MODIFICATION OF TEMPERATURE AND WIND BY AN ORCHARD COVER AND HEATERS FOR FREEZE PROTECTION

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Abstract. Five major freezes have occurred in Florida since 1977 and the devastating effect of the last two freezes was due in no small part to their advective [windy] nature. A question raised through the Statewide Citrus Advisory Committee led to a review of the cold protection potential of windbreaks in conjunction with heating and/or irrigation methods. That review resulted in the covering, with plastic mesh, of a portion of a citrus orchard on the main campus of the University of Florida in Gainesville. Wind and temperature data were collected during several cold periods in the winter of 1987-88 with a recently developed computer controlled data acquisition system. University return stack heaters were burned beneath the cover during several of these periods. The observed effect of the heating beneath the cover relative to periods during which no heat was supplied was found quite variable in space but relatively constant in time, suggesting the establishment of a circulation pattern. The ability of a porous orchard cover to contain the buoyant heat island produced by burning heaters seems to be less than might be predicted by the reduction in horizontal wind flow that has been observed.

This is the 4th report of a series (6, 7, 10) of reports to Florida citrus growers in response to the Statewide Citrus Advisory Committee request for redirection of at least a portion of the resources that had been committed to the Satellite Frost Forecast System toward freeze protection methodology. Windbreak references cited in earlier reports mentioned above are not repeated in this report.

The term “freeze” is used to distinguish between those cold events in which appreciable wind accompanies the cold temperatures, as was the case during the freezes of Christmas 1983 and January 1985, and the term “frosts” which is reserved for those events driven primarily by radiational cooling. For frosts, there are a number of protection methods available (1, 17).

Methods that provide freeze protection for young trees, or at least the lower portion of a young tree, have been described (12, 14, 15, 16) and adopted (5) leaving a void in methodology that promises protection for adult trees from advective freezes.

A method of measuring leaf temperature recommended by Oswalt (11) is described (9). Details of this method are included because others have indicated a desire to use a standardized method of measuring leaf temperature in the hope that results may be compared.

Materials and Methods

Orchard cover and heaters. A porous orchard cover, 204 ft x 199 ft, or 0.93 acre, was supported 12 ft above the ground on steel pillars and by cables with side curtains angled at 45 degrees, with Weathashade knitted polyethylene shade (termed “50%”) cloth on top, and Chicopee woven polypropylene shade (termed “80%”) cloth on the sides (10). A dual wind machine was located 100 ft north from the cover and a 50 ft inversion tower was located approximately 100 ft NW of the NW corner of the cover (Fig. 1). Fifteen University return stack orchard heaters were located as indicated by the small circles with numbers within them in Fig. 1. Plume diffusers were

Figure 1. A map of the SE corner of an orchard showing the relative tree size and placement during the winter of '88-'89 relative to the orchard cover [abbreviated to the columns and cables]. The relative locations of the data acquisition system (DAS) trailer, the wind machine, heaters [circles with numbers], thermocouples [circles with letters], inversion tower, and other sensors are marked.
Fig. 2. A diagram of a University return stack heater showing the relative position of the lid and the support holding the plume diffuser permitting the plume diffuser to remain in place when the heaters were extinguished by rotating the lid or cap over the stack.

used to avoid melting holes in the polyethylene cover (Fig. 2). Even with the diffusers in place, special care was necessary during heater lighting to avoid flaring. Holes melted in the cover were patched prior to the next experiment. The burning rate was computed from fuel height measurements made in each heater prior to and following each firing period and following refilling operations.

Leaf temperature measurement. Copper-constantan thermocouples [22 gage] were taped to metal stakes driven into sandy soil so that the thermocouple loop was 5 ft above the soil surface. Fresh detached citrus leaves were taped to the thermocouple loops with a small piece of masking tape (11), exposing the leaf in a horizontal plane (Fig. 3), the thermocouple loops were constructed by fusing copper to constantan thermocouple wire as follows. The wire pairs were stripped of insulation 1 inch from the end and then twisted together leaving a space below the insulation so the wires would not short out. The bare wires were treated with a borax flux to help form a bead at the end. The twisted end was inserted into a charcoal tube that was filled with charcoal powder, completing the electrical circuit. Next, an electrical current was applied to the untwisted end causing the metals to heat and fuse, forming a bead of equal proportion of the two metals. Thermocouples were located as indicated by the small circles with letters within them in Fig. 1. Sixteen thermocouples were used to monitor temperature inside the cover. Two leaf thermocouple stakes were positioned outside the cover, i.e. Tg and Tk (Fig. 1). Two bare thermocouple loops (without leaves taped to them) were used to determine inversion strength, one mounted at 5 ft and the other at 50 ft on the inversion tower (location shown in Fig. 1). Thermocouples were calibrated by stirring them in an ice bath.

Data acquisition system. A Hewlett-Packard [HP] minicomputer [Model 1000 MX-E] previously used in the Satellite Frost Forecast System controlled the data acquisition system (DAS) (Fig. 4). The DAS was housed in an air-conditioned surplus military trailer [location marked DAS in Fig. 1]. The major change in the acquisition system since it was described in last year's reports (6, 7) is in the computer equipment utilized after the data were transferred from the Climatology Lab. Now, a Macintosh II and a Laserwriter II NTX are available in a nearby office, and it was on that equipment that this manuscript was produced (Fig. 4). However, a bottleneck still exists in the data processing scheme which is in the transfer of data from the HP to the Macintosh.

Results and Discussion

Wind speed reduction. In last year's reports (6, 7) it was shown that wind speeds within the cover were reduced to less than 20% of their value outside the cover. Additional

wind speed observations were made during the winter of 1987-88 but seldom were wind speeds strong when temperatures approached freezing. Fig. 5 is included to show that the wind speed within the cover during the late afternoon of 25 Feb. 1988 averaged only 16% of the average wind speed outside the cover at the same height, i.e., 5 ft. Since the stall speed of the cup anemometers is approached as the wind speed falls below 2 mph, the wind speed reduction may be exaggerated by measurements during such periods. This is demonstrated in Fig. 5 as the wind speed outside falls below 6 mph. Notice that the inside anemometer has stalled when the indicated wind speed reaches a minimum value and remains at that level.

Temperature modification by the cover. The focus of the work this past winter was on temperature. Fig. 6 illustrates a tendency for the leaf temperatures within the cover to be lower than those outside especially during the early evening hours. The cover is constructed of shade material which reduces solar radiation flux beneath the cover to approximately 1/3 the value outside the cover (preliminary analyses, 4) in spite of the manufacturer’s indication that it is a 50% shade material. Reduced solar radiation beneath the cover probably leads to a reduction in heat stored in the covered soil so there is less energy to be transferred back to the air and trees above the surface as the cooling cycle begins at night. This tendency for the covered area to be cooler by several degrees than the untreated area caused a problem in computing the effect that the heaters burned beneath the cover had on its temperature. In other words, that effect was not simply the average inside temperature minus the average outside temperature. A method developed during the box model studies at The Pennsylvania State University (8) was used instead. This method superimposes the check and the treated areas. In effect, the time trend of temperature before and after the treatment becomes the check for untreated data with which to compare the treated period. With this in mind, more thermocouples were located beneath the cover (15 to 16 each) than outside the cover (4 each, counting the 2 air temperatures on the inversion tower).

Heating effect. The first night that approached freezing sufficiently to warrant a test firing was 6 Jan. 1988 (Fig. 7). The temperature leveled off after midnight and actually rose a degree or so prior to the firing period. It took longer to light the 15 return stack heaters than it did in later experiments because it was the first time that most of the heaters had been fired in many years. The heater stack flange, constructed to support the stack lid hinge, was being used, as well, for the plume diffuser support post. The lid had to be removed completely from the stack and replaced with the plume diffuser during the lighting process. It took 30 min. to light 15 heaters with this procedure and excessive time to reverse the process when they were extinguished, i.e., replacing the plume diffuser with the stack cap. One of the heaters blew its cap and with no plume diffuser in place a hole was quickly melted through the woven polyethylene cover. This experience resulted in brazing the plume diffusers to the heater stack opposite the side that the flange into which the lid hinge is inserted (Fig. 2).

The effect of heating was about 1°F if it is assumed that the temperature within the covered block would have been constant at slightly less than 36°F while the firing was taking place. Only 13 thermocouples remained operational. Two of the thermocouples were dislodged or broken during the lighting process. The problem was solved by covering the leads lightly with soil. Even though 15 heaters are
less than half the number normally recommended for an area of approximately one acre, the heating effect was apparent but less than expected for a microclimate so separated from its environment by a porous windbreak. Apparently the heater plumes rise to and penetrate the woven polyethylene with less resistance than was anticipated (3).

An analysis of the data collected during a fired period on 26 Feb. is shown in Fig. 8. The range of temperature effect on the leaf thermocouples is depicted by graphing the leaf temperature that showed the greatest effect against the average of all 14 leaf temperatures and against the leaf temperature that showed the least effect. This is a relatively large range in the effect at various locations as might be expected from a model (18) based on the manner in which a fruit tree absorbs radiant energy from heater stacks (19). Once the effect is set up it appears to remain relatively constant with time, i.e., the graphed wave form approaches the shape of a square wave by going quickly to a maximum and remaining there until the heaters were extinguished. This seems to indicate that a circulation pattern develops within the covered volume that persists throughout the firing period. This observation seems to indicate that the orchard cover may be at least partially effective in divorcing the enclosed orchard air flow from that outside the orchard cover. However, there appears to be some loss of heat through the porous cover in that the heating effects, even with a smaller number of heaters per acre, was less than expected.

**Wind machine effect.** One of the 2 engines of a dual wind machine (Fig. 1) was operated at about 0.9 throttle during a period from about 2:05 AM until approximately 4:30 AM on 28 Jan. (Fig. 9). The effect on the two outside leaf thermocouples (Tg and Tk; locations indicated in Fig. 1) is much more dynamic than the effect observed within the cover. It is likely that part of this effect is due to the slow speed with which the wind machine jet was rotated horizontally around the tower; i.e., almost 11 min. were required for a single rotation of the jet around the tower. Notice that cold air is apparently pulled into the leaf environment just as the wind machine jet arrives with a pulse of warm air that is rather short lived. It is quite interesting to note how quickly the leaf temperature returns to a cooler state after the jet leaves its vicinity.

**Heated irrigation.** The citrus block in which the orchard cover is located (Fig. 1) consists of 6 zones, each about the size of the covered area. A 7th zone consists of the border trees on the north and west boundaries of the block. A low-volume under-tree irrigation system, designed by Dalton Harrison, has been installed with materials donated by Thayer Industries. The valves controlling the flow to each zone are to be controlled by the same minicomputer that controls the data acquisition system (Fig. 4). This design will permit the pulsing of the various zones at intervals determined by a software instruction set (2, 13). Thayer Industries has promised a small Aquaheet demonstrator unit to be installed just east of the well that is to be drilled (Fig. 1). The plan is to get both the well and the irrigation water heater in place before the first frost or freeze of the 1988-89 winter season. Five General Eastern dew point sensors and associated interfaces have been granted by Thayer Industries to bring humidity sensing capability to the data acquisition system depicted in Fig. 4.

**Windbreak.** An orchard cover has been maintained and facilities nearby are being developed that permit the testing of new ideas in cold protection research. This facility has also served as a laboratory for graduate student training as well as a demonstration for undergraduate classes and visitors to the campus. The shade cloth is to be replaced with a new translucent material (sometimes referred to as white and donated by Weathershade) during the spring of 1989).

**Summary**

In response to grower advice, progress was reported in the redirection of a major portion of the resources toward cold protection methodology that were previously committed to the development of the Satellite Frost Forecast System. A porous orchard cover retards wind speed and resists the loss of heat supplied beneath it. Thus a cover can be expected to aid in the amount of protection that can be
provided during an advective freeze. However, the effectiveness of heating beneath a porous cover was not as great as would have been expected from the ability of the cover to reduce horizontal wind speed (6, 7). It seems likely that the expense of installing and maintaining an orchard cover of this type will be economically prohibitive in all but those blocks of citrus from which an unusual return is expected, e.g., a scion block.

Literature Cited

4. Fernandez, R. T. 1989. Growth, development, and gas exchange of young citrus tree trunks in California (24) and trunk paint has shown to affect trunk temperatures of citrus during freeze periods by retarding heat loss from the trunk (6, 9, 24). However, Jackson et al. (10) reported that some tree wraps cause bark damage by increasing trunk temperatures over nonwrapped trunks during the summer. Wraps have been used to prevent sunburn of young citrus tree trunks in California (24) and trunk paint has been used to reduce trunk temperatures during warm winter periods (13, 18). Similarly, tree wraps have been shown to affect trunk temperatures of citrus during freeze nights. There are no scientific studies, however, concerning the effects of wraps on growth and development of young


TREE WRAPS, TRUNK TEMPERATURES, AND GROWTH OF YOUNG CITRUS TREES

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Abstract. The effect of tree wraps on the growth and development of 1- and 2-year-old 'Hamlin' [Citrus sinensis (L.) Osb.] orange trees budded on Carrizo citrange [Citrus sinensis (L.) Osb. x Poncirus trifoliata (L.) Raf.] as related to trunk temperature was evaluated from 1986-88. Treatments consisted of 4 wraps: Tree Guard®, fiberglass, Reese®, and Tree Saver® along with a nonwrapped control. Trunk temperatures were periodically monitored over the course of the experiment. Highest and lowest daily trunk temperatures occurred 2.5 inches below the top of the wrap. Nonwrapped daily trunk temperatures were highest and lowest at 2.5 inches above the soil line. Two-year-old trees generally had lower daytime and higher nighttime trunk temperatures than 1-year-old trees due to larger canopies. Nonwrapped, Tree Guard, and Tree Saver trunk temperatures were higher during the day and lower at night than trunk temperatures under the Reese or fiberglass wraps. Trunk temperatures under the Reese wraps had the highest nighttime trunk temperatures, regardless of tree age. Trunk diameter, canopy dry weight, root growth, tree height, and the time of growth flushes were not affected by tree wraps. Tree Guard and Tree Saver wraps were nonfunctional after 15 to 16 months and fiberglass showed wear the first year but if properly maintained was effective for 2 or more growing seasons. Reese wraps showed little wear after 2 growing seasons.