Evaluation of Temperature Inversions and Wind Machine on Frost Protection in Southern Oregon

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EVALUATION OF TEMPERATURE INVERSIONS AND WIND MACHINE ON FROST PROTECTION IN SOUTHERN OREGON

Earl Bates and Porter Lombard

Much interest has developed in the last five years in ways to protect orchard crops from frost damage that are more economical than fueled heaters. Ballard has indicated that the wind machine even with supplemental oil heaters is cheaper than oil heating alone (Ballard, 1975). Also, economic evaluation of wind machine use has been carried out for southern Oregon (Table 1).

The object of this paper is to present material to answer two questions about use of wind machines in the southern Oregon fruit-producing region: 1) Does an inversion exist with suitable persistance through the spring season? and 2) does a wind machine have a beneficial effect on orchard temperature and offer frost protection for pears? The answer to both questions seems to be yes. However, the amount of inversion found in two years of measurement for this study was less than reported in some areas outside Oregon (Crawford, 1965), thus less warming effect may be the case in southern Oregon.

In 1972, a wind machine and temperature instruments were installed in the Minear orchard near Medford. A tower was built to measure and record the vertical temperature profile. In 1973, a second temperature tower was installed.

Season of 1972

Fifteen thermographs were distributed along four radials -- northeast, southeast, southwest and northwest -- from the wind machine. A 60-foot tower was erected at the south edge of the orchard and a surface temperature station was established at the edge of the orchard for a check.

An inversion was defined as the temperature differential between 4 feet and 60 feet above ground at the time of the morning's minimum temperature. This rule applied from midnight through 6 a.m. Autographic charts for the many instruments were changed and collected weekly by Robert L. Rackham, Jackson County Extension Agent. All charts were evaluated in the Weather Service Office at Oregon State University.

The test consisted of a period of 50 consecutive nights. Considering all nights and all conditions such as cloudy, rain or clear, there were seven nights with no inversion. Clouds or clouds and rain accounted for most of the cases of no inversion; on such nights there is seldom frost. The average inversion for the season was 2.4°F. J. K. Ballard (1970) has stated that an inversion of 2°F or more is useful as a source for protection from frost. He said the wind machine delays light-up time of supplemental heaters, and experience has shown that supplemental heat on most nights is not needed. Sky cover was computed at the Medford Weather Service office for all dates from midnight through 6 a.m. The average inversion for the nights with 0.5 or less of cloud cover was 3.2°F. These are the most frost prone nights and the inversion was sufficient to give 1.0 or 1.5 degrees of protection or more. On 35 of the 50 nights of the 1972 season, an inversion of 2°F or more existed.

<u>Season of 1973</u>

A wind recording system for measuring speed and direction was installed for the second year of study. A second tower, 67 feet tall, was installed 300 feet southeast of the wind machine. The control or check equipment was moved to a position 800 feet south southeast of the wind machine, inside the orchard. A 60-foot tower was set up there. With this arrangement of instruments, temperatures were measured at 100, 200, 300, 400, 500, and 800 feet from the wind machine.

Temperature and inversion measurements in conjunction with wind machine operation were started on February 18. The measurements were taken, with wind machine operation, on seven cold nights when there was no orchard heating. This gave a better picture of the inversion and the influence of the wind machine on temperatures within the orchard.

Having a tower within 300 feet of the wind machine, and inside the orchard, gave an opportunity to see if there was mixing by the fan within the orchard. Ground level instrumentation was distributed in all quadrants of the orchard, as in 1972, to determine the surface isotherm pattern around the wind machine.

The isotherm pattern showed evidence of being elongated from northwest to southeast because of controlled timing of the wind machine rotation. The speed of rotation was altered to cause the fan to blow longer on this axis than it did in the other quadrants. The average inversion for all nights during the spring season was 3.9°F, 1.5°F greater than in 1972.

Inversion and Wind Machine Action

The year of 1972, as a whole, seemed to have a poorer inversion than 1973. This is not necessarily true for nights when frost is a problem. Neither does it indicate that Medford's bowl-shaped valley has any tendency for poor or weak inversions. On the contrary, one would expect that such a valley would have inversions of several degrees magnitude. There are reasons which can explain the 1972 inversions averaging less than those of 1973. Of the 50 nights of the 1972 season, 15 had extensive cloudiness and it rained on nine dates. There was orchard heating on 10 nights when little cloudiness occurred and the heating distorted the inversion. The fact that heating methods have been successful in that valley for many years indicates that temperature inversions are frequent over the valley. Two years of vertical profile temperature measurement has confirmed that inversions are frequent. Another question: Are they of sufficient magnitude to make wind machines useful?

Figure I shows the wind machine had a positive influence on orchard temperature. The figure is a graphic display of temperature distribution in the orchard on the night of April 18-19, 1972, when temperature outside the orchard was reported at 23°F, coldest of the season. From midnight through 6 a.m. the average sky cover reported by the Weather Service Office was 0.5 and the average wind speed was 2.6 knots. This was a morning with a 3°F inversion at 3 a.m. which decreased as the fan mixed the air. The fan and 20 heaters/acre within 300 feet of the fan were activated about 10 p.m. April 18. At 2:30 a.m., April 19, more heaters 200 feet east of the fan were started. Robert Minear, owner/operator of the orchard, indicated the machine's orchard benefits extended out to 300 feet and some crop benefit extended to a maximum of 400 feet.

Even with heaters in the surrounding orchard area, as Figure I shows, temperatures were highest near the fan and decreased outward in all directions, evidence that the wind machine was having an effect.

At post-bloom stage of bud development on April 19, it is estimated that 28°F was critical for the crop for a 30 percent kill and 28.5°F was critical for a 10 percent kill. Outside the orchard, a 23°F minimum was recorded at the 4-foot level.

Within the 400-foot radius (11.5 acres) of the fan, much of the area was expected to have 30 percent kill and about 5 acres would have only 10 percent kill. Within a 500-foot radius of the fan were 18 acres where temperatures were as low as 24.5°F in part of the perimeter area which indicated 100 percent kill.

A fruit production survey by a country Extension Agent in August 1972, and reported to the authors, surveyed the crop density by counting the number of fruits/cm^2 of x-sectional area of four limbs per tree, one limb on each of four sides of the tree. A crop density of 1 to 3 is below a full crop and a crop density of 3 to 5 is a full crop. Through the first 150 feet from the wind machine, with no heaters, the average was 3.2 fruits/cm^2. Beyond 150 feet from the machine, heaters used, the average was 3.1 fruits/cm^2. High values of more than 5.0 fruits/cm^2, which indicated a full crop, were found on some trees out to 250 feet from the fan. To the west, one tree with 5.50 fruits/cm^2 was found at 350 feet. In general, the crop density dropped considerably beyond 350 feet while at the east and west borders the density was less than 1 fruit/cm^2. Again, this indicated that the wind machine had a positive influence on maintaining a safe temperature within 350 feet to produce a full crop.

The night of February 18-19, 1973, was a typical radiation frost night with clear sky and light wind. The wind machine was started at

4:15 a.m. and temperature readings were obtained for a 3-hour period on the morning of February 19. At 2 a.m. there was a 6.5° temperature inversion measured 300 feet from the wind machine. At the time the fan was started, there was a 26°F temperature at four feet above ground, but it increased 1.5° by 5 a.m. while the temperature at 67 feet dropped 1.5° during the same period, indicating mixing of the warmer air above with the cooler lower area. Temperatures at those two levels continued to converge until 5:30 a.m. when the difference remained about constant (Figure 2). The 4-foot temperature reached 28°F, a 2°F gain above the starting temperature. There was a 5.5°F inversion at the control tower, 800 feet south southeast from the wind machine at 4 a.m. After the fan started, both the 60-foot temperatures at 800 feet distance continued to drop at about the same rate, indicating the air was not being stirred at this control point. The 60-foot temperature at 800 feet distance dropped from 30.5° before the fan started to 28° by 5 o'clock. At 7 a.m. the 4-foot temperature at the 800-foot tower reached 22°F while the 300-foot location had a minimum temperature of 27°F. Therefore, the wind machine was able to maintain a 5°F temperature benefit within 300 feet as shown (Figure 3) by the isotherm pattern of the minimum temperature in the orchard.

The temperature dropped 5.5°F in 400 feet toward the northeast, 6°F in 800 feet toward the southeast and 7°F in 500 feet southwestward. There was no temperature measurement in the northwest but interpolation was made by closing the isotherms smoothly in that quadrant, so there seems to be a 4°F drop in 300 feet northwestward.

Figure 4 shows the vertical profile of air temperature up to a height of 400 feet on the morning of February 19. This is a deep inversion; it is shown on the graph as the solid line joining circles, before the wind machine was started. The dashed line shows the change in temperature profile from the surface upward to beyond 100 feet after the fan was running.

The night of April 29-30 was another example of a radiation frost night. There was a 6°F inversion at 3:30 a.m., April 30. Heaters were operated in the orchard that night in conjunction with the wind machine. Temperature data (Figures 5 and 6) indicated that wind machine action found on February 19 was repeated. After the fan was started, temperature aloft decreased and temperature near the ground held about 32°F but with a dip to 31°F at 5 a.m. (Figure 5). Figure 6 shows the decreasing temperature outward from the fan as in previous experiments. The wind machine kept temperatures at 31°F out to 400 feet except in the southwest quadrant where the temperature was 29°F. More than 11 acres were kept above the critical temperature of 28.5°F for 10 percent kill.

Reliability of the Inversion Over the Medford Valley

For a fruit grower to have confidence in a wind machine program, he must know the reliability and the magnitude of the temperature inversion for the growing area. Based on two years of temperature records of the Minear orchard southwest of Medford, a statistical analysis determined the confidence level for the occurrence of an air temperature inversion. The statistical test showed that with 95 percent confidence an inversion of 3.33°F can be expected in the spring season over the Medford Valley.

Norman Herdrich (1974) has quoted J. Ballard as saying ". . . if the orchard site consistently shows an inversion with temperatures that are at least 3°F warmer at the 30 to 50 foot zone than among the trees, a wind machine could be worth trying." In writing of California inversion studies, Crawford (1965) said, "These inversions average 4°F in the deciduous orchards of central California (Crawford and Ganser, 1961) and 11°F in the citrus orchards of southern California (Brooks and Schultz, 1958a)." Also, analysis at the Southern Oregon Agricultural Experiment Station indicated than 90 percent of the spring nights with critically low temperatures had a minimum inversion of 3°F over the Medford Valley in 1971 indicating substantial benefit on 90 percent of the nights requiring frost protection.

<u>Benefits of the Wind Machine Other Than Mixing Warm and Cold Air</u>

An important consideration in the use of the wind machine may be that of agitation of the air immediately around small, green fruit. This can be important on a night with very small inversion or when air temperature is constant with height. At such time, the agitation can prevent the bud or fruit and a thin envelope of air around it from cooling to a temperature 2° or 3°F lower than the ambient temperature.

Stirring the air also can prevent the formation of frost or ice crystals on the plant tissue. Strang (1977), from research at the Southern Oregon Agricultural Experiment Station, found evidence that prevention of ice crystals on plant tissue may be a positive contribution toward protecting the fruit crop when the temperature is lower than 32°F. Also, rapid cooling was found to increase frost damage on pears. Air temperature measurements alone cannot accurately determine frost damage.

<u>Area Influenced by Multiple Wind Machine Installation</u>

The shaded area of Figure 7 gives an indication of the advantage to be expected from multiple wind machines. The circles represent an area of influence with a 350-foot radius which can be expected with a 125 horse-power fan. The installation of four wind machines 700 feet apart should influence about 11.2 acres instead of 8.8 acres each, which would give an influence area 22 percent greater than from a single machine.

Comparative Cost of Wind Machines and Oil Heaters

With the extremely high cost of labor and fuel, frost protection methods for fruit crops must be diligently compared for efficiency and cost. It appears that wind machine operation can adequately protect the crop in the spring at Medford on most occasions. There are times when a combination of heaters and wind machine is necessary.

Wind machine operation is the cheaper of the two methods (Table 1). Heaters in combination with wind machines still constitute a cheaper method than heaters alone. See Table 1 for a detailed comparison of the two protection methods.

Conclusion

On nights with radiation frost, a wind machine kept temperatures high enough to protect about eight acres and gave partial protection over 11.5 acres. This also was true where the wind machine was used in combination with return stack heaters when air temperature outside the orchard was reported at 23°F. Some increase in temperature was found over an area of 18 acres. Multiple wind machines in operation may give more protection, per machine, than the operation of a lone machine.

It was found that inversions capable of providing some temperatures increase in the orchard occur on nights with cloud cover of 0.5 or less.

These are the frost prone nights. With 95 percent confidence, an air temperature inversion of 3.33°F over the Medford Valley area can be expected in the spring season. Air temperature in the orchard can be raised about one half the inversion value with mixing such as provided by a fan of about 1,300 pounds thrust. Therefore, a combination of some heaters and wind machine would be used when protection of 2°F or more is necessary.

From an economic point of view, the wind machine is most advantageous. Even with auxiliary heat, wind machines offer an economic advantage.

Table 1. Comparative costs, 1977 values, and energy used by three conventional frost protection methods in colder orchards in southern Oregon.

Energy and Labor

15.4 hours with 20 heaters @ ½ gallon per hour = 154 gal + 26 hours with 35 heaters @ 3/4 gal = 682.5 gal; total 836.5 gal @ 40¢ = 334.60 + lighting 61.4 hours @ $3.00 = $184.20 + 50¢ per heater for moving and cleaning + $1.00 depreciation = $35.00; Total = $571.30

Operations

Frost protection method	Avg. hours in cold orchard	Fuel oil consumption per care	Operational cost plus overhead per acre: Hourly	Operational cost plus overhead per acre: Seasonal
Return Stack Oil 15 hrs at 20/acre plus 26 hrs at 35/acre	41	837	$13.80	$571.30
Wind Machines: single 90 BHP per 8 acres	60	94	3.76	226.00
Dual 125 BHP per 12 acres	60	250	6.36	382.00
Wind machine & oil heaters: single 90 BHP and 20 heaters per acre for 8 acres	60	290	5.85	351.00
(this is with 60 hours wind machine plus 26 hours of oil heaters)				

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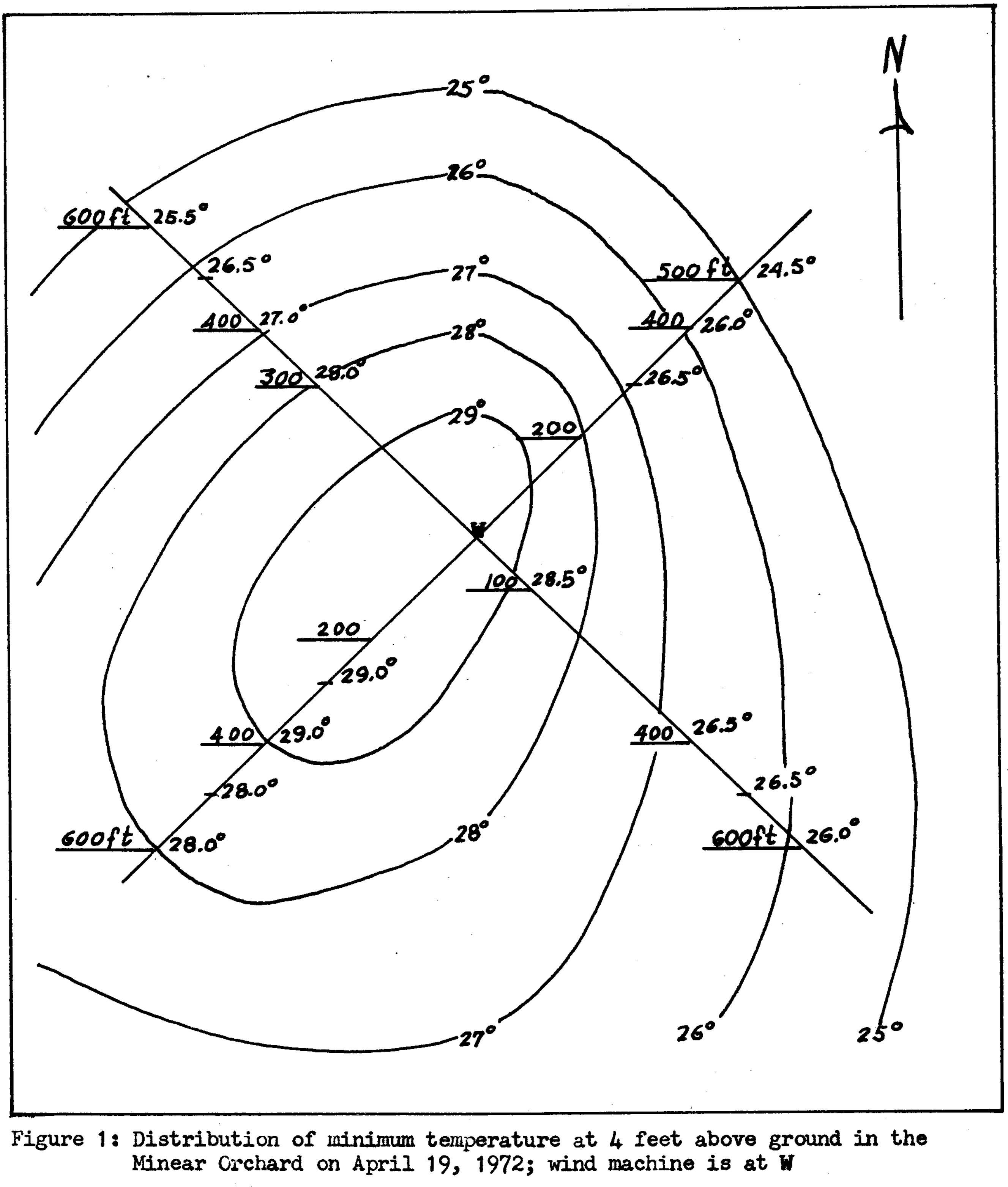
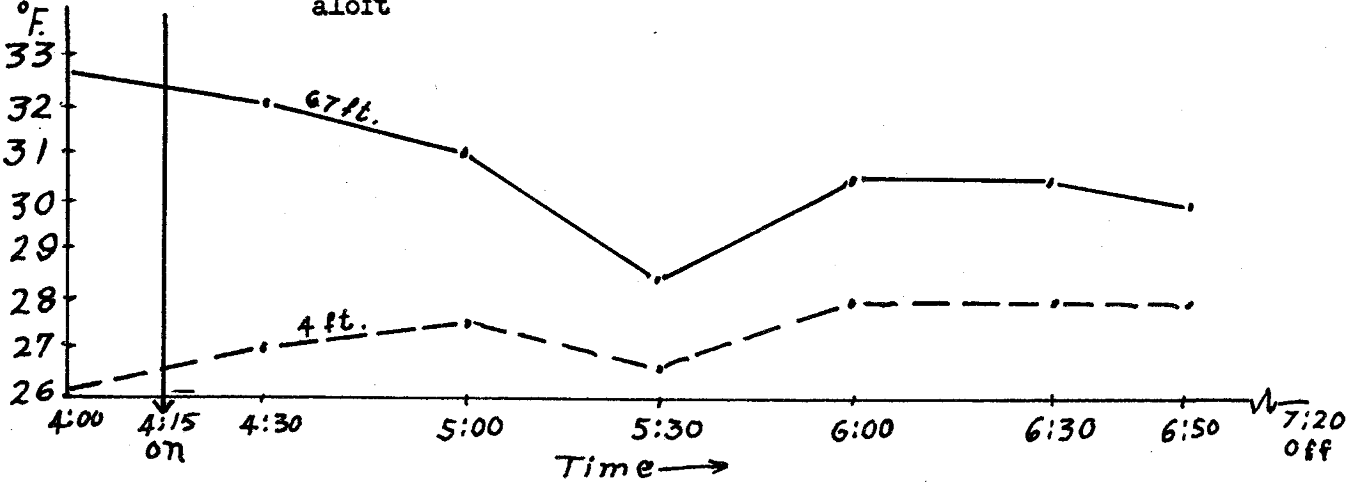


Figure 1: Distribution of minimum temperature at 4 feet above ground in the Minear Orchard on April 19, 1972; wind machine is at W

300 Ft. Tower: Temperature profile showing 4-foot temperature rose then held constant while a general temperature fall occurred aloft



800Ft. Tower: Upper and lower level temperatures parallel each other and, in general descend

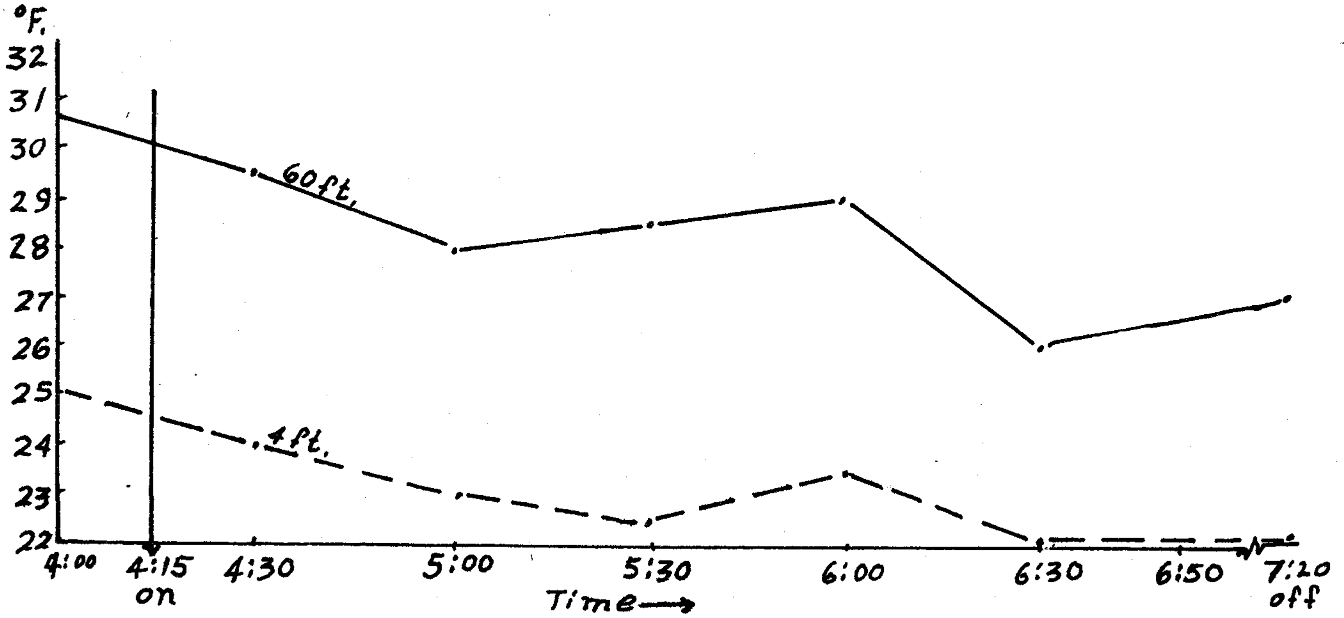
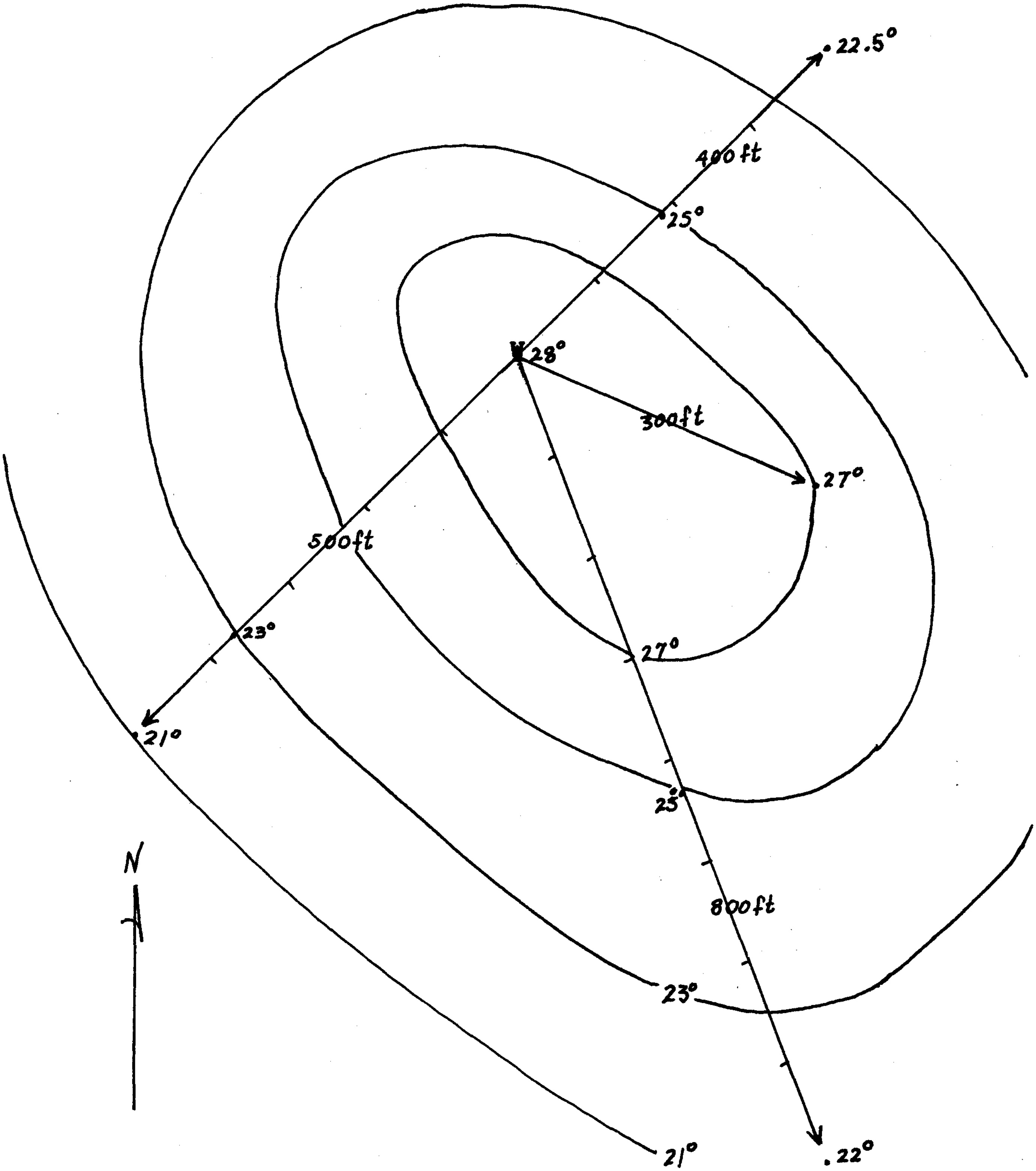


Figure 2: Air temperature profile on Feb. 19, 1973 at the Minear Orchard, without heaters, at two distances from the wind machine

Figure 3: Isotherms of minimum temperature at the 4-foot height in the Minear Orchard, February 19, 1973, in relation with the location of the wind machine, W.



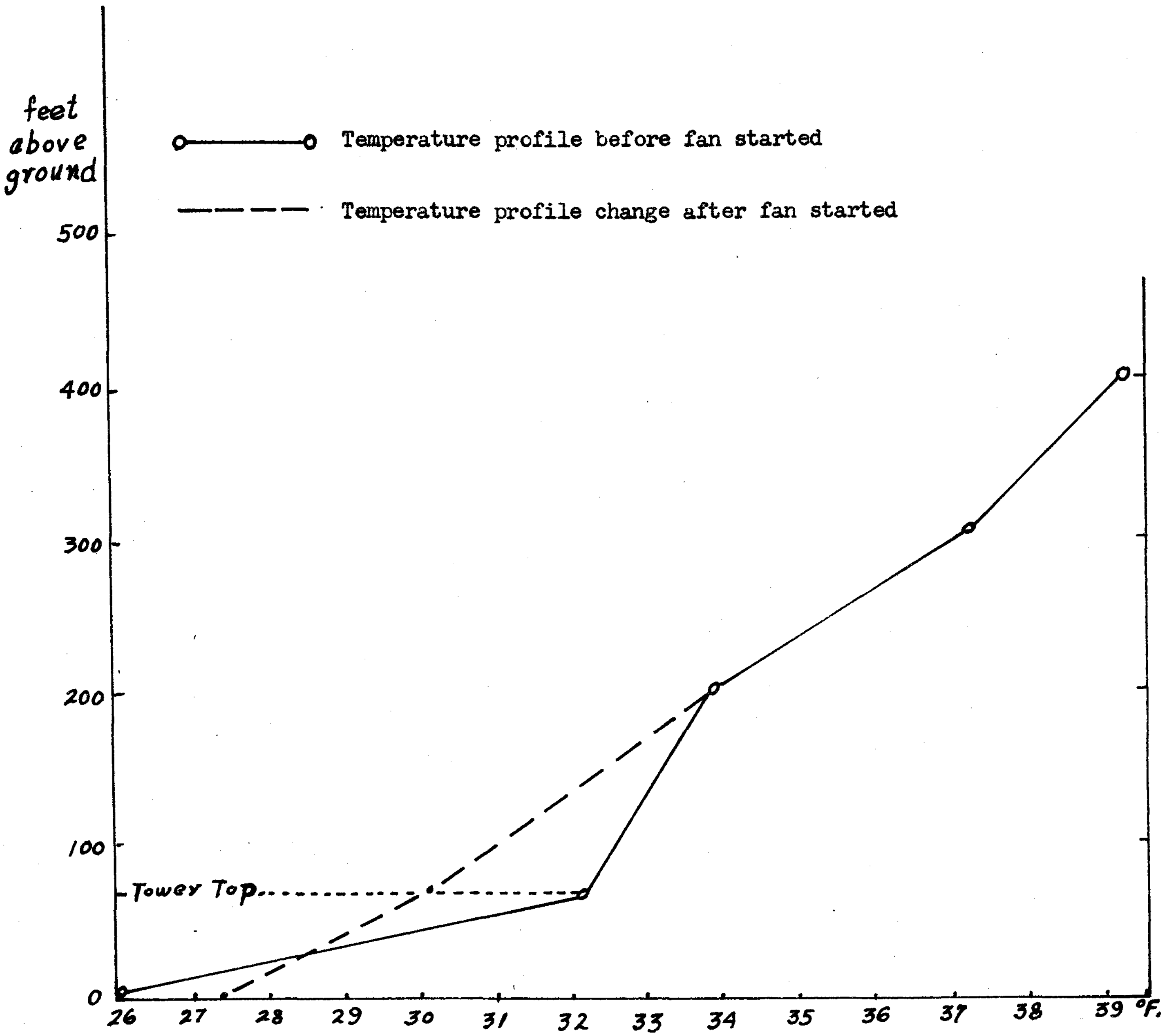


Figure 4: Vertical temperature profile over Medford Valley Feb. 19, 1973. Dashed line shows how mixing by wind machine in the Minear Orchard changed the low level temperature; no heating was used

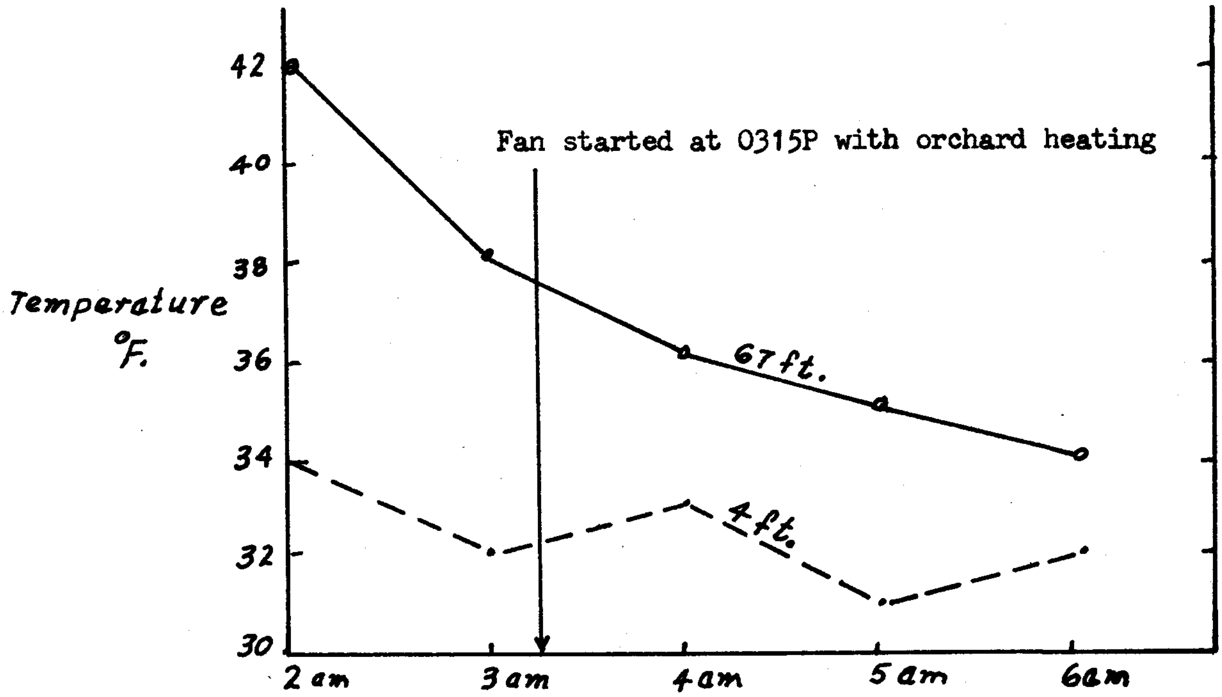
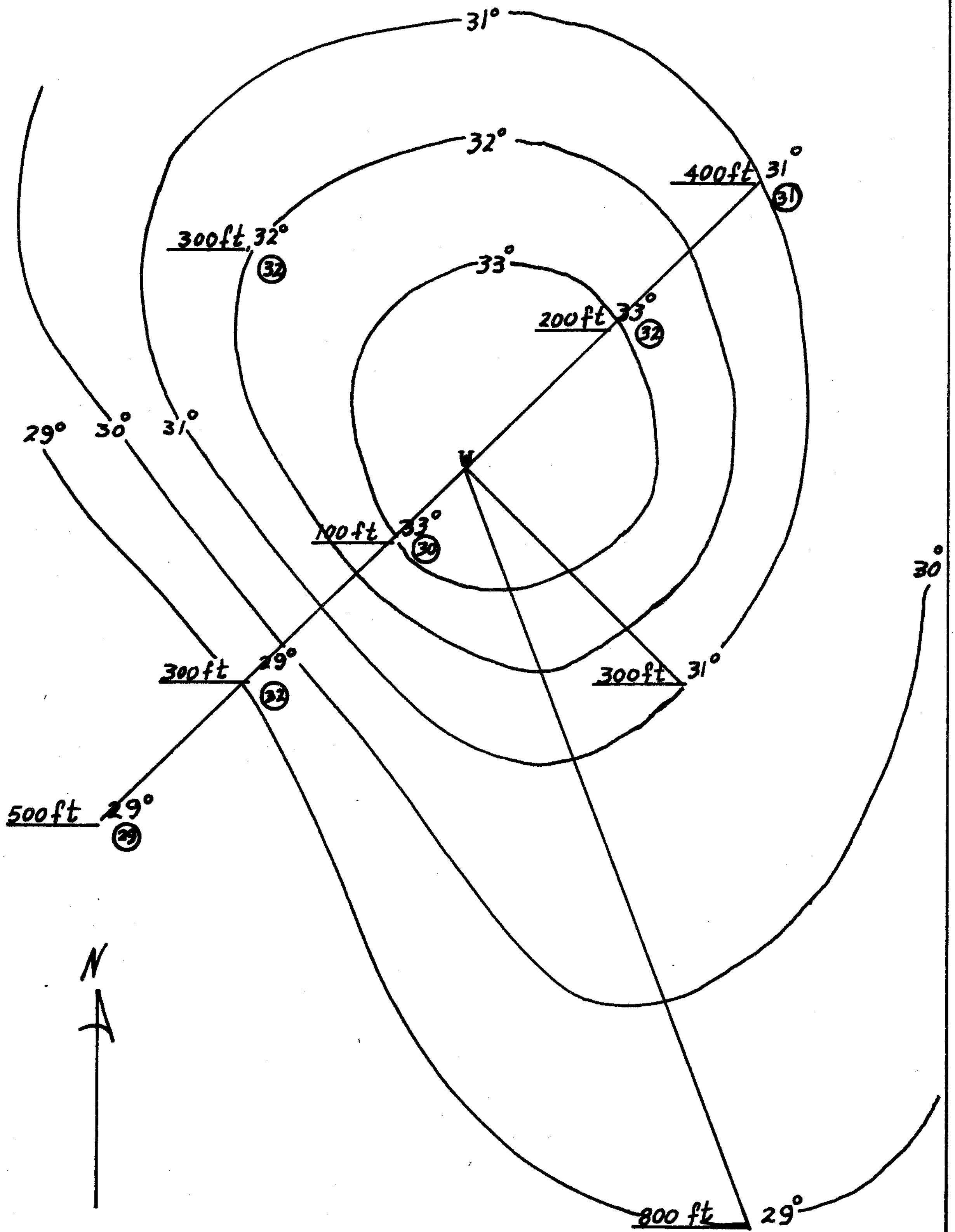


Figure 5: Temperature profile in the Minear Orchard April 30, 1973, 300 feet from the wind machine

Figure 6: Isotherm of minimum temperature after wind machine, W, and heaters were started in the Minear Orchard April 30, 1973. (Circled temperatures are those obtained before the fan and heaters were started.)



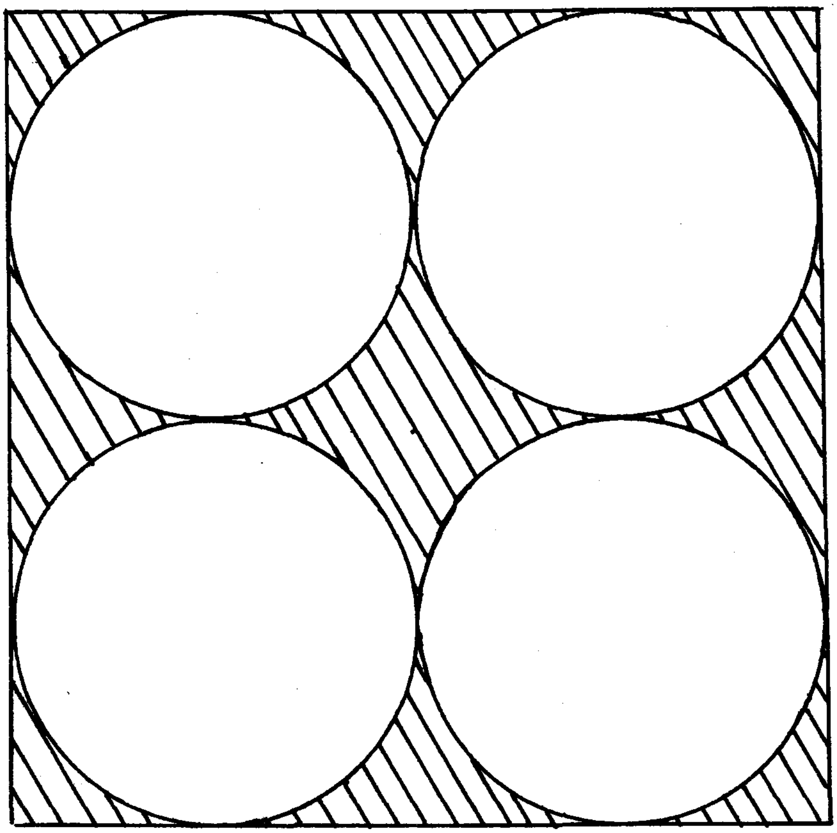


Figure 7: Area of influence of 4 wind machines installed 700 feet apart demonstrating:
Total area of circles 35.3 acres
Total area of square 45 acres, or 22% greater area than the combine areas of the circles