are generally more water use efficient with less runoff and deep percolation.

EC is not a water conservation measure and will require extra water. Total seasonal water application amounts will be from 25% to 40% greater than historical irrigation requirements since the cooling is a very "inefficient" use of water and, by design, much is lost to the atmosphere. Microirrigation (drip, trickle) methods may be a viable alternative for irrigation since the cover crop could be maintained with most EC systems. Size increases compared to previous years and/or adjacent un-cooled blocks for EC fruit is often indicative of a past history of inadequate water management practices.



**REF  
ERE  
NCE  
S**

Figure 1. Relative ranking of various irrigation methods for evaporative cooling and for irrigation

Andrews, P.K., 1993. Personal

Communication. Hort. and L.A. Department, Washington State University, Pullman, WA.

Arakawa, O., 1988. Photoregulation of Anthocyanin Synthesis in Apple Fruit under UV-B and Red Light. *Plant Cell Physiol.* 29(8):1385-1389.

- Barfield, B.J., K.B. Perry, J.D. Martsolf, and C. T. Morrow, 1990. Modifying the Aerial Environment. IN: Management of Farm Irrigation Systems. Edited by: G.J. Hoffman, T.A. Howell and K.H. Solomon. ASAE Monograph. St. Joseph, MI 49085-6959
- Barfield, B.J., J.N. Walker, and F.A. Payne, 1974. Development of prediction relationships for water requirements with irrigation cooling. Research Report No.70, University of Kentucky, Water Resources Research Institute. 41 pp.
- Businger, J. A., 1965. Protection from the cold. Meteorol. Monogr., Chapter 4. Vol 6(28):74-80.
- Chesness, J.L. and H.J. Braud, 1970. Sprinkling to reduce heat stressing of strawberry plants. Agricultural Engineering. 51(3):140-141. March.
- Chesness, J.L., L.A. Harper, T. A. Howell, 1979. Sprinkling for Heat Stress Reduction. IN: Modification of the Aerial Environment of Plants. Edited by: B.J. Barfield and J. F. Gerber. ASAE Monograph No. 2. St. Joseph, MI 49085-6959. pp 388-393.
- Gilbert, D.E., J.L. Meyer, and J.J. Kissler, 1971. Evaporative Cooling of Vineyards. Trans. ASAE 14(5): 841-843, 859.
- Griffin, R.E., 1974. Evaporative Cooling with Sprinklers for Enhancing Anthocyanin in 'Red Delicious' Apples. ASAE Tech. Paper 74-5033. ASAE. St. Joseph, MI 49085. 6 pp.
- Halverson, A.R. and A. I. Dow, 1975. Interpretation of chemical analysis of irrigation water. Wash. State Univ Col. of Agric. Cooperative Extension Mimeo 3522. Pullman, WA 99164. 5 pp.
- Hamer, P.J.C., 1986. The Heat Balance of Apple Buds and Blossoms. Ag. and For. Meteor. 37(1):175-188.
- James, L. G., J. M. Erbenbeck, D. L. Bassett, and J. E. Middleton, 1988. Irrigation Requirements for Washington-- Estimates and Methodology. Wash. State Univ. College of Agric. and Home Ec., Cooperative Extension Bulletin EB 1513. Pullman, WA 99164. 37 pp.
- Merva, G. E. and C. van den Brink, 1979. Physical Principles Involved in Alleviating Heat Stress. IN: Modification of the Aerial Environment of Plants. Edited by: B.J. Barfield and J. F. Gerber. ASAE Monograph No. 2. St. Joseph, MI 49085-6959. pp. 373-387.
- Middleton, J.E. and E.L. Proebsting, 1971. Overtree Sprinkling Effect on Cooling and Fruit Quality in Early Italian Prunes. Trans. ASAE 14(4):638-641.
- Parchomchuk, Peter, 1991. Orchard Cooling for Sunburn Prevention. Paper presented to 22nd Annual BCFGA Horticultural Forum, Penticton, B.C. Canada. November 6. 14 pp.
- Patterson, M.E. and G.N. Moore, 1983. Control of Sunburn on McIntosh Apples with Ascorbic Acid. Undergraduate Thesis Project Summary. Hort. and L.A. Department, Washington State University, Pullman, WA. 2 pp.
- Thorpe, M.R., 1974. Radiant Heating of Apples. J. of Applied Ecology. August. 11(2):755-760.
- Unrath, C.R., 1972a. Evaporative Cooling Effects of Over-tree Sprinkler Irrigation in 'Red Delicious' Apples. J. Amer. Soc. Hort. Sci. 97(1):55-58.

Unrath, C.R., 1972b. The Quality of 'Red Delicious' Apples as Affected by Overtree Sprinkler Irrigation. *J. Amer. Soc. Hort. Sci.* 97(1):58-61.

Unrath, C.R., and R. E. Sneed, 1974. Evaporative Cooling of 'Delicious' Apples -- The Economic Feasibility of Reducing Environmental Heat Stress. *J. Amer. Soc. Hort. Sci.* 99(4):372-375.