Under- and Overtree Microsprinkler Irrigation for Frost Protection of Peaches

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Additional index words *Prunus persica,* low-volume irrigation, freezing stress

Summary. **Spring frost events reduce fruit production in the southeastern United States more than any other factor, with some losses occurring in 5 out of 7 years. Orchard heaters, wind machines, and overhead irrigation are sound methods of reducing losses, but their relatively high cost is a major deterrent for fruit growers (Castaldi, 1990). A potentially leas-costly and more water- efficient approach to frost protection is overtree microsprinkling. Microsprinkler irrigation was applied either beneath or onto canopies of 4-year-old Loring peach *[Prunus persica* (L.)] trees at a rate of 38 liters/h per tree to evaluate the relative efficacy of low-volume undertree and overtree microsprinkling for frost protection. Overtree microsprinkling maintained flower bud temperatures 2C during a calm, radiative frost on 20-21 Mar. 1990 (minimum air temperature -4.4C), whereas undertree sprinkling provided 0.5C of air temperature elevation at a comparable height in trees (2 m). Twelve days later, fruit set was lower for nonirrigated and undertree-irrigated trees (none to one fruit/m of shoot length) than for trees irrigated with overtree microsprinklers (eight to nine fruit/m of shoot length). Economic analysis showed that capital costs of overtree microsprinkler systems increased annual costs of peach production by 8% to 13%, which required increased yield (or price per unit yield) of 17% to 20% before profits exceeded those of non-irrigated orchards, assuming all else equal. The estimated 1% increase in annual production costs of overtree microsprinkling compared to undertree microsprinkling appears to be justified by the increased efficacy of the overtree system.**

Overtree microsprinkler irrigation may provide growers with a resource-efficient and cost-effective method of orchard frost protection. Under typical spring frost conditions, overtree microsprinkling maintained peach flower bud temperatures above killing points, while using 50% less water and up to 87% less energy than conventional overhead sprinkler systems (Rieger and Myers, 1990). High-volume microsprinkler systems have been tested successfully in New Zealand orchards (John et al,, 1986), and low-volume microsprinkler systems are being tested currently in several small plantings in the southeastern United States.

Two questions frequently posed by growers concerning the use of microsprinklers for frost protection are: 1) given the same volume of water per tree, can undertree microsprinkler irrigation provide the same amount of protection as overtree microsprinkling?, and 2) what is the cost of microsprinkler systems relative to conventional overhead irrigation systems? Undertree microsprinkling is attractive because less labor and materials are required than for overtree microsprinkling, and the drawback of limb breakage due to ice loading is avoided. It is unclear whether low-volume microsprinkling can protect peach trees from frost, although high-volume undertree systems have been used successfully for peach and other tree fruits (Evans, 1987; Kester and Micke, 1984; von Bernuth and Baird. 1989). In citrus orchards, low-volume undertree microsprinkling generally provides 1 C warming at heights of 2 m and higher (Buchanan et al., 1982; Parsons, 1984), yet even this small amount of protection has resulted in noticeable improvement of tree condition following freezes (Oswalt and Parsons, 1981). The performance of low-volume undertree microsprinklers for frost protection in deciduous orchards has not been documented. The objective of this study was to compare the relative frost protection capabilities of overtree and undertree microsprinkler systems for peaches. In addition, an economic analysis of peach production using microsprinkler systems for frost protection was evaluated against the use of conventional overhead sprinkler systems.

Irrigation treatments and data collection

The experiment was performed in a frost-prone orchard with 4-year-old Loring peach trees, 3 m tall. Details of the overtree microsprinkler system have been described previously (Rieger and Myers, 1990). Microsprinklers (Hardie Microsprinkler III, 38 liters/h, James Hardie Irrigation, Sanford, Fla.) were suspended over the trees from a trellis wire at 3.5 m in overtree irrigation treatments. Four thermocouples were attached to flower buds 2 m above ground level and at 90° intervals around the periphery of the canopy. Bud temperatures were monitored on the center tree of 3, three-tree experimental units placed at random throughout the orchard. The water application rate at the 2-m height in the canopy was 2.5 to 3.5 mm/h.

Trees receiving undertree irrigation had identical microsprinklers to those used in overtree treatments mounted 30 cm above the ground and 1 m from the trunk. However, because microsprinklers wetted larger areas beneath trees than within trees, application rates were 1.8 to 2.9 mm/h for undertree treatments. Thermocouples were attached to limbs at 0.5-, 1-, 2-, and 3-m heights near the tree center, and shielded from the sky by small plastic funnels to avoid radiant cooling and air temperature underestimation. Air temperature was measured in undertree treatments instead of bud temperature because the mechanism of bud protection is through air warming (not through release of latent heat of fusion, as for overtree treatments); this made comparison to air temperature data in previous literature easier. However, bud and air temperatures were not significantly different in the absence of irrigation, allowing comparison of temperature data among treatments. The lowest thermocouples in undertree irrigation treatments were positioned opposite the trunk from microsprinklers to avoid direct wetting. Temperatures were monitored on the center tree of a 3 × 3 block of trees irrigated with the same microsprinklers. Temperatures in nonirrigated trees were monitored identically to trees receiving undertree irrigation.

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The orchard floor had a 3-m herbicide strip within tree rows, and sod cover (10 to 15 cm tall) between rows.

Irrigation was applied during Winter 1989 90 when weather conditions approximated those typical of spring frost events. Dates of operation were 13 14 Jan., 5 6 Feb., 25 26 Feb., 20 2 1 Mar., and 9 10 Apr. Data are presented for the 20 2 1 Mar. dates only, because results from other dates with calm, clear weather conditions were similar, and crop losses resulted from this event only. Fruit set (viable fruitlets per meter of shoot length) was assessed on 2 Apr. by surveying 20 shoots per tree on nine trees per treatment.

Air temperature and wet bulb temperature (1.2-m height) and wind speed (3-m height) were monitored at a weather screen located within the orchard. Dewpoint was calculated from wet and dry bulb temperatures (Lu, 1992). Data were collected with a Campbell CR-7 (Campbell Scientific, Logan, Utah) data logger operating on a 5-see scan and storing averages every 15 min.

The experiment was designed as completely randomized with three replications and three adjacent trees per replication. Bud and air temperature and fruit set data were analyzed by analysis of variance and Duncan s multiple range test. Temperatures in canopies of undertree and nonirrigated trees were regressed on height in canopy to detect vertical temperature gradients because this was reported previously (Davies et al., 1988; Wilcox and Davies, 1981).

Economic analysis

An economic analysis was performed using spreadsheet programs developed at the Univ. of Georgia for the central Georgia production area (G. Westberry and G. Krewer, unpublished software) and Clemson Univ. for South Carolina production (Ridley et al., 1985). The programs calculate risk-rated returns per hectare on peaches for typical commercial operations in Georgia or South Carolina, based on 1992 prices. The fixed and variable costs of conventional overhead, overtree microsprinkler, and undertree microsprinkler irrigation systems were estimated by obtaining prices of components and labor from local irrigation companies. The cost of the water source (well or pond, pumps) was not included in the analysis because it was highly variable among locations, growers, etc. Costs for the water source could range from nothing on sites currently using irrigation, to $3700/ha when installing a new well, pump, and filtration system. Annual production costs were calculated using a 9-year and a 12-year period to recapture irrigation and other establishment costs (years 1 3) in the Georgia and South Carolina programs, respectively. Returns above costs were calculated assuming that O%, 25%, 50%, 75%, and 100% normal yields were obtained. Costs of fruit thinning were reduced in proportion to the assumed level of crop reduction. Average prices for peaches in Georgia ($12 per 16-kg carton) and South Carolina ($9 .25 per 16-kg carton) and a pack-out percentage of 25~0 were used to calculate grower returns.

The most practical overtree microsprinkler system design involves attachment of microsprinklers to a stake in the center of the canopy when trees are pruned (January-February), moving the microsprinkler back to ground level during thinning (April) after the frost threat has passed. Canopy ice distribution and frost protection are comparable for this design and for microsprinklers mounted above the trees permanently, yet the stake-mounted system is more logistically feasible, and is the system favored by growers (my unpublished data). Therefore, the stake-mounted microsprinkler system was considered in this analysis.

Efficacy of irrigation treatments

The freeze event of 20 21 Mar. occurred during the post-bloom pe-

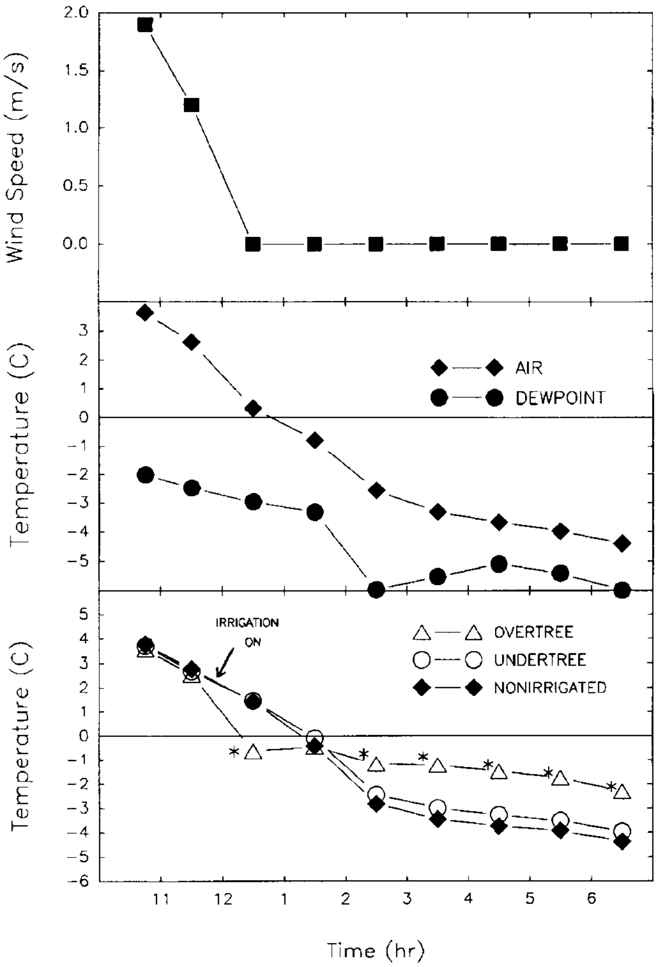

Fig. 1. *Meteorological conditions and bud (overtree) or air temperatures (undertree, nonirrigated) at the 2-m height in canopies of* Loring *peach trees on 20-21 Mar. 1990, Athens, Ga. Bud and air temperatures were not significantly different in the absence of irrigation, as seen by lack of differences between overtree and other treatments at 10:40 and 11:40* PM, *and therefore were compared statistically. Asterisk denotes significant differences* ($P < 0.05$) *in temperature between overtree and undertree/nonirrigated treatments; differences in temperature between undertree and nonirrigated trees at the 2-m height did not occur.*

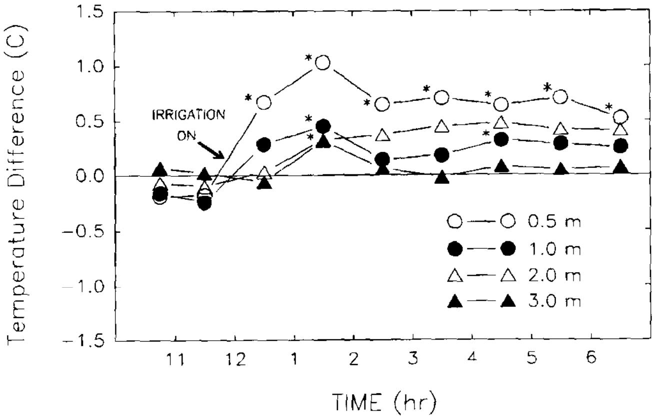

Fig. 2. *Temperature differential among trees in undertree and noniirrigated treatments at various heights in the canopy as indicated. Symbols with asterisks indicate that the temperature differential was significantly different from 0,* $P < 0.05$.

riod, and had typical weather conditions that result in peach crop losses (Fig. 1). Irrigation was started at 11:40 PM as exposed bud temperatures approached 0C. Overtree irrigation significantly reduced temperatures at the 2-m height compared to undertree and nonirrigated trees for 1 h after irrigation was started. As air temperature continued to decrease, however, temperatures of all treatments converged at 1:00 1:30 AM, after which temperatures in overtree irrigation treatments were significantly higher than both nonirrigated and undertree treatments (Fig. 1). At no time did temperatures at the 2-m height differ between undertree and nonirrigated treatments.

Air temperatures 0.5 m above ground in undertree irrigated trees were 0.5 to 1.0C higher than those at the same height in nonirrigated trees (Fig. 2). However, there were only three occurrences of temperature differences between nonirrigated and undertree treatments at heights above 0.5 m. These differences occurred sporadically and were <0.5C in magnitude. Because the flower buds were located 1 to 3 m above the ground, undertree irrigation appeared to provide little or no benefit to areas of the canopy bearing fruit.

Regressions of temperature vs. height in nonirrigated and undertree treatments revealed significant vertical temperature gradients during the coldest portion of the night (data not shown). Temperature decreased with height in undertree-irrigated trees by 0.25 to 0.45C/m, whereas temperature gradients were 0 to 0.26 C/m in nonirrigated trees. This agrees with reports of high-volume undertree irrigation performance in apple and citrus orchards, where the warming effect of irrigation decreased with height in the canopy (Davies et al., 1988; Wilcox and Davies, 198 1). Prior to irrigation commencement, gradients were either nonexistent or positive (temperature increased with height) within canopies of nonirrigated and undertree irrigated trees. Positive temperature gradients within canopies of nonirrigated trees would be expected to persist throughout the night because temperature commonly increases with height during calm freeze events when an inversion layer forms (Rieger, 1989). The reversal of the gradient from positive to negative in nonirrigated trees after irrigation began indicates that temperatures in nonirrigated trees were influenced by nearby irrigation treatments. Thus, differences between undertree and nonirrigated treatments, particularly at lower levels in the canopy, may have been greater than those reported here if nonirrigated trees could have been located further from irrigation treatments. Warming of air at ground level beneath nonirrigated trees also has been reported for citrus when neighboring trees were irrigated (Wilcox and Davies, 1981).

Fruit set was similar for undertree and nonirrigated trees, being reduced by a factor of eight compared to trees receiving overtree microsprinkler irrigation (Table 1). Fruit set was greater in the lower portion of the canopy of undertree and nonirrigated trees, in agreement with the negative vertical temperature gradients recorded in canopies of these trees. Based on a thinning recommendation of five fruit per meter of shoot length, trees in overtree treatments would have required thinning for proper fruit size, whereas trees in undertree or nonirrigated treatments experienced crop losses of at least 80%. Fruit set was not affected further by the frost event on 9 10 Apr., largely because there were few fruit remaining on trees in undertree and nonirrigated treatments, and temperature did not reach damaging levels (2C). Visual inspection of fruit load in June revealed the need for dinning in trees in overtree plots, and <10 fruit per tree in undertree and nonirrigated plots. High winds (>40 m sec^{-1}) associated with severe thunderstorms removed most of the fruit on all trees in late June, which prevented collection of accurate yield data.

Economic analysis

Capital costs of undertree and overtree microsprinkler irrigation systems were comparable, yet the conventional overhead system was estimated to be 27% more costly than the overtree microsprinkler system (Table 2). All systems required relatively large capital expenditures over the nonirrigated case in the establishment year; establishment costs were 171% ($5217/ha) and 218% ($6121/ha) higher for the microsprinkler and conventional systems, respectively, than for the nonirrigated orchard ($1922/ha). However, when establishment costs were deferred over a 9-year period in the Georgia model, the annual production costs were increased by

Table. 1. *Fruit set (viable ovaries per meter of shoot length) of Loring peaches assessed 12 days after the 20-21 Mar. 1990 frost event as influenced by frost protection measures and height in the canopy.*

Treatment	Height in the tree canopy 1 to 2 m	 2 to 3 m	Height effect
Nonirrigated	0.3 b	0.0 b	*
Undertree microsprinkler	1.0 b	0.1 b	*
Overtree microsprinkler	8.0 a	9.5 a	NS

[*,NS] *Comparisons of fruit set between the 1- to 2- and 2- to 3-m heights the canopy were significant at* $P = 0.05$ *or nonsignificant at* $P > 0.05$, *respectively.*

Table 2. *Economic analysis ofpeach production in Georgia and South Carolina using no frost protection (nonirrigated), conventional overhead sprinkler irrigation, stake-mounted overtree microsprinkling, or undertree microsprinkling for frost protection. Estimates are given for levels of crop production ranging from 0% to 100% of normal yields, where normal production is considered 535 16-kg cartons of packed fruit per hectare in Georgia and 988 cartons /ha in South Carolina.*

Treatment	Capital costs of irrigation[z] ($/ha)	Annual production costs for full crop[y] ($/ha)	Returns above costs for given yield[x] ($/ha)				
			0%	25%	50%	75%	100%
Nonirrigated							
Georgia	0	4999	–1685	–785	–42	719	1462
South Carolina	0	8477	–3181	–2221	–1260	–299	662
Conventional overhead[w]							
Georgia	4199	5780	–2468	–1568	–825	–64	682
South Carolina	4199	9238	–3942	–2981	–2020	–1060	–99
Overtree microsprinkler							
Georgia	3297	5651	–2339	–1440	–697	64	810
South Carolina	3297	9120	–3826	–2864	–1903	–942	19
Undertree microsprinkler							
Georgia	3011	5612	–2300	–1400	–657	106	850
South Carolina	3011	9083	–3788	–2827	–1866	–905	56

[z] *Includes parts and labor for sytem installation; does not include the cost of establishing a water source.*
[y] *Total fixed and variable costs of production, 1992 prices.*
[x] *Thinning costs adjusted for level ofproduction.*
[w] *Overhead impact sprinklers spaced 18.5 m (60 ft) apart, discharging 25 liters/rein (application rate = 4.4 mm/h).*

only 12%, 13%, and 16% for the undertree microsprinkler, overtree microsprinkler, and conventional overhead systems, respectively. For the South Carolina analysis, annual costs increased by only 7% to 9%, depending on the system, due to the overall higher costs of production in South Carolina vs. Georgia and the longer period over which establishment costs are recovered (12 years) for South Carolina orchards. If the costs of a water source and pumping station were included, the above estimates could be about twice as high in the most-expensive case (new well, pump, and filtration system). Caution should be exercised when extrapolating these data to other production regions because the costs of both parts and labor may vary with location.

Compared to the nonirrigated case, the expected returns above costs were reduced for the three irrigated cases by an amount equal to the increase in annual production costs (Table 2). For the Georgia and South Carolina analyses, returns increased by $31 .50/ha and $38.43/ha, respectively, for each 1% increase in yield. In Georgia, the undertree microsprinkler, overtree microsprinkler, and conventional irrigation cases would require average increases in yield (or price per unit yield) of 19%, 20%, and 24%, respectively, above the nonirrigated case for returns to be equal. In South Carolina, the corresponding yield increases were slightly less, at 16%, 17%, and 20% for the undertree, overtree, and conventional systems, respectively.

Assuming an 80% increase in yield, as predicted from data of the 20 21 Mar. frost event, the overtree microsprinkler system would have allowed a gross income of $2520/ha (Georgia) or $3074/ha (South Carolina) more than the nonirrigated case. Thus, using the 20 21 Mar. frost event as an example, more than one-half the capital outlay for the overtree microsprinkler system potentially could be recovered in one season. With some level of crop loss occurring in about 5 out of 7 years in the southeastern United States (Gibson, 1988), it seems likely that the profitability of peach production could be improved by using microsprinkler irrigation for frost protection. The undertree microsprinkler system would not be cost-effective because the protection provided is inadequate for typical frost situations. The small amount of additional capital, annual costs, and labor for the overtree vs. the undertree microsprinkler system appear to be well-justified.

As stated above, this analysis does not include the cost disadvantages of the water source/pumping station, which would increase the yield differential required for the irrigation systems to be profitable investments. The hypothetical cases presented are more reflective of situations where some form of irrigation is practiced, which is then converted to one of the three systems for frost protection, rather than a situation where irrigation is not practiced. However, the offsetting cost advantages of earlier production due to greater tree growth, improved tree survival, greater marketable yield, and larger fruit size, all of which can be obtained from irrigation (Horton et al., 1981; Layne and Tan, 1984; Morris et al., 1962; Reeder et al., 1979), also deserve consideration but are not considered here. Another economic benefit of frost protection may be the intangible cost advantage of consistent, predictable production, which stabilizes markets and ensures future sales. Costs of production may be reduced further by using the microsprinkler system for fertilizer and/or pesticide application, which is best suited to low-volume systems (James, 1988). Development of uses of microsprinkler irrigation systems other than for frost protection would help defer the associated costs and make microsprinkler irrigation a more viable frost protection alternative.

The capital costs, annual production costs, and yield differential required to cover costs were slightly greater for the conventional overhead system than for either of the microsprinkler systems, which were comparable. Solely on the basis of costs and potential returns, there appears to be a small advantage of using overtree microsprinklers vs. conventional overhead sprinklers. The reduced water and energy consumption of microsprinkler systems (Rieger and Myers, 1990) is more significant than the minor reduction in costs for environmentally conscious orchardists, particularly in areas where water supply is limited. It may be possible to protect up to twice the area with microsprinklers as with conventional overhead sprinklers, given the same quantity of water available to the site (Myers and Rieger, 1989). Thus, profitability for growers who have limited water or pumping capacity could be increased significantly by simply protecting a greater portion of their crop when using microsprinklers.

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