Temperatures and Frost Damage

measurements of temperature inversions and blossom counts show extent of frost damage in tests in deciduous orchards

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The effectiveness of all frost protection depends primarily on the temperature inversion—ceiling—but adequate measurements had not been made until an extensive field program was undertaken in northern California in the spring of 1956. Six thermographs equipped with 50′ extensions were installed with other spot-climate recording stations in selected deciduous orchards. Several growers contributed to the project by keeping the thermographs in operation.

An electric recording station was set up near Chico—to compare adjacent walnut and almond orchard temperatures—and a second recording station was established at Hamilton City—to compare pear and orange orchards. In addition to the fixed stations, two cars—equipped with collapsible masts reaching to 40′—were operated on planned routes in the Chico and Arbuckle areas.

During the 1956 growing season there was only one cold spell in the Sacramento-San Joaquin Valleys—during the nights of March 5–6 and 6–7—when temperatures went low enough to constitute a serious frost hazard. A little before sunrise on the morning of March 6, air temperatures at the 40′ to 50′ level in both the Chico-Durham and Hamilton City areas stood at 30°F. In almond orchards in the Chico-Durham area, temperatures at tree level were from 2°F to 4°F lower. At Hamilton City, air temperatures at tree level in the pear orchard were 3°F lower and in the adjacent orange orchard, about 5½°F lower. In an orchard in the Arbuckle area, an air temperature of 29°F at 40′ with a 2°F inversion was measured.

On the next night, frost struck the Modesto-Denair area and—in the early morning of March 7—air temperatures at the 35′ level dropped to 30°F with 25.5°F at tree level. On the morning of March 12, a minimum temperature of 31.5°F at the 40′ level with a 3.5°F inversion was recorded in the Escalon area. Such low overhead temperatures are real limitations on the effective use of wind machines. Therefore, it is desirable to have daily records of minimum temperatures—at least 40′ aboveground—for several years, or long enough to establish the statistical probabilities of these unfavorable weather conditions in various localities.

Table of Blossom Damage Counts, Stanislaus County, After March 7, 1956

Station	Minim. temp.	Variety	Tree stage		Sample loss	Surviving on tree
A. In almond orchard using mobile heater for frost protection						
1st row	25.5°F	Ne Plus	Full bloom	20%	70%	6%
			Petal-fall	80	75	20
						Total 26
		Nonpareil	Full bloom	50	4	48
			Petal-fall	50	44	28
						Total 76
		Mission (Texas)	Full bloom	100	20	Total 80
Middle	27.5°F	Ne Plus	Full bloom	20	45	11
			Petal-fall	80	42	46
						Total 57
		Nonpareil	Full bloom	50	3	48
			Petal-fall	50	14	43
						Total 91
		Mission (Texas)	Full bloom	100	1	Total 99
B. In almond orchard using sprinklers for frost protection						
1st row	26°F	Drakes	Full bloom	80%	54%	37%
			Petal-fall	20	87	3
						Total 40
		Nonpareil	Full bloom	20	10	18
			Petal-fall	80	41	47
						Total 65
Center		Drakes	Full bloom	80	30	56
			Petal-fall	20	60	8
						Total 64
		Nonpareil	Full bloom	20	1	20
			Petal-fall	80	12	70
						Total 90
Last row (down drift)	27.5°F	Drakes	Full bloom	80	16	67
			Petal-fall	20	40	12
						Total 79
		Nonpareil	Full bloom	20	1	20
			Petal-fall	80	5	76
						Total 96

Heat Needed

The main findings this winter—1955–56—confirmed and extended last year's observations at Chico. Then, temperature inversions on frost nights were generally only from 1°F to 4°F, which is less than half as much as normally expected in the citrus plantings in southern California. The weak inversions found at Chico mean that heating must be the basic practice for frost protection. Wind machines should help almost any heating system—except irrigation when heat released from the water may not always be adequate—but the machines cannot be expected to provide much protection without heater support under conditions of weak inversions.

According to a recent survey, 60% of the almond acreage in Yuba County has some means of frost protection, and 40% of that acreage depends on heaters. Both smudge pots and return-stack-type heaters were in use throughout the area, and it was noticeable that those orchards using stack-type heaters were rather free of smoke. Except for only a few orchards in and around the city of Chico, most of the streams of heavy smudge seemed to originate well outside the city.

Frost protection installations are extensive also through San Joaquin and Stanislaus counties. In a search for uniform orchards—with different protection systems but exposed to natural air drift—relatively few large blocks of unprotected orchard were found. Of the protected orchards, most employed heaters. A survey in Stanislaus County showed the use of heaters was always successful, usually giving a rise of about 5°F.

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During the frost at Chico before sunrise March 6, heating a Butte County orchard was so successful that it almost completely filled in the inversion, while in an adjacent unheated walnut orchard the air at tree level averaged 2.1°F colder than at 40′.

Local Cold Spots

The weak inversions which were found—occurring sometimes in spite of daytime temperatures exceeding 65°F—indicate rather minor air chilling by bare branches losing heat by radiation to the cold sky. The weak inversions also indicate the rather free flow of air in the wide Sacramento Valley that is usually strong enough to provide natural frost protection. Such natural protection is to be expected from Hamilton City to Orland and Arbuckle. Shielded areas, however, can be much colder because of local calm air. In a hollow near an orchard at Arbuckle, a minimum of 22°F was measured when the exposed orchard was at 28.5°F. And near Loomis—on the east side of the Valley opposite Arbuckle—the steep ridges running perpendicular to the direction of the general overhead air movement provide such positive shielding from general air circulation that cold spots usually develop. Those cold spots might be handled by wind machines if the overhead air was warm enough.

The cold-air conditions found in a rather open pear orchard on the north slope of a hill near Colfax were very different from those found in the wide valley. In the foothill location there were several local cold spots which were adequately handled by wind machines. Some improvement might have been obtained by removing obstructions to the drainage of cold air on the lower side of the orchard. However, it is significant that most frost damage usually occurs on a small flat bench area a little higher than the down side of the orchard. Possibly a nearby house acts as a minor obstruction to the cold air drainage, but the topography indicates that the bench land is untouched by the main flow of cold air down the draw. The bench therefore has the most stagnant air which tends to be chilled by the orchard itself.

At Chico there is often a rather deep but slow drift of cold air from the mountains on the east and northeast. The slow drift is sometimes topped by a rather strong general overhead drift from the north as indicated by smoke plumes which rise to a height of several hundred feet and then are usually carried almost due south rather rapidly. In addition, even more localized variations may develop within this larger flow pattern. An example of this is the rather typical sequence of events during the cold spell of March 27–29. On the first night, the United States Department of Agriculture Plant Introduction Station—located near the mouth of a large canyon coming out of the mountains to the east—was the coldest spot in the area. On the second night, Durham—located several miles out in the flat Sacramento Valley—was the coldest. These conditions were caused—apparently—by the progressive shift in direction and decrease in strength of the general overhead air flow typical of most cold spells in this area.

On the first night of the cold spell the overhead flow was in such a direction as to oppose the natural drainage of cold air down the canyon. Also, the overhead flow was of such strength it was able to bring the natural drainage more or less to rest in the area around the mouth of the canyon. At the same time, the relatively strong overhead air flow provided natural protection to exposed areas out in the flat valley floor.

On the second cold night, the natural overhead flow had shifted in direction and there was such a strong movement of air in the canyon area that temperatures in the orchards were kept quite high. Out in the flat valley, the relatively weak overhead flow permitted stronger inversions to develop in the orchards and temperatures at tree level fell to lower values than on the first night.

Mobile Heater-Blower Unit

In the Denair area on the morning of March 7, when a killing frost occurred, thermometer readings in a 15-acre block of almonds—under the protection of a mobile heater-blower machine—indicated that safe temperatures were not being maintained. The mobile rig was then rerouted—in closer rows through the orchard—to provide more intense protection but for only eight acres.

During the afternoon of the same day, counts—to determine the extent of damage, if any—were made on 150 blossoms in full bloom and 150 blossoms which had shed their petals. The Ne Plus Ultra trees were at approximately 80% petal fall, the Nonpareil at 50% petal fall, and the Mission were at full bloom.

The total blossom losses—depending on variety—ranged from 20% to 75% on the updrift side of the orchard where the minimum temperature was 25.5°F. In the center of the orchard the total blossom losses were 1% to 21%—about what would be expected—at a minimum temperature of 27.5°F. If more temperature rise could have been obtained, there might have been a larger crop on the outer periphery of the trees. If a frost of the same intensity had come later—when the trees were at a more susceptible stage—the loss to the grower might have been serious. As a comparison to this mobile heater unit, an adjacent orchard—equipped with return-stack heaters—had a minimum temperature of 29.5°F and suffered no damage from frost.

Tests of a Sprinkler System

The sprinkler irrigation system in an almond orchard—Nonpareil and Drake varieties—in the Denair area was used for frost protection on the morning of March 7. Damage counts were made on 150 open blooms and 150 blooms which had shed their petals. The Nonpareil variety was at approximately 80% petal fall, and the Drakes at 20% petal fall.

There seemed to be an advantage of 1°F to 2°F with damage to Drakes in the petal-fall stage, decreasing linearly from 87% on the east row to 60% in the center and 40% at the downdrift edge. The outside temperature minimum was 26°F. The damage to Nonpareils showed a similar pattern with much less injury.

In this orchard the sprinkler heads—$\frac{3}{64}$ #20—were spaced on 60′ × 80′ centers and wet about 35% of the ground area at a rate of about 0.1″ per hour. Although a good crop was obtained in this case the same degree of protection would have been inadequate if a frost of the same severity had come later.

Jet-Powered Wind Machine

Preliminary tests were run on an experimental model of a ramjet-rotor wind machine. The configuration of this machine is quite similar to that of conventional machines. The propeller shaft is mounted on top of a tower and points downward at 15° below the horizontal into the orchard. Turning slowly about a vertical axis, the machine's blast sweeps the orchard every seven or eight minutes. The principal difference between the ramjet-rotor and the conventional machines is in the means of supplying the power which turns the propeller. Instead of the usual electric or gasoline engine, this machine is driven by ramjets mounted on the tips of its propeller. The ramjets burn many times as much fuel as an internal combustion engine of equal power, so the heat release is comparable to the combined output of orchard heaters. Therefore, the ramjet-rotor machine is roughly equivalent to a more conventional wind machine with heater support, but without the labor costs and management problems associated with the operation of heaters.

As it turned out, the ramjet-rotor machine was not set up for operation until after the last frost of the 1956 growing season and so could not be tested under

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Caterpillar Damage to Tomatoes

results based on one-year survey indicate no evidence of resistance to insecticides in nine commercial tomato fields

John Underhill and A. E. Michelbacher

Suspected resistance to DDD and DDT in controlling caterpillars attacking tomatoes—the corn earworm, in particular—was investigated in San Joaquin County during the 1955 season.

Nine commercial tomato fields were selected in several localities from the west to the east side of the county. The growers co-operated in the project and kept records of the material used and the date and rate of application.

During the growing period, four surveys were conducted to determine the seasonal trend of infestation. Excellent control of caterpillars was obtained with two to three treatments. Very little evidence of infestation was found during the maturing of the crop, and nearly all the loads delivered to the cannery were graded as being free of worm damage.

The results based on this one year survey would not indicate any evidence of resistance. However, further investigation is needed for it is possible that the 1955 season was one which was unfavorable to the development of large caterpillar populations. Evidence obtained on other crops indicated that this might have been the case. For example, caterpillar pests of walnut appeared to be less abundant and destructive in 1955 than in previous years.

The activity of other pests was observed in the selected fields. In none of them was any damage by the tomato mite encountered. By midseason some increase in the leaf miner population was observed in some of the fields. However, in only one out of the nine did the population reach a moderate level, and in three not enough were found to make it worth while to record.

The effectiveness of the tomato insect control program has held up remarkably well. Cases of poor control are probably due—in part—to inadequate timing and improper application. Fields should be watched closely, and thorough and even treatments applied before destructive populations develop.

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Treatments and Per Cent of Tomatoes Infested During Growth of Crop and the Degree of Worm Damage Found in Tomatoes Delivered to the Cannery.[a]

Location	First application			Second application			Third application		
	Date	Insecticide	Pounds per acre	Date	Insecticide	Pounds per acre	Date	Insecticide	Pounds per acre
Vernalis	July 23	5% DDD 75% sulfur	30	Aug. 27	5% DDD 50% sulfur	35	.....	...	..
Tracy	July 11	5% DDD 50% sulfur	30	Aug. ?	5% DDD 75% sulfur	35	.....	...	..
Tracy	July 13	5% DDD 50% sulfur	30	Aug. 14	5% DDD 75% sulfur	30	Sept. 5	10% DDT	30
Union Island	July 20	5% toxaphene 60% sulfur	30	Aug. 8	5% DDD 75% sulfur	30	.....	...	..
Roberts Island	June 28	5% DDT	25	July 12	5% DDD 50% sulfur	30	Aug. 26	5% DDD 75% sulfur	35
Roberts Island	Aug. 1	5% DDD 50% sulfur	30	Sept. 1	5% DDD 50% sulfur	35	.....	...	..
Linden	July 22	5% DDD 75% sulfur	35	Sept. 3	5% DDD 75% sulfur	35	.....	...	..
Linden	July 26	5% DDD 75% sulfur	35	Aug. 29	5% DDD 50% sulfur	50	.....	...	..
Linden	June 23	5% DDD 75% sulfur	25	Aug. 7	5% DDD 75% sulfur	40	.....	...	..

Per cent of infested tomatoes on indicated dates and worm damage in delivered loads.[b]

Location	July 26	Aug. 15	Aug. 30	Sept. 15	Number of loads delivered to cannery	
	Corn earworm	Corn earworm	Corn earworm	Corn earworm	No worm damage	Graded ½% worm damage
Vernalis	0.0	1.0	0.0	0.0	69.0	3.0
Tracy	0.0	0.0	0.3	0.0	[c]	..
Tracy	0.0	0.0	0.0	0.0	61.0	0.0
Union Island	..	..	..	0.0	243.0	5.0
Roberts Island	0.0	0.0	0.3	0.0	131.0	5.0[d]
Roberts Island	0.0	0.3	..	0.0	71.0	0.0
Linden	0.0	0.0	0.0	0.0	81.0	0.0
Linden	..	0.0	0.0	1.0	9.0[e]	..
Linden	0.0	0.0	0.0	0.5	204.0	2.0

[a] With exception of one first treatment all applications were made by airplane.

[b] No evidence of recent infestation by hornworms, western yellow-striped armyworm, beet armyworm, potato tuber moth or tomato pinworm were encountered in any of the four surveys conducted.

[c] Field harvested for green market.

[d] One load graded 1% worm damage.

[e] Many more loads delivered and grower believed all were free of worm damage.

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actual frost conditions. However, tests were made under atmospheric conditions which were quite similar to those occurring under actual frost conditions.

During these tests—just before sunrise—no hot air from the ramjets escaped as every bit of it was drawn into the propeller blast. The warm blast from the machine did reach the ground out in the orchard. So much air had been mixed with the hot exhaust from the ramjets that by the time the blast reached the ground the temperature of the mixture was not appreciably higher than that of the air in an orchard under the protection of heaters. The blast had no more tendency to rise out of the orchard than the air in an orchard under any other form of adequate protection.

The results of these preliminary tests are encouraging and some reduction in the noise is promised. Further tests of the ramjet-rotor machine under actual frost conditions are planned for 1957.

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Harry Hansen, United States Frost Warning Service, members of the University of California Agricultural Extension Service, and individual growers co-operated in the studies reported in the above progress report.