Knauss (1988). A relatively small number of samples contain Na, Cl, B, or F concentrations at potentially toxic levels, but high concentrations of these ions occured in every state.

Using these data, greenhouse operators can characterize a given water source and how it compares to other water sources being used by the greenhouse industry. These data also may be helpful in determining research priorities in the area of water quality for greenhouse crop production. As the greenhouse industry changes to low- and nonleaching irrigation systems, understanding differences in IWS is one key in developing more refined state and regional fertilizer recommendations for greenhouse crop production.

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Effects of Cooling by Over-tree Sprinkler Irrigation on Fruit Color and Firmness in 'Sensation Red Bartlett' Pear

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ADDITIONAL INDEX WORDS. *Pyrus communis*, red pears

SUMMARY. Over-tree sprinkler irrigation cooling treatments were applied to 'Sensation Red Bartlett' pear trees during the final 30 days of fruit maturity in 1992 and 1993 when orchard air temperatures were >29 °C. Fruit from cooled trees were more red and less yellow than fruit from noncooled trees, resulting in lower hue values by the middle of the harvestable maturity period in both years of study. In 1992, cooled fruit had a greater portion of the fruit surface covered with red blush than fruit that were not cooled. Fruit firmness decreased more rapidly in fruit from cooled trees than in fruit from noncooled trees, indicating advanced maturity. Accordingly, cooled fruit should be harvested earlier than noncooled fruit to maintain postharvest quality. Differences between cooled and noncooled fruit with respect to hue, surface blush, and rate of firmness loss were more pronounced in a warm season requiring frequent cooling than in a cooler season.

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Red color development in fruit is influenced by cultural and environmental factors. The most important environmental factors are temperature and light (Creasy, 1968; Faragher, 1983; Saure, 1990). Temperature has a profound effect on the accumulation of anthocyanin and consequent red color formation; low temperatures during the growing season generally promote anthocyanin synthesis, while high temperatures tend to inhibit this process (Mazza and Miniati, 1993; Saure, 1990).

Cooling by over-tree sprinkler irrigation has been effective in enhancing red color in apple and currently is practiced in apple production (Unrath, 1972; Williams and Mayles, 1990). Cooling may promote anthocyanin formation in a warm climate by reducing the negative effect of heat on anthocyanin accumulation and decreasing the fruit respiration rate, thereby conserving energy and providing substrate for anthocyanin synthesis (Ryugo, 1988; Saure, 1990). Over-tree sprinkling also removes dust particles from leaves, thus improving their photosynthetic capacity (Ryugo, 1988).

The fruit of 'Sensation Red Bartlett' pear appear dark red during most of the growing season. As the fruit approach maturity, the fruit appear less red, described by growers as "fading." Our objective was to measure the effects of modifying temperature by cooling during the final 30 d of fruit maturity on fruit color and firmness in 'Sensation Red Bartlett' pear. Fruit firmness is the principal index of harvestable maturity in pear (Williams et al., 1978).

Materials and methods

Thirteen-year-old 'Sensation Red Bartlett' pear trees on *Pyrus communis* rootstock spaced 10 × 12.5 feet (3 × 3.8 m) were cooled by over-tree sprinkler irrigation in Medford, Ore., in 1992 and 1993. Each cooled tree was paired with a noncooled tree located two to three trees distant in the row. Four cooled–noncooled replicate pairs of trees were selected randomly along the row. Two spinning microsprinklers were installed 4 inches (10 cm) apart above each cooled tree. Each sprinkler delivered water at 308 gallons/min per acre (2881 $L \cdot min^{-1} \cdot ha^{-1}$) over a radius of 3.8 feet (1.15 m). The over-tree system was activated manually at ≈29 °C (84 °F) (Lombard et al.,

Table 1. Effect of evaporative cooling on fruit color in 'Sensation Red Bartlett' pear fruit. Fruit color is expressed as hue angle (radians), calculated as $\tan^{-1}(b^*/a^*)$ from component values measured with a Minolta tristimulus colorimeter and as percent surface blush (estimated visually).

	1992				1993			
	Days after full bloom				Days after full bloom			
Variable	104	122	133	139	112	125	131	148
Shaded surface								
Noncooled	52.7	61.6	72.7	70.3	32.8	36.0	38.4	46.2
Cooled	52.1	56.1	54.6	58.4	31.6	35.3	34.2	40.7
Significance	NS	NS	*	*	NS	NS	NS	*
Sun-exposed surface								
Noncooled	25.7	30.1	35.6	39.4	23.7	25.3	26.9	31.3
Cooled	24.9	28.2	31.0	34.2	23.5	25.8	27.4	31.0
Significance	NS	NS	**	*	NS	NS	NS	NS
Fruit surface blushed (%)								
Noncooled	75.2				94.4			
Cooled	83.8				96.2			
Significance	*				NS			

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively, based on Student's *t* test (paired). Percent values were transformed to arcsine-square root before analysis.

1966; Unrath, 1972) during the final 30 d of fruit maturity in each year. The sprinklers were operated continuously at ambient temperatures in excess of this value and were shut off when the temperature outside the treatment area cooled to the starting temperature. The frequency of application of over-tree irrigation for cooling differed in the 2 years of study. Duration of sprinkler operation ranged between 4 and 7 h. A maximum-temperature recording thermometer was located on the trunk of each tree (cooled and noncooled) at an ≈1.5-m height, and the daily maximum air temperature in the tree canopy was recorded following days when cooling was applied.

Color and fruit firmness were measured at four maturity stages: 104, 122, 133, and 139 d after full bloom (DAFB) in 1992 and 112, 125, 131, and 148 DAFB in 1993. The earliest measurement occurred before initiating cooling treatments, while the subsequent timings represent early, middle, and late stages of harvestable maturity. Commercial harvest usually occurs between 130 and 140 DAFB. Twenty fruit on the periphery of each tree were wiped with a cloth to remove dust or spray residues and color was measured on sun-exposed and shaded fruit surfaces. Measurements were taken on a marked spot [0.3 inch (8 mm) in diameter] on the fruit at the midpoint between the stem and calyx using a portable tristimulus colorimeter (Minolta CR-200b). Chromaticity was recorded in Commission Internationale de l'Eclairage L*, a* and b* (CIELAB) color space coordinates (Hunter, 1975; Singha et al., 1991). The colorimeter was calibrated at illuminant condition C (6774K) with a white standard (Minolta calibration plate CR.A43; L* = 97.6, a* = –0.5, b* = 2.4). L* represents the saturation or relative lightness of colors from 0 to 100, being small for dark colors and large for light colors. The a* and b* scales range from –60 to 60; a* is negative for green and positive for red, and b* is negative for blue and positive for yellow. At any level of L*, the hue angle can be calculated as $\tan^{-1} b^*/a^*$, which is considered representative of human visual color experience (Francis, 1980; McGuire, 1992).

In addition to colorimetric evaluation, the percentage of red blush on each fruit was visually estimated at 133 DAFB in 1992 and 131 DAFB in 1993. Ten fruit were removed from each tree at each evaluation date and flesh firmness was measured on two sides using a UC penetrometer (Western Ind. Supply, San Francisco, Calif.) with a 0.31-inch (8 mm) tip.

Results and discussion

In 1992, cooling was applied on 15 of the 30 final days of fruit maturity; while in 1993, temperatures high enough to require cooling occurred only on 7 d. The average difference in maximum temperature between cooled and noncooled trees was 9.9 °F (5.5 °C) in 1992 and 6.8 °F (3.8 °C) in 1993.

Sun-exposed fruit surfaces in both treatments had higher a* values (more red) and lower b* values (less yellow) than the shaded surfaces, resulting in lower hue values (Table 1). Cooled fruit had lower hue values (more red and less yellow) than control fruit at 133 and 139 DAFB on both surfaces in 1992 and at 148 DAFB on shaded surfaces in 1993. Sun-exposed and shaded surfaces in both treatments gained in hue value as fruit matured (Table 1), which reflects the "fading" observed by growers. Cooled fruit tended to increase in hue value as fruit matured less than the control fruit, indicating that cooling can reduce this effect.

The percentage of blush was higher in cooled fruit than in noncooled fruit in 1992, but the difference in blush was not significant in 1993 (Table 1). This improved blush is consistent with results in apple where over-tree irrigation produced fruit with greater surface coloration and red surface area than fruit which received under-tree or no irrigation (Unrath, 1972).

Over time, firmness of fruit from cooled trees decreased faster than fruit firmness in noncooled trees (Fig. 1). Promoting maturity by cooling with over-tree irrigation also was noted by Lombard et al. (1966) in 'Bartlett' but not in 'd'Anjou' pears. Since cooled 'Bartlett' pears matured earlier, they suggested earlier harvest for optimum keeping quality. Cool temperature treatments also have induced premature ripening on the tree in 'Bartlett' pears (Wang et al., 1971), while this response is not seen in other pear cultivars grown in the United States (D.S., personal observation). Unrath (1972) reported that in 'Red Delicious' apple trees receiving over-tree sprinkler irrigation, harvest was completed 1 week earlier than in those with under-tree or no irrigation.

Anthocyanin synthesis in apple is promoted by low temperatures, whether applied during a light or dark period and in poorly exposed skin areas as well as in sun-exposed surfaces (Creasy, 1968). The greater red color (lower hue values) on the exposed surfaces of cooled fruit in this study may have resulted from the direct effects of cooling and from the indirect effects of cooling in advancing fruit maturity. Anthocyanin accumulation in apples approaching maturity may be more directly related to the ripening

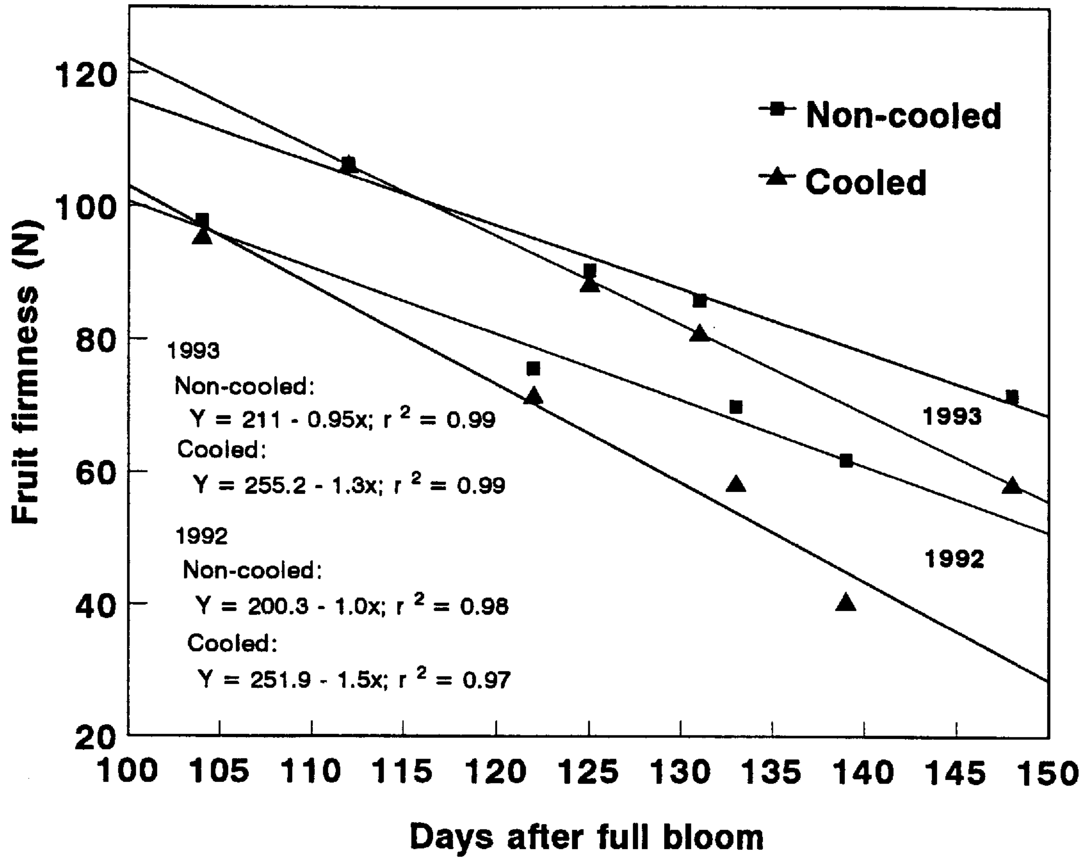

Fig. 1. Firmness of evaporatively cooled or noncooled 'Sensation Red Bartlett' pears measured four times during fruit maturation.

process than to a fall in temperature (Faragher, 1983; Arakawa, 1991).

Fruit color in 'Sensation Red Bartlett' pear appears to respond to temperature similarly to other anthocyanin-containing fruit. Cool temperatures promoted red skin color and adecline of fruit firmness. Modifying red pear fruit color by over-tree sprinkler irrigation has potential value to producers, provided that the earlier fruit maturity is managed appropriately.

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