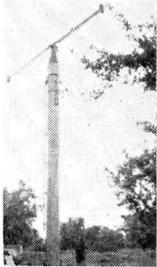


Effectiveness of Wind Machines

frost protection by ramjet or conventional wind machines in deciduous orchards depends on the strength of the inversion

G. E. Goodall, D. E. Angus, A. S. Leonard and F. A. Brooks



Ramjet wind machine used in frost protection studies in prune orchard.

When the atmosphere 40' to 50' above ground is 13°F or more warmer than it is a few feet above the soil surface, the temperature inversion condition—in frost protection research—is considered to be strong. When the temperature difference is less than about 5°F the inversion is considered weak. The weak inversions usually found in the deciduous orchards on the floor of the Sacramento Valley appear to limit the usefulness of wind machines for frost protection unless additional heat is supplied from orchard heaters.

In tests during 1957 the performance of a conventional high powered, dual-engine wind machine in an almond orchard near Chico was established with reasonable accuracy over the range of inversions encountered. For the same inversions, the machine's performance was nearly equal to that in previous tests in southern California citrus orchards.

Tests with a ramjet-rotor wind machine in a prune orchard near Meridian—made in 1957—indicate that it also gives a typical temperature response. The heat added to the air stream by the ramjet burners is beneficial but the noise appears to be a limiting factor in the widespread use of such machines.

There is some evidence that a tall cover crop reduces the effectiveness of a wind machine in raising temperatures in the lower parts of the trees.

At Chico, temperature responses around the conventional machine were obtained with thermocouple equipment and at Meridian, the responses to an experimental ramjet engine machine were measured with thermistor equipment.

To make a direct comparison of thermocouple and thermistor equipment for temperature measuring, thermistors—used for several years in frost protection work in Australia—were set up at Chico.

The thermocouple layout at Chico had been standardized at a height of 10' above ground, but in Australia work with thermistors had been standardized at 3', therefore, the thermistors at Chico

were set at heights of both 3' and 10'. Under the virtually closed canopy of tree foliage, the temperatures at the 3' and 10' levels were the same, and in the absence of a cover crop, the responses at these levels were also the same.

Although only two test nights were sufficiently cold to require growers to provide frost protection, tests on other nights with suitable weather conditions—but with temperatures in the high thirties—gave response patterns similar to those of the cold nights.

Conventional Machine

A conventional wind machine with dual gasoline engines of 75 bhp—brake horse power—each, 40' above the ground, was tested in the same almond orchard where a single 30 bhp electric machine was tested two years before with disappointing results.

It was concluded then that a more powerful air jet would be better able to penetrate the intertwining branches of the trees with their dense foliage.

In analyzing the results of the 1957 trials with the more powerful machine, test-run periods of approximately one hour—during which the wind-drift direction and strength and the temperature inversion remained substantially constant—were chosen.

The average of the temperatures—registered every three or six minutes by each thermocouple—before and after a run was subtracted from the average of the temperatures during the run.

These differences were corrected for any temperature changes shown by control thermocouples outside the influences of the machine, but within the orchard. Responses obtained in this way at 58 points in the orchard permitted the plotting of equal response lines, so that areas of different temperature responses could be determined with reasonable accuracy. The diagrams on page 8 show typical response areas for medium and weak inversions respectively. These particular tests were made on nights when general heating was required in the surrounding groves soon afterwards.

Results of the tests at Chico were plotted to evaluate the relationship between the response areas of different temperature rises and the corresponding

inversion strengths. Good relationships were found as shown in the small diagram on page 9. The lines drawn in are the calculated regression lines, or lines of best fit, and are believed to give a reasonably good indication of the performance to be expected under weak to moderate inversions. The inversions encountered in this work were generally weak, which appears to be a characteristic of orchards on the floor of the Sacramento Valley. It is unlikely that stronger inversions would occur in this area, so the lines were neither extended, nor curved as would be expected for strong inversions.

The performance at an 8°F inversion was nearly the same as that of a similar sized machine with a similar inversion in previous tests—in citrus in southern California—suggesting that the performance of such machines is about the same in citrus and in almonds. Australian results, using about 10 bhp, show approximately equal—but smaller—areas of protection in citrus and grape-vines, for equivalent inversions. Therefore, it can be concluded that, for a given machine, the inversion strength is the main determinant of wind machine response.

Ramjet-rotor Machine

The ramjet machine tested had a propeller 23' in diameter, with a ramjet engine mounted on each end to provide rotation at 550 rpm. The hub of the blades was 36' above the ground, with the shaft set to give an air thrust of about 1,100 pounds downward at 15° from the horizontal. The power unit rotated once in six minutes and used 96 gallons of fuel per hour. It has been observed during tests that all the heat in the exhausts of the ramjet engine is drawn into the air jet and distributed around the orchard. The designers hoped that on nights of weak inversion the exhaust heat would be adequate to afford protection without lighting additional heaters, as is necessary with conventional machines.

The information collected in the tests at Meridian was evaluated in the same way as that from the Chico tests, but the progressive interferences of the growing cover crop in the prune orchard

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prevented plotting an adequate curve relating response to inversions. The response areas for the nights of medium and weak inversion immediately after the cover crop was rolled are shown in the diagrams on the page to the right. Comparing the diagram on the left with the Chico results, the 3°F response area under a 7°F inversion is considerably better, and the 2°F response slightly better than the conventional machine. The 7°F inversion at Chico resulted in a 3.5°F response, while at Meridian a 7°F inversion gave a 7°F response, due to the added heat.

The test run in the diagram on the right on the next page was conducted with practically no inversion—actually only 1.4°F. Under these conditions less than a 1°F response could be expected from a conventional machine. The ramjet machine, however, produced a rise of 2°F over one fourth acre and 1°F over 1¾ acres. This appears to be the effect of exhaust heat from the motors, with little aid from natural inversion.

The net results of these ramjet trials suggests that the heat added to the air jet by the engines is of benefit, although decreasing as the inversions become weaker, and may in certain locations justify the high fuel consumption. This benefit unfortunately does not extend over a large area, so complete protection in many orchards would still require the

use of orchard heaters around borders. The air temperature responses with orchard heaters under weak inversions would also be small, but most of the protection would be provided by their radiant heat.

In the case of multiple wind machine installations in large orchards, it is expected that more of the heat produced by the ramjet would be usable and better distributed. However, this should be determined by field tests. Considering the heat from the ramjet, 150-200 orchard heaters could be operated for the same fuel cost and would give the same temperature rise over a larger area.

Another characteristic of the ramjet—which could be considered to be a major limiting factor—is the noise. Unfortunately the roar of the engines can be reduced only slightly without interfering with the machine's performance. Therefore, the machines may be limited to regions remote from residences.

Cover Crops Affect Response

An effect—not reported heretofore—was observed in both the almond and the prune orchard test locations: a tall cover crop reduces the wind machine response in the lower parts of the trees.

In the Meridian tests, a thick cover crop of mustard and clover had been sown, and had grown rapidly early in the season. This was rolled flat just prior to the beginning of the first tests. Later tests were conducted at 3-5 weeks when

the cover crop was knee-high, and again at seven weeks when the average height of the cover crop was 3', the same height as the thermistors.

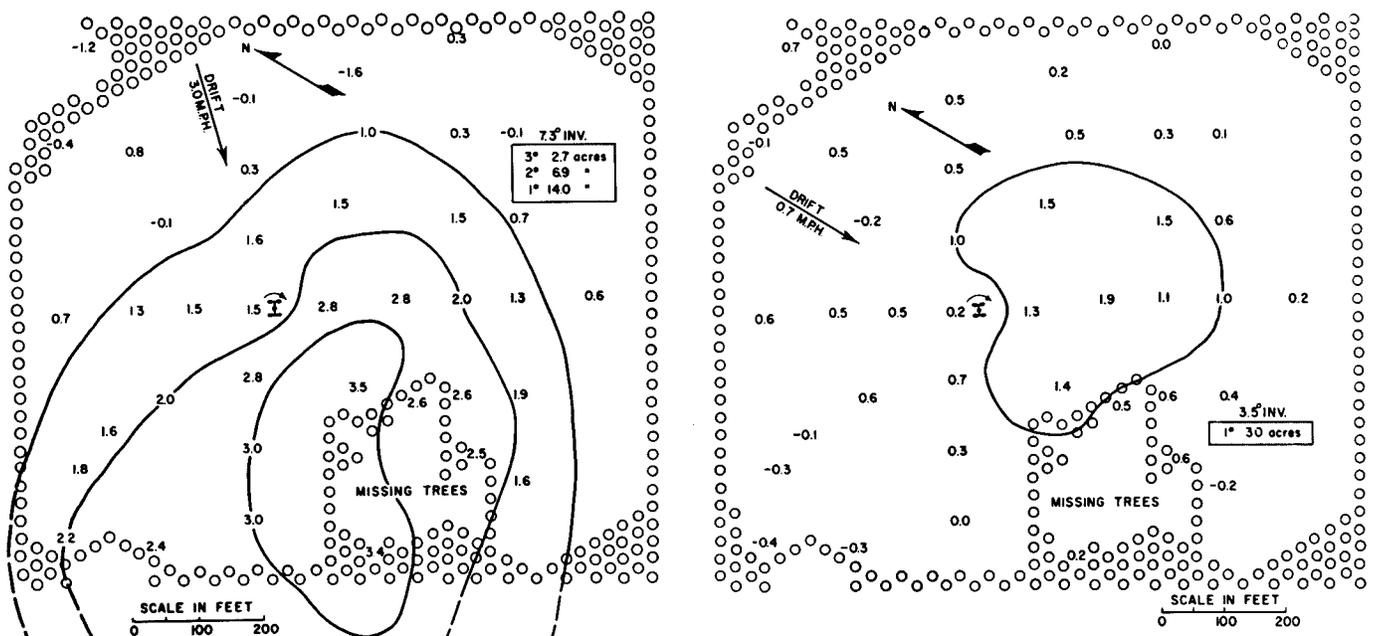
The temperature response due to the machine as measured at 3' decreased steadily as the season progressed. It is believed that as the top of the cover crop moved up, the full effect of the air jet from the machine was not felt at the level of the thermistors.

At Chico, the thermocouple measurements at 10' above ground showed a consistent performance throughout the whole season, so that it is unlikely that the cover crop, which did not grow more than knee-high, had any effect on these measurements. Half-way through the test period the orchard was disked, leaving a bare, level soil surface. After the disking, thermistors at 3' showed the same temperature responses as the thermocouple layout at 10'. However, while the cover crop was growing, the temperature responses at 3' were appreciably less than those at 10'.

There has been some evidence in past studies that the presence of a cover crop in an orchard may cause slightly lower temperatures than would exist without it. It now appears that a cover crop may hinder the adequate protection by wind machines of the fruit on the lower portions of the trees.

At present, wind machines can be considered to provide more economical protection than orchard heaters, only in favorable locations.

Plot diagrams showing typical responses to 150 bhp machine in 22 acres of mature almonds at Chico under weak and moderate inversion conditions, occurring on nights when heating was required later in the completely surrounding orchards. The left diagram shows the response obtained with a 7.3°F inversion, much of the protection extending beyond the instrumented area. On the right a much smaller response is shown during a 3.5°F inversion. The numbers give the response in °F at the points indicated. Lines show the approximate response areas for 1°F, 2°F, and 3°F and illustrate the importance of inversion and drift in wind machine performance.



The sum of capitalization costs, stand-by charges and maintenance expenses may run \$30-\$60 per acre per year without operating. Therefore, a grower needs to evaluate his particular situation carefully to determine whether a wind machine can be advantageously used.

At locations where frequent light frosts occur, a wind machine can provide economical protection. However, if damaging temperatures are experienced once every four or five years, or if heater

support is needed frequently—because of temperatures going 3°F or more below the damaging point—a wind machine on its own would not be justified.

To evaluate the usefulness of a wind machine in a particular orchard, the grower should have reliable information pertaining to the number of nights of damaging temperatures per season. Such information can be obtained from grower's minimum orchard thermometer daily records for several seasons or possibly from the Fruit Frost Service records.

The grower must also know the minimum temperatures which occur on frosty nights—without protection—in relation to the critical temperatures for the various stages of growth of the crop. A good crop of almonds, for example, can be produced even after an 80%-90% loss of buds in one frost, but if a second frost should occur a few weeks later, there may be no commercial crop. Critical temperature information for a particular crop and area as the season advances is essential.

Inversion temperature data—on several typical frost nights—should be known. Usually the air temperatures are compared at heights of 5' and 40' to 50'. Simultaneous readings at the two heights, or thermograph records, should be obtained.

The direction and speed of the air drift above the trees on several typical frost

nights, and the variations during any one night, or from night to night must be known to properly locate a wind machine.

With such information, the selection, location, and operation program of a wind machine or orchard heater system, or a combination, can be determined with reasonable confidence.

G. E. Goodall, Farm Advisor, Santa Barbara County, University of California, participated in earlier wind machine tests in this project in citrus and was on loan to the Department of Agricultural Engineering for these studies.

D. E. Angus, Assistant Specialist in Agricultural Engineering, University of California, Davis, conducted the frost research program of the Division of Meteorological Physics, Commonwealth Scientific and Industrial Research Organization, Australia, and was granted leave to cooperate in these studies in California.

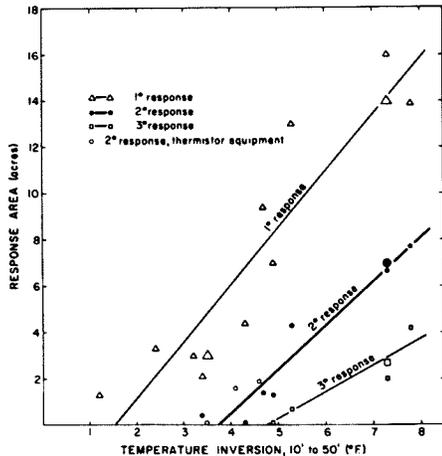
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Plot of 12 test runs in the Chico almond orchard. The diagrams below are shown as bolder points. This graph plots the acreage within the isolines for the 1°F, 2°F, and 3°F responses against the inversion strength in °F. The straight lines are calculated lines of best fit, and provide a reasonable evaluation of wind machine performance under these conditions.

Diagrams of typical responses for the ramjet wind machine in 20 acres of prunes near Meridian with open fields on three sides. The left plot illustrates the response under moderate inversion condition of 7.5 F. This shows the substantial areas of improved response due to the added heat. The right plot represents a test period several nights earlier when almost no inversion—1.4 F—occurred. Under this very weak inversion condition, a conventional wind machine would be expected to produce less than a 1 F response. This test shows that although the ramjet machine produced more than a 3 F maximum response, the 1 F area was still very small. The heat added by the ramjet is concentrated in an area rather near the machine and is of little benefit along the borders of the orchard. These diagrams illustrate the wide range of protection which may be realized under widely different inversion strengths.

