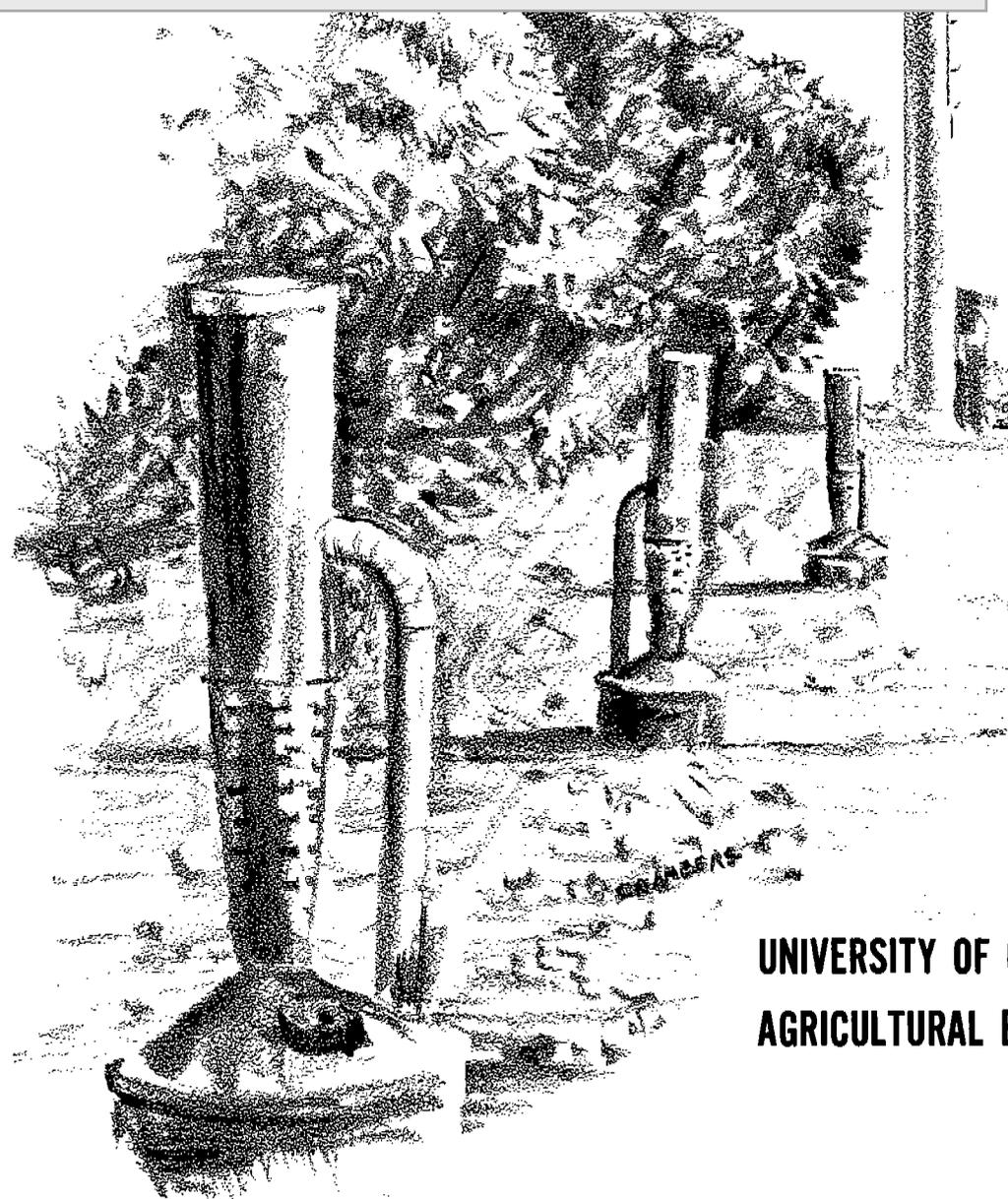


FROST PROTECTION IN CITRUS

Note: This is a reference cited in AP 42, *Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources*. AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

The file name refers to the reference number, the AP42 chapter and section. The file name "ref02_c01s02.pdf" would mean the reference is from AP42 chapter 1 section 2. The reference may be from a previous version of the section and no longer cited. The primary source should always be checked.



684 Buena Vista Street
Ventura, Calif. 93001

**UNIVERSITY OF CALIFORNIA
AGRICULTURAL EXTENSION**

IMPORTANT FACTORS TO CONSIDER FOR ALL TYPES OF FROST PROTECTION

HEAT TRANSFER. Heat is always transmitted from a warmer to a cooler body. It is transferred in three ways.

Conduction is the transfer of heat through a solid body, or bodies in physical contact, as when heat moves through soil.

Convection is the transfer of heat through a liquid or a gas-like air. Cold air moves toward a lighted heater, is warmed, and rises naturally. In forced convection, a wind machine blows air past a heater, thus circulating and mixing air in the orchard.

Radiation is a direct transfer of heat through space from a hotter body to a colder one. There is very little heat absorbed by dry air. Water vapor absorbs part of the radiant energy. Radiation travels only in straight lines, so that only the part of a tree that "sees" the heater will be warmed.

FREEZE in citrus districts is an invasion by cold air at low levels from the Arctic regions and air temperatures may drop to 20 F or lower. In California, freeze periods occur every 8 to 14 years and sometimes may occur 2 to 3 years in succession and usually occur during dry weather cycles.

FROSTS occur when an orchard loses heat by radiation to the cold sky. On a frosty night the sky temperature will be 0 to -15 F. Orchard air becomes chilled, mainly from contact with the exposed surfaces of trees and ground. California citrus districts usually have from 2 to 12 radiation frost nights each winter.

DEWPOINT is the temperature at which moisture will condense out of the air. High dewpoints reduce the net rate of radiation to the sky and orchard conditions tend to be steady with a slow drop in temperature. Low dewpoints permit a large radiation loss, and orchard temperatures drop rapidly.

When air temperature falls lower than the dewpoint temperature, dew will form. If the air temperature is below the freezing point of water, ice crystals form and the frost is called white frost.

When the dewpoint temperature is lower than the freezing temperature of the air, neither dew nor frost forms. The effect of the combination is called black frost.

TEMPERATURE INVERSION. During the day, the sun warms ground and trees. In turn, these warm the air in contact with them, leaving cool air above. During the night, radiation cools the ground and the ground cools the air close to it. This reversal of daytime conditions is known as temperature inversion, since now warmer air is above the cool air at the ground.

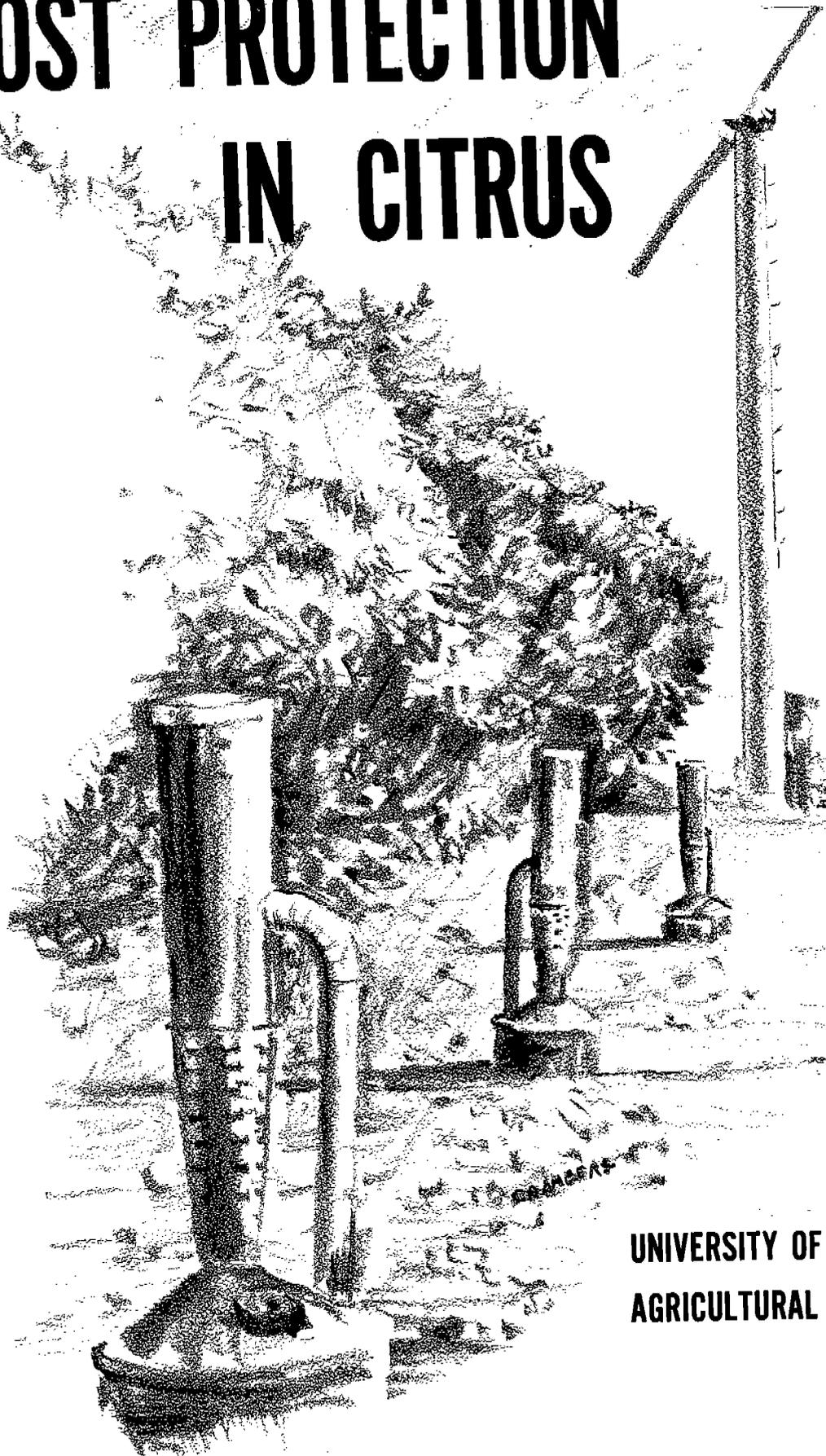
LARGE INVERSION. Overhead air is considerably warmer than orchard air and is known as a "low ceiling," because warm air from heaters rises only a short distance before it reaches air warm enough to stop its rise. Large inversions provide a good source of heat which wind machines can pull down and distribute in the orchard.

SMALL INVERSION. When overhead air is only a few degrees warmer than the air in the orchard it is known as a "high ceiling," because the heated air must rise much higher before it reaches equally warm air above. Much convective heat is lost, making orchard heating more difficult. Neither heaters nor wind machines are as effective with small inversions. With low orchard temperatures, more heaters are necessary. Supplemental heat from heaters also may be necessary for efficient wind machine protection.

COLD AIR DRIFT. Air chilled by contact with the ground flows downhill slowly, filling low spots. In isolated and border orchards, border heaters must be used to heat this incoming cold air. If wind machines are used and there is a large inversion, border heaters may not be necessary.

AP-42 Section 9.2.3
Reference 2
Report Sect. _____
Reference _____

FROST PROTECTION IN CITRUS



684 Buena Vista Street
Ventura, Calif. 93001

**UNIVERSITY OF CALIFORNIA
AGRICULTURAL EXTENSION**

AXT-108 (Rev.)

FROST PROTECTION IN CITRUS

This bulletin is divided into the following sections:

- IMPORTANT FACTORS TO CONSIDER WITH ALL TYPES OF FROST PROTECTION
- USE OF WATER IN CONDITIONING THE ORCHARD FOR FROST PROTECTION
- METHODS OF FROST PROTECTION

Water
Heaters

Wind Machines
Wind Machines and Heaters

This publication is intended as a guide to growers seeking information concerning methods, equipment, and principles used in frost protection.

It is not possible to give a "rule of thumb" for protecting all orchards. The decision on which type of equipment to use, and under what conditions, must be made by the grower. Conditions from grove to grove and from district to district vary considerably.

The decision as to the economic feasibility of frost protection must be made by each grower. It depends upon many factors, such as cost of frost protection, total grove costs, value of trees and crop, and probable life of the orchard.

The authors are Richard E. Puffer, Farm Advisor, Los Angeles County, and Franklin M. Turrell, Plant Physiologist, Citrus Research Center, University of California, Riverside.

The authors wish to express their appreciation to Robert G. Platt, Karl W. Opitz, and Marvin P. Miller of the University of California Agricultural Extension Service for their help in preparing this publication.

Acknowledgement is due also to University of California circulars and bulletins by R. A. Kepner, and to articles by F. A. Brooks, et al, published in the University of California publication, CALIFORNIA AGRICULTURE, for sources of information.

Co-operative Extension work in Agriculture and Home Economics, College of Agriculture, University of California, and United States Department of Agriculture co-operating. Distributed in furtherance of the Acts of Congress of May 8, and June 30, 1914. George B. Alcorn, Director, California Agricultural Extension Service.

NOVEMBER 1967

IMPORTANT FACTORS TO CONSIDER FOR ALL TYPES OF FROST PROTECTION

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COLD AIR DAMS. Windbreaks that are not kept clean at the bottom, highway and railroad embankments, and upward sloping ground on the downwind side create obstructions which block the flow of cold air from the orchard. Extra heaters are needed in such locations, or powerful wind machines can be used to push the heavy cold air over the dam. To help prevent these dams, keep windbreaks clean at the bottom.

WINDBREAKS may be helpful in areas exposed to cold winds during a freeze, but will be a detriment during a frost. In some locations, the advantages of the partial protection provided by windbreaks in a freeze might outweigh their disadvantages during frosts.

WIND. During a temperature inversion, a wind of as little as 3 or 4 miles per hour mixes the warm and cold layers of air, causing orchard air temperature to rise. When there is little or no inversion, winds bring cold air into the orchard, increasing heating requirements.

HEAT FROM SOIL. The soil stores heat from the sun during the day and releases it at night by radiation. Cover crops, loose soil, wood mulches, and dry surface soil reduce this heat flow in and out of the soil. Moist, firm, bare soil increases heat flow and makes more heat available during the night.

ONE- AND TWO-YEAR-OLD TREES should have their trunks wrapped with some insulating material, or should be covered so that they cannot "see" the sky. Sometimes both are done. Place covers so they do not touch the foliage. Heaters probably need not be lighted as much or as early for covered trees.

YOUNG ORCHARDS cool faster, and the trees are usually much colder than large trees in mature orchards. More heat should be added to young orchards, older groves with young replants, and groves where recent pruning has been heavy. Wind machines should be started and heaters lighted sooner in young orchards than in mature ones. Young orchards also require protection on more nights. When heat is added, young groves tend to warm quickly.

MATURE ORCHARDS. Young orchards mature at no specific age and change gradually. Frost protection methods for the young orchard also change gradually each year until the trees are large enough to be treated as a mature orchard.

Older groves containing large trees with a good canopy of leaves retain much more heat than young orchards. The leaves make good insulators to hold the heat rising from the ground, and the trees help to shade one another so that fewer leaves "see" the cold sky. Under inversion conditions tall trees are often up in the layer of warm air.

Because of the additional heat, the mature orchard does not need, on many radiation-frost nights, additional protection or protection as early in the night as a young orchard. However, if big trees are allowed to get cold, up to 8 hours are needed to warm them again. This is important when there are series of cold nights, when protection must be started before the orchard gets too cold. If there is a freeze predicted, start protection early. If freezing temperatures are expected for several nights, keep the grove warm.

FRUIT THERMOMETERS are very helpful in deciding when to provide frost protection in mature orchards during radiation frosts. Use several fruit thermometers. Select fruit of average size on the outside of a tree at about eye level. Place thermometers on sides of trees not facing a heater.

Read fruit temperatures often. Single readings may not show the situation in the fruit. A series of readings will show that the fruit temperature follows the air temperature, dropping until the fruit begins to freeze. At this point, the temperature inside the fruit rises to the freezing point of the fruit and remains there until the fruit is frozen solid, no matter how low the air temperature falls. After fruit is frozen solid, fruit temperature will follow the trend of the air temperature.

When the fruit temperature first reaches the fruit's freezing point and when the reading of the sheltered air thermometer is lower than fruit temperature, it is time to light heaters.

Allow enough time to light the necessary heaters. The time needed will vary between orchards, depending upon lighting arrangements and whether wind machines are used.

Example of a Series of Radiation Frost Nights: Daytime temperatures of 45 F to 60 F for several days before the frost; first-night low temperature of 26 F for oranges and 28 F for lemons. Young orchards will need wind machines or heaters, or both. Older orchards probably need no protection the first night. During the second and third nights, both young and older orchards need frost protection.

WEAK TREES freeze more easily than healthy trees. Every effort should be made to improve grove conditions so that the trees can withstand colder temperatures.

ICE ON FRUIT cools the fruit several times faster than cold air alone. Heaters should be started early. Start wind machines after the sleet-storm stops, and run after daylight until fruit dries off.

SNOW ON FRUIT does not cool the fruit as ice does. Heaters are not needed during snowstorms unless fruit temperatures drop below 28 F. Do not use wind machines unless wind is less than 4 miles per hour, and then not until snow has nearly melted. If snow is on the trees after sunrise, start wind machines when snow starts to melt on south sides of the trees. Run wind machines after daylight until fruit dries off to help prevent fruit damage.

UNDERCOOLING occurs when temperatures inside the fruit drop below the freezing point of the fruit

without starting to freeze. Mature fruit usually undercools to temperatures of 22 F to 25 F without freezing. Fruit thermometers help to indicate the amount of undercooling and should be read frequently. When fruits freeze, temperatures inside the fruit rise to the freezing point of the fruit and stay there, no matter how low the outside air temperature, until the fruit is completely frozen. There is very little undercooling when ice is on the fruit. The freezing points of the various fruits are published by the Fruit Frost Service (see page 9).

AIR THERMOMETERS should be sheltered; face them north, 5 feet from the ground, and away from heaters. Usually several stations are needed in the orchard in order to check for cold spots.

TREE HARDINESS TO COLD. Three cold nights and cool days before a frost make trees hardier. Three warm days and nights before a frost destroy this hardiness.

PREPARING FOR FROST PROTECTION. Make all preparations for frost protection by November 1. During the frost season—watch the weather maps presented on television; listen to the Fruit Frost Service on the radio for predicted low temperatures; keep a record of grove low temperatures and compare them to the Fruit Frost key stations. Check orchard temperatures to find how many degrees above or below the key station the orchard usually is so you can predict low temperatures in the grove.

USE OF WATER IN CONDITIONING THE ORCHARD FOR FROST PROTECTION

The importance of water in conditioning the orchard for frost protection cannot be overemphasized. There are two points to consider:

1. Citrus trees freeze faster under moisture stress. One test on lemons during the winter showed that 14 days are required for the fruit on dry trees in gravel soil to regain normal moisture content after irrigation. If trees are allowed to go dry, then irrigated, a frost or freeze occurring within the 2-week period will find the trees reacting as in a dry condition and therefore more easily damaged. Do not wait for rains. Maintain adequate moisture in the root zone for the tree's needs at all times during the winter. Tensiometers help the grower decide when water is needed.
2. At 18 inches below the surface winter soil temperatures are approximately 55 F. Dry soil acts as an insulator holding this heat below the surface. Water fills the air spaces in the top 12 to 18 inches of soil and helps to conduct this subsurface heat. Wet soil also helps the soil to absorb heat from the sun during the day and to conduct it out during the night. If trees are adequately drawing moisture from the deeper soils and the top 12 to 18 inches are dry, a light irrigation before an expected cold spell will be helpful.

METHODS OF FROST PROTECTION

Solid fuels, ramjet wind machines, overhead sprinklers, gas burners and new tree sprays must be considered experimental.

Water

Water has a large heat capacity, and if run in the grove on a cold night will supply quite a lot of heat. (Running water has little effect if there is a cover crop.) When water freezes, its latent heat is also released by the freezing process. Underhead sprinklers may be used as heat sources on cold nights but overhead sprinklers should not be used. Don't use running water if the orchard is not well drained; all surface water must be carried out of the orchard.

Running water may cause root rot problems. However, in a severe freeze, a grower may decide to risk running the water for several nights. If ice forms, the water should run over it. If heaters are used and the orchard soils are heavy (25 percent or more clay), running water makes it impossible to refill the heaters.

Heaters

Smoke Nuisance. All growers must have permits to operate heaters in counties with Air Pollution Control District regulations. Only heaters listed as Class I or Class II can be used in counties with these regulations. The maximum burning rate for each heater in Class II is specified. All heaters must be kept reasonably clean. Open burning for frost protection is prohibited in Air Pollution Control Districts.

Every grower who uses heaters should more than simply abide by the regulations of the Air Pollution Control District. In the interest of maintaining good relations with urban neighbors, growers should do everything possible to hold smoke nuisance at the absolute minimum.

The winters of 1948-49 and 1949-50 brought about the present regulations. A repetition of such a winter with careless heating and too much smoke may bring about much stricter regulations and the outlawing of more heaters, such as those in Class II. Class I and Class II heaters, if burned properly, give off little or no visible smoke.

Smokiness depends upon burning rates (excessive burning rates produce more smoke), soot accumulation (frequency of cleaning depends upon the type of heater and rate of burning), air leakage (increases soot accumulations and smoke and makes it difficult to control burning rates accurately), and wind (stack-type heaters are more smoky in a breeze than during calm weather).

Heaters should be regulated 3 minutes after lighting. Regulate Return-stack and other hot-stack types of heaters 1 minute after lighting. Burning rates should not exceed those set by regulation for each type of Class II heater. Check heaters regularly during the night and adjust to maintain burning rates, or to conserve fuel if the temperatures can be maintained.

If more heat is needed in the early morning, it is better to light more heaters than to open regulators too far. If the oil is low in the bowls and there is some residue, opening the regulators usually produces excess smoke.

With the exception of the Return-stack, heaters should not burn the residue because of the excessive smoke produced. Clean out residues from these heaters at least once a year to maintain full-bowl capacity. In severe winters, it may be necessary to remove the residue more often. Too much residue reduces the number of hours a heater can be burned.

Clean and remove soot from the heaters at least after every 20 to 30 hours of normal burning. The Jumbo Cone, Exchange 6-inch diameter stack, Hy-Lo 1929, and all lazy-flame type heaters need to be cleaned more frequently. Tests show that lazy-flame type heaters need to be cleaned after 8 to 10 hours of normal burning to stay within the legal smoke output. Heaters also should be cleaned to avoid fuel contamination. Repair and replace leaky heaters to help maintain proper burning rates, reduce soot accumulations, and reduce smokiness.

Types of Heaters. When the inversion is large, both convective and radiant heat are useful. Under these conditions, there is no difference among the heaters that can be used legally in Air Pollution Control Districts. The temperature response for a given fuel rate is about the same,

regardless of the kind of heater, provided it is clean and has no leaks.

When the inversion is small, heaters with highest radiant output are most effective. The hot-stack or combustion-chamber types, such as Return-stack, or Jumbo Cone heaters, have 25 to 30 percent of their output available as radiant heat at normal burning rates. Hy-Lo 230A, a lazy-flame type of heater, has 20 to 22 percent; while Fugit, a generating type of heater, has 18 percent.

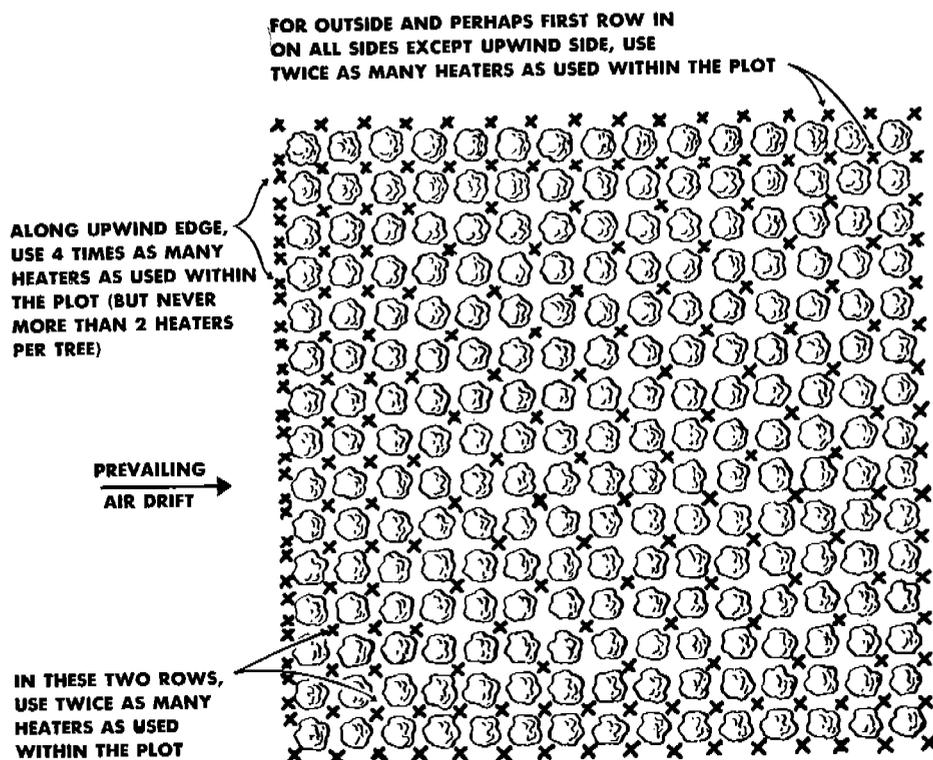
Keeping lazy-flame heaters clean increases the amount of radiant heat produced. The amount of radiant heat increases with the burning rate. Heaters, such as the Return-stack, that can be burned at higher rates without producing too much smoke provide the best source of radiant heat.

Heater Placement. The location of heaters has much influence upon the total amount of radiant heat received by the trees, and upon the uniformity of distribution to the trees. A large number of small fires give better distribution of heat, either

radiant or convective, than a fewer number of heaters at higher burning rates.

If one heater is used for every two trees, the most uniform distribution of radiant heat is obtained when the heaters are placed in each row in the orchard. One heater is placed in the center of the space between each set of four trees. The heaters in one row should be staggered with the next row. Repeat this pattern throughout the orchard. The heaters would have to be moved to one side in drive rows to allow all heaters to be filled. If only every other row of heaters is needed (one heater per four trees), the pattern would still result in equal amounts of radiant heat to all trees.

Placing the heaters in the tree rows reduces the loss of radiant heat to the sky (more of it strikes the trees), but the distribution is not so uniform because the heaters are close to one side of the trees. If every other row is lighted, the trees in the other rows will receive only about one-third as much as the heated rows.



Typical example of border heater spacing, when using one heater per two trees within the orchard. Small crosses indicate heaters.

Taken from U.C. Bulletin No. 723, *Effectiveness of Orchard Heaters*.

Border Heating. Extra heat is needed on exposed sides of an orchard. As an orchard is heated, the rising hot air draws in cold air from the sides. The air will be colder for 10 rows or more in from the edge of the orchard. Border heaters should not be concentrated on the outside of the orchard, but distributed over the first two or three rows in from the edge.

On the upwind edge, where the prevailing air drift enters the orchard, use two heaters per tree on the outside and one heater per tree in the first two rows in from the edge. Never use more than two heaters per tree on the outside, nor less than one heater per two trees on the outside and the first row in from the outside.

On the downwind side of the orchard, use one heater per tree on the outside. On the remaining two sides of the orchard, use one heater per tree on the outside and first row in from the outside.

In mass district heating, the border effects are confined mainly to the orchards on the edges of the heated area. If an orchard within the district does not have another heated area reasonably close, it will probably need extra border heaters.

If there are several types of heaters, use the hot-stack or combustion-chamber type for the border heating. Do not operate border heaters at excessive burning rates. It is much better to operate a larger number of heaters at normal burning rates.

In the center portion of the orchard, burning rates should be kept as low as possible to give adequate protection, to reduce the amount of cold air drawn in by the updraft over the orchard.

When to Light Heaters. Lemons generally require higher temperatures than oranges and grapefruit. The temperatures at which to start firing for lemons will depend upon the type of fruit the grower wants to save. See the recommendations for firing by the Fruit Frost Service (page 9).

For oranges and grapefruit, use the Fruit Frost Service recommendations on page 9 for young orchards and for all orchards during a freeze. In mature orchards firing can be delayed and fuel saved. (See the paragraphs on mature orchards and fruit thermometers on page 2). Be sure to allow enough time to light at the necessary temperatures.

Light only a portion of the heaters scattered throughout the orchard at first, such as every fourth row or every other row if needed. As temperatures continue to drop, light additional heaters. If there is very little wind, with an inversion of 10 F (5 to 60 feet above ground), and heaters are burning at $\frac{1}{2}$ gallon per hour, eight heaters per acre would give a 1 F rise in temperature. If only eight heaters per acre are needed, all exposed borders should have the minimum of one heater per two trees on the outside. The first row in from the upwind side also should have one heater per two trees.

Precautions in Lighting Heaters. Observe carefully all safety precautions, especially with oil-soaked clothing, and when lighting torches and extinguishing heaters.

Lighting Crews should be trained during the daylight before they are needed. Show them how to light heaters quickly and safely, and how to regulate the heaters immediately after lighting and during the night. Most lighting crews are inexperienced.

If they do a better job as a result of the training, costly delays can be avoided, fuel saved, and less smoke produced. The time it takes a crew to light a given number of heaters in an orchard will be a factor in deciding when to light heaters.

Wind Machines

Recent cold winters have proved that wind machines can protect citrus down to 22 F, if the machines have enough horsepower per acre to do the job and if the orchard is in the right condition to withstand low temperatures.

Wind machines with sufficient horsepower move the air at 4 miles per hour and are most effective in still air, during frosts, with moderate to large inversions. During a freeze the air is usually dry, wind movement is better than 4 miles per hour, and there is small inversion. Even with small inversions, wind machines have helped.

One orchard with a small inversion had a wind machine with sufficient horsepower per acre. Temperatures outside the orchard were as low as 18 F. When the wind machine was started early, there was complete protection. In another orchard under similar conditions, where the wind machine was started late, damage was severe.

When to Use Wind Machines. If fruit and twigs are cooler than air, wind machines are helpful. This is usually the case in younger orchards. On rare occasions when there is no inversion layer and no outside source of heat, such as heaters or running water, and the air is colder than the fruit, wind machines would be harmful and should not be used.

If the temperature inversion difference plus the air temperature is below 22 F, a wind machine will be helpful; but it will not protect unless it is used with heaters or running water. For example, if the temperature inversion is 5 F and the air temperature is 15 F, the total is less than 22 F and wind machines will not provide protection. These temperatures prevail when the orchard is healthy and not stressed for moisture and the soil including the surface is moist.

Horsepower Needed Per Acre. Generally from 5 to 8 bhp* per acre is necessary for frost protection. If there is a multiple installation of wind machines, or if wind machines are on a slope, less bhp is needed.

Higher bhp is needed in a cold spot, such as behind a cold dam, with little or no air drainage. A 15 bhp wind machine is not powerful enough to take advantage of a large inversion. In citrus frost protection, two or four wind machines running together provide a greater temperature response per machine than one alone. A multiple installation of three 15 bhp machines may protect the same size area as one 90 bhp machine, but not with the same degree of protection as the 90 bhp, especially in low spots. The 90 bhp would give a larger percentage of higher temperatures.

Area Protected. In figuring this area for a single machine, the air usually will blow only one-third as far upwind as it will downwind. Air from wind machines blowing at 4 miles per hour protects not more than 300 feet crossdrift.

Spacing for Multiple Installation. Wind machines with 15 bhp should be spaced 300 feet by 450 feet. Wind machines with 90 bhp should be spaced 600 by 800 feet. (The 450 feet and 800 feet are along the line of drift.)

Temperature to Start Wind Machines. The temperature at which to start wind machines depends upon the bhp of the machine and the predicted low

temperature. If temperatures not more than 6 to 7 F below freezing are predicted, start the machines at 32 F.

If lower temperatures are predicted, start low-horsepower machines (less than 7 bhp per acre) at 35 F and high-horsepower machines (above 7 bhp per acre) at 32 F. If in doubt, start the machines at 35 F on nights when low temperatures are predicted.

There is a special problem with electric wind machines near cities. Usually they are set to start running at 30 F; otherwise, they would start running on many mornings when it was not necessary. Wind machines make noise, and in some areas disturb the sleep of many city neighbors. Therefore, they should be run only when necessary. This would not be much of a problem with gasoline or diesel machines, because they are started by hand. With electric wind machines, the setting should be left at 30 F. If the prediction is 25 F or lower, change the setting for that night only to 35 F. Be sure to change the setting back to 30 F the next day. In country areas, it may be desirable to leave electric wind machines set to start at 35 F all the time.

When to Shut Off Wind Machines. The machines should run until the fruit is dry and air temperatures reach 32 F. Usually this is 1 to 2 hours after sunrise. In severe frosts, running the machines well past sunrise can save some fruit that has been frozen solid.

Use of Wind Machines in Sleetstorms and Foggy Weather. Wind machines should not be run in this kind of weather unless the machine has a metal propeller and the exhaust can be turned so that it blows on the propeller. Otherwise, ice forms on the propeller, puts it out of balance, and may cause the motor to break loose. Sometimes the wind machine tower is damaged also. Do not start the wind machine until after a sleetstorm. Protection will be needed only rarely on foggy nights.

Wind Machines and Heaters

Wind machines, when used in combination with uniformly distributed heaters, help to give a response greater than the sum of the normal responses when either heaters or wind machines are used

*In this bulletin, bhp (brake horsepower), or the horsepower at the propeller, is used.

alone. Within the area of disturbance, the air mixing caused by the wind machine tends to make the convective heat from the heaters more useful than when heaters are used alone. A 90 bhp machine, plus 15 heaters per acre, is 20 to 30 percent better than the sum of the individual responses.

Heaters must still do the job, outside the influence of the wind machines, such as the corners in a square grove or exposed borders, and high radiant output heaters are important.

If a wind machine with adequate bhp per acre is used during nights with radiation frosts, there probably will be no need for heaters on the majority of nights except in the areas of the orchard unprotected by the machine.

Frost protection by heating alone has become increasingly costly. In general wind machines reduce the number of heaters needed to about one-third, and the heater hours of operation to about one-sixth.

A wind machine plus 15 heaters per acre generally is recommended. This is 39 percent cheaper than 50 heaters per acre in medium winters, even when

overhead costs for each system are included, and 53 percent cheaper in severe winters. The costs are about the same for mild winters.

The mild winter was figured at 10 hours, and the medium at 50 hours with large inversions. The severe winter was figured at 100 hours, including 50 hours with small inversions.

If heaters are used on nights when low temperatures are predicted, the slowing down of the temperature drop by the wind machine allows time to light the heaters as they are needed. See the section on heaters for operation of the heaters.

Operation of Heaters with Wind Machines. Heaters should be distributed uniformly in the grove, and lighted on the upwind side first. No heaters should be in the area 30 to 50 feet from the base of the wind machine. There should be no double heaters or banking of heaters within the grove. Strong rising hot air from a bank of heaters acts as a wall to the blast from a wind machine and turns it up out of the orchard. Heaters can be banked on the borders of the grove. The rising hot air at the border helps to keep the beneficial effects from the wind machine within the orchard.

Frost Protection Information

U.S. Weather Bureau Fruit Frost Service

ORANGES - GRAPEFRUIT - MANDARINS

Fruit temperatures at which freezing begins:

Green oranges.....28.5 F to 29.5 F

Half-ripe oranges, grapefruit and
mandarins.....28.0 F to 29.0 F

Ripe oranges, grapefruit and
mandarins.....27.0 F to 28.0 F

Your sheltered thermometer indicates air temperature. Fruit temperatures are practically always higher than air temperatures when the temperature is falling, but with a stationary temperature for an hour or more the fruit may be as cold as, or even slightly colder than, the air. When the air temperature falls rapidly, the fruit may be as much as 7 F warmer than the air.

On cold nights following warm days (highest temperature 60 F or more) with steady temperature fall to the danger point: protect ripe oranges, grapefruit, or mandarins at 26 F (sheltered thermometer), and green or half-ripe fruit at 27 F.

On cold nights following cool days (highest temperature 59 F or lower) with very slow temperature fall near danger point: protect ripe oranges, grapefruit, or mandarins at 27 F (sheltered thermometer), and half-ripe fruit at 27.5 F.

Keep your sheltered thermometer up to 28 F on either kind of night after protection begins.

Damp nights are more dangerous than dry nights with similar temperatures. Citrus fruits begin to freeze at a higher temperature when they are covered with ice than when they are dry. The temperature fall usually is slow and steady on damp nights. On dry nights look out for sudden and rapid drops in temperature. If air temperature fluctuates rapidly up and down due to wind, take the average of the high and low points as the effective temperature.

On the basis of the limited information available, mandarin fruit should be protected on the same levels as oranges; however, most varieties of the mandarin tree exhibit more frost hardiness as far as vegetative growth is concerned.

LEMONS

Fruit temperatures at which freezing begins:

Button lemons
(up to ½-inch diameter).....29.5 F to 30.5 F

Tree-ripe lemons.....29.5 F to 30.5 F

Green lemons
(larger than ½-inch diameter).....28.5 F to 29.5 F

Buds and blossoms.....27.0 F

Your sheltered thermometer indicates air temperature. Fruit temperatures in lemons exposed to the sky will be as low or slightly lower than air temperatures. Lemons sheltered by foliage generally will be at least a degree warmer than those exposed to the sky.

To save all button lemons, shelter temperatures should be held at 30 F or above.

To save only the larger green lemons (larger than ½-inch in diameter) keep the sheltered thermometer above 28 F.

Damp nights are more dangerous than dry nights with similar temperatures. If ice forms on the fruit early in the night, the larger size green lemons may show rind injury even though the temperature does not fall below 31 F. Such damage occurs infrequently in most districts. It also has been caused by wet snow remaining on the fruit throughout the night.

If the air temperature fluctuates up and down rapidly due to wind, take the average of the high and low points as the effective temperature.

To simplify information, trade names of products have been used. No endorsement of named products is intended, nor is criticism implied of similar products which are not mentioned.

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about UCAES ?**

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