Frost Protection in Almonds

wind machine studies in 1955 frost season indicate protection in mature almond orchards below that obtained in citrus

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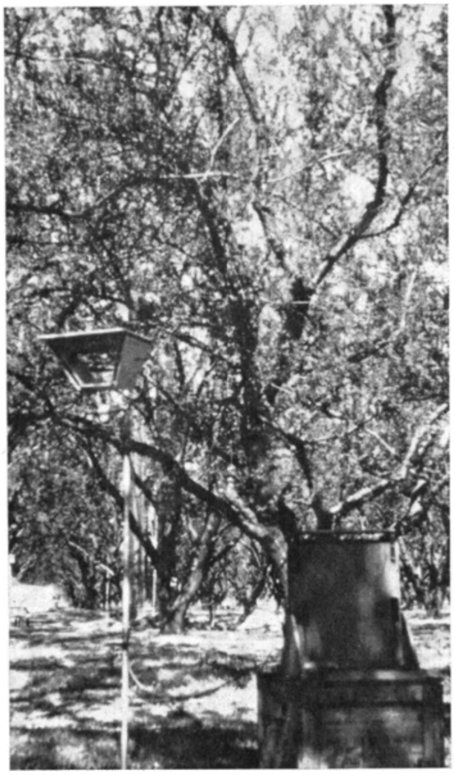
In the Chico area, almond orchards need frost protection—on the average—six nights a year, two years out of three, with one or two of those nights needing 2F or 3F of protection. Late frosts—in April—generally occur only once in eight years. This year there were about one third more frosty nights than usual, and several of those nights occurred in April. This made it possible to conduct a good series of wind machine tests both when the trees were relatively bare and when they had considerable foliage.

Instrumentation

The instrumentation used in the tests measured air temperatures with thermocouples at the 10′ height at 40 different locations in the orchard. At eight locations, temperatures were measured at the 20′ height; at four stations, at the 35′ and 50′ heights; and at one station, temperatures were measured from 10″ down in the soil to 72′ in the air. All temperatures were automatically recorded on electric typewriters in degrees Fahrenheit, with each temperature being measured every three to six minutes. The air drift velocity and direction at the 35′ level at each corner of the test plot were continually recorded.



Photograph showing the extensive interference in the path of the air jet from the propeller—near the upper left corner of the picture—to the ground, for a down pitch angle of 18½°. Note the open space under the trees.

Natural Conditions

Interpretation of the actual protection from a wind machine is often difficult because of the natural temperature pattern in the orchard. The diagram at the top of page 4 represents a plot of 10′ air temperatures averaged over a half-hour period, just before the wind machine was started for frost protection. The propeller-like symbol for the machine is in an area naturally warmer than the borders—especially the corners—as indicated by the curving isotemperature lines. Many orchards have cold borders and corners because they are exposed to alfalfa or grain fields or other cold air sources. A logical method of frost protection for such an orchard would be to first raise the temperature of the borders and then—if the temperature continues to fall—provide protection for the entire block.

A natural temperature pattern such as this will lead to a false impression of the value of a wind machine when only the pattern of nuts not frozen around the machine is used to make an evaluation. Therefore, to determine the actual protection pattern of a wind machine, temperatures must be measured over the whole orchard on many frosty nights both with and without the machine in operation.

Wind Machine Performance

Two wind machines were tested. Both had 25 hp electric motors, but one had a 9′ diameter propeller which turned at about 900 rpm and delivered 280-pound thrust, while the other had a 12′ propeller which turned at 600 rpm and produced 340-pound thrust. On each machine the propeller was 42′ above the ground and the turning time was about four minutes.

The diagram at the lower left on page 4 represents the average temperature response—rise in air temperature at the 10′ level produced by the machine—to the 280-pound thrust machine for four test nights before the almonds were foliated. Similarly, the diagram at the lower right represents the average response to the 340-pound thrust machine for two test nights with the same down-pitch and rotation time, and before the trees were foliated. The larger thrust machine has a 1F response area of only 1.8 acres, while the smaller machine could not do that well.

Response and Inversions

Compared with the performance which had been obtained in a citrus grove near Riverside with a wind machine of nearly equal thrust, this is a poor showing. The principal reason for the small temperature responses obtained at Chico was the small inversions—air temperature difference between 50′ and 10′ levels—with which the wind machines had to work. The air above the tops of the trees was not enough warmer than that in the trees to provide a good source of heat. The table on page 5 shows temperatures and inversions during 16 typical radiation frost nights, including the very cold period during the middle of March. These inversions average a little less than 6F and are about half as large as those measured in citrus at Riverside on the same type of night. These inversions are so small that no present design of wind machine should be expected to raise the temperature as much as 2F over a 10-acre area as was achieved at Riverside.

The inversions became somewhat larger as the leaves developed. Since the leaves and branches cool by direct radiation to the sky, the increased leaf area as the leaves develop provides greater contact area for cooling the air below the 50′ level. Also, the thick foliage in the tops of the trees tends to prevent the warmer air, which is drifting across the orchard above the tree tops, from reaching down and picking up the colder air which has settled among the trees.

Considering the conditions under which the machines had to operate, the maximum temperature response which they produced at Chico was not much lower in proportion to the inversion than at Riverside. As shown in the lower dia-

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gram on the right on page 4, the maximum response measured is 1.7F. This is 37% of the 4.5F inversion. In citrus, a wind machine with 240-pound thrust produced a maximum response of 2.7F on a 6.5F inversion—41% of the inversion.

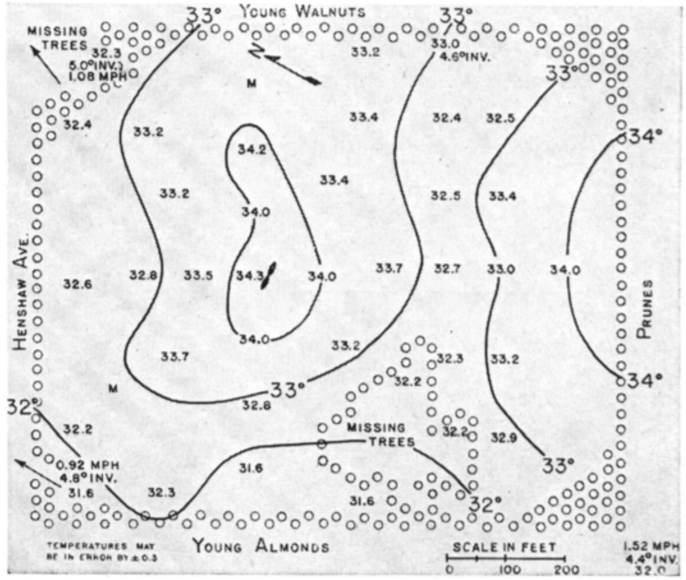
These tests show the dependence of wind machines of current design on the presence of a reasonably large inversion for satisfactory frost protection. Since the magnitude of the inversion may be influenced by several factors—slope of the orchard, nearby and more distant topography, proximity to large bodies of water, size and spacing of trees in the orchard, size and type of vegetation on the surrounding land, time of year, and possibly others—tests to establish the presence of an adequate inversion should be made before a wind machine is installed in any new area. These tests should be designed to measure air temperature at about 10′ above the tree tops and at eye level and should cover the latter part of the night—when frost protection is most likely to be needed—on most of the frosty nights of at least one average frost season.

What little protection the wind machine did provide in the almond orchard covered a smaller area than that found in citrus. The principal reason for this was the difference in size, shape, and planting of the trees. In the citrus grove the trees were planted on a rectangular pattern. Although their size and spacing in one direction were such as to make them almost touch each other, in the other direction there was a space 6′ to 8′ wide, clear to the ground. This gave a channel by which the jet of air, produced by the propeller of the wind machine, could easily reach the ground.

In the almond orchard, the trees were planted on a triangular pattern, and they were so large that their upper branches were almost completely interlocking in all directions. Not only were there no channels between the rows of trees, but there was little more than an occasional hole through which the jet of air might reach the ground. Before the tests were made, it was thought that the relatively open structure of the almond trees, especially before the leaves came out, would allow the jet of air from the wind machine to reach the ground quite easily. The tests proved otherwise and showed that even though there was much space between the twigs and branches, their interference to the free flow of air was quite strong.

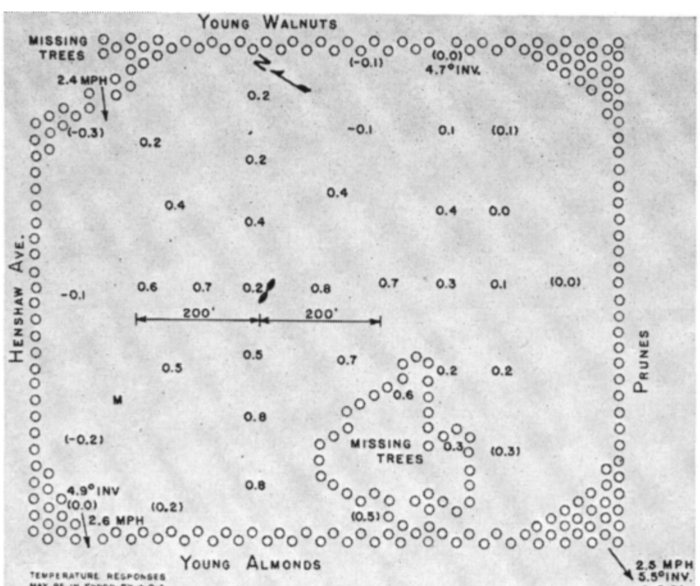
As the almond leaves increased in size, the response from the wind machine became less and less. By the middle of March it was difficult to follow the jet—twig and leaf movement in the tree tops—beyond 150′ from the machine, and the jet was not reaching the ground anywhere. On March 14, the down-pitch of the larger machine was changed from 7½° to 18½°. This made the center line of the jet intersect the ground only 127′ from the machine.

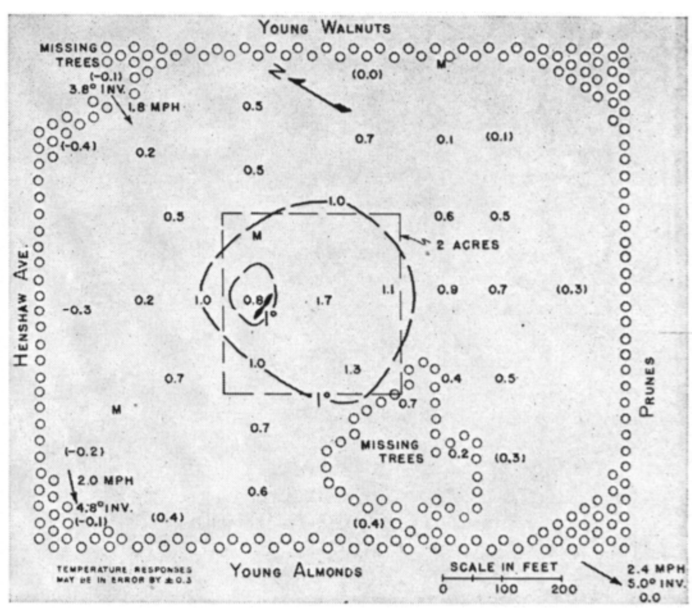
This radical change of down-pitch was made with the hope that it would increase both the degree and area of protection. It was reasoned that the much greater down-pitch angle would give a path from the propeller to the more distant parts of the orchard which would include a much smaller footage of dense twigs and leaves. Once the jet had gotten through to the space under the trees, it would be relatively free to continue out



Plot diagram of the 10′ air temperatures just before the wind machines were started for frost protection. The cold borders and warm area under the machine falsely make it appear that the wind machine was already operating.

Plot diagram showing the response to 25 hp machines both with 7½° down-pitch and turning through 360° in approximately four minutes. The diagram on the left is for 280-pound thrust machine with a 9′ propeller turning at 900 rpm. The diagram on the right is for the 340-pound thrust machine with a 12′ propeller turning at 600 rpm. The larger machine has a 1F response over 1.8 acres, while the smaller machine did not produce a 1F response.





to the borders of the orchard. Even this path offered considerable obstruction, as shown in the photograph on page 3, which was taken from a point on the axis of the propeller shaft only 90′ from the machine.

The machine was operated with this steep down-pitch during the middle of March cold spell and the 1F response area increased slightly. It was observed that against the cold air drift, the jet could not penetrate the trees to the ground, whereas with the drift, the jet reached the ground nicely. Where the jet penetrated, it could be easily followed to 200′ from the machine. Later in the season when the leaves were nearly full size—even with the 18½° down-pitch and the machine not rotating—the air jet from the 340-pound thrust machine could not reach the ground either with or against the air drift. The jet did not have enough momentum for penetration.

The effectiveness of large, dual gasoline engine wind machines was checked by making counts of damaged and undamaged nuts in an orchard near Durham. The results of these counts are shown in the diagrams in column 1 on this page. The numbers near the symbols for the wind machines indicate the amount of nuts saved in terms of quarters of the original crop—which was not a really good commercial crop to start with.

The range of temperature response for the first frost—March 15, 16, and 17—represented by the range of numbers from *4* to *0* probably was 1F to 2F. During this frost, wind machines Nos. *1* and *2* saved only 25% or more of the crop over an area of about nine acres each. Machines Nos. *1*, *2*, and *3* are spaced too far apart—1300′—to be of mutual aid. The patterns of Nos. *2* and *4*, which are 900′ apart, do overlap and show some mutual aid.

The lower diagram in column 1 shows the crop remaining after the more difficult frost for wind machine protection during the first week end of April. This can be explained in several ways: *1*, the foliage had increased to the point that made it very difficult for the warm air jet to pierce through the trees; *2*, the

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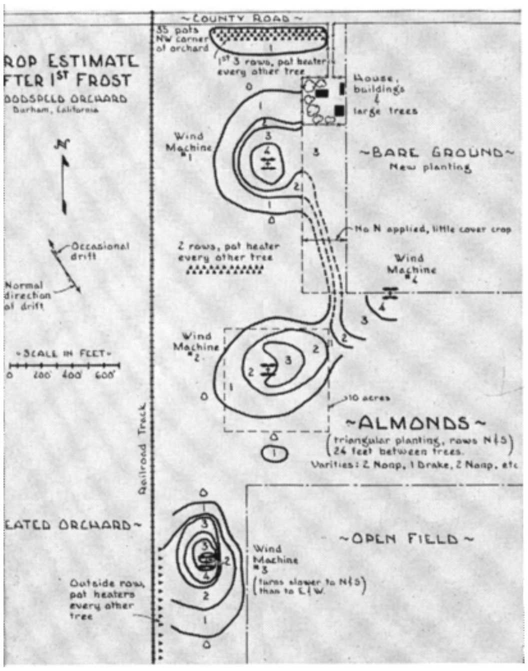
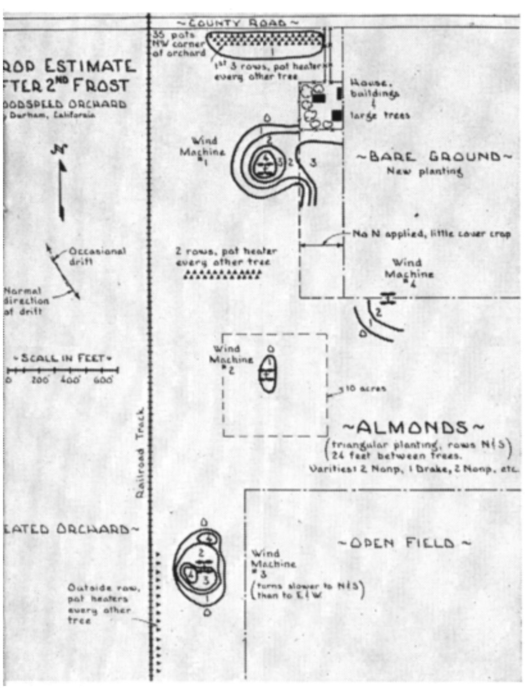


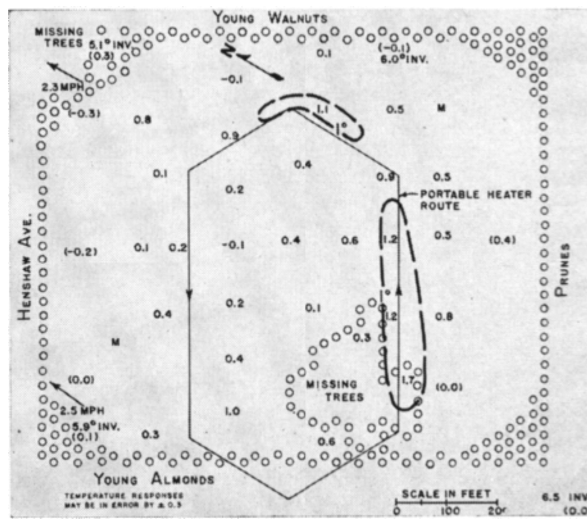


Plot diagrams of the crop that came through the frost season under large dual engine machines. The machines gave some protection over about nine acres each during the first—*above*—frost, and show very little protection in the second—*below*—frost.

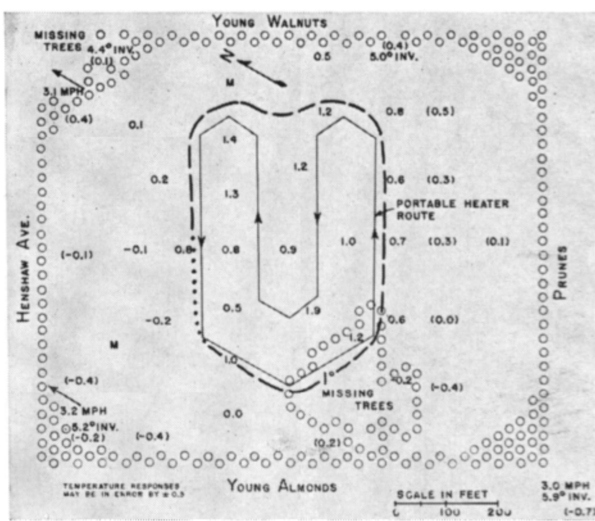
Average Inversions on Test Nights, for Outside Stations

Temperature difference between 50′ and 10′

Chico, 1955			
Date and time	50′	10′	Inversion
February			
21–22	°F	°F	°F
2:00–3:00	40.0	35.2	4.8
4:00–5:00	35.3	31.6	3.7
6:00–7:00	33.7	29.4	4.3
22–23			
10:00–11:00	40.5	35.8	4.7
12:00–1:00	38.1	32.0	6.1
2:00–3:00	35.7	31.9	3.8
4:00–5:00	36.2	31.4	4.8
6:00–7:00	33.6	30.1	3.5
23–24			
10:30–11:30	46.0	41.1	4.9
12:30–1:30	43.9	39.7	4.2
2:30–3:00	39.5	34.4	5.1
4:00–5:00	36.8	32.6	4.2
6:00–7:00	34.1	30.7	3.4
Feb. 28–March 1			
10:30–11:30	40.1	36.5	3.6
12:30–1:30	40.0	37.4	2.6
2:30–3:00	35.7	32.2	3.5
4:00–5:30	34.5	30.2	4.3
6:30–7:00	33.2	28.8	4.4
March			
1–2			
12:00–1:00	42.4	37.2	5.2
2:00–4:00	39.8	34.6	5.2
2–3			
12:30–1:30	44.1	40.1	4.0
2:30–4:30	40.1	35.7	4.4
5:30–6:30	38.6	32.2	6.4
5–6			
2:30–3:30	39.9	34.1	5.8
4:30–5:30	36.2	30.0	6.2
15–16			
2:00–2:30	37.8	32.2	5.6
16–17			
11:30–12:30	40.9	34.3	6.6
1:15–2:15	41.3	32.8	8.5
3:00–4:00	34.7	30.0	4.7
17–18			
11:18–12:06	46.0	35.9	10.1
1:30–3:00	42.9	32.6	10.3
3:30–4:30	38.7	30.9	7.8
18–19			
12:30–1:30	42.2	37.4	4.8
2:30–4:30	41.7	33.9	7.8
23–24			
1:30–2:00	47.8	40.3	7.5
3:00–5:00	43.7	37.9	5.8
5:30–6:30	43.6	35.8	7.8
29–30			
12:00–12:30	44.4	38.3	6.1
2:30–4:30	39.0	33.6	5.4
April			
6–7			
2:00–3:00	49.6	43.2	6.4
4:00–5:00	45.2	37.3	7.9
11–12			
12:00–1:00	47.8	41.3	6.5
2:00–4:00	47.6	41.7	5.9
5:00–5:30	45.2	38.2	7.0
14–15			
11:30–12:00	46.9	40.2	6.7
1:00– 3:00	42.5	37.4	5.1
3:45– 4:15	36.9	32.2	4.7



Plot diagram showing the temperature response to a portable heater wind machine. Over the large singular route—*above*—the machine could raise the temperature slightly only along the path. When traveling the back and forth route—*below*—the heater raised the temperature about 1F over four acres.



PRUNES

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quirements in these studies resulted from delayed harvest.

An evaluation of quality suitable for packaging indicates that the quality was essentially the same for all 1952 lots except the first lot and the last two. The first lot was slightly immature, with poor skin color, whereas the last two lots were overmature and dark-fleshed. It was assumed that prunes that dropped before harvest would suffer heat damage sufficient to render them below package quality.

The highest yield-quality factors were obtained for the harvest dates from August 15 to August 21, but acceptable factors were also recorded for the August 8 and 11 harvest dates. The graph on page 13 illustrates the yield of package quality fruit in relation to total yield at different harvest dates.

Maximum orchard temperatures in 1952—during the entire month of August and early September—were below those known to cause heat injury to fruits on the tree. Had injurious temperatures occurred during the harvest season, as is not uncommon, prune quality would have been influenced considerably. Such damage becomes progressively more severe as the prunes advance in ripeness.

Range of Harvest Period

On the basis of these investigations, French prunes harvested after chlorophyll has disappeared from the flesh and skin will result in a dried fruit with desirable dark skin color and light amber flesh—when properly dehydrated. The skin color of fruit harvested at dates progressively later will continue to be of good quality, but flesh color will become an undesirable dark brown late in the harvest season or following exposure to temperatures above 100F.

If harvest in the interior valleys is begun as soon as chlorophyll has disappeared from the skin and flesh, the loss of potential tonnage may be great and premiums for large sizes reduced because the prunes are still growing rapidly. However, if harvest is delayed until full size is attained, quality in the latter part of the harvest season—as measured by air pockets and dark flesh color—may be greatly impaired.

Where several weeks are required for harvest, best results for the entire crop may be expected if harvest begins about a week after sampling shows that chlorophyll has disappeared from the flesh and the skin. Such a practice should eliminate much of the tonnage loss that results when harvest begins immediately after chlorophyll disappearance, and under most conditions should permit completion of harvest before the flesh color has darkened seriously—exclusive of periods of excessive heat.

Flesh firmness measurements may be used as an aid to the color index as to when harvest should start—usually at from three to five pounds—but the soluble solids measurement is a more important index. When the crop is normal or less, harvest might well start when soluble solids attain 24%. If the crop is very heavy, soluble solids may not reach as high as 20% while the fruit is turgid. In that case, the soluble solids index of maturity is of little value.

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John Kilbuck was Assistant Specialist in Food Technology, University of California, Davis, at the time the above study was made.

The above progress report is based on Research Project No. 1457.

This study was stimulated by a more extensive investigation conducted under contract with the United States Department of Agriculture as authorized by the Research and Marketing Act of 1946.

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amount of protection necessary may have been greater; and *3*, the inversion may have been weaker. To have protected the crop during this frost, the wind machines would have had to have a large amount of heater support.

The section east of wind machine No. *1*, which had little cover crop and firm ground and with a bare field to the east, shows to have been a warm spot. Here is a case that shows the value of solar heat absorbed during the day to aid in combating frost conditions. The soil, being bare and packed, was in perfect condition to conduct heat readily, making the soil surface warmer at night than otherwise. The condition of the soil surface may not be such an important factor in other years because usually there are rainy spells during the spring with the frost nights following. But for years like this and to aid in protecting against late frosts, it is a good idea to have no cover crop or only a sparse one.

Portable Wind Machine Tests

On three nights a mobile heated wind machine, which blows a warm air jet to each side of its path, was tested.

The upper diagram in column 3 on page 5 shows the response pattern for this machine operated to protect 15 acres. The machine took 6⅔ minutes at 3.2 mph to make one round trip. The poor temperature response was obtained because over the 15 acres only 4 Btu/hr ft^2—British thermal unit per hour per square foot—was added, while with smudge pots in the same orchard on a frosty night about 32 Btu/hr ft^2, not counting the extra heat from the border pots, would be released. It was also found that the portable heater could not raise the temperature of a very sensitive, quick-responding thermometer 100′ from the track. At 75′ distance, the thermometer would give a small response about every third trip of the heater, but after each rise the temperature would fall completely back to the starting temperature.

Since the throw of the warm air jet from the portable heater was only one third the distance necessary to cover the space inside of the path, a test was made with the heater traveling a back and forth route, as shown in the lower diagram in column 3 on page 5. The towing speed was increased to nearly 10 mph so that a round trip was made in three minutes. The resulting 1F response covers 4.1 acres with an average heat input of 15 Btu/hr ft^2 showing that it is necessary to add heat in sizable amounts when responses over 1F are needed.

Protection by Other Means

Many almond growers in the Chico area rely entirely on orchard heaters for frost protection. It was observed that 20 or more heaters or pots per acre—properly operated and with extra units around the borders—did provide complete protection during last spring's frosts.

One orchard in which sprinkling was used was observed. Evidence of some small amount of protection to the crop and no damage to the trees was shown. From this one observation, however, it was not possible to make a reasonably good appraisal of the value of sprinkling for frost protection.

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Data, from which the effectiveness of the large, dual gasoline engine wind machines—Goodspeed orchard near Durham—was determined, were obtained by D. E. Kester, D. S. Brown, and W. P. Pierce, University of California, Davis.

Walter Stile, almond grower; the Frost Master Co.; Harry Hanson, U. S. Weather Bureau; and Ralph Parks, Extension Agricultural Engineer; Henry Everett, Farm Advisor, Butte County; C. E. Barbee and E. L. Tippie, of the University of California, co-operated in the studies reported here.

The above article is the seventh annual report of progress in the study of wind machines in orchards published in California Agriculture.