LOW VOLUME MICROSPRINKLER UNDERTREE IRRIGATION FOR FROST PROTECTION OF YOUNG CITRUS TREES

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Abstract. The effectiveness of low volume microsprinkler irrigation for citrus frost protection was examined during 7 cold nights in central Florida. Air temperature along with leaf and trunk temperatures of young citrus trees were monitored. Air temperatures were generally 1 to 2°C (0.6 to 1.1°F) warmer in the irrigated area than in the nonirrigated area with temperature increases ranging from 0 to 5°F (0 to 2.8°C). Leaf and trunk temperatures in the direct water spray frequently were 11 to 14°F (6.1 to 7.8°C) warmer than those in the nonirrigated area. Microsprinkler irrigation was effective in protecting the trunk and lower branches of young trees, partly due to the heat of fusion release during ice formation. In one case, evaporative cooling caused trunk temperature to drop below nonirrigated trunk temperatures when the system was first turned on. Because of the potential for evaporative cooling during dry, windy nights, microsprinkler irrigation may not be useful in advective (windy) freezes. During calm radiation conditions, microsprinkler irrigation may be one alternative to burning petroleum products for citrus frost protection.

The freezes that occurred in Florida in January and February, 1981, caused major damage and resulted in a loss of 30 million boxes of 15% of the oranges in Florida in 1980-81 (5). Because of tree limb damage, particularly in the northern part of the state, it will be several years before the most damaged groves will recover to prefreeze production levels. Grove heating has become prohibitively expensive for freeze protection. Heaters are commonly spaced at 35/acre (86 per ha) and burn fuel at approximately 1 gal/hr (3.8 liters/hr) (8). This means that four 8-hr nights of frost protection for 100 acres (40.5 ha) could consume over 112,000 gallons (433,000 liters). Therefore, alternative less expensive frost protection measures are needed.

Various methods of water application or irrigation have been used for frost protection. These included flooding, fog generation, high volume undertree or overhead irrigation, and low volume irrigation. Any form of irrigation can increase soil thermal conductivity, soil heat capacity, and evaporation (6).

Flood irrigation has been used successfully in Florida and California citrus. Flooding is apparently most effective in Florida groves with a full canopy but not as effective when trees are small (6). Fog has been successfully used for citrus frost protection in a few cases (11) but fog can be blown away by winds.

High volume undertree sprinkling has been used successfully in citrus. Davies (4) found that an application rate of 0.4 to 0.5 inches/hr resulted in leaf temperature increases of 2 to 4°F in radiation frosts and 1 to 2°F during an advective freeze. Much work has been done on high volume overtree sprinkling (9). This method is only effective if application rates are high enough. Although high wind, low dewpoint, and limb breakage due to ice loading can all cause tree damage, overhead sprinkling was used successfully for lime protection in Dade County in the 1977 freeze.

Low volume undertree microsprinkler irrigation systems have been used for frost protection to a limited extent, but the effectiveness of such systems has not been critically evaluated. The purpose of this study was to evaluate the effectiveness of such microsprinkler systems during cold nights.

Materials and Methods

A microsprinkler irrigation system was installed as part of a high density planting experiment. Red jet emitters with a 270° spray pattern that delivered 18 gal/hr (68 liter/hr) were arranged in a 10 x 11 ft (3.1 x 3.4 m) spacing. Given the arrangement of the rows and middles, this plot had 294 emitters per acre. A pressure of 18 psi (1.3 kg/cm²) was maintained at the sprinkler head. Due to spray pattern overlap, precipitation rates in the irrigated areas were approximately 0.26 inches/hr (0.66 cm/hr). Young potted citrus trees (Citrus sinensis (L.) Osb. cv. Hamlin on Flying Dragon (Poncirus trifoliata Raf.)) rootstock were planted in the microsprinkler plot. During freeze nights, microsprinklers were turned on in the eastern portion of the study plot.

Air temperatures were measured with 24 gauge copper constantan thermocouples shielded from the sky at heights of 2 feet (60 cm) and 4 ft (120 cm) above the ground. Trunk and leaf temperatures were monitored with 36 gauge copper constantan thermocouples at heights of 8 inches (20 cm) and 16 inches (40 cm), respectively. One tree was monitored in the nonirrigated zone and 3 trees were monitored in the irrigated zone. Data were collected with an Esterline Angus PD 280 data logger powered by a portable generator. The data logging thermocouple system had an accuracy of ±0.5°F (±0.3°C) or better when calibrated with an ice bath. Dew point temperatures were monitored with a Foxboro dewpoint recorder 20 miles south of the study plot (courtesy Mr. Tom Oswalt, Polk County Extension Service) and were considered representative of the study area.

The nonirrigated plot was similar to the irrigated plots, but the microsprinklers were not operated. Temperatures were monitored 60 feet inside the irrigated plot and 50 feet into the nonirrigated plot. During the frost nights, winds were from the northwest and were normally less than 5 mph (8 km/h). Hence, mist did not drift over the trees that were monitored in the nonirrigated plot.

Data were collected on 7 nights when leaf temperatures dropped below 32°F (0°C). Data from selected representative nights are presented to illustrate general observations.

Results

During the 7 cold nights observed, air, leaf and trunk temperatures were consistently warmer in the irrigated plots than in the nonirrigated plot. In several other locations, mature trees under microsprinkler irrigation during the freeze retained more leaves and looked healthier than nonirrigated trees (12). While fog was generally not produced by the microsprinklers, a great deal of fog was gener-
ated during the morning of January 14, 1981 (Fig. 1) when the dew point was around 23°F (—5°C).

Fig. 1. Fog generated by microsprinkler system on the morning of January 14, 1981. Note darker iced zone in rows with emitters and frosted zone to the left of the rows.

A. Air temperature

Air temperatures ranged from 0 to 5°F (0 to 2.8°C) warmer in the irrigated plot and were consistently 1 to 2°F (0.5 to 1.1°C) warmer than the nonirrigated plots (Fig. 2). Depending on the tree spacing, most groves commonly would not have more than 100 to 200 emitters per acre. Because of the larger number of emitters used in this high density planting, observed temperature increases may be more than would be found in a normal grove. The amount of warming varied but appeared to be related to the dew point temperature. When the dew point was low (14 to 17°F), the degree of warming in the irrigated plot ranged from 0 to 2°F (0 to 1.1°C) with a mean near 1°F (0.6°C). When dew point temperatures were higher (23°F or —5°C), air temperature warming was commonly 2 to 2.5°F (1.1 to 1.4°C) and ranged from 0 to 5°F (0 to 2.8°C).

B. Leaf temperature

Dry leaves in the nonirrigated plot were consistently cooler than the dry air around them, an occurrence typical of a radiation frost. Leaves in the irrigated plots were commonly warmer than those in the nonirrigated plot. Lower leaves in the direct water spray zone stayed above freezing and were as much as 11 to 14°F (6.1 to 7.8°C) warmer than the dry leaves in the nonirrigated plot (Fig. 2).

C. Trunk temperature

The dry trunk temperatures were normally 1 to 1.8°F (0.5 to 1°C) cooler than the air temperature in the nonirrigated plot. Trunks in the irrigated zone were constantly wetted with water and always remained near 32°F (0°C). Clear ice commonly accumulated on the trunk indicating good frost protection (10) (Fig. 3). Normally, irrigated trunks were warmer than nonirrigated trunks. However, on one night when the irrigation system was first turned on, the irrigated trunk temperature dropped about 3°F (1.7°C) below the dry trunk temperature. In this case, the wet trunk remained cooler than the dry trunk for approximately 2 hours. A similar initial drop in temperature when irrigation was started has been described (2, 13). This initial temperature drop was probably due to evaporation before the air became saturated. After several hours, the evapora-

Fig. 2. Individual air, leaf and trunk temperatures on the night of January 17-18, 1981. Wet air temperatures were measured at a height of 4 ft and were above the microsprinkler spray zone. The wet leaf and wet trunk were directly in the spray zone and were coated with ice when temperatures were below freezing. Dry air, leaf, and trunk temperatures were at similar heights in the nonirrigated plot. Vertical arrow indicates when irrigation system was turned on.
Fig. 3. Clear ice buildup on trunk of young Hamlin tree. This trunk was maintained at 32°F (0°C) as long as sprinkler operated.

Discussion

It is not entirely clear why low volume irrigation increased air and plant temperatures in freezing environments. Models for frost protection using overhead sprinklers have been developed (3, 7) but these do not directly explain why microsprinklers can be beneficial during frosts. Several possible explanations exist. First, water in this test was obtained from a well with water temperatures above 55°F. In addition to the energy released by warm water, the release of the heat of fusion during ice formation is a major source of energy in the lower part of the canopy. Water droplet formation can reduce long wave radiation loss, with droplets 10μ in diameter being the most effective for reducing such loss (11). Increasing vapor pressure, humidity, or dew point can also reduce radiation loss. Barfield et al. (1) emphasized the importance of humidity in overhead irrigation models. By raising the local dew point tempera-
ture inside the plot, microsprinklers can help raise the ultimate minimum temperatures reached. Any form of irrigation, including microsprinkler irrigation, can also increase soil conductivity which can improve the transfer of energy from the soil to the atmosphere near the soil.

In the case of young trees, ice formation and release of the heat of fusion (80 cal g⁻¹) can protect the bud union, trunk, and lower limbs. This was particularly noticeable in young trees one week after the first freeze night. Irrigated trees in a second plot 1/2 mile from the first study site were observed. The trunk and lower leaves that were iced over during the freeze (Fig. 5) showed little damage whereas leaves above the iced zone showed noticeably greater damage (Fig. 6). In this case, protection of the base of young citrus trees by heat of fusion release is similar to protection of any low growing fruit or vegetable crop by overhead sprinkling (13). With young citrus trees, protection of the bud union and trunk is of major importance. Loss of some upper leaves is not of as great a concern because regrowth can be rapid under favorable growing conditions. Depending on orifice size, pressure, and spray pattern, precipitation rate on the immediately wetted zone can range from 0.11 to 0.5 inches/hr (0.28 to 1.27 cm/hr) for a 360° spray pattern. Closer spacing or spray overlap can increase local precipitation rates. A precipitation rate of 0.26 inch per hr (the amount used in this study) is sufficient to provide protection in the ice zone down to 15°F (—9.4°C) if the wind speed is below 1 mph (2 km/hr) (8). Adequate irrigation rate is essential for protection of the wetted zone. Extensive tree damage occurred in the 1962 Florida freeze in which overhead sprinklers applied water at inadequate rates (0.1 inches/hr or 0.25 cm/hr) (7).

The measurements and observations made during these tests support the hypothesis that microsprinklers can provide some protection to citrus during radiation frosts with low winds. Caution must be used, however, during dry (low dew point) advective freezes for evaporative cooling could drop temperatures of irrigated trees below those of non-irrigated trees. For that reason, the use of microsprinklers may not be beneficial in all types of freezes.

**Fig. 5.** Iced over zone on lower half of citrus tree after a subfreezing night. Microsprinkler is in the foreground.

**Fig. 6.** Appearance of tree on January 19, 1981, similar to the tree in Fig. 5, approximately one week after the coldest freeze night. Note healthy appearance of lower leaves and damage to upper leaves.

**Literature Cited**

MODIFICATION OF AIR TEMPERATURE AND CITRUS LEAF TEMPERATURE WITH HIGH VOLUME UNDER-TREE SPRINKLERS

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Abstract. Irrigation with high volume under-tree sprinklers, 0.4-0.5 acre-inches/hr (0.41-0.51 cm-ha/hr), increased leaf and air temperatures for 15-year-old 'Orlando' tangelos (Citrus paradisi Macf. x Citrus reticulata Blanco) and 'Pell' navel orange (Citrus sinensis (L) Osbeck) trees during 2 radiation-type freezes in 1981. Leaf temperatures decreased from the canopy base to the top under all experimental conditions. This pattern was similar in both 8 ft (2.4 m) and 20 ft (6.1 m) trees, although temperature gradients were more pronounced in the larger trees. The temperature of upper canopy leaves was similar in irrigated and non-irrigated blocks. However, leaf temperatures in the lower canopy of irrigated trees were as much as 13°F (7.3°C) greater than those in non-irrigated trees. Furthermore, leaf survival was greatest and fruit pack-out best in the lower third of the canopy of irrigated trees.

High volume under-tree sprinklers have been used successfully for citrus cold protection in California (1, 7, 8) and Florida (3, 4). Air temperatures were increased and freeze damage decreased by use of Senninger® pop-up systems during the 1979 Florida winter (3, 4). Irrigated trees sustained a smaller % leaf drop and less fruit damage than non-irrigated trees (4). Additionally, leaf temperatures were higher in irrigated trees under both advective and radiation-type freeze conditions in Florida (3).

Leaf temperature during a freeze can also be affected by leaf position in the tree canopy (5, 11). Temperature gradients between leaves and air under freeze conditions were greater in the upper than in the lower canopies of apple trees (11). Leaf temperatures in the exterior canopy of citrus trees were 2.5°F (1.7°C) lower than those of interior canopy leaves (5).

Another factor affecting leaf temperature as air temperature decreases is tree size (6). The temperature of large trees, because of their greater mass and insulating qualities, may be higher than that of small trees at the same air temperature (6). Similarly, twig temperatures decrease more slowly with decreasing air temperature than do leaf temperatures, and tree trunks cool more slowly than small wood.

Leaf, twig and trunk temperatures were 9.5°F (—12.4°C), 11.5°F (—11.4°C), and 21.1°F (—6.11°C) respectively, at an air temperature of 12°F (—11.1°C) during the 1982 freeze in Florida (5).

Post-freeze injury to citrus is often observed to be more severe in small than in large trees (6). Leaf and twig injury generally occur before injury to scaffold branches and trunks (5). The specific pattern of freeze injury may be related to differences in critical temperatures between various tree tissues, and differences in minimum temperatures to which tissues were exposed. High volume under-tree sprinkling can increase the minimum temperatures to which different tissues are exposed during a freeze (3) and decrease tree injury (4).

The objectives of this study were twofold: 1) to determine the effects of high volume under-tree sprinkling on leaf temperatures throughout the canopies of small and large citrus trees and 2) to relate thermal patterns throughout the canopy to tree damage and fruit pack-out.

Materials and Methods

Temperature measurements were made during freeze conditions on 15-year-old 'Orlando' tangelo trees on Cleopatra mandarin (Citrus reticulata Blanco) rootstock and 13-year-old 'Pell' navel orange trees on sour orange (Citrus aurantium L.) rootstock located at the University of Florida Horticultural Research Unit approximately 8 km (4.3 miles) northwest of Gainesville, FL. The tangelos were approximately 20 ft (6.1 m) tall and were located in a block of 100 trees on the northern border of a 2.8 acre (1.1 ha) planting. The navel trees were approximately 8 ft (2.4 m) tall and were located in a 1.4 acre (0.6 ha) block directly south of the tangelos. The eastern halves of both blocks were irrigated for cold protection with Senninger® pop-up sprinklers at a rate of 0.40-0.50 acre-inches/hr (0.41-0.51 cm-ha/hr). The western halves of both blocks were not irrigated and received no cold protection.

Temperatures were sensed on exterior leaves of irrigated and non-irrigated trees. Canopies were divided into upper, middle, and lower thirds. Leaf temperature data represent the average of measurements made on 3 trees in each block. Tree temperatures were sensed with a Barnes Instatherm infrared thermometer (series 14-220D). Air temperatures were measured at a 4.5 ft (1.4 m) height with a sheltered Taylor minimum temperature orchard thermometer located in each experimental block.

January 3, 1981. Irrigation was started at midnight when the air temperature was 27°F (—2.8°C) and terminated at 8 AM the following morning. Canopy and air temperatures...