# *Evaluation of*

# MAN-MADE FOG FOR FROST PROTECTION OF CITRUS IN CALIFORNIA

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Field evaluations of two fogging systems designed and marketed for frost protection of citrus in California indicated that, under ideal conditions, some protection to the area under the fog could be obtained. However, the major limitations still remaining with use of fog for frost protection include: producing enough fog particles of an effective size, and holding the fog in the area to be protected.

TWO SYSTEMS BASED on man-made fog have been promoted for protecting crops from freeze damage during the last five years. The first system, marketed under the trade name "Frostop" by Applied Technology Corporation, used cetyl-alcohol-coated water droplets produced by immersing a blowtorch-like burner in a tub containing a mixture of water and cetyl alcohol. The monomolecular layer of cetyl alcohol reportedly increased the heat reflectivity, or back scattering, of the water droplets. The cetyl alcohol layer also suppressed evaporation, thereby overcoming the need to saturate the air with water vapor before fog forms.

The second system, developed and marketed by Mee Industries, produces a non-protected atomized water fog with water droplet diameters between 10 and 40 microns (the range found most effective in reducing radiation heat loss). The manufacturers claimed heat retention effectiveness approaching 90% or 1.5 million BTUs per acre/per hour for this system.

Both the Frostop and Mee fog systems attempt to lay a blanket of heat-reflecting fog over an area, thereby preventing the loss of heat energy. If heat energy is not lost the temperature will not go down; if the fog blanket is only partly effective in reducing heat loss, the temperature will go down, but slower than it would under a clear sky. In addition, a water saturated atmosphere, such as exists with Mee-type fog, may actually warm exposed leaves by means of the heat energy released when water vapor condenses on the cold surfaces of the leaves. Leaf or fruit surfaces cooled below air temperatures by radiation heat loss will condense moisture out of the air because their surface temperature is below the dew point of the surrounding air. When water vapor condenses, the latent heat of condensation (approximately 8100 BTU per gallon) is released to the surroundings, in this case the leaf, fruit and adjacent air.

The three trials reported here were conducted in privately owned orange orchards in three widely separated citrus growing areas of California. Cetyl alcohol protected fog was evaluated in Riverside County during the winter of 1969–70 and in Tulare County the following winter. Mee-type fog was evaluated in Ventura County during January and February of 1971.

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TREATMENT OF FREEZE-DAMAGED CITRUS AND AVOCADO TREES. Leaflet 214. A guide to effective treatment of citrus and avocado trees damaged by the freezes that occur in California at approximately 10-year intervals. Certain techniques have been found to maximize desirable growth responses.

MANAGEMENT OF CLOVERS ON CALIFORNIA ANNUAL GRASSLANDS. Circular 564. Discusses the advantages of seeding clovers on grasslands, describes several species, recommends management practices, and suggests suitable mixtures for California's various rainfall and planting zones.

One of two temperature and radiation monitoring stations used in these frost protection tests at the Topa Topa Ranch, Ojai.

## Riverside County trial

The tests with cetyl-alcohol-stabilized fog were conducted in the narrowest portion of an hourglass-shaped swale in Eagle Valley on land belonging to Corona Foothills Lemon Company. The fog generation system, consisting of a gasoline-powered air blower, propane storage tank and six fog generator pots, was located in the narrowest portion of the swale. The swale, considered one of the coldest areas on the ranch, and the surrounding hills were planted to 10-year-old Valencia orange trees spaced 22 ft apart on the square. The ground under the trees was clear of vegetation but row middles were planted to closely mowed Bermuda grass. Automatic temperature and radiation monitoring equipment were placed approximately 300 ft north (presumably upwind) and 300 ft south of the generators. Temperature only was recorded approximately 1,000 ft south and slightly down slope from the fog generation equipment.

Air flow was not always downhill as had been expected, even when the drift was less than 2 mph. On each of the five nights that the generators operated, the direction of drift changed from approximately due north to approximately due south sometime between midnight and 2 a.m. This reversal required 15 to 20 minutes to stabilize but then persisted until daybreak.

Air temperatures were usually about 1°F higher under the fog than in the clear area. Outside leaves were about 2°F warmer as compared with those outside the fog. Fruit temperatures seemed to be little affected by the presence or absence of fog. Measurements of incoming and net radiation indicated that the fog cover increased incoming radiation and reduced the net loss of heat to the sky. Approximately 100,000 BTU per acre per hour were retained by the fog—approximately 7 to 10% of the total heat being lost.

Another factor greatly influencing fog performance in these tests was relative humidity, as indicated by the dew point. When the dew point was close to the prevailing temperature (higher relative humidity), the fog persisted and spread downwind for 1,000 ft or more. When the dew point was 10°F or more below the orchard temperature, the fog sometimes disappeared before reaching the monitoring station 300 ft downwind. The average acreage covered in these tests was about 5 acres, rather than the 20 to 60 acres claimed by the manufacturers.

## Tulare County trials

During the winter of 1970–71 temperature and radiation monitoring equipment were set up in a 2-year-old navel orange orchard at the base of the Sierra foothills in northern Tulare County, about five miles northeast of Orange Cove. Six Frostop fog generating pots were located at 50-ft intervals across the northern border of the orchard to intercept air drifting downhill toward the south and west from the foothills to the north and east. Temperatures were measured at three locations: (1) 250 ft and (2) 450 ft downwind from the fog generators, and (3) approximately 200 ft west and 100 ft south of the western-most generator—presumably well out of the path of the fog.

Performance of the fog generating equipment was monitored on four nights, January 3–4, 5–6, 6–7, and 13–14. Some difficulties with the equipment occurred the first two nights, because of low gas pressure to the fog generating burners. On all the nights, excessive drift velocity and changing drift direction complicated the trial. Drift velocity averaged about 4 mph near the fog generators and sometimes approached 7 mph, greatly thinning out the fog cover. The direction of drift swung 90°, from about 10° east of south to about 10° south of west. Most of the time the drift was about 15° west of south. Whenever the drift was more than 25° west of south, one or both of the monitoring stations were out of the fog. The high velocity of drift also interfered with the expected spread of the fog over the alluvial fan below the mouth of the canyon. Measurements made on several occasions indicated the fog band increased in width from approximately 250 ft at the generators to about 350 ft at the first drive road (600 ft downwind) and to about 500 ft wide at the second drive road (1200 ft downwind) and beyond. Very seldom did the fog spread out to cover more than a 500- to 600-ft-wide band—which, because of changing drift direction, swung back and forth like a pendulum during the night.

## Radiation loss

Temperature and radiation loss measurements therefore had to be correlated with the presence or absence of fog. Graph 1 shows the air temperatures recorded during the night of January 6–7 as influenced by the fog cover. On this particular night the drift was mainly towards the southwest, but on several occasions the drift swung almost due west, missing all but a corner of the citrus orchard. On several other occasions the drift velocity became so high (exceeding 7 mph at times and averaging 5 mph between midnight and 2 a.m. and between 4 a.m. and 5 a.m.), that fog cover density was greatly diminished. When there was good fog cover, air temperatures under the fog were 1 to 3°F higher than in comparable areas outside the fog. Radiometer measurements indicated that net radiation, a measure of heat lost to the sky, was reduced 5 to 20% by the fog cover. As was the case in Eagle Valley, protection afforded by the fog depended on direction of drift, which—although more consistent than at the Riverside County location—was nevertheless far from stable. Drift speed was a greater limiting factor than drift direction at the Orange Cove location.

Area effectively covered by the fog varied as a function of the drift velocity. At drift speeds approaching 7 mph the fog cover was extremely thin within yards of the fog generators. When drift speed was under 3 mph the fog cover appeared quite dense for a distance of 1200 ft or more. Under close to ideal conditions, therefore, the unit came close to covering 20 acres with visible fog, but this was the exception, and not the usual situation.

## Ventura County trials

During January and February of 1971 an opportunity was provided to evaluate a Mee Industries fogging system (non-protected, atomized water) on the Topa Topa Ranch near Ojai in Ventura County.

The trial took place on a 40-acre block of 15-year-old Valencia oranges, located in a wedge-shaped valley about five miles east of Ojai. The rows ran north and south with a slope towards the south. A small drainage ditch ran diagonally from NW to SE. The area along this ditch was one of the coldest on the ranch, as indicated by many cold-damaged trees.

The fog generation system, consisting of a high pressure (600 psi) electric motor powered pump, filters and several hundred feet of schedule 80 PVC pipe fitted with special atomizing nozzles, was located slightly above the last row of trees at the north end of the valley and at the base of a steep slope.

### Monitoring equipment

Temperature and radiation monitoring equipment (see photo) were located about midway between the fog generators and the drainage ditch and also to the west, across the ditch and out of the expected fogged area. A portable gasoline powered electric generator provided power for the two potentiometric multi-point temperature recorders and for the radiometers. Thermocouples on 100-ft extension cables extended both 100 ft uphill (toward the fogger) and 100 ft downhill (toward the drainage ditch) from the recorder, which was itself appproximately 300 ft downhill from the fogger. Air, leaf and fruit temperatures were thereby monitored at 200, 300 and 400 ft downwind from the fog-generating nozzles.

Detailed meteorological data were collected on three different nights. The most comprehensive temperature and radiation data were recorded on the night of February 18–19, 1971. On this particular night the fog-generating equipment was started at about 8 pm and allowed to stabilize until about 9:45 pm, at which time the pump was shut off for approximately one hour, then restarted and run for one hour before being shut off for the night, because there was no longer any threat of damaging cold.

Turning the system off and then on again provided an opportunity to observe the effects of fog cover on heat loss (radiation) and orchard temperatures (see graphs 2 and 3). While the fogging system was in operation from 8 pm to 9:45 pm air and leaf temperatures gradually decreased. When the fog cover cleared away at about 9:50 pm these temperatures immediately started downward at about 3°F per hour. This trend stopped immediately when the fogging system was restarted an hour later, and within an hour the temperatures had climbed back to about where they had been before the shutdown. Considerable condensation of moisture on leaf surfaces was evident at this time, indicating that released heat of condensation was probably responsible for a considerable portion of the observed temperature rise under the reestablished fog cover. Temperatures plunged abruptly again about 11:30 pm, when the fogging system was shut down for the night.

Net radiation data for this same period looks like a mirror image of the temperature response—that is, heat loss increased in the absence of fog and was reduced 35 to 40% by the return of the fog cover. The Mee-type fog seemed considerably more efficient (35 to 40% versus 7 to 15%) than the cetyl alcohol type fog in containing the orchard heat within the orchard. In spite of these apparent successes, the Mee system did not live up to expectations. In no case was the temperature increase greater than about 3°F, and even under close-to-ideal conditions only about five acres were effectively covered by the fog.

As in previous tests, unpredictable air movements complicated the experiment. When air drift was slow fog covered the approximately five acres of lowland fairly uniformly. Increases in drift velocity or shifts in drift direction immediately disrupted the fog coverage and pushed the fog uphill to normally warmer areas—where it was not needed as badly as in the lower basin.

During preliminary trials on the night of January 4–5, 1971, temperatures in the orchard were found to range from 30°F near the fog nozzles to 23°F at the lower end of the ranch, and out of the fog blanket. Considerable tree and fruit damage occurred after this episode.

### Summary

Both systems tested produced copious amounts of fog but never enough to do the job claimed for them. Changing drift patterns and excessive drift velocity were the principal stumbling blocks to efficient operation. When conditions were close to ideal, both types of fog afforded some protection to the area under the fog. In these trials the Mee fog performed considerably better than the Frostop fog, reducing outgoing radiation more significantly and actually raising air and leaf temperatures several degrees due to condensation of moisture from the saturated air on colder than air surfaces. The major limitations with using fog for frost protection therefore remain: 1. producing enough fog particles of an effective size to cover the desired area and 2. putting and keeping the fog where you want it.

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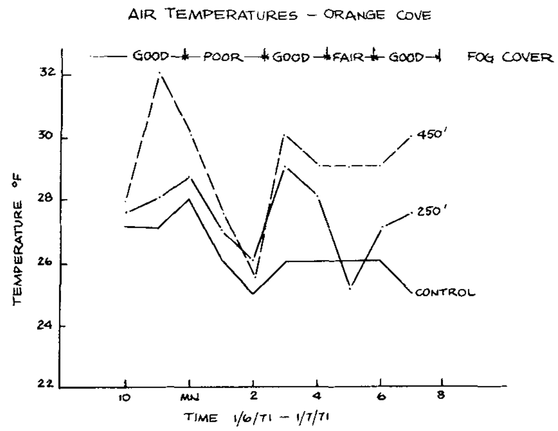
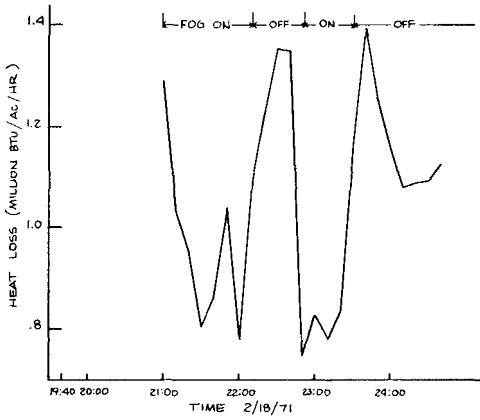
GRAPH 1. RECORDED AIR TEMPERATURES AT ORANGE COVE TRIAL DURING NIGHT, JANUAAY 6–7, 1971




GRAPH 2. MEASUREMENTS OF NET RADIATION (HEAT LOSS) AT NIGHT AT THE TOPA TOPA RANCH, FEB. 18, 1971




GRAPH 3. MEASUREMENTS OF AIR TEMPERATURE AT NIGHT AT TOPA TOPA RANCH, FEB. 18, 1971