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Orchard Cooling with Pulsed Overtree Irrigation to Prevent Solar Injury and Improve Fruit Quality of 'Jonagold' Apples

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Abstract. **Pulsed application of overtree irrigation for evaporative cooling of 'Jonagold' apples (*Malus domestica* Borkh.) reduced visible solar injury by 15.8% (1991) and 9.4% (1992). Maximum fruit surface temperature was reduced by 8.1 °C on a day when the average surface mean of nonsprayed fruit rose to 45.6 °C. Air heated more slowly than the exposed fruit surface and was cooled only 1 to 2 °C by overtree irrigation. Cooling did not affect fruit size, firmness, or redness but reduced soluble solids concentration and increased titratable acidity. Storage breakdown was unaffected in the first year but was reduced by 6.0% in the second year.**

Apple growers in the southern interior of British Columbia recently began producing cultivars, such as 'Gala', 'Jonagold', and 'Fuji', in high-density orchard plantings. However, these cultivars are prone to solar injury (SI) under the hot and semiarid climatic conditions of this region. The injury appears to be more prevalent in high-density plantings because of a greater degree of fruit exposure than in conventional (lower density) planting systems.

Solar injury results from tissue damage caused by radiant heating of the fruit surface when directly exposed to sunlight (Atkinson, 1971). On a bright, sunny day surface temperature (t_s) of an apple may exceed 50 °C even though the air is 10 to 15 °C cooler (Unrath, 1975). The critical t_s at which SI is initiated or the cumulative temperature effects are unknown, but Bergh et al. (1980) observed SI on several apple cultivars when t_s exceeded 50 °C for only a single day. Susceptibility of apples to SI varies with cultivar and rootstock (Bergh et al., 1980) and the extent of exposure to direct sunlight (Atkinson, 1971).

The use of overtree irrigation systems to provide evaporative cooling for improving fruit quality or preventing SI has been studied by several researchers. Unrath (1972, 1975), using overtree sprinklers to apply water at 2.5 mm·h^{-1} when air temperature (t_a) exceeded 28 °C or t_s exceeded 35 °C, reported improvements in red pigmentation, soluble solids concentration (SSC), and size of 'Delicious' apples. Williams (1993) noted an improvement in grade pack-out for 'Delicious' subjected to evaporative cooling. Recasens et al. (1988) reported larger fruit and higher SSC for 'Jonee' and 'Golden Smoothee' apples when water was applied at 3 mm·h^{-1} whenever t_a exceeded 32 °C.

Kotze et al. (1988) reported a 50% reduction in the incidence of SI on spray-cooled 'Granny Smith' and 'Golden Delicious' apples. They applied water at 6 mm·h^{-1} through a system of microjet sprinklers whenever t_a exceeded 28 °C. The cycle of a 2-min on pulse was followed by either 6 or 9 min off until t_a decreased below the set value. Provided that the cycle time is short enough to maintain a wetted fruit surface during the off period, pulsed application of spray cooling is preferred to continuous operation since the water delivery rate can by minimized by using the same water source to cycle through several orchard zones in sequence.

In this study, we investigated the effect of pulsed application of water on t_s and incidence of SI in 'Jonagold' apples. The effects of cooling on red pigment development, SSC, fruit size, acidity, and storage disorders also were evaluated.

Materials and Methods

This study was conducted during 1991 and 1992 in a 1-ha planting of 5-year-old 'Jonagold' trees on M.26 rootstock. The trees were planted in double-row beds with 1.5 m between rows and 3.6-m alleyways between beds. Trees were spaced 1.5 m within rows. The site was divided into 8 blocks, each 30 m long × 3 double-row beds wide. The planting was irrigated by drip emitters along each tree row.

Microsprinklers with a 40-L·h^{-1} discharge rate were installed 0.30 m above the tree canopy at 3.6-m intervals along the center of each double-row bed to give a precipitation rate of ≈2 mm·h^{-1}. One-half of each block was evaporatively cooled and the adjacent half was used as a control.

Other studies have relied on t_a or t_s to activate their spray cooling systems. However, air heats more slowly than an apple (Parchomchuk et al., 1991) and apples are prone to decay when thermocouples are inserted to measure skin temperature. To overcome these problems, an artificial sensor was used to simulate the thermal response of an apple surface. The sensor was constructed by positioning a copper-constantan thermocouple against the inner wall of an opaque 250-mL polyethylene cup (5.5 cm diameter × 10 cm height × 1 mm wall thickness). The cup was filled with a green gel prepared by dissolving 15 g of agar granules in 1.0 L of near-boiling water and adding 5 mL of green food coloring. Temperatures measured by thermocouples on the inner surface of the plastic cup were similar to those measured beneath the skin of apples (data not shown).

Sensors were positioned in a fully exposed location above the tree canopy within 1.0 m of a sprinkler and activated a pulsed cooling cycle of 2 min on and 4 min off when their temperature rose above 30 °C (1991) or 32 °C (1992). The intermittent cycling continued until the temperature decreased below 28 °C. The system was operated from 5 July in 1991 and from 14 July in 1992 until the fruit were harvested.

Surface temperatures of one cooled and one noncooled fruit in each of three blocks were measured to within ±0.5 °C by 0.6-mm-diameter copper-constantan thermocouples inserted just beneath the skin of the most exposed surface. Air temperature was measured by shaded thermocouples placed within the tree canopy 1.0 m above ground. Temperatures were recorded with a datalogger at 15-min intervals between 0900 and 1900 HR daily and at 15-s intervals during spray cooling cycles.

Fruit were harvested on 8 Oct. 1991 and 22 Sept. 1992. Samples of 200 to 300 apples for evaluation of SI and fruit quality consisted of all the fruit harvested from two or three randomly selected trees located near the middle portion of each plot. The severity of SI on apples from each of the 16 plots (eight blocks × two treatments) was visually rated as: none = no evidence of surface discoloration; slight = surface discoloration noticeable upon close examination; moderate = surface discoloration readily noticeable; or severe = solid brown or black areas.

Subsamples of 15 fruit from each plot were assessed for average fruit weight, proportion of red skin color, flesh firmness, SSC, and titratable acidity (TA). Additional samples of ≈65 fruit were placed in 0 °C air storage for 120 days. Upon removal from cold storage, 15 fruit were assessed for flesh firmness, while the remaining 50 fruit were ripened for 7 days at 20 °C and evaluated for disorders.

Red skin pigmentation was estimated visually. Flesh firmness was determined with a Magness–Taylor penetrometer (11.1-mm tip) using two readings from opposite sides of the fruit from which the skin had been pared. SSC and TA in the composited juice sample were measured by refractometry and titration (endpoint pH 8.1), respectively. Statistical analysis was performed using SAS's GLM procedure (SAS Inst., Cary, N.C.) as a randomized block design.

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Results and Discussion

Fruit surface temperature. Maximum t_s recorded for the 'Jonagold' apples was 48.2 °C in 1991 and 45.9 °C in 1992, but daily maximums changed with weather conditions. Significant ($P < 0.05$) differences in maximum t_s of cooled and noncooled apples occurred in both years, especially when t_s of noncooled fruit exceeded 35 °C (Fig. 1). Surface temperature of cooled fruit rose above the setpoint (30 °C in 1991, 32 °C in 1992), but at a slower rate than for noncooled fruit. Average maximum daily t_s of cooled and noncooled fruit differed by as much as 6.3 °C in 1991 and 8.1 °C in 1992. The reduction in t_s obtained by pulsed application of cooling water approached the 9 °C reduction recorded by Evans et al. (1993) for continuous cooling at the same precipitation rate used in our study. However, our pulsing procedure discharged only one-third as much water as continuous application.

In most cases, t_s of the artificial fruit sensors used to initiate and terminate overtree irrigation were maintained at or below the setpoint (data not shown). The continued temperature rise above the setpoint of apples suggests lower precipitation rates on the apples than on the sensors. The monitored apples, located at 1.0-m height within the tree canopy, but fully exposed to afternoon sunlight, were less favorably exposed to the cooling water than the sensors, which were located above the tree canopy and, in most cases, closer to a sprinkler. The preferentially cooled sensors may have triggered termination of the cooling water cycles before the actual fruit had been cooled to the setpoint. In retrospect, it would have been more desirable to place the control sensors within the tree canopy where they would receive the same exposure to cooling water and sunlight as the real fruit.

Air temperature. Maximum t_s exceeded maximum t_a by as much as 10 °C. Despite close correlation between maximum daily t_a and t_s in noncooled plots ($r^2 = 0.89$) over the season, temperature patterns throughout the day were not so closely related. The fruit surface heated more rapidly than air and started to cool 2 to 3 h before the maximum t_a had been reached so that t_a and t_s differed by as much as 15 °C in the early afternoon (Fig. 2). In 1991, average t_a varied from 20 to 29 °C at the time that average fruit t_s had reached 30 °C. The poor correlation between t_a and t_s confirms that t_a is not a reliable indicator for activating an irrigation cooling system. Furthermore, the limited decrease in t_a in the cooled plots (Fig. 1) indicates that cooling systems controlled by air temperature would continue to apply water after the desired cooling of the fruit had been achieved.

Solar injury. Evidence of SI was present on >35% of the noncooled fruit in 1991 and 1992, but mostly in the slight category (Table 1). Cooling did not reduce the incidence of slight SI, but it did reduce the amount of moderate SI. Severe SI was low in both years but was reduced by cooling in 1991. Despite substantial cooling of the fruit surface from overtree application of water, the net effect on SI was a 5% to 8% reduction in moderately to severely injured fruit. In view of this modest reduction, the economic benefit of installing an overtree cooling system solely to prevent the disorder is questionable. Nevertheless, it might prove feasible for apple cultivars with a high return.

The poor effectiveness of 2-min-on, 4-min-off pulses in reducing SI of 'Jonagold' apples in this study may be attributable to interception and diversion of the applied water by tree foliage, which resulted in variable amounts of water impinging on fruit surfaces at various locations within the tree canopy. Longer run times or higher application rates than those used in this study may be required for the cooling water to penetrate through the

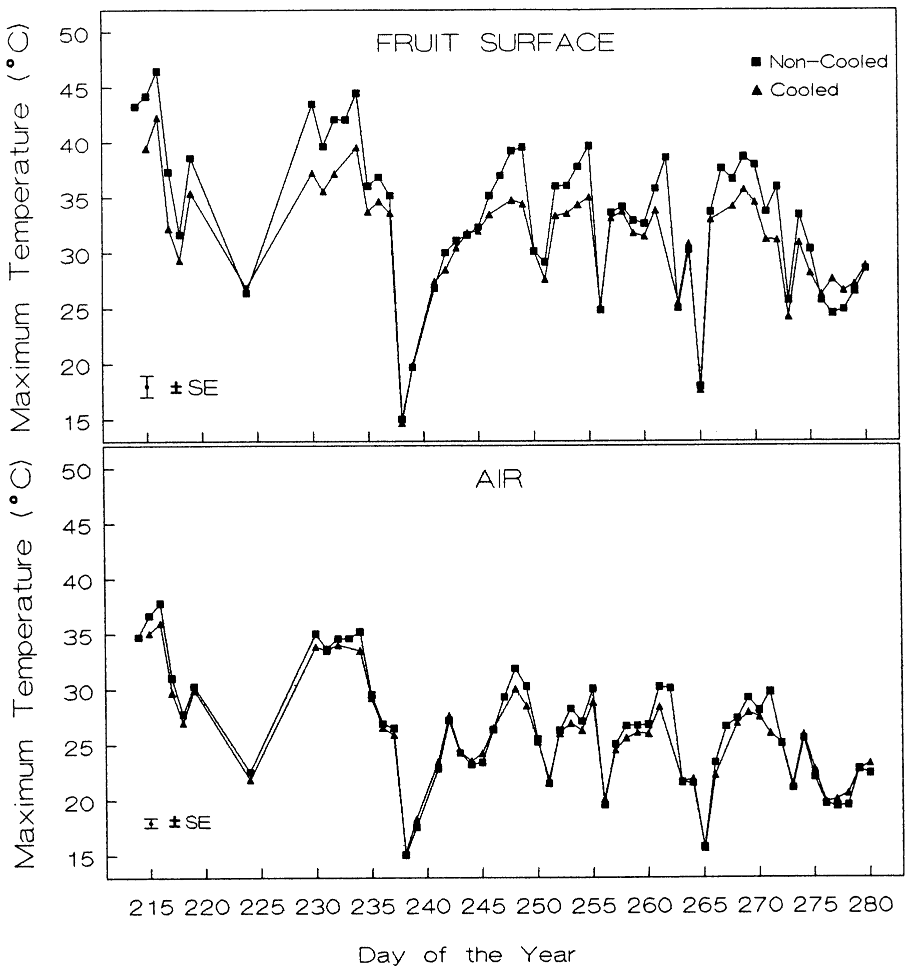

Fig. 1. Daily maximum temperature of fruit surfaces and air in cooled and noncooled plots during 1991 (e.g., Day 215 = 3 Aug., Day 280 = 5 Oct.).

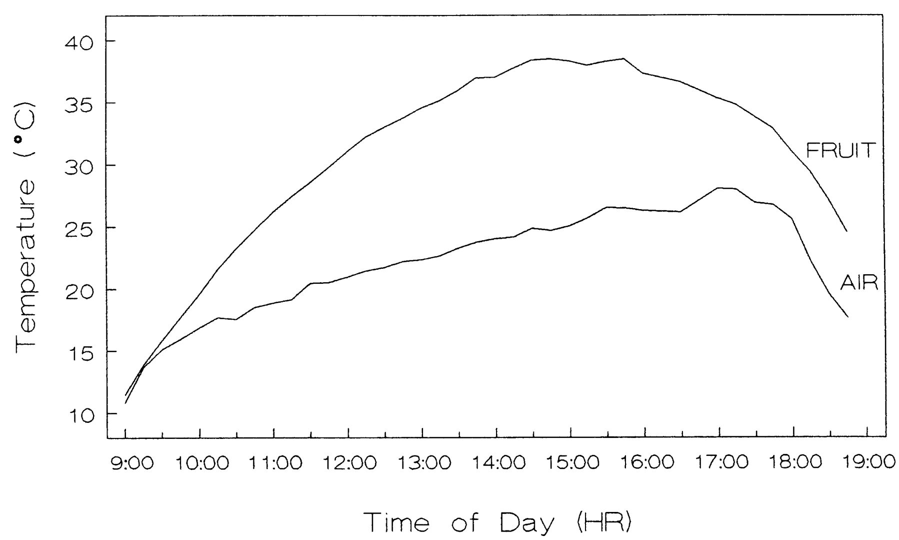

Fig. 2. Fruit surface and air temperature in a noncooled plot on a warm sunny day (26 Sept. 1991).

tree canopy and provide more complete and uniform wetting of fruit surfaces.

Fruit quality. Contrary to reports of improved redness, fruit size, and SSC in studies with other cultivars, pulsed cooling of 'Jonagold' apples in our study had no effect on average fruit weight, red pigment development, or firmness in either year (data not shown) but reduced SSC in 1992 (Table 2). Cooling resulted in higher TA in 1991 and less storage breakdown in 1992. Although Unrath (1975) reported improved redness of 'Delicious' apples when cooling was started in early June, the lack of effect on 'Jonagold' in our study could be related to the later starting date of cooling, differences in the way that cultivars respond to cooling, or to differences in climatic conditions. For instance, cool nights conducive to red pigment development are common in the apple-growing regions of British Columbia where this study was conducted. Thus, the potential for evaporative cooling to enhance redness or other fruit quality characteristics was low in this region compared to other regions where less favorable climatic conditions exist.

Table 1. Effect of cooling by overtree irrigation on the incidence and severity of solar injury in 'Jonagold' apple.

	Incidence of solar injury (%)							
	Slight		Moderate		Severe		Total	
Cooling	1991	1992	1991	1992	1991	1992	1991	1992
No	26.1	26.7	12.4	7.5	0.6	2.2	39.1	36.4
Yes	18.8	21.8	4.4	3.4	0.1	1.6	23.3	26.8
Significance	NS	NS	**	**	*	NS	*	*

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 2. Effect of overtree evaporative cooling on fruit quality and breakdown of 'Jonagold' apple.[z]

	Soluble solids concn (%)		Titratable acidity (% malic acid)		Breakdown incidence (%)	
Cooling	1991	1992	1991	1992	1991	1992
No	15.5	16.2	0.55	0.49	21.3	8.9
Yes	15.4	15.3	0.60	0.49	27.0	2.9
Significance	NS	**	*	NS	NS	*

[z]Values at harvest, except for breakdown, which was evaluated after 120 days at 0 °C + 7 days at 20 °C.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

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