Orchard Heating Effectiveness

protection against radiation frosts by orchard heaters and by wind machines alone and in combination compared

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The following article is the tenth annual report of progress in studies on orchard frost protection, based on report given at the 15th International Horticultural Congress in Nice, France, April 1958, now at Press.

Orchard frost-protection costs have been greatly reduced by using blowers—wind machines—which, in general, reduce the number of heaters needed to about one third, and the heater hours of operation to about one sixth.

Frost protection by heating alone has become too expensive for most citrus growers, and it is uneconomic for the deciduous fruit industry as a whole, although some individual growers need springtime frost protection. In a citrus grove, during a medium winter—10 nights totaling 50 hours of protection—the operating cost, including maintenance, is about $100 per acre with heaters alone, but only $38 per acre with a wind machine and occasional heater support. The installation cost per acre for the lazy-flame type of heaters—50 per acre—including fuel storage tank and other equipment, is about $340 per acre, whereas the installation cost of blower plus 15 return-stack heaters is close to $450 per acre.

Typical dual-engine wind machine in a citrus orchard.

Night Temperature Inversion

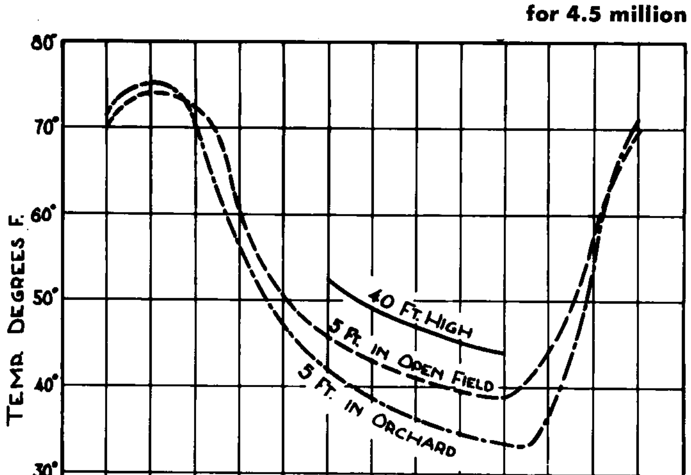
An examination of the average hourly temperatures for 15 nights of frost—or near frost—reveals that in citrus, because of its dense foliage, there is a horizontal difference in temperatures as well as the well-known vertical difference in temperatures—inversion. For these 15 nights, at 5′ height, the average difference between an open field and inside the orchard was 5.4°F, while at 40′ height the average hourly temperatures were the same at both places. Such horizontal differences are not found in deciduous orchards with nearly bare branches, which partly explains the weaker vertical inversions found when almonds need frost protection.

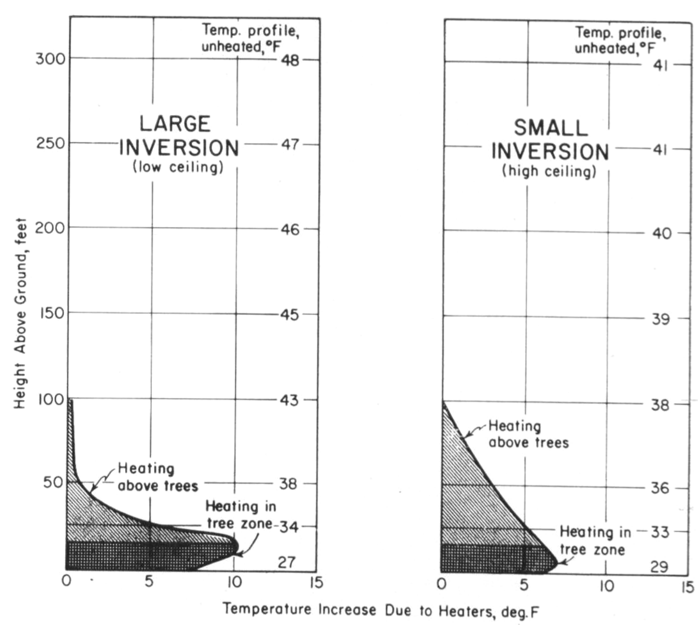
Another reason for weak inversions in deciduous fruit areas is that there is less warming of overhead atmosphere by air-mass subsidence in the spring than in the winter.

Orchard Heating

Because radiation loss to the cold night sky is area-wide, heat sources must be distributed rather uniformly throughout any area to be protected. Heating effectiveness depends on the strength of the inversion and increases with the size of the area heated, but regular practice calls for 45–50 heaters per acre for oranges and about 100 for lemons. Ordinarily, the air temperature is allowed to go slightly below the danger point—incurring some frost damage—and not all the

Left—Average hourly temperatures of 15 clear winter nights, Riverside, showing the two-part inversion in citrus orchards—vertical and horizontal. Right—Vertical distribution of heating effect in weak and in strong inversions—both examples for 4.5 million Btu per acre-hour.





heaters are lighted on the first trip through the orchard. Two workers—running—can light and regulate one fourth to one third of the heaters for five acres of oranges in about 15 minutes. Additional firing is usually needed after 1½–2 hours, but very close watch is kept on temperatures to keep fuel use at a minimum. Sometimes no additional protection is attempted in the last hour around sunrise even though some losses often result from the temperature drop then.

Comparable studies of heating effectiveness in deciduous orchards were not made but the usual burning rate per heater was observed to be about the same as for citrus. The outstanding differences are that the number of heating hours per night is very much less in deciduous orchards but cooling below the danger point always results in damage. However, there is considerable spread in susceptibility and a great surplus of blossoms, so total loss is rare unless there are two frosts. The openness of the orchard underneath the twig canopy seems to favor heating effectiveness, but not wind-machine performance.

Heaters

Only small heat sources can be used if the entire heat of combustion is to be kept low, close to the trees well within the inversion. Ordinarily, the lazy-flame heaters use less than one-half gallon of fuel oil per hour. In weak inversions, burning at the high rate of one gallon per hour may produce a convective plume of hot air buoyant enough to pierce the ceiling. In one such case, reducing the burning rate by 50% actually increased orchard temperature.

Heater effectiveness depends somewhat on heater design, particularly with weak inversions. Tests of temperature responses were made with four heater types in the middle of a one-acre heated portion of an extensive unheated orange orchard near Riverside. The results were all adjusted to a rather high average heat output—7 million Btu per acre-hour—including 25 border heaters in addition to the 45 distributed heaters. Perforated-drum, coke heaters were best because of strong radiation output, largely horizontally from red-hot metal and white-hot solid fuel. The pipe-line heater was poorest, because its red-hot cover radiated mostly upward, to the sky. The lazy-flame heater was nearly as effective as the return-stack, because the lower burning rate per heater favors lower-level dispersion of convective stack heat. Exclusive of border heaters, at least two times as much heat is needed in a one-acre plot per degree temperature response as would be expected in a larger area. However, the one-acre results can be applied directly to the outer portions of a large heated area. The advantage of strong midwinter inversions when using heaters is even more pronounced when large blowers are used for frost protection.

Heating Requirement to Produce a Temperature Rise of 1°F in Citrus Orchards of Various Sizes. (Lazy-flame type heaters)

Orchard area	Air-drift velocity at 20′	Temperature inversion 5′–40′		
		3.6°F	9.0°F	13.5°F
Acres	mph	Million Btu/acre-hour		
1[1]	1.8	2.4	2.0	1.7
7	1.5	...	0.8	0.7
15[2]	1.6	...	0.6	0.5
28	1.1	0.9	...	...
7–28[3]	1.4	0.9	0.6	0.5
600	...[4]	...	0.6	...

[1] Heater test plot with 25 border heaters, in addition to 45 distributed inside.

[2] Using Exchange-stack heaters (flame inside a tall 7″ diameter stack).

[3] Omitting border heaters.

[4] Heaters burning in every sixth row of trees (120′), transverse to direction of air drift.

Large Blowers

Dual-engine wind machines send out two jets of air in opposite directions, each pointed down by 7° or more into the orchard. Since the whole top of the tower turns slowly on a vertical axis—about one revolution in eight minutes—each jet sweeps the orchard, like the beam from a lighthouse, but the outward velocity decreases quickly. Beyond approximately 650′ from a 70-b.h.p.—brake horsepower—propeller, the outflowing air lags so far behind the axis of the propeller that the jet advances outward almost broadside as an expanding toroidal ring. The size of this spiral system decreases if the turning speed of the jet is increased. In general, therefore, the protected area in which overhead warm air is effectively mixed with chilled air in the tree zone depends on tower rotation rate as well as propeller thrust and power. Results with a heated jet were disappointing because the increased buoyancy lifted the jet out of the orchard too quickly. Even the jet from a small machine in a strong inversion often does not carry as far as expected.

When spacing is close enough to cause interaction, multiple towers provide frost protection to more acres per machine than do isolated towers. For 70-b.h.p. single-motor towers, multiple spacing—700′ apart transverse to the cold-air drift, and maybe 900′ apart along the line of drift—seems a maximum for citrus orchards near Riverside for a response of 2°F or more. For small machines—15 b.h.p.—the maximum temperature response is less and average spacing probably is 400′ × 550′. Heater support is

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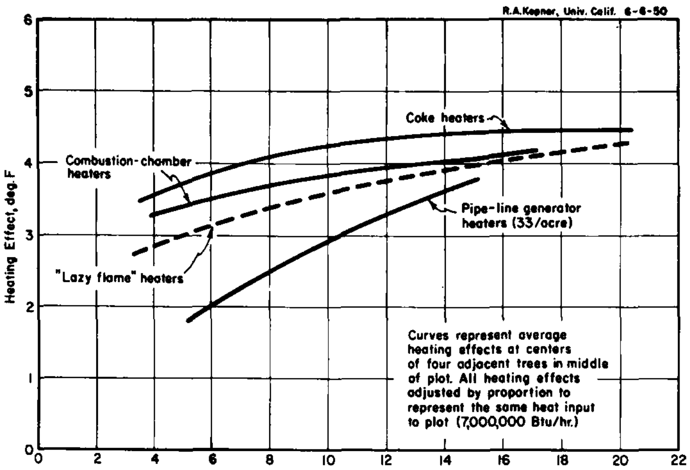
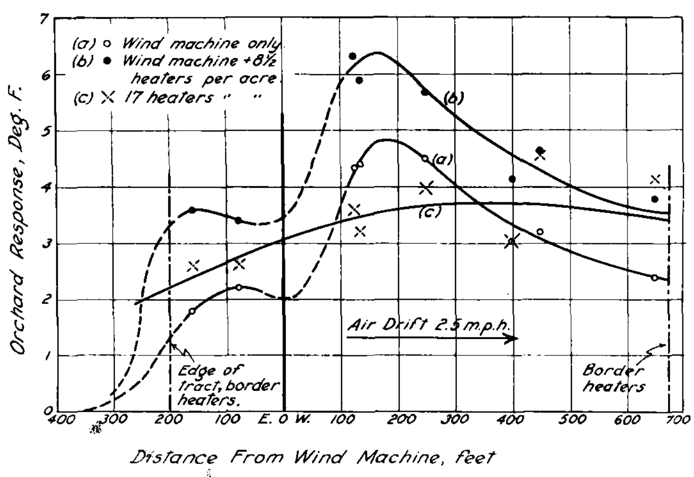
Left—Average single-acre temperature response to four types of heaters as a function of temperature inversion—all for 7 million Btu per acre-hour. Right—Temperature response along axis of air drift from one 93 b.h.p. motor with tower turning speed of 180° in four minutes in the downdrift direction and 180° in 1⅓ minutes when facing in the up-drift direction.





PRUNES

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plot. All rows—treated and control—were protected by guard rows.

Three severely injured trees near the plots received limb injections of boric acid on May 24, 1956. Two holes were bored in each branch, and one gram of boric acid was placed in the bottom of each hole. The injection treatment is used only in diagnosing the trouble.

In another part of the orchard, three trees were given soil treatments—one-half pound, one pound, and two pounds of borax—on June 19, 1956. The treatments were followed by a sprinkler irrigation.

All the trees in the plots were graded on June 19 and 20, 1956 and again on June 13, 1957.

The sprayed trees produced considerably more prunes in 1957 than the adjacent controls and there was a definite reduction in the brushy branch symptoms.

The soil treatments did not significantly increase the yield, but on the basis of experience with other fruit crops in other nonirrigated areas, they are expected to show effectiveness in 1958.

Leaf samples collected on June 18, 1957 were analyzed, and the results showed that the soil treated and sprayed trees absorbed substantial amounts of boron. This preliminary evidence indicates that the one-half pound treatment may be adequate and that the two-pound treatment may result in some injury. However, definite conclusions can not be drawn until after the 1958 results are obtained.

Apparently boron applied to the soil of a nonirrigated orchard in the fall does not get into the tree fast enough to eliminate symptoms the next year. However, the trees that received a soil treatment on June 19, 1956 followed by a sprinkler irrigation were free of brushy branch symptoms in 1957.

The branches that received the diagnostic injections of boric acid were free of symptoms in 1957 while the untreated parts of the same trees still showed injury. In addition, the treated branches produced a much heavier crop of prunes.

Because a single foliage spray in early summer gave good and quick results, such treatment probably should be the first given injured trees. Whether soil or spray treatments should be given later depends on the preference of the grower. However, if no boron is added to the soil, annual foliar sprays will be necessary. From experience in other areas, it is likely that a single soil treatment will be effective for from three to five years. The best rate of treatment for the affected Sonoma County areas involved is not yet known, but approximately 50 pounds of borax per acre appears to be effective. Boron fertilizers vary in strength but the label on the container usually gives a conversion factor, so the exact amount to use may be calculated.

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ASPARAGUS

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The original profile curves plotted for these studies had somewhat convex or concave shapes. But by graphical adjustments—shifting the profiles along the height axis—straight profile curves were obtained from which the zero-plane distances above the ground—the equivalent surface heights—could be read.

In unprotected fields the equivalent surface was 4″–6″ below the asparagus ridge tops, under all wind directions, including winds parallel to the ridges and those perpendicular to the ridges. Snow fences improved the conditions a little by providing a modest lifting of the equivalent surface approximately to ridge heights. However, in fields with interplanted barley the equivalent surface was raised to around 5″ above the asparagus ridges in case of cross-wind direction. But when the wind hit the rows at an angle somewhat less than 90° the protection was still more effective, raising the equivalent surface to about 10″ above the asparagus ridges. The cause of the rise might be the greater number of barley blades which oppose the air motion than in the case of the perpendicular wind. Another reason might be the ability of the barley heads to bend, which tends to lower the equivalent surface more in cross-wind. Even in parallel wind blowing along the rows some valuable protection was obtained because the equivalent surface height was 2″ above ridge tops. The explanation might be in the turbulent structure of the wind with its unsteadiness of direction—always recognizable from the unrest of a wind vane—which intermittently causes the wind to hit the rows under an angle. The larger graph on page 6 shows some curves of velocity change near the ground after the determination of the equivalent surface height.

Calculations by the power law—in which the exponent characterizes the surface roughness—resulted in a roughness increase by about 50% from both the snow fence and the barley row protection methods. The reason that the snow fences looked so competitive with the interplantings could be the different temperature stratification during the snow fence tests—caused by overcast sky—which tends to increase the exponents. Future measurements probably will call for some adjustments. Unfortunately, ridging for white asparagus does not reduce the soil erodibility as does plowing in some midwestern plain states, where heavy clods are brought to the top of the soil. The ridging of white asparagus beds in the Delta area accumulates just the erodible material at the ridge tops. Continuing investigations on increasing soil surface roughness—by supplementary methods to decrease the shear stress of wind at the soil surface—are being conducted in the Delta area.

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FROST PROTECTION

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needed more often with small than with large machines.

The temperature responses for all three systems—heaters alone, machine alone, and machine plus heaters—are shown in the graph on page 5. Temperature increments are along the direction of natural air drift from the machine. The machine is a single-motor tower 93 b.h.p. arranged to turn slowly—180° in four minutes— when with the drift, and three times as rapidly against the drift. Curves *c* and *a* compare heaters alone with the machine alone. The temperature difference in the orchard—5′–40′ high—was 11°F. The combination curve *b* is for the machine operating concurrently with half the heaters used for heating test *c*. The great advantage of the combination is that the machine often gives adequate protection for the whole night, and in general, the heater-hours of support—when required—amount to less than one sixth those needed without the machine.

The temperature response tests conducted with four types of heaters in an orange orchard in Riverside County were conducted by R. A. Kepner, Professor of Agricultural Engineering, University of California, Davis, and reported by him in University of California Agricultural Experiment Station Bulletin No. 723, available for consultation in most agricultural reference libraries.

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