In the pruning experiment, the raked area, *left*, stored more heat in the soil and had a higher nighttime air temperature than the area covered with unraked shredded prunings, *right*.

Cover crops, mulch lower night temperatures in citrus

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Winter often brings cold temperatures that can damage fruit or foliage in the San Joaquin Valley, posing an economic threat to citrus producers. Our experiments show that cover crops or mulch can lower minimum nighttime temperatures 0.9°F to 2.2°F in orchards, increasing the threat of freeze (frost) damage. Wind machines are typically used to protect commercial acreage from frost by mixing warmer air aloft with colder air near the surface, thus maintaining warmer minimum temperatures within the orchard. In locations where wind machines are not cost effective, management of the orchard floor is even more important. By using temperature forecast models that adjust for cover crops and mulches, growers can use wind machines more efficiently. Regardless, the decision to use cover crops must take into account all of their cultural benefits and drawbacks.

The potential for cover crops to lower nighttime temperatures has long been a concern among citrus producers. It is well known that bare soil has a greater capacity to absorb incoming radiation during daylight hours and transfer heat back to the surface at night (Gradwell 1963; Cochran et al. 1967; Fritton et al. 1976; Fritton and Martsolf 1981). Cover crops reflect more solar radiation, allowing less to reach the soil surface. They also evaporate more water from the surface soil layer, reducing its thermal conductivity and heat capacity. As a result, less energy is captured at the drier soil surface, and heat transfer and storage are impeded. Consequently, bare soil has better heat storage during the day and improved heat transfer during the day and night.

In addition, limited observations and trials suggest that citrus orchards with groundcover of sufficient height and density have lower air temperatures than orchards with bare ground (Pehrson 1989). Similar observations have been made for deciduous trees (Snyder and Connell 1993) and in grape vineyards (Donaldson et al. 1993).

The extent of freeze damage is related to how far the temperature drops below the damage threshold and the duration at the minimum temperature. Cover crops increase reflection of incoming radiation and shade the soil surface underneath. Groundcovers also remove water from upper layers of the soil and reduce thermal conductivity and heat capacity. Therefore, soil heat storage during daylight is reduced when a cover crop is present.

Similarly, USDA, UC and the University of Arizona have historically maintained that leaving shredded prunings on the orchard floor lowers the orchard temperature. Like cover crops, shredded material theoretically will reduce the amount of solar radiation reaching the soil surface. Therefore, the absence of cover crop and shredded material should enhance daytime heat storage. In light of these phenomena, citrus growers have been reluctant to allow vegetation on the orchard floor.

Recently, there is new interest in using cover crops in citrus orchards be-

This data logger records temperatures. Maintaining clean orchard floors will provide 0.9°F to 2.2°F of protection against freezing on many nights.

cause of perceived beneficial effects on erosion and pest management. However, the benefits from using cover crops may be offset by the potential for freeze damage.

To evaluate the effect of orchard floor management on minimum temperatures and on the potential for freeze damage, we conducted trials in citrus orchards in Tulare and Kern counties during the winters of 1994 and 1995.

Pruning and orchard temperature

We established an orchard floor management trial in a commercial Valencia orange orchard in northern Kern County on Feb. 3, 1995. The 10-year-old trees were in a 22-foot-by-22-foot (6.7-meter-by-6.7-meter) spacing with rows facing north to south. The orchard floor was not tilled, and herbicides were applied for weed suppression. All trees were pruned in September, then the prunings were shredded, leaving a substantial residue of approximately half an inch (1.25-centimeters) depth on the soil surface. Two treatments, raked and unraked, were imposed. In the raked treatment, the shredded material was removed from an area 44 feet (13.5 meters) in all directions from the centrally located tree where temperature was monitored. A second sample tree was located in the unraked plot. Temperature was monitored using model 107-thermistor temperature probes and a datalogger. Thermistors were placed inside of Gill shields and mounted on tree trunks at a height of 5 feet (1.5 meters) above the ground. Temperatures were recorded hourly to evaluate treatment differences.

Cover crop effect on temperature

To study the effect of cover crops on minimum temperature, we also initiated an experiment on March 2, 1995, in southern Tulare County in two adjacent commercial navel orange orchards. Both orchards had 20-year-old trees planted on a 20-foot-by-20-foot (6-by-6-meter) spacing. There was approximately 40 feet (13 meters) between the two plots. One block was nontilled with herbicides applied for weed suppression. The cover-crop block had an established cover crop planted in fall 1994. The cover crop — bell bean, lana vetch and oats — averaged approximately 30 inches (about 0.75 meter) tall, with complete ground shading between the tree rows. Within the tree rows, volunteer weed growth was 12 to 16 inches (0.3 to 0.4 meters) tall with partial to complete shading. One tree was instrumented in each treatment block in the same manner as the pruning experiment.

Minimum temperature analysis

We recorded temperatures after sunset and before sunrise and analyzed them to determine treatment effects. Rainfall was recorded at a nearby California Irrigation Management Information System (CIMIS) station (Snyder and Pruitt 1992) and days with rainfall were eliminated from the analysis. Comparisons were made by computing the regression of the raked versus unraked, and the no-cover-crop versus cover-crop nighttime temperatures. If there are no treatment effects, the temperature at the Y-axis intercept should be 32°F (0°C). If the slope of the regression line is less than unity, the difference between treatments is increasing as the temperature drops.

Raked vs. unraked prunings

In the pruning experiment, the raked area had a higher temperature than the unraked area, and the difference was increasing at lower temperatures (fig. 1). When water evaporates, the air temperature decreases because heat is removed from the environment to break hydrogen bonds between the molecules. When water vapor condenses (i.e., dew or fog formation), heat is released as hydrogen bonds form between molecules and the air temperature rises.

The temperature increased at about 6 P.M. on Feb. 14 (fig. 2), so it is likely that fog formation was the cause. If dew was forming, we would expect a more rapid temperature drop after the initial temperature rise. If clouds were passing over, the rate of temperature drop would decline but the air temperature would not increase.

The treatment temperatures began to separate at about 11 A.M. on Feb. 15 as the fog lifted; the sunlight began to warm the raked treatment more than the unraked treatment. Most likely a short period of fog or cloud passage blocked the sunlight between 1 P.M. and 3 P.M. until the sunlight again began to heat the soil and air, again more in the raked than the unraked plot. Because more heat was stored in the soil of the raked plot, there was more energy to keep the surface warmer during the night of Feb. 15. Where the soil surface is warmer, the air temperature is also warmer.

From Feb. 3 until Feb. 15 the raked plot also stored additional heat in the soil. Even when there was a small difference in the soil heat storage on a daily basis (such as, if soil under the raked treatment accumulated 0.1% more heat per day), we found that the mean soil temperature would increase relative to the unraked treatment over time. On any given day, the surface temperature range may be the same for the two treatments, but because the mean soil temperature is higher for the raked treatment, the minimum surface temperature will be higher. In both the long term

(over weeks and months) and the short term (on a daily basis), removing prunings improves freeze protection.

Cover crop comparisons

In the 1995 cover-crop experiment, the cover-crop treatment had lower nighttime temperatures and greater potential for freeze damage, as demonstrated by the treatment temperature traces from 9 A.M. on March 22 to 6 A.M. on March 25 (fig. 3). The effects of weather on temperature and treatment benefits are complicated. On March 22, weather conditions were sunny and windy during the day. Clouds formed in the evening and rain started at about 10 P.M. While it was raining, the temperature of the two treatments was nearly the same, and stayed about the same until about 1 P.M. on March 23. During March 23, the bare-ground treatment was warmed more by the sun and increased to a higher air temperature than the cover-crop plot. During the night of March 23, the treatment temperatures separated somewhat, but rainfall around midnight temporarily stopped the separation. The next day, the bare-ground temperature increased considerably more than the cover-crop treatment due to sunny conditions. Heat stored in the soil then contributed to keeping higher air temperatures during the night of March 24.

Nights cooler with cover crops

In our experiment, removal of a 0.5-inch (0.0125-centimeter) depth of prunings from a citrus orchard floor increased the nighttime temperature relative to an orchard floor covered with prunings. The shielded temperature at 5-foot (1.5-meter) height within a tree canopy in the raked area was about 33.2°F (0.67°C) when the unraked temperature was 32°F (0°C). The difference in temperature between treatments was greater at lower temperature.

When a tall cover crop with 100% shading was compared to an orchard without a cover crop, the no-cover-crop treatment had higher nighttime temperatures, and the difference was greater at lower temperatures (fig. 4). The orchard without a cover crop is expected to have a 34.2°F (1.24°C) temperature when the orchard with a cover crop is at 32°F (0°C). Clearly, the removal of prunings and maintaining orchard floors clean of cover crops will provide between 0.9°F and 2.2°F (0.5°C and 1.2°C) of protection against freezing on many nights.

The results of this study suggest that a cover crop or mulch can lower minimum temperature at night, posing an increased threat from freeze damage. A 1.0°F difference in minimum temperature can result in a significant increase in damage to fruit during a freeze episode.

However, the cover crop or mulch may offer cultural benefits in overall crop production. Cover crops may increase water infiltration, mulches may reduce weed seed germination and either of the two may reduce erosion on hillsides. The disadvantages of a cover crop include (1) increased evapotranspiration, (2) increased rodent, snail and ant activity, (3) disruption of water application patterns (uniformity) and (4) greater potential for freeze damage. Clearly, selecting the appropriate orchard-floor management practice depends on a number of considerations relative to local conditions.

The decision to use wind machines on any given night depends on the nighttime temperature trend. Historical records demonstrate that each of these machines is operated about 100 hours during a typical freeze season. Higher minimum temperatures may be maintained by properly managing groundcover or eliminating cover crops and mulches, thereby reducing the need to use wind machines and the subsequent operation times. By using temperature forecast models that adjust for cover crops and mulches, the operation of wind machines can also be minimized to save time and money.

For orchards that are not actively protected, removing cover crops and mulch will reduce the chances of freeze damage. If a cover crop is necessary for some reason, planting late in the fall will minimize the potential for freeze damage. Late-fall-planted cover crops are shorter during freeze season

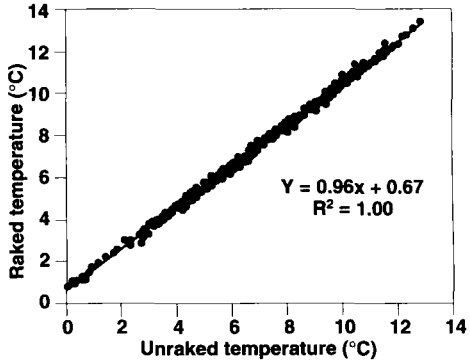

Fig. 1. Regression of raked versus unraked shielded temperatures during nighttime from the pruning removal experiment.

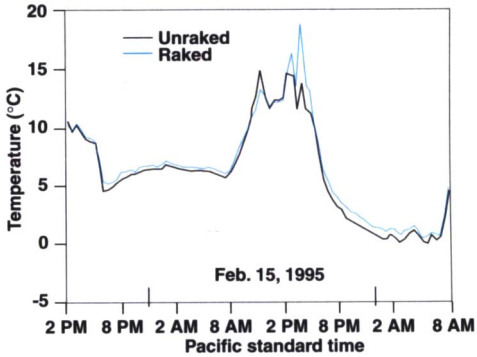

Fig. 2. Shielded temperature values measured in the raked and unraked treatments from 2 P.M. on Feb. 14 to 8 A.M. on Feb. 16, 1995.

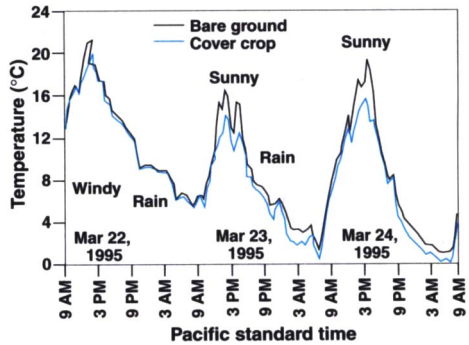

Fig. 3. Shielded temperatures for treatments with and without cover-crops from 9 A.M. on March 22 to 6 A.M. on March 25, 1995.

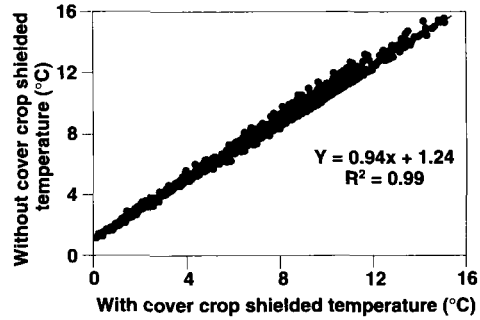

Fig. 4. Shielded nighttime temperatures for without-cover-crop plots versus with-cover-crop plots, 1995.

An orchard with a cover crop had lower nighttime temperatures than an orchard without a cover crop.

(November through mid-February) and the potential for damage is smaller than for earlier plantings, which allow the crop more time to grow.

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