FROST PROTECTION

with multiple wind machine-heater units

Spacing wind machine-heater units close enough together to allow an overlapping effect offers more efficient frost protection than is possible with single isolated installations. A spacing interval of 300 feet is probably the optimum for most conditions, according to last year's tests with nine ground-level revolving units, producing 60 pounds thrust and burning 20 gallons of diesel fuel per hour.

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WITH ANY FROST PROTECTION system, efficiency improves as the size of area being protected increases. The reason is that the warmer air in the area being protected rises and draws in the colder air around the borders. With a larger area involved, this border effect is proportionately smaller. This effect is present when orchard heaters are used as the frost protection system, and influences the protection provided by a wind machine. Large installations of orchard heaters, as well as multiple installations of wind machines with overlapping patterns, offer more efficient frost protection than single installations.

When the protection obtainable with a wind machine must be supplemented by the addition of heat, the use of orchard heaters around the border of the area being protected is most effective. Adding heat at the wind machine offers possible labor and system management efficiencies, however. But the air jet from the wind machine is so buoyant that the increased border effect makes the heat added to a single wind machine of little value.

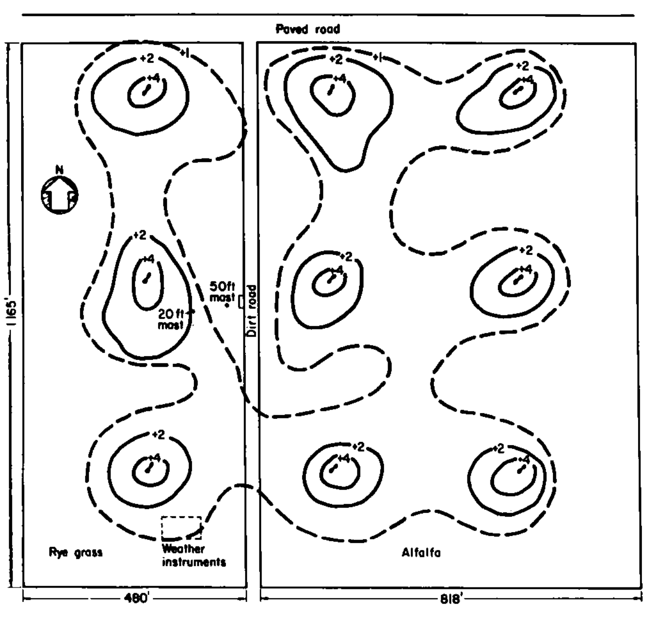
The purpose of this research was to investigate the possibility that multiple installations of wind machine-heater units would minimize the border effect and to determine the optimum spacing for the units used in these tests. The nine wind machine-heater units borrowed for these tests were the sled-mounted, under-tree type which are easily moved. Each unit consisted of a 25 hp air-cooled engine, a 28-inch diameter fan, an oil burner, and the necessary fuel tanks. Each machine produced 60 pounds thrust, burned 20 gallons of oil per hour, and rotated completely every 45 seconds. One-third of the 35-acre Davis campus test area was planted in rye grass and the other two-thirds was in alfalfa.

Temperature data

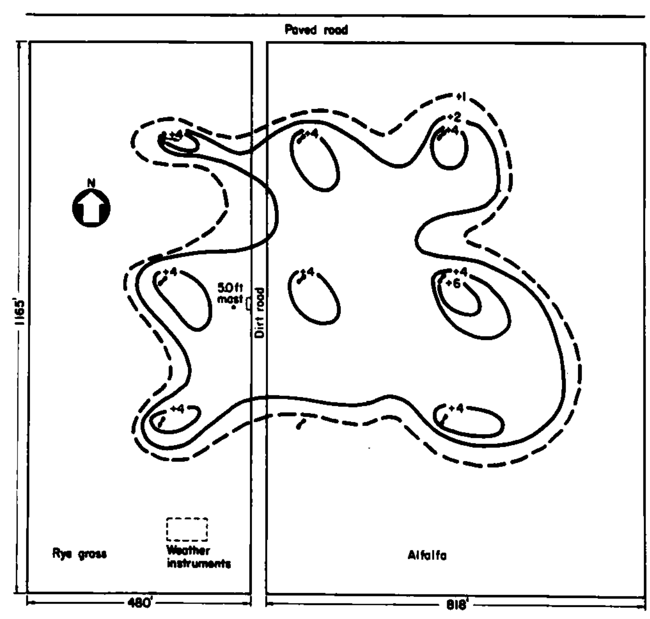
The main temperature data were obtained with 48 mercury thermometers distributed over the test area. The thermometers were mounted horizontally 3 feet above the ground and unshielded to simulate exposed parts of a crop. A continuous record of temperature was also obtained at 10 different heights from 4 inches to 50 feet above the ground. Wind speeds and directions were recorded at elevations of 7 and 50 feet during all tests.

Thermometers were read by observers walking specified routes. The natural temperature patterns throughout the test area were determined by reading all thermometers twice prior to starting the wind machine-heater units. The natural temperature pattern was very uniform over the entire test area. Temperatures over the alfalfa (which varied in height from 10 to 18 inches during the period of

Test 1. Temperature change (°F) caused by operating wind machine-heater units spaced 400 feet apart. March 23, 1962, 5:03 a.m. to 6:07 a.m.



Test 2. Temperature change (°F) caused by operating wind machine-heater units spaced 300 feet apart. April 5, 1962, 5:10 a.m. to 5:47 a.m.



the tests) were generally 1° to 2°F colder, however, than those over the rye grass (which varied in height from 4 to 5 inches).

Thermometers were read four to six times during the operation of the wind machine-heater units. Natural conditions during a test were measured by a few thermometers placed beyond the effect of the machines.

First test

Results from the first test, with the wind machine-heater units spaced 400 feet apart, are illustrated on the accompanying diagram and summarized along with all of the tests in the table. Light northerly winds shifted the protection pattern southward, especially over the shorter rye grass, and caused a complete lack of interaction between the three northernmost units. When spaced every 400 feet, each unit acted almost as a single wind machine-heater unit, with little benefit from the multiplicity of the installation. White frost also formed that morning and the frost free area around each unit was 120 to 150 feet in diameter.

Second test

For the second test, the units were spaced 300 feet apart. The temperatures did not get down to freezing (they were in the 40's), but winds and the temperature inversion were similar to what would be found under frost conditions so the temperature changes reported would still be valid. Results of this test indicated much more interaction between adjacent units although the effect of the northwest wind still appeared in the cold tongues protruding inward from the north and west.

SUMMARY OF WIND MACHINE-HEATER UNIT TESTS

Date (1962)	Time	Temperature inversion (50'–5') °F	Wind at 50 ft. mph	Wind at 7 ft. mph	Spacing of wind machine-heater units	Temperature rise °F	Acres over which rise occurred
March 23	5:03 a.m.	4	NE	Less than	400 ft.	1°	15.7
	6:07 a.m.		1.7	1.5		2°	5.0
						4°	.9
April 5*	5:10 a.m.	5	NW	Less than	300 ft.	1°	12.2
	5:47 a.m.		4.7	1.5		2°	9.2
						4°	1.4
						6°	.1
April 12	4:40 a.m.	5	N	N	200 ft.	1°	13.3**
	5:30 a.m.		4.5	1.5		2°	11.0**
						4°	5.4
						6°	1.3
April 12	8:45 p.m.	8	WSW	SW 2.9	around a	1°	11.8**
	9:30 p.m.		3.6	until	566-foot	2°	8.8
				9:00 p.m.	diameter	4°	3.4
				then calm	circle	6°	.5

* One unit not rotating and another not operating.
** These areas are taken to the edge of the field.

This condition was accentuated by the failure of the rotation mechanism on the wind machine-heater unit in the northwest corner. This machine pointed east during the entire test, and the center unit in the south row was completely inoperative. These two malfunctions obviously affected the areas over which the temperature rises occurred and should be considered when comparing the results from this test with the others.

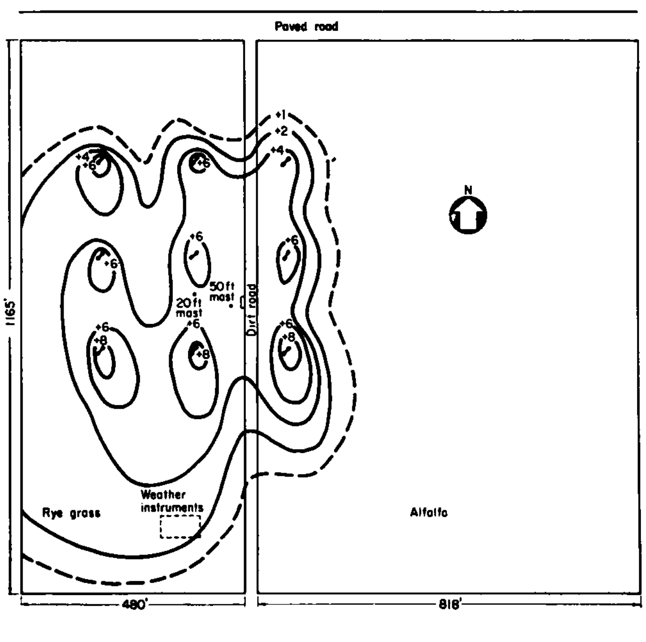
Third test

In the third test, the units were spaced 200 feet apart. The effect of the northerly wind was again indicated and is shown on the diagram as cold tongues extending southward between the three northernmost units. The light northerly wind did not carry the effect of the wind machine-heater units as far south over the alfalfa as over the rye grass. By that time the thermometers were only about 18 inches above the growing alfalfa.

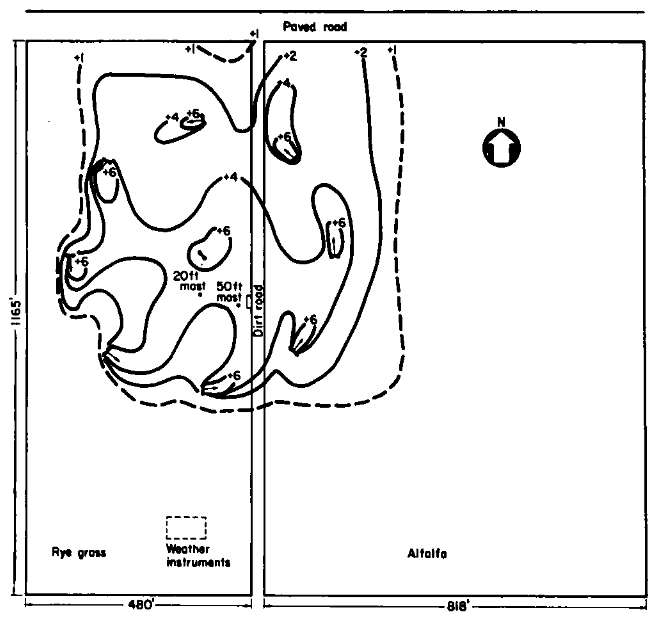
Inversions

In discussing temperature inversions and their effect upon frost protection systems, it has been traditional to talk about the temperature difference between 50 feet and 5 feet above the ground. This is important when discussing frost protec-

Test 3. Temperature change (°F) caused by operating wind machine-heater units spaced 200 feet apart. April 12, 1962, 4:40 a.m. to 5:30 a.m.



Test 4. Temperature change (°F) caused by operating wind machine-heater units pointing around a 566-foot diameter circle. April 12, 1962, 8:45 p.m. to 9:30 p.m.



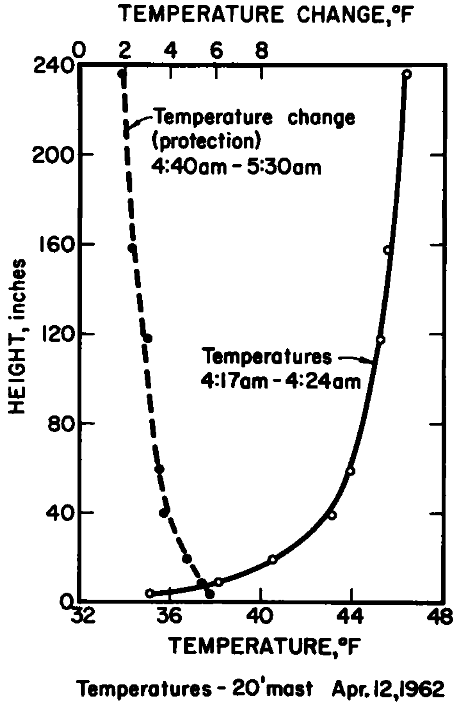
tion for orchards because the fruit to be protected usually lies somewhere in the region of 5 to 25 feet above the ground. There is usually little difference in temperature between the ground and the 5-foot levels.

In field crops, however, the coldest temperature may be only a few inches from the ground in the vicinity of the top of the crop. The temperature profile taken during the third test indicates a 9°F temperature difference between 4 inches and 60 inches above the ground. This profile is typical of others that were obtained during these tests, and is indicative of how much the temperature at the ground might be increased if the air layer in the lower few feet could be completely mixed. In fact, it would be difficult to raise the surface temperature by heaters alone as most of the heat produced rises vertically in a hot plume of gases.

Without trees to intercept the radiant heat from an orchard heater, most of it will also escape to the night sky with only a small fraction benefiting the crop within a few feet of the heater. The dashed curve on this same diagram is the temperature change at the location of the 20-foot mast, caused by the operation of the wind machine-heater units. The greatest change took place in the lower levels, probably due to a general increase in the mixing of the air caused by the wind machines and the strong temperature differences existing there previously. If the temperature rise had been due solely to the addition of heat from the burner, the greatest temperature rise would have been expected at a greater distance from the ground.

Fourth test

For the fourth test, eight of the units were placed on the circumference of a 566-foot diameter circle. The ninth unit was located in the center. Rotation mechanisms were disconnected on machines at the circumference of the circle, and they were pointed counter-clockwise. The idea was to see if it was possible to produce a general rotation of the air mass which would act as a barrier to the inflow of cold air from the borders of the area being protected. The wind machine-heater units were too far apart to get much interaction between adjacent units. In most cases the air jet was not detectable more than 75 to 85 feet away from the unit. The effect of the southwest wind was evident in the distorted temperature pattern in the southwest part of the area being protected as shown in the diagram.



Temperature change curves plotted from recordings of thermometers mounted on 20 foot mast in center of test plot area.

Conclusions

Adding larger amounts of heat to a wind machine with a given thrust will cause the air jet to lift off the ground closer to the machine. Conversely, increasing the thrust will cause an air jet with a given amount of heat to carry further from the machine before rising off the ground. However, the table showing the acres of 2°F temperature change indicates that a multiple installation of wind machine-heater units, when spaced close enough together to have an overlapping effect, is more efficient than a single installation.

For a multiple installation of wind machine-heater units, producing 60 pounds thrust and burning 20 gallons of diesel fuel per hour, a spacing of about 300 feet between each unit is probably the optimum for most conditions. A 400-foot spacing does not provide enough interaction between adjacent units and a 200-foot spacing provides more protection than would be needed under most conditions. If all nine units had been operating properly during the test of the 300-foot spacing arrangement, the area of 2°F temperature change would probably have been 12 to 13 acres.

The amount of temperature rise caused by these wind machine-heater units can be significantly increased by decreasing the spacing between the units. Semi-portable units thus offer a distinct advantage over the permanent installations in case a very severe frost is forecast, because the usual spacing can be decreased. This means an adequate job of frost protection could be done for at least a part of the crop instead of doing an inadequate job of protecting the entire crop.

Todd V. Crawford is Assistant Agricultural Engineer, University of California, Davis, and Arthur S. Leonard is Agricultural Engineer, U. C., Davis, Ralph Parks, Robert Parsons, and Herbert Schultz, Department of Agricultural Engineering, Davis, assisted in these studies.

The wind machine-heater units and fuel were provided by Robinson Blower and Engineering Corporation; a Ford tractor used in the experiments was loaned by Pacific Tractor Co.; and the fork lift attachment was loaned by Blackwelder Manufacturing Co.

1961 INDEX AVAILABLE

CALIFORNIA AGRICULTURE INDEX, Volume 15, January through December, 1961, is still available—listing articles published in California Agriculture, by subject matter, with page number and issue of appearance.

PLUM ROOTSTOCKS FOR ALMONDS

Corrected Reprint

Reprints are available with corrected photo labeling for the article, "Plum Rootstocks for Almonds," page 10, California Agriculture, June, 1962.

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