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WARREN R. SCHOONOVER, ROBERT W. HODGSON
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FROST PROTECTION IN CALIFORNIA ORCHARDS[1]

WARREN R. SCHOONOVER[2], ROBERT W. HODGSON[3]
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Although California is favored with a climate which is essentially subtropical, winter and spring temperatures sufficiently low to cause damage to fruit crops are occasionally experienced. All weather records from the earliest indicate that such temperatures occur at periodic intervals.

When the fruit producing industry was small and the value of the crops commensurably low, the losses caused were not of great magnitude. With the rapid extension in fruit culture which has characterized the past three decades and the great increase in the value of the crops produced, losses from frost damage have become exceedingly important, amounting to millions of dollars during the past five years. Few if any localities are entirely free from the danger of low winter and spring temperatures and with minor exceptions every fruit crop of commercial importance is subject to occasional loss from this cause.

The greatest and most frequent losses occur with the sub-tropical fruits, on account of their greater susceptibility to frost damage. This is particularly the case with the evergreen sub-tropicals such as the citrus fruits and the avocado, which never enter a condition of complete dormancy and which normally mature their crops during the winter or spring months. With this class of fruits, therefore, losses may arise not only from the destruction of a part or all of the crop but from the killing of a part of the fruit-bearing wood as well. With mature trees, the damage to the fruit-bearing wood may be sufficient to delay fruit production for several years, and with young trees may so impair their usefulness as to render them practically worthless, sometimes even resulting in death.

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[1] This circular is a revision of Bulletin 398 ''Orchard Heating in California'' published in 1925 and supersedes it. The section ''Laboratory Tests of Orchard Heaters'' has been adapted from the bulletin by that title written by A. H. Hoffman, and published in 1927.

[2] Extension Specialist in Citriculture.

[3] Associate Professor of Subtropical Horticulture and Subtropical Horticulturist in the Experiment Station.

[4] Senior Meteorologist, United States Weather Bureau, in charge Fruit Frost Service.

With the deciduous fruits, the principal damage occurs in the late winter or early spring months and usually consists only in the partial or entire destruction of the flowers or young fruits, with a consequent reduction or entire failure of the crop for the season following the frost.

In the citrus fruit industry at least, the importance of losses from low winter temperatures is widely recognized and the protection of the orchards, as much as practicable, against such losses, is now generally admitted to be one of the essentials of success. Since there are practically no frostless areas in the state, there is every reason to believe that orchard heating may also be regarded as a necessary factor in the permanent and successful culture of many of the other sub-tropical fruits grown in California.

Character of the Losses Sustained.—The losses resulting from frost damage affect in varying degree the individual grower, the community, the fruit-growing industry, and the consuming public.

Direct losses suffered by the growers consist in the partial or entire destruction of the crop for the current season and, in the case of the evergreen sub-tropicals, reduction in crop for one or more seasons afterward, a fact which is often underestimated.

The importance of frost injury as a factor in influencing yield the season following a frost is shown in table 1. Estimated[5] yields for 1921–22, the winter of a severe frost, were compared with actual yields for 1922–23, a winter during which no frost occurred, from seven packing houses in one district. Three of these houses pack fruit from orchards where very little heating is done and the other four serve

TABLE 1

YIELD FOR 1922–23, THE YEAR FOLLOWING A FROST, FROM THE ORCHARDS SERVED BY SEVEN PACKING HOUSES IN ONE DISTRICT

(The estimated yield for the frost year 1921–22 is taken as 100 per cent.)

	1922–23 *Per cent*	1921–22 *Per cent*
House No. 1, orchards not heated	71	100
House No. 2, orchards not heated	72	100
House No. 3, orchards not heated	89	100
House No. 4, most orchards heated	104	100
House No. 5, most orchards heated	105	100
House No. 6, most orchards heated	113	100
House No. 7, most orchards heated	134	100

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[5] Actual yield records for 1921–22 are not available because of extensive damage to fruit by the frost of that year. The estimated yields are fairly accurate because the frost occurred late in the season after the fruit had grown to full size.

orchards in colder locations most of which have been adequately protected by orchard heating. The table shows a general increase in yield from heated orchards as a result of protecting the trees themselves from injury and a decrease from those not heated.

These increases reported for houses 4, 5, 6, and 7 are in addition to the fruit saved in 1921–22 when the crop in the unheated orchards was practically all lost. If frost losses were uniformly distributed among all the fruit growers there would be little complaint because of the well-known fact that after a frost the portion of the crop which escapes damage usually brings a net return to the industry equal to or sometimes exceeding that normally received for the entire crop. Thus it is not at all uncommon for growers who have recently installed orchard heating equipment to reap a return from the saving of one crop sufficient to pay for the cost of the equipment and the overhead costs of its maintenance for a period of years.

Since it seems probable that the enhanced value of the fruit saved during a cold winter will be reduced more or less in proportion to the extent to which orchard heating is adopted, some growers have questioned the advisability of educational efforts designed to stimulate interest in orchard heating. It is their belief that when orchard heating becomes sufficiently widespread to reduce markedly the variations in crop production, the profits returned from the use of heaters will be greatly reduced. But even if orchard heating should become very general, which is highly improbable, the use of orchard heaters will undoubtedly continue to be profitable for reasons which will be given later.

In addition to the losses from crop and tree damage which are immediate and therefore most in evidence, there are losses of an indirect character, in many cases equally serious in their effects on the community, and spread over so long a period that they are frequently overlooked or at least under-estimated. The indirect losses arising from frost damage, so far as the individual grower is concerned, in most cases result from reduction in the working capital available for upkeep of the orchards. The loss of one or two crops has been responsible in many instances for inability on the part of the grower to properly fertilize the orchard or to provide for adequate insect pest control measures, both of which are necessary to continued profitable fruit production. The effects of neglect arising from losses through frost in some cases have persisted for years, and in certain communities have been responsible for a marked decline in orchard values.

The losses to the community are no less serious than the losses to the grower. They include decreased employment of persons engaged in fruit handling operations, as well as reduction of the general community income. In fact the serious losses sustained by certain communities as a result of repeated frost damage have led to the recognition of orchard heating as a community problem. Cooperation of the business men has enabled the growers to finance the purchase of orchard heating equipment and thus to afford protection which would otherwise have been unobtainable.

In the case of the citrus fruits the sudden loss of a crop ready for market results in serious losses to all individuals, agencies and organizations concerned in packing, shipping and marketing the crop. The frost damage occurs after arrangements have been completed for the purchase of packing materials, appropriations have been made for national advertising, and schedules for moving the crop have been worked out with the railroads. The necessary cancellations of orders for material, and services result in losses of a widespread character.

Although the maintenance of an absolutely constant source of supply of any agricultural product is manifestly impossible, the adoption of orchard heating, where practicable, furnishes an important means of reducing variation. The ability at all times to supply the market demand for their product becomes a necessity to cooperative selling organizations in developing and holding markets against competition. The California citrus fruit marketing agencies have on many occasions been unable, because of frost damage, to supply sufficient fruit to meet the market demand, and the efforts of years expended in developing and holding certain markets have thus been undone in a few months.

While the high prices which frequently follow a frost may be beneficial to the growers who have sound fruit to ship, the growers with little or no fruit to market lose heavily. Excessive prices cause consumers to turn their attention to other products and the marketing problems of the industry are rendered more difficult for the years in which no frost damage occurs.

The Present Status of Orchard Heating.—It is not strange, therefore, that the prevention of losses of fruit crops occasioned by damaging winter and spring temperatures should have come to be regarded as among the most important problems confronting California fruit growers. Nor is it surprising that orchard heating, an ancient practice in fruit culture, should have reached its highest development and most extensive utilization in California. As an evidence of the rapid extension of this practice in California fruit orchards in recent years may be cited the fact that, so far as records are available, in the past twenty years approximately 3,500,000 orchard heaters have been purchased by California citrus growers, the greater part of which are now in use. The unusual frequency of damaging winter temperatures during recent years has given a decided stimulus to the installation of orchard heating equipment. The present investment in this state in orchard heating equipment is certainly not less than $5,000,000 and the area under frost protection is approximately sixty-three thousand acres. There is reason to believe that in the citrus fruit industry alone there is need for approximately 5,000,000 orchard heaters.

WHEN DOES IT BECOME ADVISABLE TO INSTALL ORCHARD HEATING EQUIPMENT?

The question of when or under what conditions it becomes advisable for the grower to install orchard heating equipment is difficult if not impossible to answer satisfactorily, since there are so many variable factors such as differences in topography and air drainage concerned. In the last analysis this question must be answered by each grower for himself. There are, however, certain factors entering into the decision as to whether or not to install heating equipment which are capable of determination with some degree of accuracy.

There is every reason to believe that over wide areas in the fruit producing sections of the state the occurrence of temperatures occasioning severe damage is so infrequent that the savings effected by the use of heaters would not in the long run equal the costs of installing and operating the heating equipment. It is also probable that there are certain localities planted to fruits where frost damage is so extensive and so frequent in occurrence that over a period of years the cost of heating would exceed the value of the crops saved. Orchards so situated should be top-worked to varieties either more resistant to frost damage, or, on account of later blooming or earlier maturity of the fruit, offering fewer hazards. Unless this is possible it is doubtful whether such orchards should continue to be maintained and in most cases, they must eventually be abandoned or replaced by other crops.

It is unsafe to make a decision concerning the advisability of installing orchard heaters from the experience of only one season. The question should be given careful study and a decision arrived at only when it is apparent from the experience of a number of years that orchard heating is not only necessary to obtain satisfactory crops but that it will probably pay returns on the investment in capital and labor involved in its installation and operation. It is the purpose of the present discussion to emphasize the fact that orchard heating should be undertaken only where it is likely to pay, and to indicate a method of determining when orchard heating is advisable.

The primary factors which should determine the advisability of orchard heating are the *overhead and operating costs* involved, and the *probable savings* which may result. The overhead costs of orchard heating can be determined with some degree of accuracy from the extensive experience at hand. Operating costs can be estimated with a fair degree of accuracy providing the average number of hours of heating per year required to save the crop is known. In the majority of cases it will be necessary to make an estimate on this point since in many districts comprehensive temperature data are lacking. Estimates should be based on available data and in all cases should be liberal.

The probable savings from heating are difficult to compute since they are determined by the production per acre which may be expected under the methods of management in use and the average price which may be expected for the fruit saved. It is necessary, therefore, to estimate the production per acre that may be expected under competent management and the percentage of the crop that is likely to be lost over a ten-year period as a result of frost. As previously indicated, the average price received for fruit saved during a frosty period is generally somewhat higher than the average received during normal seasons. It is believed, however, that the safest procedure is to use average prices for the entire period rather than to base the calculations on average prices received in years of frost damage.

The factors of *production per acre* and *average price* received for the fruit are of great importance in determining the probable profits from orchard heating. With a given cost of heating over a ten-year period, it may prove to be a profitable investment if large crops are produced, even though prices received for the fruit may not be abnormally high. Heating may also prove profitable in districts or with varieties where on account of local conditions the price received for the fruit is above the average even though the production per acre is not unusually high. It is clear that where both average yields and prices are low heating is likely to result in a loss. These general relations can be expressed in the statement that the *average value of the crop* is a factor of the greatest importance in determining the advisability of orchard heating. In this connection a fundamental difference between orchard heating and frost insurance may be emphasized, namely that in the former the cost is relatively constant for any given area and is independent of the value of the crop, whereas in the latter the premiums are proportional to the value of the crop.

To illustrate the method of determining the advisability of orchard heating several hypothetical cases of heating oranges will be considered in tables 2 to 8. The figures used are on a cost per acre basis and are only approximate. Further details concerning actual heating costs will be found in another section.

In making the computations the cost of the equipment is placed at $150 per acre exclusive of fuel in storage. A 10 per cent depreciation rate is allowed and interest at 3 per cent which will give an actual return of 6 per cent on an investment depreciating at the rate of 10 per cent per annum. Interest on fuel in storage is charged at 6 per cent. Typical operating expenses are $1.00 per acre per hour for fuel and labor, $2.00 per acre for refilling, $2.00 per acre for placing heaters in the orchard, including the initial filling, and $2.00 per acre for emptying and removing heaters from the orchard. On this basis the annual fixed charges per acre will be those shown in table 2.

TABLE 2

FIXED CHARGES (WHETHER HEATERS ARE LIGHTED OF NOT)

Depreciation on equipment	$15.00
Interest on investment (including oil)	6.00
Placing and filling heaters	2.00
Emptying and taking up heaters	2.00
Total	$25.00

In the hypothetical cases considered the following values for production, price, value and cost are assumed:

Average production: 200 packed boxes per acre.
Average price of fruit: $2.25 a packed box net to the grower.
Average value of crop: $450 per acre net to the grower.
Average cost of production: $240 per acre (excluding heating).

CASE I

TABLE 3

ORCHARD HEATING COSTS PER ACRE FOR A TEN YEAR PERIOD (ORANGES)

Overhead charge	$250.00
Operation costs	
3 years not necessary to light up	
1 year (15 nights, 90 hours, 8 refillings)	106.00
2 years (10 nights, 50 hours, 5 refillings)	120.00
4 years (5 nights, 25 hours, 3 refillings)	124.00
10 Total	$600.00

Average number of hours heating required, 29.

TABLE 4
SAVINGS MADE BY HEATING OPERATIONS

	Per cent of crop	Value of crop saved, per acre
3 years	none	....
1 year	100	$450.00
2 years	50	450.00
4 years	25	450.00
10 years		Total, $1,350.00
Cost of heating		600.00
Saving per acre for 10-year period		$750.00

Average saving per acre per year, $75.00, on investment of $60.00.

TABLE 5
SUMMARY OF RETURNS PER ACRE FOR TEN YEAR PERIOD

With heating		*Without heating*	
Income (2,000 packed boxes @ $2.25)	$4,500.00	Income (1,400 packed boxes @ $2.25)	$3,150.00
Production costs	3,000.00	Production costs	2,400.00
Profit	$1,500.00	Profit	$ 750.00
Or at the rate of $150.00 per acre.		Or at the rate of $75.00 per acre.	

It is clearly apparent in this case that the installation of heating equipment paid a substantial return on the investment and that through the addition of heating to the orchard management program the rate of return from the orchard was doubled.

CASE II

Data used in computations same as in Case I with exception of orchard heating costs.

TABLE 6
ORCHARD HEATING COSTS PER ACRE FOR A TEN YEAR PERIOD (ORANGES)

Overhead charge	$ 250.00
Operation costs	
10 years (average 8 nights, 80 hours, 8 refillings)	960.00
Total	$1,210.00

Average number of hours of heating required, 80.

TABLE 7
SAVINGS MADE BY HEATING OPERATIONS

	Per cent of crop	Value of crop saved, per acre
4 years	100	$1,800.00
4 years	50	900.00
2 years	25	225.00
10 years		Total, $2,925.00
Cost of heating		1,210.00
Saving per acre for period		$1,715.00

Average saving per acre per year, $171.50, on investment of $121.00.

TABLE 8

SUMMARY OF RETURNS PER ACRE FOR TEN YEAR PERIOD

With heating		*Without heating*	
Income (2,000 packed boxes @ $2.25)	$4,500.00	Income (700 packed boxes @ $2.25)	$1,575.00
Production costs	3,610.00	Production costs	2,400.00
Profit	$ 890.00	Loss	$ 825.00
Or at rate of $89.00 per year.		Or at rate of $82.50 per year.	

It will be observed that in this case the addition of heating to the orchard management program has changed the situation from one of loss to profit. The profit, however, is relatively small although the saving resulting from heating is large. Undoubtedly there are many citrus orchards where this situation obtains.

Some relations between average price received for the fruit and amount of fruit produced (per acre) and the savings effected by orchard heating will be noted in tables 9 and 10.

TABLE 9

RELATION BETWEEN PRICE RECEIVED FOR FRUIT AND RETURNS PER ACRE MADE FROM ORCHARD HEATING

All data used same as in Case 1 with exception of price received for fruit.

	Ten-year production, packed boxes of 75 lbs.	Ten-year cost of production	Net profits over 10-year period			
			2 cents per pound	3 cents per pound	4 cents per pound	5 cents per pound
Orchard heated	2000	$3000.00	—Cost and value same (no profit)	$1500.00	$3000.00	$4500.00
Orchard not heated	1400	2400.00	$300.00 loss	750.00	1800.00	2850.00
Difference due to heating	600	600.00	$300.00 saved	750.00	1200.00	1650.00

TABLE 10

RELATION BETWEEN PRODUCTION PER ACRE AND RETURNS MADE PER ACRE BY ORCHARD HEATING

All data used same as in Case 1 with exception of production per acre.

	Ten-year cost of production	Net profit over 10-year period from varying yields				
		100*	200*	300*	400*	500*
Orchard heated	$3000.00	$750.00 loss	$1500.00	$3750.00	$6000.00	$8250.00
Orchard not heated	2400.00	825.00 loss	750.00	2325.00	3900.00	5475.00
Difference due to heating	600.00	75.00 saving in loss	750.00	1425.00	2100.00	2775.00

* Packed boxes of 75 pounds.

Although in the case of deciduous fruits both the cost of heating and the savings effected will be much lower than those used in the hypothetical cases above discussed, the methods used in determining the advisability of installing orchard heating equipment are applicable.

PHYSICAL PRINCIPLES OF FROST FORMATION AND FROST PROTECTION

Frost may be purely local or of general occurrence and may be either ''white'' or ''black'' depending on atmospheric conditions. The terms for frost may be defined as follows:

Frost. The occurrence of any temperature below 32° F.

White frost. Frost accompanied by a deposit of white ice crystals on exposed surfaces.

Black frost. Frost unaccompanied by such a deposit.

If local cooling by radiation causes the frost it is spoken of as a local frost or as a radiation frost.

The widespread occurrence of temperatures below 32° F accompanied by or following a period of heavy winds and an influx of cold air from distant areas is called a general frost, or technically a freeze. All frosts or freezes will be ''white'' if the air is sufficiently moist and ''black'' if the air is very dry. Frost, i.e., temperatures of 32° F or less, may occur on the ground or exposed objects as a result of rapid cooling by radiation even though the temperature of the air in the vicinity of the exposed surfaces may be above 32° F.

How Frost Occurs.—Many persons apparently believe that frost and dew ''fall'' in the same way that rain falls, as evidenced by the fact that a number of inventions have been patented which were designed with the idea of preventing the frost from ''falling'' on the trees. Deposits of frost or dew are formed directly on the ground or other exposed objects as a result of local cooling.

In order to understand the underlying principles of frost protection, it is necessary to know something of the methods by which the ground surface and the air near the ground cool during the night. The heat from the sun comes to the earth in the form of waves, a method of heat transfer which is known as *radiation.* Heat is also lost to the intensely cold upper limits of the atmosphere by this same process of radiation. The earth loses heat by radiation continuously, both day and night, but during the day the amount of heat received from the sun is much greater than that radiated into space, and the temperature rises. Radiant heat passes through clear dry air without much heating of the air itself. Air is warmed much more effectually by contact with a warmer body, that is by *conduction* of heat from the warm body to the cooler air in contact with it. The transfer of heat by *radiation* occurs at very high speed (the velocity of light) while *conduction* is relatively a very slow process.

During a clear, calm day the radiant heat from the sun heats the ground surface until its temperature is higher than that of the air in contact with it. As soon as this occurs, heat is slowly conducted from the ground into the surface layer of air, which soon becomes warmer than the air at higher elevations. Warm air is lighter (less dense) than cold air, and as soon as a small body of air in contact with the ground becomes warmer than that above or surrounding it, it is forced upward and is replaced by colder air. A circulation is thus established, in which cool upper air is progressively brought into contact with the warm ground, heated by conduction, and then forced upward to make room for more cool air. By sunset the air to a height of 300 to 1000 feet has been warmed to some extent. The fact that heating the air reduces its density, operates to prevent the heat received from the sun being concentrated in the surface layer of air alone, and causes distribution of the heat through a layer of considerable thickness. The transference of heat as described above from one portion of a liquid or gaseous medium such as the air to another through the circulation of portions of the medium is called *convection.*

After sunset, no heat is received from the sun to make up for that lost by radiation from the ground to the sky, and the ground soon becomes colder than the layer of air in contact with it. Heat is conducted from the air to the ground and the surface layer of air soon becomes colder than the air a few feet above. In this case, however, the surface air becomes relatively heavier as it continues to cool during the night, so that the tendency is for the same air to remain in contact with the ground all night. Since air conducts heat very slowly, atmospheric cooling does not extend to great heights as a result of which the temperature of the air 300 feet above the ground changes but little during the night. Thus over a level plain on a clear, calm night there is a relatively thin layer of cold air near the ground, with an increase in temperature up to an altitude of between 300 and 800 feet. This phenomenon, which is known as temperature inversion, is illustrated in figure 1, shows continuous records of the temperatures from 4 P.M. to 9 A.M. at the base and at different heights above the base of a steep hillside. Note the great differences in temperature that sometimes develop on a clear, still night. Although the temperature at the base was low enough to cause considerable damage to fruit, the lowest temperature 225 feet above the base was only 51° F. Note that the duration of the lowest temperature was much shorter on the hillside than at the base.

When the loss of heat by radiation from the ground has been sufficient to cool it to 32° F or lower, a true radiation frost occurs. Under radiation frost conditions the force of gravity tends to cause the thin surface layer of cold air to move down slopes and to gather in depressions. On a frosty night this movement of air, which is known as air drainage, operates to create a difference in temperature between the hillsides and the flat valley floors. The air cooled by contact with the cooler ground constantly drains away from hillside locations and is replaced with warmer air from the same or slightly higher elevations.

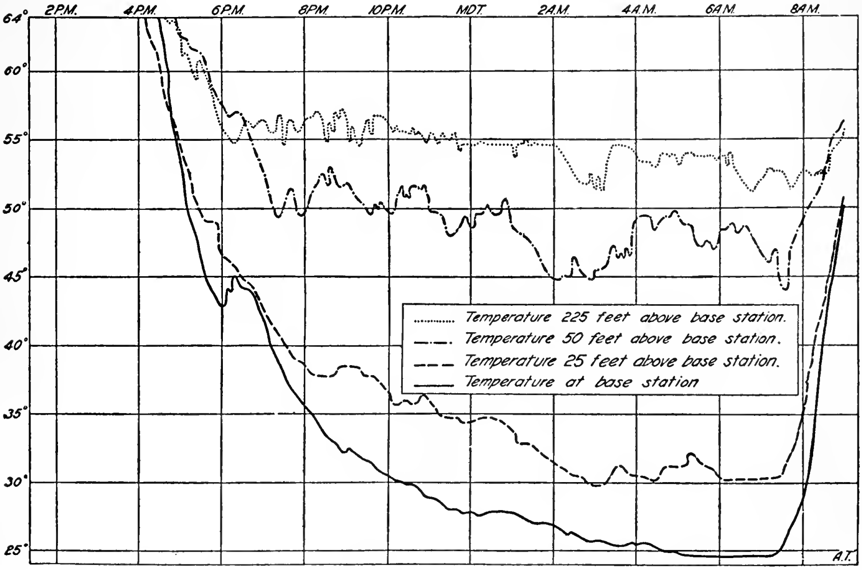

Fig. 1.—Temperature records taken at different altitudes on a frosty night.[6]

Over level areas the cold air tends to remain more nearly stationary, growing colder and colder as the night progresses. Cold air from surrounding slightly higher areas flowing into depressions that either have no outlets, or outlets too small to permit the draining away of the cold air as fast as it flows in creates pools of still and usually relatively very cold air which are sometimes called 'frost pockets.'

Difference Between Frosts and Freezes.—As has just been noted true frosts result from excessive local cooling by radiation and occur

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[6] Young, Floyd D. Frost and the prevention of damage by it. U. S. Dept. Agr. Farmers' Bul. **1096**:1–48. 1922.

on relatively calm nights. There are occasional periods of extremely cold weather, however, accompanied or preceded by high winds in which a general cooling of the air takes place to great heights on account of the influx of large masses of cold air from the North or Northeast. Such cold periods are designated as freezes if the temperature drops below 32° F. A true freeze of this kind rarely occurs in southern California. If a freeze as just described is followed by a dying down of the wind and accompanied by atmospheric conditions permitting rapid loss of heat by radiation the result is a general low temperature with only a slight temperature inversion—a condition very difficult to control with orchard heaters.

How Temperature Inversion Makes Heating Possible.—The difference in temperature between the air near the ground and that at higher levels on a frosty night, as illustrated above, is what makes orchard heating practicable. If the atmosphere were uniformly cold up to great heights, the air heated by the fires in the orchard would rise rapidly above the orchard without materially benefiting the trees or fruit. As a matter of fact, the warmed air from the heaters rises, cooling at the same time, until it reaches the height where its temperature is the same as that of the surrounding air. As the hot gases leave the fires, they mix rapidly with the surrounding colder air, so that the resulting temperature of the whole mass is not very high. So long as the mixture of gases rising from the fires is warmer than the surrounding air it will continue to rise; but as soon as it reaches an elevation where its temperature is the same as that of the surrounding air it will stop and remain stationary.

As an example of a typical case, let us assume that the air in the orchard at a height of five feet from the ground has a temperature of 24° F and that the air forty feet above the ground has a temperature of 32°. When the orchard heaters are lighted, the relatively small quantities of hot gases produced are mixed with air which has a temperature of 24°. If the mixture which results has a temperature of 32° its specific gravity will be lower and it will rise until the 40-foot level is reached. At that height it will stop rising because the surrounding air is of the same temperature and specific gravity. Successive additions of the heated gases will come to a stop below the first layer and the process continues until the temperature of the air down to the ground has been raised to 32°. The temperature inversion will then have disappeared, and the temperature in the orchard at the five-foot level will have been raised eight degrees, from 24° to 32° F. It is plain that in this case the heat produced by the orchard heaters has been expended in heating the air within forty feet of the ground, and has not been wasted in a futile attempt to "warm up all out-of-doors." The stratum of warm air above the orchard acts as a ceiling to prevent the escape of the heated air.

The example given above describes the effect of orchard heating under ideal conditions, with a perfectly calm atmosphere in and immediately above the orchard. Occasionally these conditions occur, but on most frosty nights there is a light drift of air, which carries heat out of the heated orchard, and affords protection to a few rows of trees in the immediately adjoining orchard on the leeward. For this reason it is more difficult to raise the temperature when only one orchard in the neighborhood is protected with heaters than when all the surrounding orchards are thus protected.

The amount of temperature inversion varies greatly on different nights and in different localities. It is mainly determined by the range in temperature from afternoon to early morning. If the afternoon temperature is high and the temperature falls to the freezing point on the following morning the inversion in temperature is likely to be great. Since the thickness of the layer of air to be heated, in order to obtain a given rise in temperature in the orchard, depends on the amount of temperature inversion it follows that it is easier to raise the temperature following a warm afternoon than following a cold, windy day.

Atmospheric Conditions Influencing the Occurrence of Frost.—It has been noted previously that the earth cools at night through loss of heat by radiation from the ground. The more rapid this loss of heat, the faster is the rate of fall in temperature. The rate of radiation is influenced considerably by the amount of water vapor in the atmosphere. The greater the amount of water vapor in the atmosphere the lower is the rate of radiation loss, and conversely. On calm nights the temperature falls more slowly if the air is damp than if it is dry.

The amount of moisture that the atmosphere can hold depends upon the temperature. As air is warmed its moisture holding capacity is increased; as it cools its capacity for moisture is decreased. If the air contains water vapor up to the limit of its capacity, it is said to be "saturated." If the temperature of saturated air is reduced, a portion of the moisture is condensed. This is what occurs when dew or white frost forms. At night the temperature of the air continues to fall until moisture is deposited on exposed surfaces. The temperature at which dew or white frost begins to form is called the "dew point." By measuring the amount of moisture in the air at any time, we are able to tell its dew point; in other words, we can know in advance at what temperature dew or white frost will begin to form if the cooling of the air continues.

In addition to decreasing the rate at which heat is lost by radiation to a clear sky at night, the moisture in the air has another important function in controlling temperature changes; when water vapor changes from a gaseous to a liquid state, in other words, when dew or white frost forms, heat is released in the process. The amount of heat released is proportional to the amount of moisture condensed. If the dew point is high, a great deal of dew is formed before the temperature falls to the freezing point and a large amount of heat is released, which will materially decrease the rate of fall in temperature. If the dew point is low, 18° F, for example, neither dew nor white frost will form until the ground surface and objects exposed to the sky are cooled to 18° F. Under such conditions the temperature fall will be rapid.

Fig. 2.—Temperature records taken on two different nights during the freeze of January, 1922.[7]

Figure 2 shows the influence of the amount of moisture in the air, or in other words, of the dew point, upon the rate of temperature fall under radiation frost conditions. The upper record (dotted line)

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[7] Young, Floyd D. Conditions which occasion injurious freezes in the south. Calif. Citrograph. 7:381. 1922.

indicates the temperature on the night of January 22–23, 1922, when the dew point was 29° F. The lower record (solid line) shows the temperature on the night of January 19–20, 1922, when the dew point was 18° F. The temperature, in degrees, is shown at the left of the diagram, and the time is shown at the top of the diagram. Note that the temperature was practically the same on both nights, a few minutes after 7 P.M.

Heat is also released during the process of freezing of water, in the same way that it is released when dew or white frost is formed. The amount of heat liberated in the process of freezing a given amount of water is slightly more than one-seventh as much as that liberated in the condensing process. However, when the ground over a large area is wet from previous heavy rains, the amount of heat given off in the freezing of the surface moisture is sometimes sufficient to hold the temperature stationary near the freezing point for two or three hours. Evaporation from a wet surface soil interferes with the normal rise in temperature during the day, particularly if the air is relatively dry and a strong wind is blowing. However, a thoroughly saturated surface soil is far more effective in preventing the occurrence of an extremely low temperature at night through the release of heat in the freezing process, than it is in cooling the air during the day through evaporation. The greatest danger of extremely low temperatures in California comes when both the soil and the air are very dry.

A heavy blanket of low clouds composed of particles of liquid moisture practically eliminates the radiation of heat from the ground for which reason there is little danger of frost in California so long as clouds of this type exist. Thin, high clouds often are composed of tiny ice particles, which do not interfere materially with the escape of the heat from the earth by radiation, and heavy frosts often occur when the sky is entirely overcast with clouds of this type.

The occurrence of a heavy frost accompanied by a strong wind is extremely rare in the fruit-growing sections of California. Frosts usually occur on calm nights, and even light gusts of wind usually cause the temperature to rise rapidly above the danger point. This effect is due to the mixing of the warmer air above the orchards with the cold air down among the trees. The "freezes," accompanied by strong winds, which may occur at intervals of from fifteen to twenty-five years, make necessary the most strenuous efforts to protect fruit and trees by orchard heating.

When to Expect Frost in California.—The weather in California is controlled by atmospheric disturbances of wide extent and varying intensity, which move down the coast from the vicinity of Alaska, or inland from the Pacific Ocean. These disturbances are of two types, one of which is marked by low barometer, overcast skies, and rain or snow; the other by high barometer and clear skies.

The important requirements for the occurrence of frost, a clear sky and little wind, are present during the passage of an area of high barometer. As the first-mentioned type of disturbance, the area of low barometer with overcast skies and rain, nearly always precedes the area of high barometer, the local belief that frosts are likely to follow a rain has some basis. In many cases, however, the rain area does not reach southern California, and extremely severe frosts may occur in that section without any rain preceding them.

During the passage of a well-defined area of low barometer the radiation from the sun is more or less completely cut off by heavy clouds and the ground is not warmed much during the day. If rain has fallen, the evaporation from the wet ground uses up a great deal of heat, and this also tends to keep the temperature low during the day. Therefore, during the frost season, on the first clear night after a rain the temperature at sunset is likely to be within 15° or 20° of the freezing point and not much cooling by radiation is necessary to form frost. Although the moisture in the ground after a rain tends to prevent warming of the ground during the day, it also tends to prevent a large fall in temperature during the night. The water vapor taken up by the atmosphere from the wet ground diminishes radiation. When the dew point, which is likely to be high under these conditions, is reached, the latent heat released retards the rate of cooling still more, and when the freezing point is reached the conversion of the soil moisture into ice also liberates heat and aids in preventing a further fall in temperature. By the second night following the rain the surface of the ground has usually dried out considerably. The dew point is likely to be lower and a more damaging frost is likely to occur. In California, before the third night the day temperature usually has risen high enough to make unlikely the occurrence of a severe frost, although there are exceptions to this rule. When the air and soil have been unusually dry and an area of high barometer lies to the north or northeast, damaging frosts have been known to occur on as many as fifteen successive nights in the colder portions of a very limited area in southern California.

Freezes in California, as explained previously, are caused by the influx of great masses of cold dry air from the north and northeast, together with local conditions favorable for the rapid loss of heat by radiation. The progress of a freeze usually can be traced southward from the Canadian border, and sometimes from Alaska, the journey to southern California often requiring several days. The weather map is absolutely necessary for forecasting the approach of a freeze.

Frost Forecasts by the United States Weather Bureau.—General weather forecasts, including frost forecasts when necessary, are issued twice daily, morning and evening, from the regular stations of the Weather Bureau. Forecasts for the entire state are issued from the San Francisco office, while the forecasts given at other stations apply only to the immediate vicinity of the station from which they come. If frost forecasts are desired for use in connection with the protection of crops, the matter should be taken up with the San Francisco office of the Weather Bureau.

Fruit Frost Service.—During the past fifteen years the Weather Bureau has maintained a small corps of specially trained meteorologists in some of the fruit growing sections where interest in frost protection has been sufficient to warrant the expense. It has been the effort of these trained men to remove as much as possible of the uncertainty connected with orchard heating operations, and to increase their efficiency. The work has been conducted along the following general lines:

Predicting the lowest temperature to be expected each night in the district where operations are conducted.
Giving expert advice to fruit growers in connection with orchard heating.
Conducting a temperature survey of each district to determine temperature differences, and to enable crop losses to be determined accurately immediately after the frost.
Conducting experimental work in connection with frost and fruit protection.

The experimental work includes studies on the subjects mentioned below together with others of less importance.

Increasing the accuracy of the minimum temperature forecasts for each district.
Determining more accurately the temperatures at which damage occurs to buds, blossoms, and fruit.
Testing new devices for frost protection.
Developing improved types of thermometers for orchard heating work.
Determining the influence of covercrops on the frost hazard.

Measuring the amount of temperature inversion on different nights, and determining the causes for variations.

Determining the character of air drainage on different types of slopes.

Measuring the value of the smoke cover in preventing radiation of heat from the ground at night.

The fruit frost work has in all cases been carried on in cooperation with various fruit growers' organizations or other cooperative agencies. The local financial cooperation amounts to about one-half the total cost of the service. All thermometers brought in by the fruit growers in each of the fruit frost districts are tested for accuracy at the beginning of the frost season by the fruit frost specialist, without charge. The tests have shown that a considerable percentage of the thermometers used in orchard heating are inaccurate, although there has been a remarkable improvement in this respect during the last few years.

METHODS OF PREVENTING HEAT LOSSES AND OF ADDING HEAT

From the foregoing discussion it will be seen that frost occurs mainly because of heat losses through radiation and that protection can be obtained only by prevention of these losses or by the addition of sufficient heat to make up for losses which would otherwise cause the temperature to fall below the danger point.

Prevention of Heat Losses.—The greenhouse is an application of the principle of reducing radiation losses. Glass is transparent to the heat waves of short wave length radiated by the sun, but is practically opaque to the longer waves re-radiated from the soil. Therefore a glass screen is very effective in preventing loss of heat, but is not practicable for an orchard. Different kinds of cloth and lath screens have been tried for the same purpose with but little effect on account of the fact that radiation takes place from the outside of the screens and unlike glass, they are unable to prevent an interchange of air between the protected area and the outside. Heavy cloth screens so near the ground that there is little movement of air beneath afford considerable protection to tender vegetables.

Water vapor is very effective in retarding loss of heat by radiation; for this reason various means of increasing the humidity of the air have been tried. When serious frosts occur in California, the air is generally very dry and any moisture added is rapidly lost by diffusion and air movement so that it is seldom, if ever, possible to produce fog artificially on frost nights. It was formerly thought that the smoke from smudge pots was effective in preventing loss of heat by radiation but careful measurements by the Weather Bureau have shown that the densest smoke screens produced by smudge pots are effective only in decreasing the rate of radiation about 10 per cent, and that the final temperature reached under a smoke screen may be as low as under a clear sky. A lath covering makes heating easier and lath-protected nursery stock is easily saved by heaters.

The principle of prevention of heat losses is applied to the protection of young trees by means of wrapping the trunks with insulating materials. Some growers use thick bundles of newspaper, but corn stalks, Sudan grass, or tules are preferable. The wrappings should be tight enough to prevent air movements. In applying corn stalks or similar materials enough should be placed around the trunk of one, two, or three-year-old trees to make a covering about three inches thick on all sides. They should be tied firmly at the bottom, middle, and top of the trunk, the tops of the stalks extending up through the branches. Treatment of this kind will prevent trunk damage and reduce injury to the branches. If the latter are frozen back a new head can be grown on the sound trunk and the tree saved. Young citrus trees should be protected in this manner in all districts in California. In windy districts it is advisable to tie the wrapped trees to stout stakes such as grape stakes, because the wrappings greatly increase the danger of blowing over. The wrappings should be applied in November and removed as soon as all danger of severe frost is past. If left on too late in the spring, during periods of rainy weather, they may promote infection with various bark diseases.

Addition of Heat.—The addition of heat to the air in the area to be protected is the only practical means so far developed for protecting a large area. As pointed out previously it is not necessary to ''heat all out-of-doors'' in order to raise temperatures above the danger point. Many methods of adding heat to the orchard air have been suggested, the more important of which will be discussed in the following paragraphs. Almost every year new devices are suggested, some for adding heat, and some, according to the inventors, designed to absorb cold. Since cold is merely the absence of heat, obviously it cannot be absorbed and therefore devices which do not add heat can hardly be expected to succeed.

Use of Water.—The spraying of trees with water has been tried as a means of adding heat to the air. The water generally is at a temperature considerably above the freezing point and gives up heat as it cools, and in addition gives up its latent heat when it freezes, thus greatly delaying the fall of temperature below 32° F. Latent heat is that heat which is associated with a change of physical state. A pound of water changing to ice liberates 144 times as much heat as it does in falling one degree Fahrenheit. Starting with water at 62° F, cooling it to the freezing point and then freezing all of it liberates about 10,800 B.t.u.[8] per cubic foot. The cooling and freezing of twelve cubic feet of water will just about equal the burning of one gallon of oil. This cannot be looked upon as a net gain of heat since part of the water may evaporate, giving a cooling effect. The evaporation of one cubic foot of water absorbs heat equivalent to the burning of one-half gallon of oil. The melting of a pound of ice absorbs 144 B.t.u. Therefore, if much ice is formed when water is used there is little gain of heat from the sun the next day and the soil is kept cool, so that more water or more fuel will be required if freezing temperatures occur the next night. Unfortunately even where water is available for sprinkling, the weight of ice formed is so great as to severely damage or even totally destroy trees. Figure 3 shows a tree thus destroyed.

Fig. 3.—Tree broken down by ice formed by sprinkling with water in an attempt to protect it from frost.

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[8] (B.t.u.) a British thermal unit is the amount of heat required to warm one pound of pure water one degree Fahrenheit.

Water in basins or running in furrows liberates a like quantity of heat in freezing and affords a small amount of protection. If a grower has plenty of water available and no other means of protection he ought certainly to run the water both day and night during the entire period of the freeze; but running water is to be looked upon as a means of partial rather than complete protection.

Blowers.—A large number of devices have been tried for adding heat to the air in the orchard. Among these are the blowers or so-called "wind-jammers." As pointed out previously, on a night of a radiation frost there is a marked temperature inversion, wherein it is frequently as much as ten degrees warmer at the 40-foot level than it is near the ground. The blowers were originally designed to mix this warmer upper air with the cold air in the orchard, but they have not succeeded in raising the temperature in the orchard as much as one degree as a result of the mixing. Later models of these blowers include furnaces in which heat is produced, but they have shown little if any improvements in results over those merely mixing the air. It is believed that these devices have had adequate trial and all of them have proved unsuccessful.

Use of Orchard Heaters.—The only method of effecting complete protection which has been successfully demonstrated by field experience is *to have a large number of small heating units distributed over the area to be protected.* As explained previously, on frosty nights, because of temperature inversion, there is a relatively thin layer of air below the danger point while the air higher up may be at a temperature above the danger point. If the air overhead is as cold as that near the ground successful heating will be very difficult, if not impossible. This usual layer of warmer air overhead serves as a ceiling, so to speak, which retains the heat added to the layer below. By means of the heaters all of the air under the "ceiling" is gradually warmed until it is above the danger point. Enough fires are then maintained to compensate for losses of heat through radiation and air drift. Success in orchard heating, therefore, is attained by heating a large volume of air a few degrees rather than by heating a small volume to high temperatures.

There are, on this basis, two fundamental requirements for adequate frost protection: (1) a sufficient number of heaters per acre to heat a large volume of air without overheating any part, and (2) sufficient fuel to keep these heaters burning the entire duration of the frost. The number of heaters and proper field supply of fuel will be discussed on the basis of full protection for cold locations. Anything short of full protection is a poor investment. One may lose an entire crop as well as the money spent on heating if the number of heaters is too small or if the fuel burns out before morning. If protection is inadequate a portion of the crop may be frozen and the grade of the whole crop reduced. Frequently the difference in price between first grade fruit and so-called ''merchantable grade'' is sufficient to pay the entire cost of equipping an orchard for full protection.

The number of fires per acre which must be kept burning to heat a large volume of air a few degrees will vary from less than 20 to about 100 according to the size of the fires, the degree of cold, the crop to be protected, and the atmospheric conditions determining the efficiency of heating, such as air drift, humidity, and amount of inversion. With a relatively small number of fires burning, the temperature can be raised by increasing the rate of fuel consumption up to a certain point; but beyond that, further increase merely results in overheating part of the air and losing heat to the upper atmosphere. Under these circumstances more heaters should be lighted. To sum up, the basic principle of frost protection is to keep a relatively large number of small heating units burning the entire period during which the temperature outside the heated area is below the danger point.

EQUIPMENT AND FUELS

The necessary items of equipment for orchard heating are heaters, fuel, storage facilities, filling equipment, torches, torch fuel, and thermometers. In addition to these some growers have thermographs and frost alarms.

Heaters

Many types of heaters have been put on the market during the last fifteen years. New types are brought out each year, but we are still far from an ideal heater.

We have come to have rather definite ideas, however, as to the requirements of a heater for a citrus orchard under California conditions. These are that it should:

Hold sufficient fuel to burn all night without refueling, even though a gallon or more of oil per hour be burned at times.

Be capable of sufficient regulation to give its greatest heat just before sunrise even though the fuel in the reservoir is low by this time.

Be able to burn any of the ordinary grades of heating fuels on the market without leaving a heavy residue or making too much smoke.
Give reasonably complete combustion without delivering the heat and products of combustion too far from the ground.
Be easy to light and regulate by inexperienced labor under all weather conditions.
Be easy to take apart, clean, and store.
Be so designed that if it burns dry the bottom of the heater will not be damaged.
Be made of good material and show small annual depreciation.
Be of reasonable cost.

No heater meets all of these qualifications, and the grower must therefore choose the one which will most nearly meet his conditions.

At the present time there are a number of types to choose from, the principal features and adaptations of which are as follows:

The Lard Pail Heater.—"Bolton" and "Canco" types (fig. 4*a*). This heater is a simple pail with sloping sides, a spider or flame spreader and a cover. It is made in two sizes, holding five and ten quarts of oil. A few eight-quart heaters of this type are in use. This type is very efficient in "heating a lot of air a little," and burns satisfactory the present type of fuel oils of 27° Baumé or higher. It gives as much heat per gallon as the newer and larger types of heaters. It meets the last six of the nine requirements listed above. The chief objections to it are that it will not burn all night without refilling and that it produces a smudge. It is, however, very satisfactory for deciduous fruit orchards, because it is economical, and quite as efficient as more expensive types. Deciduous fruit orchards do not usually require long hours of burning and since there is no ripe fruit on the trees when frosts occur, the smudge does not lower the grade of the fruit. For deciduous fruit orchards 80 to 100 of the ten-quart size should be used per acre or 150 of the five-quart size. These sizes actually hold eight and four quarts of oil respectively when filled to proper level. The time of burning is about 3 to 3½ hours for both sizes without the spider and 9 to 10 hours with the spider. The spider is put on to reduce the rate of burning, but is rarely used except with very light oil. Obviously the ten-quart heater produces heat twice as rapidly as the five-quart size. In order to prolong the hours of burning, or provide greater heat just before sunrise, a portion of the heaters are held in reserve so that additional heaters can be lighted after those first lighted have burned low.

Low Stack Distilling Type Oil Heaters of from Seven to Ten Gallons Capacity (fig. 4, *b, c, d*).—This and the two following types burn in the reservoir with just enough fire to generate gases which burn in or above the stack. Two makes of this type are now on the market, and there are several other makes previously sold and still in general use. This type of heater is very satisfactory. The chief objection to some models of the low stack heater is that they produce considerable smoke, which is objectionable in thickly settled regions, and also when the heaters are burned for several nights the fruit becomes coated with soot, which increases the difficulty of washing. Some makes also have the drawback of choking the stacks with soot which often makes it necessary to clean them while still burning. On the whole, however, heaters of this type have proved efficient and easy to handle and are very popular with the growers. They are the lowest in first cost of any of the large capacity heaters and because no parts get excessively hot the depreciation rate is low. It is possible to convert some makes of this type to the medium stack type. Some growers who have bought low stack heaters in order to get protection at low cost convert them later to reduce the smoke nuisance.

Medium Stack Down Draft Distilling Oil Heaters of from Seven to Ten Gallons Capacity (fig. 4e).—The so-called ''Supply Company'' heater is an example of this type. Certain earlier models were difficult to light and regulate and also sooted up badly but the newer models burn freely, make only a small amount of smoke if properly regulated, and are generally efficient. They meet most of the requirements listed above. The cost is higher and the annual rate of depreciation heavier than with the low stack types. They are popular, however, because they are efficient and are reasonably smokeless.

Tall Stack Distilling Oil Heaters.—These heaters, with a three-joint stack, are no longer manufactured and are rather unpopular because of the strong upward draft which dissipates much of the heat into the upper atmosphere. Where these heaters are still used many of the growers pull off the top joint of pipe, thus making medium stack heaters. If this is done special precautions must be taken to prevent sooting up at the stack collar. These heaters require frequent regulation.

Large Capacity Heaters with Burner and Oil Reservoir Separate.—There are several types of these, those feeding oil through a needle or shut-off valve, those with a vacuum feed (figure 4*f*) and those with a gravity feed (fig. 4*g*). The main advantage of this general type is that clean oil of constant composition is burned, while in the other types the lighter fractions of the oil are distilled off first. Another advantage is low depreciation on the oil reservoir. Some makes are nearly smokeless and others very smoky, according to the efficiency of

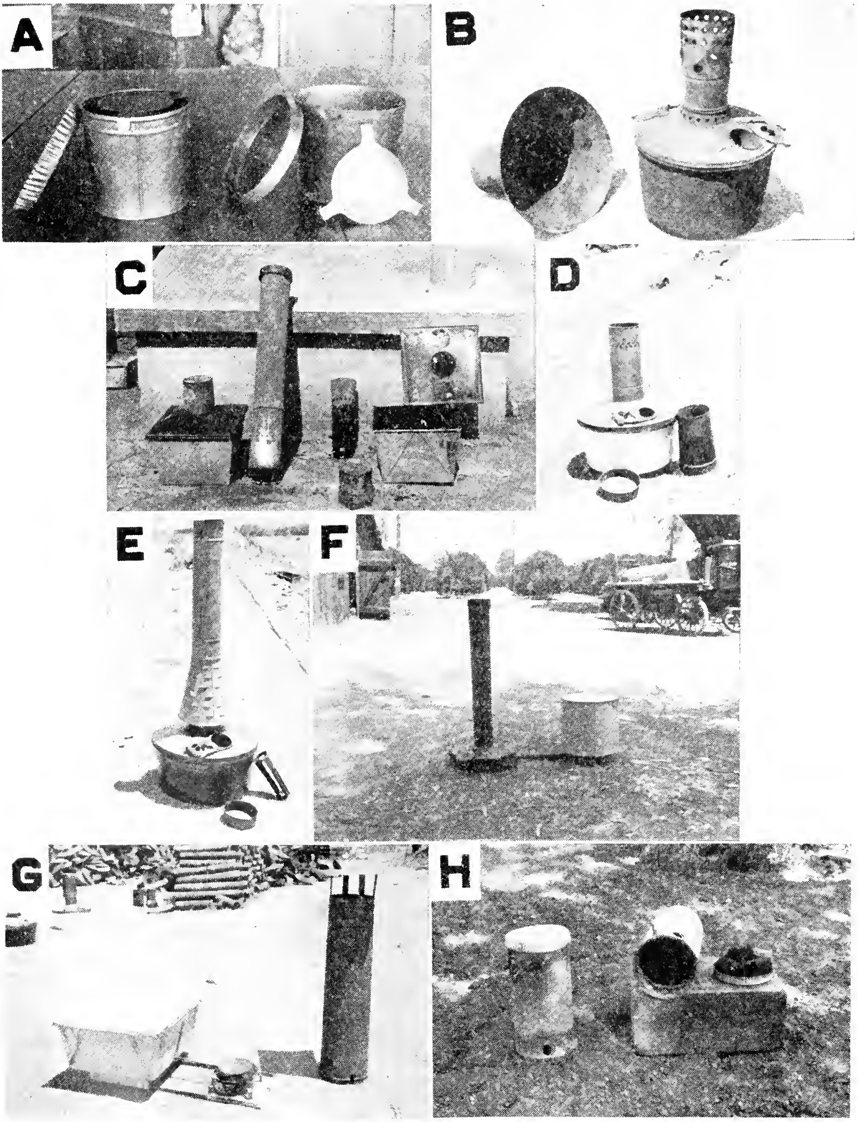

Fig. 4.—Types of orchard heaters in common use. A. Lard pail heaters, "Bolton" and "Canco" types. B. Dunn heater with umbrella cover removed. C. "Citrus" heater, showing low stack and medium stack attachment. D. Scheu "Double Stack" heater with outer stack removed. E. Scheu "Baby Cone" or latest "Supply Company" heater model. F. Scheu vacuum feed. G. Kittle heater. H. Briquet heater.

the burner. There are certain disadvantages to be found in heaters of this type. The makes with valves for feeding oil require constant regulation as the viscosity and, therefore, the rate of flow of the oil changes as the oil warms up. The vacuum feed type is cumbersome and hard to fill but burns all right if the oil is free from water and asphaltum. If water is present it may freeze and prevent discharge of oil; asphaltum may gradually work back into and clog the feed pipe with some types of burners. The gravity feed type is subject to the very serious disadvantage of delivering fuel to the burner less than half as rapidly when the reservoir approaches emptiness as when it is full. In the morning when the need for heat is greatest the oil flows at the lowest rate. This makes it imperative to fill the heaters as full as possible every day.

Briquet and Coal Burners.—Some of the first orchard heating was done with coal baskets but these were abandoned because they were hard to handle and of too small capacity. Coal heaters with grates were used for years but they have now been discarded, largely because of the extremely high labor charges and the difficulties in lighting and extinguishing them. Another serious disadvantage is the variation in the rate of burning. Some heaters burn rapidly while others smoulder for hours. This variation is due to variation in the draft produced by uneven sizes of pieces of coal. With the development of uniform-sized briquets of both carbon-black and coal, there has been renewed interest in solid fuel. Several types of heaters burning either coal, coke or carbon briquets are now on the market (figure 4*h*). They are effective if used at the rate of twice as many per acre as oil heaters, and have the advantage of using a fuel which is easily stored and distributed in the field. The first cost is less than that of large capacity oil heaters even though twice as many heaters are required. They also make much less soot than the oil burning heaters and have the added advantage of delivering the heat near the ground. The principal disadvantages of this type of heater as compared with oil burning types are that more labor is required for lighting and handling; frequent refueling is necessary to maintain constant heat, particularly if coal briquets are used; the fuel costs are higher in California for the same amount of heat; and fuel losses are greater because the heaters must be kept well filled until after sunrise, and the fires are difficult to extinguish.

Heaters of this type are particularly adaptable to small orchards (three to five acres) when the owner has plenty of help for firing and refueling but no facilities for handling oil. They are an economical type of equipment for locations where the frost hazard is so slight that overhead is a more important cost item than labor and fuel.

Choice of Heaters.—In choosing heaters growers should endeavor to meet all the requirements for their conditions at the lowest possible cost, taking into consideration first cost, annual depreciation and operating costs. For oranges 40 to 50 large capacity oil burners per acre will be needed (more for very cold locations), and for lemons and avocados 60 to 80. If briquet heaters are used the number should be doubled. For deciduous fruits the range will be 150 five-quart lard pails, 80 to 100 ten-quart lard pails, 40 large size oil burners, or 80 briquet heaters. The recommendations for deciduous fruits apply to berries and vegetables in a general way. These recommendations are based on field experience as to number of heaters required for cold locations. Local experience may indicate that one can succeed with a smaller amount of equipment than that suggested here as necessary for full protection, but it must be remembered that different districts have been the cold areas in different years and that a fair margin of safety beyond the usual expectation must be provided.

Initial cost is an important item and should be kept down as far as is consistent with full protection. In many districts the number of heaters lighted is rarely more than from twenty to twenty-five per acre at any one moment but severe frosts have been known in those same districts which would require fifty heaters per acre for at least two or three hours and sometimes longer. Some growers have taken advantage of this situation by installing 20 to 25 large capacity modern oil heaters per acre to take care of the usual burning. They then fill in with smaller heaters or old types filled with oil or briquets, for emergency use.

Hillsides and high locations have lower frost hazards than level fields and so-called ''frost pockets,'' but they also have less favorable temperature inversions. Therefore heating the former locations, while not often necessary, will be more difficult than heating the latter. Even though the temperature is not likely to fall so low on the hillsides as in the ''frost pockets'' as many heaters per acre are likely to be required when heating becomes necessary.

Deciduous fruit growers are rarely justified in the purchase of more expensive heaters than the lard pail types which are very efficient for their needs. However, where it is difficult to haul oil into wet orchards or orchards on rolling ground some growers use large-size heaters, holding from 8 to 10 gallons each, at the rate of about 20 heaters per acre, and then fill in with 30 to 40 ten-quart lard pails for use in emergencies when more than twenty sources of heat are required. In this way they get through the season with fewer refillings. Because of the difficulty of filling oil heaters on wet heavy soil, briquet heaters are sometimes used as emergency reserves in the same way.

Fuels

Any sort of fuel which can be kept burning in properly distributed heaters without too much difficulty will raise the temperature, but oil is the most popular because it is cheap, easy to get at all times, easy to light and extinguish, and easy to handle. The oil used for orchard heating should be a wholly distilled product sold under the name of orchard heating oil or Diesel oil, varying from 24° to 36°, preferably above 28° Baumé. It should be practically free from water and asphaltum. The better the grade the less trouble will result from smoke and non-burnable residue.

Coal and carbon briquets and petroleum coke are obtainable in California at about the same prices. If carbon briquets are used they should be bought well in advance of the heating season so as to be thoroughly cured and free from water. Coal briquets are the least satisfactory because their ashes clog the heater grates. For this same reason coal coke is entirely unsatisfactory.

Electricity has been suggested many times as a source of heat. Electrical heaters were tried in a small way at Riverside in 1913. The use of one-horsepower per tree prevented tree damage but did not save any fruit. The electrical equivalent of 20 gallons of oil per acre per hour burned at full efficiency is a continuous current flow of about 750 kilowatts or 1000 horsepower per acre.

Comparative heat values for different fuels, assuming complete combustion, are as follows:

1 gallon average orchard heating oil equals
  8 to 9 pounds petroleum coke
  9 to 10 pounds carbon briquets
  10 to 11 pounds coal briquets
  16 pounds dry oak wood
  14 pounds dry pine wood
  37 kilowatt-hours electric energy.

Fuel Requirements Per Acre.—In addition to having enough fires per acre there must be enough fuel actually on hand in the field to burn the entire duration of the cold on any one night if full protection is to be had. With the different fruits in cold districts for full protection the following amounts of fuel per acre might be required during one severe night; they therefore constitute safe limits of field fuel capacity or fuel actually in the field and ready for use every night.

Oranges: oil, 400 to 450 gallons in heaters; briquets, 1500 to 2000 pounds in heaters, 1500 to 2000 pounds near heaters in field.

Lemons and avocados: oil, 600 gallons of oil in heaters.

Deciduous fruits: oil, 150 to 200 gallons in heaters, briquets, 1250 pounds in heaters, 800 pounds near heaters in field.

Refilling should take place after each burning and every possible effort should be made to keep the field fuel supply at a safe point.

Fig. 5.—Briquet heater with funel to facilitate filling and tub for fuel storage.

Storage for Fuel.—The customary reserve storage on hand or in the community storage reservoirs nearby should be two or three times the heater capacity for oil, or the whole amount of solid fuel the grower might reasonably expect to burn during the season. If the orchard is far from the source of oil supply even more than three times the heater capacity should be carried in reserve. The usual oil containers are rivetted galvanized iron tanks. Since haste is required in refilling heaters after a long cold night, it is advisable to have storage tanks elevated so as to deliver oil rapidly into the wagon tanks by gravity. If elevated storage is not used, motor-driven pumps are recommended as of assistance in refueling operations. If the pump is driven by a portable gasoline engine and mounted on a suitable carriage, it can be used for taking up oil in the spring. Many growers, especially those on heavy soils, where hauling is difficult, have small storage tanks scattered throughout the grove. If these tanks can be secured cheaply enough their use may be practicable as a means of reducing the amount of hauling when the soil is wet. At present prices for new tanks they cannot be recommended. The importance of having an adequate fuel supply near the heaters cannot be everestimated.

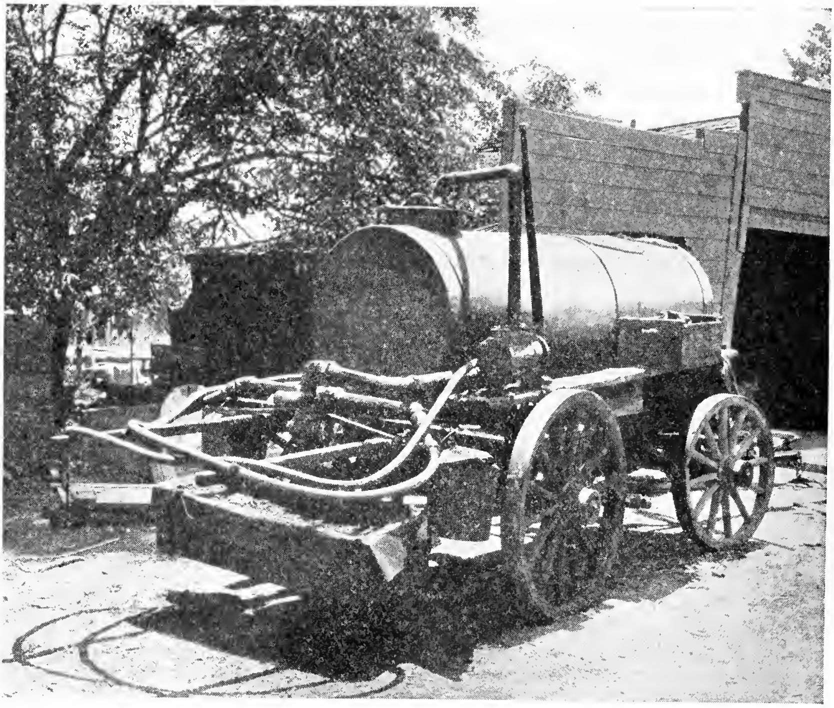

Fig. 6.—Tank wagon used for filling heaters and also for taking up oil.

Filling Facilities.—Solid fuel heaters are filled from a reserve supply usually stored in the orchard near the heaters. The filling of heaters during the day is facilitated by the use of large funnels fitting into the heater tops (fig. 5). A recent innovation is the introduction of unit heater charges of various sizes. These unit charges consist of the usual coke or briquets sealed up in a water proof paper bag along with a little kindling. The bags are dropped into the heaters whole.

The reserve supply of briquets may be stored under the trees in sacks, boxes or old tubs. Refueling of burning heaters is accomplished by throwing in enough briquets to make a new layer over the fire. A double layer is likely to slow down the fire too much.

Filling of oil heaters is accomplished by the use of tanks of various sorts on horse or tractor drawn wagons or light trucks. The most popular tank size is 463 gallons, but the size varies according to soil type and other factors. Figure 6 shows a tank wagon fitted with a sludge box, hose and filling buckets, and a hand pump for taking up oil. The oil is carried in five-gallon filling buckets from the wagon to the heater or is run through 1½ or 2-inch hose. For hose filling it is necessary to drive along every row of heaters; if the soil is wet many growers prefer to use filling pails, the oil being carried two rows—in rare cases, three rows—on each side of the driveway. The majority of growers report that filling can be accomplished much more quickly with pails, but the work is harder. A team with a 463-gallon tank and a crew of four men carrying oil in pails can distribute about 4000 gallons of oil a day if the haul is not too far and the tank can be refilled quickly. One tank and crew will take care of ten to fifteen acres of oranges. Labor and teams for filling are becoming a problem in many districts, and the grower should make definite arrangements for these services well in advance of the danger period.

Torches and Torch Fuels.—Lighting is accomplished by the use of torches which drip burning torch fuel into the heaters (fig. 7). A torch consists of a container with a spout, a wick, and a wire gauze in the base of the spout. The wick is made of asbestos, usually wrapped in a piece of screen. It is placed either directly in the spout, loosely enough so that the fuel will flow freely through it, or in a slot close to the end of the spout. In either case the wick must be so arranged that the fuel leaving the spout flows over or through it. The lighted wick ignites the torch fuel as it flows out. The most important feature of the torch is the protective wire gauze at the base of the spout and under no circumstances should a grower use a torch in which the wire gauze is lacking or defective. The gauze is of fine mesh brass or copper screen and is generally soldered into the base of the spout. It works on the same principle as the miner's safety lamp, the flame of the burning gas being cooled below the kindling point by the screen and not passing through to the reservoir below. Slight explosions sometimes occur in the spout but the gauze prevents a disastrous explosion of the container. The spout should screw tightly into the container against a metal gasket. The torches are usually filled with a mixture of equal parts of gasoline and kerosene. This mixture will carry fire clear to the ground if poured from a burning torch, and give a hot enough fire to light heaters readily. An extra supply of well-mixed torch fuel should be kept in some tight container such as a five-gallon can or a fifteen-gallon oil drum in the field. It is a wise precaution to fill torches only by electric light.

Fig. 7.—Lighting torch.

Thermometers.—Accurate thermometers are a very important part of orchard heating equipment. After every freeze it is possible to find examples of losses of fruit or needless burning of oil by growers who either have no thermometers at all or depend upon inaccurate ones. The grower cannot afford to economize on thermometers. Each ten-acre block should have three or four, one of whch should be placed outside of the heated area as a check. If the orchard is on sloping ground a thermometer should be supplied for every change in elevation of fifty feet.

The horizontal alcohol minimum thermometer, which indicates the lowest temperature reached, is the most satisfactory type. The minimum temperature is marked by a glass indicator which is set at the top of the alcohol column by turning the thermometer upside down. The thermometer is then placed with the bulb about one inch lower than the top of the stem and as the temperature falls the glass indicator is pulled down by surface tension. When the temperature goes up again the alcohol flows past the glass indicator leaving it in such position that the top end indicates the lowest temperature reached since the last setting. Note the indicator in figure 8. Thermometers of this type designed by the United States Weather Bureau especially for orchard heating work, cost about $3.00 each. One or two of these in an

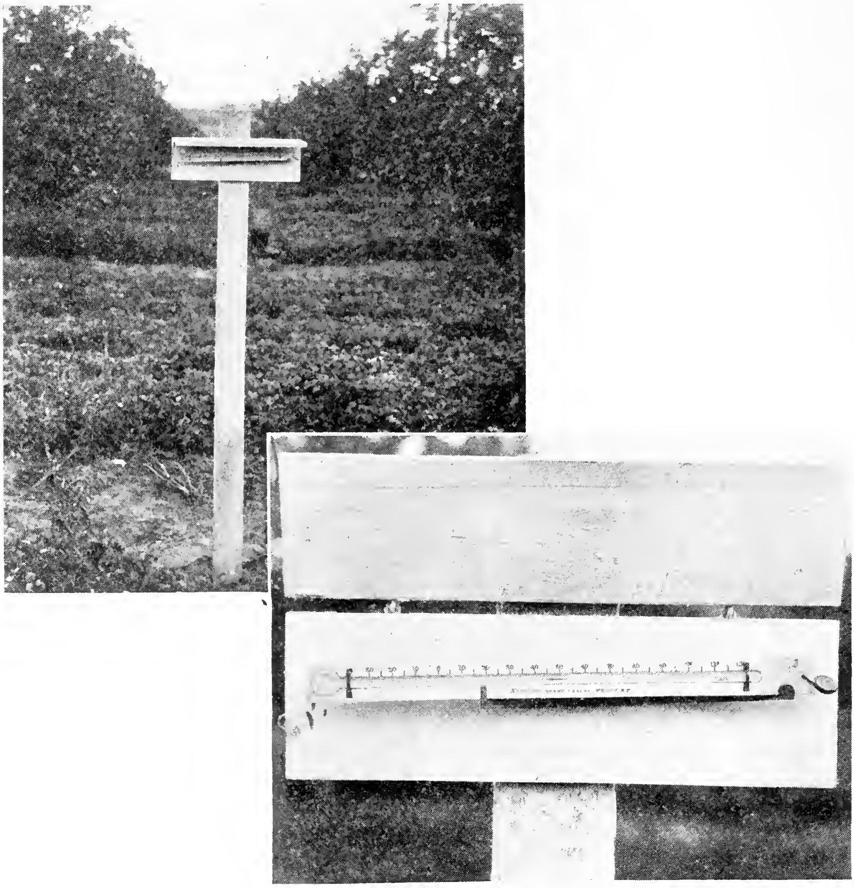

Fig. 8.—Above, minimum thermometer in simple shelter. Below, detail showing position of thermometer.

orchard may be supplemented by somewhat cheaper vertical short range instruments, also of Weather Bureau design. Even carefully constructed thermometers are sometimes inaccurate, so it is advisable to have all thermometers tested when purchased, and before each danger season. The Fruit Frost Service of the Weather Bureau performs this service free of charge in all districts where they have field men. If there is no local representative of the Fruit Frost Service in the district, the county farm advisor sometimes arranges to have thermometers sent to the nearest place where tests are made.

If thermometers are so placed in the orchard that the bulbs are exposed to the sky they will lose heat by radiation, the amount depending on the type of instrument used, and the temperature recorded will therefore be the radiation temperature of the thermometer. This may vary as much as three or four degrees from the true air temperature. To provide accurate reading thermometers must be placed in shelters which shade them from the sky and also prevent the formation of dew on the bulbs. A very satisfactory shelter may be made from two thin boards about 9 or 10 inches wide and 16 or 18 inches long. One board is placed at rights angles to the other, one constituting the back of the shelter, the other furnishing a cover for the thermometer. The cover is hinged so the indicator can be set, which is done by elevating the bulb end of the instrument. Figure 8 shows a minimum thermometer in a single shelter. The standard exposure is at a height of 4½ to 5 feet from the ground with the shelter facing north so as to prevent the sun from striking any part of the thermometer. The best thermometers of this type are graduated to a short range and may be injured by extreme heat. During the summer they should be removed from the shelters and stored with the bulb ends down, in a cool place.

An open flame from match or torch should never be used to read a thermometer. The only safe light is that from an electric flashlight. The reading should be made quickly and the observer must take care not to breathe on the bulb of the thermometer.

If the minimum thermometer is roughly handled or improperly exposed the column of liquid may separate. The thermometer can sometimes be put back into condition by attaching a three-foot length of stout string to the top end and whirling it rapidly. Repairs should be made by a Weather Bureau representative if possible.

The U tube type of thermometer which reads both maximum and minimum is very likely to be out of order and is not recommended for use in connection with orchard heating.

Many growers have thermographs so that they have an exact record of the temperatures they have maintained in the orchards. The temperature record charts shown in figures 11, 12 and 13 are taken directly from orchard thermograph records.

A thermograph properly exposed in a special Fruit Frost Service instrument shelter is shown in figure 9. The thermograph should be checked daily against a tested thermometer in the same shelter.

Fig. 9.—Thermograph in special Fruit Frost Service shelter.

In districts where there are no frost warning patrols, frost alarms are frequently used. In order to be safe they should be of the type than rings when the circuit is broken, rather than when a contact is made. If anything goes wrong with the line the bell rings. This will occasionally result in the grower being called too soon.

The alarm should be tested each night during the danger season by pulling the switch. These alarms are set for 28°, 30°, or 32° F. They should be exposed in proper shelters in the coldest locations.

ORCHARD HEATING METHODS

Complete success in orchard heating is not attainable without an adequate number of heaters of sufficient fuel capacity and proper accessory equipment. Equipment itself, however, merely renders success possible but does not assure it. The individual whose personal efficiency is high may save his crop with rather inferior equipment while his neighbor with much better equipment may fail. *The essential of success is sufficient heat at the proper time.* To provide the necessary heat the grower must be fully prepared at all times during the period of possible danger and must understand how to handle the firing under his own conditions with the type of heaters at his disposal. In this section suggestions are offered as to operating methods but each grower must learn how to solve his local problem by actual experience in heater operation. An excellent precautionary practice is the lighting of a few heaters after they are in the field and supposedly ready for emergency use. It is especially advisable to burn new heaters an hour or two as a means of getting them in condition to light readily later.

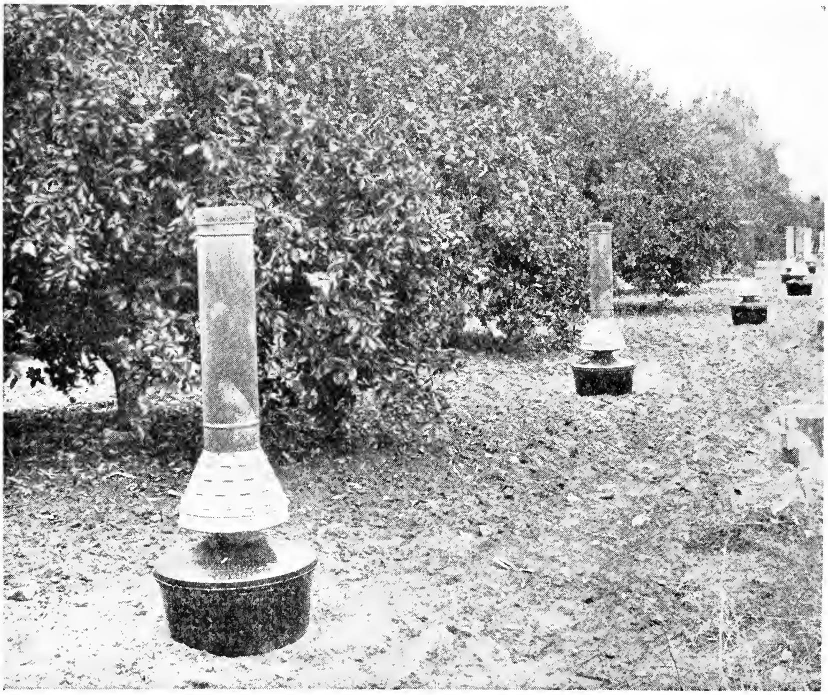

Fig. 10.—Citrus orchard banked with heaters on the windward side; one large capacity heater per tree.

For citrus orchards heaters should be placed in the field not later than November 15th and for deciduous orchards well in advance of the first indications of swelling of the buds. The heaters should be placed so as to give a uniform distribution of heat. It is advisable to have a row of heaters, one to a tree, outside of the orchard on the side from which the air is drifting. Figure 10 shows an orange orchard banked with one heater of large capacity outside each tree. In some districts it is advisable to bank two sides in this way and in cold locations two outside rows may need to be banked with a heater to each tree. As pointed out previously, the orchard heating problem consists in part of replacing the heat lost to the drifting air but mainly in making up for losses from radiation. Inasmuch as radiation occurs uniformly throughout the orchard, the ideal manner of lighting the heaters would be to leave no dark or unlighted rows. For this reason it is believed that it is better to have a heater to every other tree in every row than to place them one to a tree in alternate rows. Convenience and speed in firing and ease of filling must be taken into consideration, however, in placing the heaters. When the heaters have been placed in the field the thermometers should be set up, torches filled, and placed together with a reserve supply of torch fuel in a convenient location.

Accurate information concerning weather conditions is helpful in determining firing plans. The forecasts issued by the Weather Bureau every evening where a local Fruit Frost Service representative is available, include an estimate of the minimum temperature likely to be reached at a certain key station, information as to the probable dew point, wind conditions and the amount of temperature inversion. A forecast of this kind provides the grower with exactly the information necessary for determining approximately how difficult the heating problem is likely to be for any given night. If local Fruit Frost Service forecasts are not available, special evening forecasts may sometimes be had from a district office of the Weather Bureau. The county farm advisor should be consulted concerning the frost forecasting service available in the district.

If a severe and early drop of temperature is expected lighting should begin at a higher temperature than if the duration of cold is expected to be only for a short time. If the temperature drop has been rapid and occurs late in the night the fruit temperature will lag behind the air temperature and lighting may be delayed somewhat. (See section on damaging temperatures.)

Lighting Heaters.—The danger point as explained in another section varies according to the type and severity of the frost expected but when it is reached the grower should take steps to make heat available at once over the entire acreage. The first heaters lighted should be the border rows, especially on the windward side, and then about one-fourth of the heaters throughout the orchard. It is better to light one-fourth of the heaters in each row rather than all of the heaters in every fourth row. Periodic inspections of the thermometers should be made and if the temperature continues to drop more heaters should be lighted, this operation being repeated as often as may be necessary. The greatest economy in fuel usage may be obtained by maintaining the temperature just above the danger point rather than by allowing it to fluctuate greatly. This is accomplished in two ways, first by varying the number of heaters burning per acre and second, by controlling the rate of fuel consumption through heater regulation. When a marked fall in temperature occurs the most efficient way to increase the heat is to light more heaters and regulate all of them to a moderate fire. If still more heat is required after all of the heaters are lighted it may be provided by opening the drafts and increasing the rate of burning. This procedure is in harmony with the basic principle of a relatively large number of small fires per acre which provides for the most uniform distribution of the heat generated.

The thermograph records from heated and unheated orchards shown in figures 11, 12[9] and 13[9] illustrate satisfactory as well as unsatisfactory temperature control. Figure 11 shows superimposed thermograph records from instruments located in neighboring heated and unheated navel orange orchards the same night. The solid line shows the temperature in the unprotected grove and the dotted line the temperature record for a grove protected with fifty 7-gallon oil heaters per acre. The following facts should be noted: (1) The heat from the border rows of heaters merely checked the fall in temperature of the heated orchard with the outside temperature steadily falling; (2) the burning of twenty-five heaters per acre from 10 P.M. until 1 A.M. did not maintain a safe temperature even though these heaters were burned at the maximum rate; (3) fifty fires per acre did maintain a satisfactory temperature as long as they were kept burning; (4) failure to provide sufficient field fuel capacity by having heaters of larger size or some unlighted heaters in reserve, coupled with the waste of oil early in the night from improper regulation was responsible for the severe drop in temperature starting at 4.15 A.M. when the first

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[9] Young, Floyd D., and C. C. Cate. Damaging temperatures and orchard heating in the Rogue River Valley, Oregon. Mo. Weather Rev. **51**:617–631. 1923.

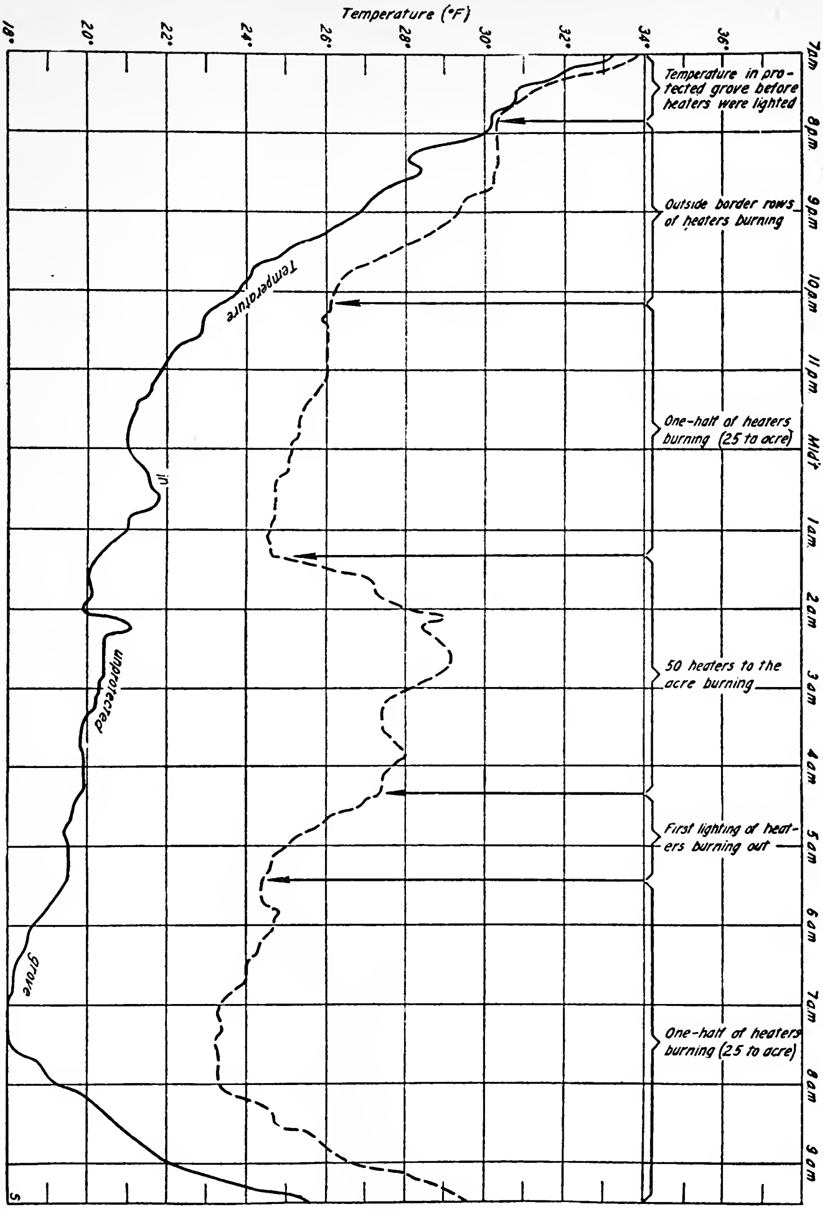

Fig. 11.—Thermograph records for the same night from neighboring heated and unheated navel orange orchards.[10]

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[10] Young, Floyd D. Notes on the 1922 freeze in southern California. Mo. Weather Rev. 51:484. 1923.

lighted heaters burned dry. The loss of fruit in this orchard was not great but if fifty properly regulated heaters had been kept burning from 9:30 P.M. until 8 A.M. a much more satisfactory temperature control woul have been obtained.

Figure 12 shows superimposed thermograph records from neighboring pear orchards, one protected with small lard pail type heaters and the other unprotected. The records were taken during the night of April 13–14, 1919, when the temperature inversion was only 3° F in 35 feet and heating conditions were difficult. It will be noted that with no other regulation than an increase in the number of heaters

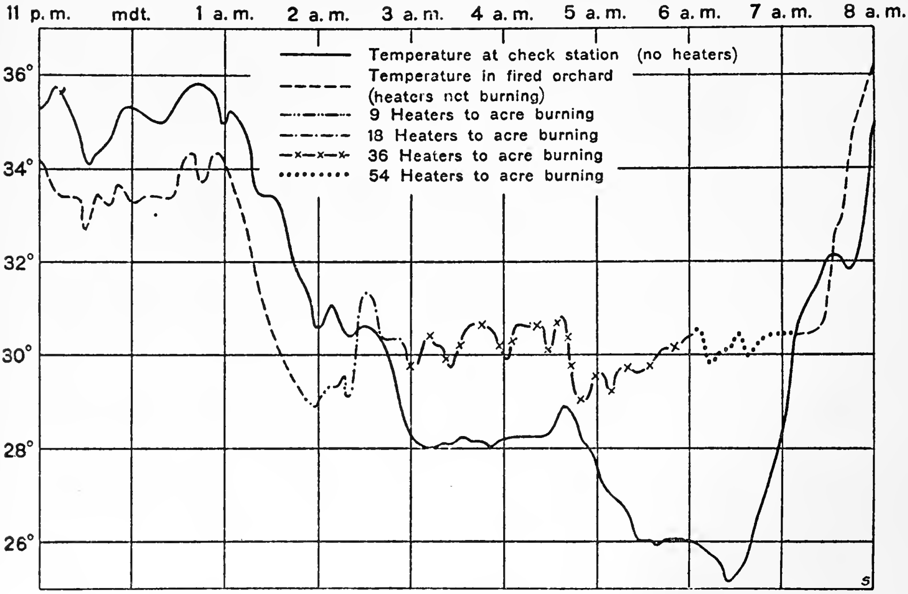

Fig. 12.—Temperature records in a heated orchard and at an outside check station on the night of April 13–14, 1919.

burning per acre a satisfactory temperature was maintained all night with the exception of a few minutes following 4:40 A.M. when the first lighted heaters burned dry. Reserve heaters were lighted until a total of fifty-four per acre were burning. Economy of fuel usage was obtained by keeping the temperature just above the danger point.

This pair of records should be contrasted with another pair (figure 13) obtained in two pear orchards on the night of May 4–5, 1919, when weather conditions were almost ideal for heating and the temperature inversion was about twice as great as on the night of April 13–14. The burning of thirty-six heaters per acre of the five-quart lard pail type rapidly raised the temperature several degrees above the danger point. Less oil would have been consumed if the grower had lighted only nine heaters per acre at the first firing and then more if necessary, as was done the night of April 13–14.

If the grower is to maintain a safe temperature with the minimum fuel consumption it must be done by intelligent firing based on a careful check of actual temperatures at frequent intervals.

Extinguishing Heaters.—The time for extinguishing heaters should be determined from the temperature shown by the check thermometer situated outside the heated area. The temperature is frequently below the danger point for an hour or more after sunrise, and the fires should not be put out too soon. It is necessary to keep briquet heaters refueled up to sunrise even though they cannot be put out and some loss of fuel will be inevitable. All types of heaters are best extinguished by closing the drafts tightly and capping the stacks.

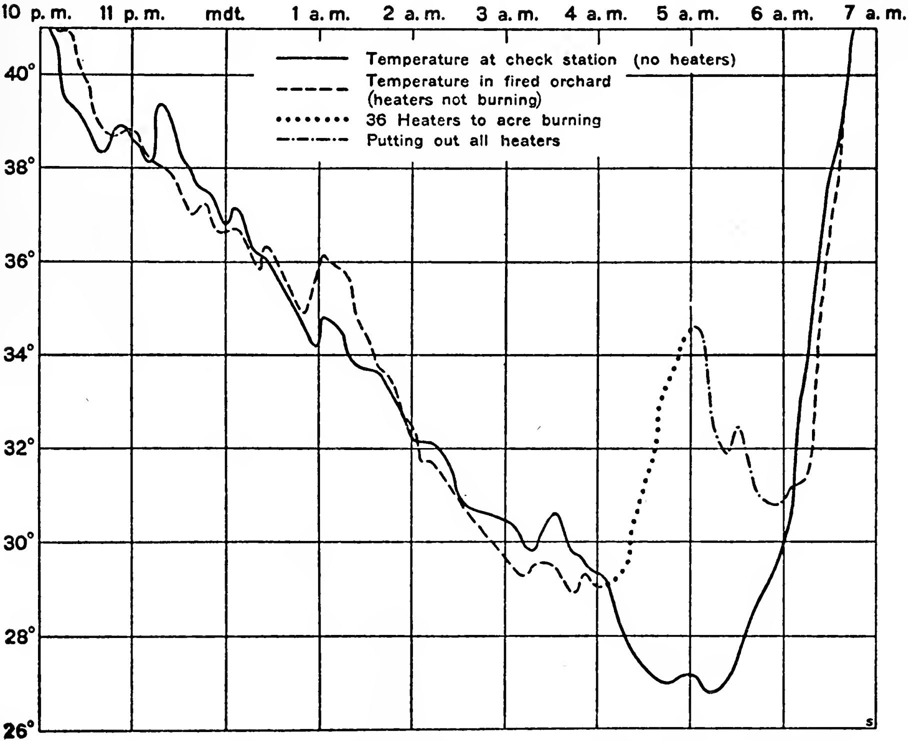

Fig. 13.—Temperature records in a heated orchard and at an outside check station on the night of May 4–5, 1919.

Refilling.—Refilling should begin as soon as the heaters are completely extinguished and should continue until all have been filled.

Many losses have occurred through failure to refill after each night of burning, even though only a small part of the oil had been burned. If, for any reason, refilling is not completed, the full heaters from the reserve of the previous night should be lighted first the next night, so when the most fires are needed, usually about 4 or 5 A.M., there will be some fuel in all of the heaters. At the time of filling, all lighting cups in stacks or drafts should be primed with heater oil. *Great care should be taken to keep oil from being spilled on the ground, as it will kill roots with which it comes in contact.*

Labor for Operations.—One man can light 2½ to 5 acres, depending on the type of heaters and the amount of regulating required. Fruit pickers and high school and college students furnish the usual source of labor for orchard heating operations.

LIGHTING INSTRUCTIONS FOR DIFFERENT TYPES OF HEATERS

Lard Pail Type.—Remove the cover and pour a ring of fire from the torch around the edge of the heater. After the heaters have been burned once they will light easily with a few drops of burning torch fuel because the crust of soot around the rim of each heater serves as a wick.

Low Stack Heaters.—Dunn heaters or Scheu "Double Stack" heaters should be wicked with a small amount of excelsior in the downdraft tube, especially when new or clean. They can be lighted with one draft hole open. They should be lighted by pouring burning torch fuel around the inside of the stack or in the stack lighting cup and also through the draft. New low stack heaters will light more easily if they are burned an hour or two when first placed in the orchard.

In order to keep heaters of this type burning satisfactorily, they should be regulated two or three times during the night and as the oil burns low the draft must be increased. If the drafts are open too wide, the amount of smoke produced is excessive. This is true of nearly all heaters.

The foregoing instructions apply to the "Citrus" heater except that wicking should be placed in the stack instead of the draft. This is very necessary with new heaters being burned for the first time. The best wick is a wad of burlap wedged into one of the stack openings just at the surface of the oil. Pieces of palm leaf, cornstalks, or eucalyptus bark placed in the reservoir and sticking up into the stack will serve as satisfactory wicks. Heater bowl covers should fit tightly onto the fuel reservoirs so that all air entering the combustion chamber will have to pass through the draft openings.

Medium and Tall Stack Heaters with Down-draft Tubes or Plates.—These heaters must be set level and all models previous to 1925 are hard to light if filled too full. The 1925 models will hold ten gallons but the same size bowl on previous models will not work satisfactorily with more than nine gallons. To light these heaters, the draft covers should be thrown back and burning torch fuel poured around the outside of the stack and into the draft. Pouring the torch fuel around the stack assists in starting an upward draft and insuring lighting.

One man should light and another should follow, five minutes later, closing the draft covers and regulating the holes so that the tip of the flame barely emerges from the stack. The efficiency of heaters of this type is greatest with this sort of regulation.

If the draft deflector is of the fluted plate type it must slant toward the center of the bowl from the top down. If V-type deflectors are used, the open side of the V must be next to the side of the bowl, or away from the stack. The lighting of heaters with these two latter types of deflectors is facilitated by wicking with shook rope or other material hung down in the draft hole.

If the heater is too full or regulated too soon after lighting it is likely to go out. Heaters of this type should be regulated several times during the night to keep the flame tip coming out of the stack. The stacks should be desooted when refilling, if necessary.

Separate Reservoir Types.—The Kittle heater should be lighted by pushing the handle one-third of the way down and pouring burning torch fuel at the base of the stack. Regulation is accomplished by pushing the handle down further every three or four hours. The vacuum feed types of heaters are automatic in feed, the rate of flow being controlled by the draft regulation. They are lighted in the draft and down or around the stacks. The valve feed types are lighted by turning on the valve and lighting in the burner or stack. The rate of flow varies as the oil warms up and the viscosity changes; this type of heater therefore requires frequent regulation for best results.

Briquet Heaters.—These are easily lighted if proper kindling is used. They should be filled nearly full, the kindling put in and then a few more briquets added. They are lighted from the top with burning torch fuel. Oil-soaked shavings or shaving briquets, pieces of automobile tire about two or three inches long cut across the casing, or a large handful of peach pits are satisfactory kindling materials.

Coal briquets can be lighted without kindling if previously primed with smudge oil. This should be done after the briquets are in the heaters and several days in advance of the period when damaging temperatures are expected. A good kindling for carbon briquets can be made by soaking small blocks of seasoned wood in crank-case drainings and adding a few of these to the charge for each heater. These will retain enough oil to ignite satisfactorily after several weeks. Briquet heaters require little or no regulation but should be refueled every 1½ to 2 hours with only one layer of fuel each time so as not to depress the fire too much by the addition of cold fuel.

General Directions.—Lighting heaters is a more difficult task on a cold night than on a warm day. If the night is damp the covers may be frozen on and the drafts frozen shut when lighting should begin. Pliers and draft tools should always be at hand. Some growers with a large acreage to heat remove the caps and open the drafts before night, if the forecasts and general weather conditions indicate the probability of a need for rapid lighting.

CARE OF ORCHARD HEATERS

When the extreme conditions of moisture and temperature which orchard heaters must undergo in their use and storage are considered, the average rate of depreciation is surprisingly low, being, in fact, much less than was anticipated when oil-burning heaters first came into use on a commercial scale. Many heaters have been in use in citrus orchards for ten or twelve years and are still in reasonably good condition, even though comparatively little care has been given to them. The high cost of heating equipment makes it desirable to extend their period of service as much as possible.

The essential points in the care of orchard heaters are to prevent rusting and to keep them relatively free from the accumulations of soot and residue which reduce their fuel capacity and burning efficiency.

The effective life of heaters may be prolonged appreciably if, immediately after delivery and before placing in the orchard, the bowls or reservoirs are dipped in asphaltum paint or some similar compound which will protect the metal against rust. As the efficiency of this coating diminishes, it is advisable to renew it; this is generally done at the time of removing the residue. As an additional means of preventing rusting of the bowls, many growers use some sort of support intended to keep the heaters from resting directly on the ground when in the orchard. Tar-paper squares, wooden platforms, small cleats, and bricks have been used for this purpose. Since, if the heater is lighted at all, the bowl cover and stack usually reach a temperature which will destroy the efficiency of whatever compound is used to prevent rusting, there seems to be no particular reason for using expensive materials for coating these parts. Dipping them in heavy oil, such as the sludge remaining at the end of the season, appears to be as satisfactory a treatment as any. This should be done every season, and especially in the case of the parts of the stack which are most subject to rust. Such treatment may be given in the orchard or at a central point, in case the heaters are removed from the orchard for cleaning and storage.

Cleaning the accumulations of soot and residue from the heaters presents a problem of special importance, since if this is not done from time to time their fuel capacity and burning efficiency may become seriously reduced. The accumulation of asphaltum resulting from a prolonged period of burning of the distilling types of heaters may reduce the fuel capacity as much as 25 per cent and, therefore, automatically renders it difficult to secure as much heat after six or eight hours of burning as may be necessary to save the crop. Such accumulations also increase the difficulty of relighting the heaters in case this must be done before they are refilled. The heaters should be cleaned, therefore, as often as may be necessary, which depends on the length of time they have been burned and on the quality of fuel used.

Methods of cleaning vary greatly and must be determined in large part by the conditions under which the heaters are operated. Some growers have attempted to clean heaters by burning them dry in the orchard. With some types of heaters, such as the lard-pail types, this is impossible, because the draft is insufficient. Lard-pail heaters are generally used over so short a period, however, that accumulations of residue are small and, therefore, not particularly objectionable. It is possible to burn most of the distilling types dry; the charred and caked residue may then be removed by jarring the bowls. Burning dry must be done with caution, in the case of the down-draft types, because the heat generated may be sufficient to warp the bottoms and produce rapid deterioration. The system of burning the residue out at a central point by the use of distillate, which was formely used somewhat, has been practically abandoned. If the heaters are stored under the trees, which many growers do, a common practice is to empty them and clean them thoroughly with scraping tools designed for that purpose, before storing them. A special cleaning crew of two or three men and a team and wagon equipped with sludge tank and platform for scraping and dipping the covers and stacks, is usually employed for this purpose. The heaters are then placed under the trees, where they remain until fall. In seasons when the heaters have not been burned much, many growers omit the emptying and cleaning operations and store the heaters full of oil under the trees. Where this is done there is the possibility of damage from oil seeping out or being spilled from the heaters and killing some of the tree roots. This may be minimized by carefully inspecting the heaters at the time they are placed under the trees, and repairing all leaky heaters.

When the accumulation of residue becomes large, such as occurs following a season of prolonged burning, or at intervals of several years of ordinary use, most growers find it advisable to assemble the heaters at a central point, where they can be thoroughly cleaned and coated with suitable rust-preventing compounds. The procedure usually followed is to empty the heaters and haul them to an open place on waste land, preferably in a dry river bed, which permits of easy disposal of the sludge. Some means of heating the bowls in batches of a dozen or more at a time is provided. A trench covered with sheet iron and with a flue at one end, is often used for this purpose. The fuel used is usually the sludge oil left in the heaters after emptying. When the bowls are hot they are picked up by means of tongs, and the residue shaken out. They are then scraped or brushed with steel brushes, tested for leaks by immersing in kerosene or distillate, repaired if necessary, and dipped in hot asphaltum paint. After drying, the bowls and covers are usually nested together and the stacks placed in piles. Some growers store them under cover, others merely stack them on well-drained land close to the orchard.

Repairing of heaters consists principally in stopping leaks and in straightening out the few bowls and covers which are bent. The average grower does not attempt to do this work himself but sends such heaters to a tinsmith to be repaired. Some of the larger Citrus fruit producing companies have found it profitable to repair their own heaters on account of the large number they have to use. Holes are repaired where possible by means of soft copper rivets or by welding or brazing. Soldering has been used to some extent but the solder melts if it comes in contact with the flames.

There is wide variation among growers with respect to storage of heaters during the period when they are not in use. The principal factor determining the place and method of storage appears to be the system of handling the heaters which is followed. Some growers take the heaters apart, clean and dip them and store them under cover every year. This is probably more care than is necessary under most conditions. Others go to this trouble only when residue accumulates to the point where the heaters must be cleaned, storing them under the trees or alongside the orchard during the periods between cleanings. Some store them under the trees full of oil, while others store them empty.

No blanket recommendations can be offered concerning methods of care of orchard heaters. These must of necessity be determined by each grower for himself in accordance with the type of heaters he has, the amount of burning required, the humidity and rainfall in the district, and the most economical and efficient method of handling them in his orchard.

With good care the depreciation of heaters should not be excessive, the bowls and covers lasting from ten to fifteen years, and the stacks from three to five years.

TEMPERATURES AND CONTRIBUTING CONDITIONS CAUSING FROST DAMAGE

So many factors must be taken into consideration in determining whether a given temperature will cause damage to fruits, buds, or blossoms, that the matter is one of considerable complexity. The length of time the low temperature persists, the vigor of the tree, and the weather preceding the frost, all have considerable influence on the amount of damage that will be done. If the sky clouds over before sunrise on a frosty night, so that the direct rays of the sun do not strike the trees until after the ice is out of the fruit, the damage is likely to be lessened. Other conditions being the same, the fruit or blossoms on a weak, undernourished tree will show more injury than those on a vigorous, healthy tree, after both have been subjected to the same low temperature.

When soil and atmospheric conditions are favorable for growth, which may be the case during warm, sunshiny weather, the sap is likely to be watery and its freezing point high. For this reason a frost which follows a period of weather favorable for rapid growth will cause more damage than the same temperature following a period of cold, cloudy weather and consequent slow growth. Under certain conditions the blossoms and fruit may endure temperatures without damage which under other conditions would destroy the greater portion of the crop. In the following paragraphs data are given regarding temperatures which have caused damage to various deciduous and citrus fruits in different stages of growth. These data are based on field observations made by weather bureau officials over a long period of years and are considered safe as a basis of recommendations for successful heating operations. However, long experience is the best guide in deciding when to light the orchard heaters. Some fuel will be wasted in maintaining temperatures according to these recommendations, but the grower who has orchard heating equipment cannot afford to take chances. All temperatures mentioned are in degrees Fahrenheit as registered on sheltered thermometers.

Temperatures Damaging to Deciduous Fruits.—Table 11 gives the temperatures as registered by sheltered thermometers which will be endured for thirty minutes or less by deciduous fruits in various stages of development.

It must be admitted that the data in the following table are unsatisfactory because they do not go enough into detail. The three stages of development given are not sufficient to cover all the changes in susceptibility to damage which are found during the period of development of a fruit bud through the blossom stages to the green fruit. Detailed information to supply the deficiency is not available except in the case of a few fruits.

TABLE 11

TEMPERATURES (DEGREES F) ENDURED FOR THIRTY MINUTES OR LESS (SHELTERED THERMOMETERS) BY DECIDUOUS FRUITS IN VARIOUS STAGES OF DEVELOPMENT

Kind of fruit	*Stage of development*		
	Buds closed but showing color	Full bloom	Small green fruits
Apples	25	28	29
Peaches	25	27	30
Cherries	24	28	30
Pears	25	28	30
Plums	25	28	30
Apricots	25	28	31
Prunes, Italian	23	27	30
Almonds	26	27	30
Grapes	30	31	31
Walnuts, English	30	30	30

The fruit buds of nearly all deciduous fruits are extremely susceptible to damage during the period of from 24 to 48 hours before they open. The petals are still folded, but the flowers are growing rapidly and are extremely tender. Buds in this condition are often injured by temperatures as high as those given in the table for small green fruits. Fortunately, most deciduous fruit trees come into full bloom gradually, so that even if all the buds about to open at one time are killed, the size of the crop is not reduced materially. Buds of the Bosc pear often open almost simultaneously, and a low temperature just before the flowers open sometimes destroys most of the crop.

At the time generally designated as "full bloom" most deciduous fruit trees have large numbers of fruit buds which are still tightly closed, in addition to the flowers which are fully open. This makes the loss of the entire crop, or even the greater portion of the crop, on one cold night, extremely improbable at this stage. This has led fruit growers in some districts to believe that frost can do no damage before the fruit has set. Some growers even follow the hazardous practice of leaving heaters unlighted on frosty nights during this period. While a single frost at full bloom seldom affects the size of the final crop, a series of heavy frosts, each killing a portion of the blossoms, may leave too few undamaged buds or blossoms for a full crop.

The most dangerous stage in general is after all the petals have fallen and the fruit has set. All of the fruit being in nearly the same condition, the entire crop may be killed on a single night. It is at this time that orchard heating operations should be most carefully conducted. Apples and pears at this stage of development usually are not seriously injured by a temperature of 28.5° F for thirty minutes or less, provided the duration of temperatures below 32° does not exceed three hours. If the temperature drops to 29° only a short time before sunrise and has not been below 32° more than three hours, heating is unnecessary. However, if it appears that the lowest temperature during the night will be below 29°, or if the temperature falls below 32° more than three hours before sunrise, heaters should be lighted and the temperature maintained as near 31° as possible throughout the remainder of the night. Small, green apricots are extremely tender just after the shucks (dried calices) have dropped and before the pits have hardened. Apricots in this condition have been injured at long continued temperatures of 31°, and many growers think it necessary not to allow the temperature to fall below 32° as long as the pits are soft.

Different varieties of the same fruit often differ considerably in their susceptibility to frost damage. The Delicious apple appears to be more tender than most other varieties of apples grown commercially on the Pacific Coast. The Bosc pear is more susceptible to damage by frost than most other varieties of pears at similar stages of development, while the Winter Nelis is hardier than most varieties.

Temperatures Damaging to Citrus Fruits.—We are confronted with the same limitations in attempting to name definite critical temperatures for citrus fruits as for deciduous fruits. The length of time the low temperature persists, the vigor of the tree, the weather preceding the frost, the maturity of the fruit, and the rate at which the temperature has been falling, all are factors in determining the amount of frost damage to oranges, lemons and grapefruit that will result from a given temperature. The size of the fruits also is an important factor, since small fruits cool more rapidly than large fruits.

The thick, pithy rind of the orange is a poor conductor of heat, and the protection it affords causes the temperature of the interior of the fruit to fall more slowly than the temperature of the outer air. When the air temperature is falling rapidly the interior of the fruit may be as much as seven degrees warmer than the air surrounding it, and the temperature inside the fruit may lag from an hour to an hour and a half behind the temperature of the air. In other words, when the temperature of the air is falling rapidly, the air temperature may be 27° F when the temperature of the interior of the fruit is 34°.

After the fruit begins to freeze, its temperature will remain at, or very near the freezing point of the juice until the orange is frozen solid, no matter how low the temperature in the orchard may fall. The temperature at which freezing of the juice begins is slightly different in different oranges of the same variety, even on the same tree. In the experimental work done by the Weather Bureau, the freezing points of ripe navel oranges varied from 27° F to 28°. Half-ripe Washington navels began to freeze at fruit temperatures of from 28° to 29°, and green navels at from 28.5° to 29.5°. The freezing point of green Valencia oranges varied between 29° and 29.5°. The fruit itself must reach the temperature given above, before freezing will begin; the air temperature may be, and usually is, several degrees lower.

All objects exposed to the sky on a clear night lose heat steadily to the sky by radiation, and therefore cool more rapidly than objects sheltered from the sky. Citrus fruits on the outside of the tree cool more rapidly than those sheltered by foliage. On a calm, clear, frosty night, the most exposed oranges on a tree may be as much as three degrees colder than oranges on the interior of the tree. This explains why fruit on the outside of the tree is often frozen on a night when sheltered fruit is not damaged. It often happens that a moderately low temperature will freeze only the exposed portion of the rind of the orange, giving it a water-soaked appearance, usually called the ''water mark.'' If the orange is colored, the portion of the rind that has been frozen turns a very light yellow on the day following the frost. Such oranges are called ''shiners.''

The problem of determining what temperatures will damage oranges is further complicated by a phenomenon known as ''under-cooling,'' by which is meant the cooling of the fruit below the freezing point of the juice without the formation of ice. Navel oranges have been known to cool as much as three degrees below their freezing point before freezing began. Undoubtedly oranges are often under-cooled several degrees, after which the temperature rises again without the formation of ice and without any damage to the fruit resulting. The first formation of ice crystals in an under-cooled fruit is accompanied by a rise of the fruit temperature to approximately the freezing point of the juice. The amount of under-cooling which the fruit will undergo on a given night cannot be determined in advance, although there appears to be less undercooling when the fruit is covered with ice than when it is perfectly dry. However, until further information regarding under-cooling of fruit on the tree under natural conditions is obtained, it will not be practicable to take this factor into consideration in determining when to light the heaters.

In general, the nights on which heating will be necessary to protect oranges and grapefruit may be divided into two classes. The first class will include nights on which a local frost occurs, when the cooling is due principally to loss of heat by radiation. Such nights usually follow warm afternoons. The temperature drops rapidly, but does not reach 27° F until 2 or 3 o'clock in the morning. The fruit temperature is likely to be several degrees above the air temperature on such nights, and so long as the air temperature continues to fall steadily, lighting of heaters to protect ripe, or nearly ripe navels or grapefruit can be delayed until the sheltered thermometer registers 26°. Under similar conditions, heating for protection of green navels or Valencias should start at 27°. In any case, it is best to keep the temperature above 28° after heating starts.

The second class of nights on which heating is necessary includes the "freeze" nights. The preceding afternoons are usually cold and windy, often with a cloudy sky. The temperature slowly falls below the danger point early in the night and remains there until sunrise; or the temperature may fall only slightly below the freezing point of the fruit early in the night and remain practically stationary until morning. On such nights it is necessary to light the heaters before the temperature has fallen much below the freezing point of the fruit. Lighting of heaters for nearly ripe navels should be started when the sheltered thermometer reaches 27° F. Green navels or Valencias should be heated when the temperature has been stationary at 28° for two hours, or when the temperature is falling slowly and has reached 27.5°. On a night when the temperature falls to the previously indicated freezing point of the fruit before 1 A.M., the temperature in groves protected by heaters should be maintained at this point until morning.

The temperature at which heating is begun for the protection of lemons will depend on whether it is desired to save the blossoms and small "button" lemons, or only the nearly mature fruit. If blossoms and small fruits are to be protected, the temperature must be held at 30° or higher, while the larger lemons will withstand a temperature of 28° for several hours without injury. The small green fruits are more susceptible to damage by frost than the blossoms. In the protection of avocados the general recommendations for ''button'' lemons should be followed.

Damage to Citrus Trees by Frost.—The amount of injury to citrus trees during a freeze will depend to a great extent on the weather preceding the freeze. If the soil and air have been warm, and there has been a plentiful supply of nitrate available in the soil during early winter, the trees will be in a succulent growing condition and a freeze will cause the maximum amount of damage. If the preceding weather has been cold and cloudy, so that the trees are semi-dormant, damage by a freeze will be considerably less. Trees that have been weakened by lack of proper care will be damaged by higher temperatures than trees that have been kept strong and vigorous. Mature navel orange trees in rather poor condition were about 75 per cent defoliated by a temperature below 20° F for six hours, with a minimum temperature of 18°, during the freeze of 1922. Another navel orange grove nearby, in good condition, was about 10 per cent defoliated by a minimum temperature of 19.8° during the same year. On the morning of January 3, 1924, a mature orange grove endured a temperature of 16° for one and one-half hours, with thirteen hours below 27°, with only about 10 per cent defoliation. In the last case the trees were almost dormant, while in 1922 the trees had been in a growing condition all winter. A mature lemon grove was entirely defoliated during the 1922 freeze by a minimum temperature of 20°, and the bark on the trunks of ten-year-old lemon trees was split on a night when the minimum temperature fell to 19°. During the winter of 1924–25 several temperature stations were maintained by the Weather Bureau in the same lemon grove of old trees. In the lower portion of the grove, where the lowest temperature was 22.6°, the trees were completely defoliated. On slightly higher ground, where the lowest temperature was 24°, the trees were about 50 per cent defoliated. On still higher ground, where the lowest temperature was 26.5°, only the tender new growth was killed. In the San Joaquin and Sacramento valleys the trees become more nearly dormant under average winter conditions than in southern California and will consequently endure somewhat lower temperatures without damage.

Influence of Cover Crops on Orchard Temperature.—During recent years the belief that a cover-crop in an orchard lowers the temperature several degrees has become quite widespread. Careful experiments by the Weather Bureau, covering two entire winter frost seasons, have shown that the temperature is lowered one degree on the average, at a height of three feet above the ground, by the presence of a heavy cover-crop. At a height of five feet above the ground the temperature is depressed only about one-half degree on the average. On nights when the temperature barely reaches the danger point in clean, cultivated orchards, a temperature one degree lower in orchards with cover-crops may be responsible for considerable damage to fruit within three feet of the ground. In comparison with the total production of fruit in the orchard, however, the increase in the amount of damaged fruit in the cover-cropped orchard would be rather small. The soil temperature, soil moisture, and availability of nitrates in the soil are factors influencing the state of dormancy of trees, which in turn determines to a certain extent the resistance of both trees and fruit to frost damage. All of these soil conditions are influenced by a growing cover-crop which may account for observations by some growers that the cover-crop is a benefit and by others that it is a detriment on frosty nights.

ORCHARD HEATING COSTS

Costs of orchard heating vary markedly both with respect to the annual overhead charges, which are determined in large part by the initial cost of equipment; and also with operation costs, which depend upon the frost hazard and the efficiency of operation. Many growers are inclined to underestimate the annual overhead costs properly chargeable to orchard heating, since the greater part of these consists of the two items of depreciation and interest on the investment, which do not represent annual cash outlays. Indeed, with some growers, it has been the practice either to include the initial cost of orchard heating equipment in the total orchard investment or to write off this item in the savings made following a year of severe frost damage and thereafter to merely charge cash outlays. If, as previously stated, however, orchard heating is to be regarded as an investment which, in order to be profitable, must show a return, the overhead cost is a proper annual charge and should include both interest on the capital invested, and a depreciation charge sufficient to return the invested capital by the time it becomes necessary to purchase new equipment. Although it has been shown that if given reasonable care orchard heating equipment depreciates slowly, many growers feel that the depreciation charge should be high enough to return the investment in a period of ten to twelve years, since advances in heater design may render it desirable to replace the equipment before its period of usefulness has been passed.

Initial Cost of Equipment.—The initial cost of orchard heating equipment varies in accordance with the requirements of the different classes of fruits, being highest with the lemon and avocado, which, on account of their tenderness and long fruiting season, require the greatest amount of protection, and lowest with the temperate zone fruits, such as the peach, apricot, and apple, which are susceptible to frost damage for only relatively short periods. It varies also with the type of equipment chosen.

Typical cases illustrating cost of equipment for the various classes of fruits using equipment of different types are shown in tables 12 to 16. Prices of heaters vary greatly according to the type chosen. In making up the tables average prices of different makes in the same class were used rather than actual prices of any make. Oil reserves were calculated on a safe basis of three times the heater capacity. In districts where deliveries are slow or uncertain, larger reserves than this will be necessary.

TABLE 12

Initial Cost of Orchard Heating Equipment for Ten Acres of Oranges, Using "Smokeless Heaters" of Large Capacity

500 heaters at $3.50 each	$1,750.00
13,500 gallons oil at 4 cents (in storage tank)	540.00
Storage tank (capacity 13,500 gallons)	350.00
Wagon and tank (capacity 463 gallons)	150.00
Pipes, connections, buckets hose and valves for filling and emptying	50.00
Double action hand pump for emptying	20.00
4 thermometers (horizontal minimum type)	12.00
4 lighting torches (1-gallon capacity)	10.00
10 gallons lighting fluid in container	3.00
Total	$2,885.00
Approximate cost per acre	290.00

For lemons or avocados the number of heaters should be increased to 800 and the oil storage accordingly, which will bring the cost to approximately $440 per acre.

TABLE 13

Initial Cost of Orchard Heating Equipment for Ten Acres of Oranges, Using "Low Stack" Heaters of Large Capacity

500 heaters at $2.00 each	$1,000.00
13,500 gallons oil at 4 cents (in storage tank)	540.00
Storage tank (capacity of 13,500 gallons)	350.00
Wagon and tank	100.00
Pipes, connections, buckets, hose and valves for filling and emptying	25.00
Double action hand pump for emptying	20.00
4 thermometers	12.00
3 lighting torches	7.50
10 gallons lighting fluid in container	3.00
Total	$2,057.50
Approximate cost per acre	205.00

For lemons or avocados the number of heaters should be increased to about 800 and the oil storage increased accordingly which will bring the cost to approximately $300 per acre. In this case lower costs than used in table 12 are given for some other items of equipment as well as for the heaters.

TABLE 14

INITIAL COST OF ORCHARD HEATING EQUIPMENT FOR TEN ACRES OF ORANGES, USING BRIQUET HEATERS

1,000 heaters at $1.00 each	$1,000.00
60 tons of briquets at $15.00	900.00
Trailer for distributing fuel	40.00
4 filling funnels	10.00
4 thermometers	12.00
4 lighting torches	10.00
20 gallons lighting fluid in container	6.00
2 tons of kindling at $15.00	30.00
Total	$2,008.00
Approximate cost per acre	200.00

TABLE 15

INITIAL COST OF ORCHARD HEATING EQUIPMENT FOR TEN ACRES OF DECIDUOUS FRUITS, USING "LARD PAIL" TYPE OF HEATERS

1,000 heaters at 40 cents each	$ 400.00
6,000 gallons oil at 6 cents (in storage tank)	360.00
Storage tank (capacity of 6,000 gallons)	200.00
Wagon tank, buckets and fittings	85.00
3 thermometers	9.00
2 lighting torches	5.00
10 gallons lighting fluid in container	3.00
Total	$1,062.00
Approximate cost per acre	105.00

TABLE 16

INITIAL COST OF ORCHARD HEATING EQUIPMENT FOR TEN ACRES OF DECDUOUS FRUITS, USING BRIQUET HEATERS

800 heaters at $1.10 each	$ 880.00
30 tons of briquets at $15.00	450.00
3 filling funnels	7.50
3 thermometers	9.00
3 lighting torches	7.50
10 gallons lighting fluid in container	3.00
1½ tons kindling at $15.00	22.50
Total	$1,379.00
Approximate cost per acre	140.00

The costs indicated above are considerably higher than those under which many fruit growers are now operating. This is in large part due to recent general increases in cost of heating equipment and to the use of types of heaters of large capacity. There are many opportunities for reducing the initial cost and fixed charges of heating which enterprising and economical fruit growers can employ with advantage, such as the purchase at low prices of used equipment, the repair of old water tanks or cisterns for storage of fuel, the use of the farm wagon or truck for hauling and distributing oil.

Annual Fixed Charges or Overhead Costs.—These charges include all items of expense that are properly chargeable against orchard heating regardless of whether it becomes necessary to light the heaters or not. As already mentioned the most important of these are depreciation and interest on the capital invested in orchard heating equipment. Other items properly classed under this head include the cost of setting the heaters in place and filling them in the fall, of emptying, cleaning and painting them in the spring, and of storing them during the summer months. In determining annual overhead costs it is safe to allow a ten per cent depreciation rate on all equipment and an annual interest charge of three per cent on the initial costs of the equipment which will give an average return of six per cent on the depreciated value over a ten-year period. Interest on reserve supplies of fuel which, if properly handled, should not depreciate is figured at six per cent.

An example of the method of calculating annual overhead costs is given in table 17, using the costs for an orange orchard with smokeless heaters as stated in table 12. The same method may be used to calculate costs for any other case.

TABLE 17

ANNUAL OVERHEAD COST PER ACRE

Depreciation, 10 per cent on $234.50	$23.45
Interest, 3 per cent on 234.50	7.04
Interest on oil, 6 per cent on $54.00	3.24
Setting heaters in field and filling	3.00
Emptying and taking up in spring	4.00
Repairs, painting, etc.	2.00
Total	$42.73

The last three of these items are typical costs taken from data secured in a field survey. Obviously, the costs of these items vary widely according to the methods used. The total, while rather high for oranges, represents typical overhead costs where expensive equipment is used. Calculated in a similar manner the annual overhead costs per acre for deciduous fruits where lard pail heaters are used will amount to about $14.00

Operating Costs.—Costs of operation include all items of expense involved in the actual lighting and burning of the heaters and should occur only in seasons when damaging low temperatures occur. They may vary, therefore, from nothing, in years when the heaters are not lighted, to relatively high figure in cold seasons. The principal items involved are the costs of fuel, of lighting and regulating the heaters, of refilling them, and of cleaning and dipping or painting the bowls and stacks. From these items the cost of operation per hour of burning can be calculated. Cost data covering these various operations as gained from a recent field survey showed wide variations. Average oil consumption per acre per hour for oranges during the winter of 1924–25 varied from ten to thirty gallons, giving a variation in cost of from $.40 to $1.20. Filling costs varied from four-tenths of a cent to one and five-tenths cents per gallon of oil, and labor costs from less than ten cents to more than thirty cents per acre per hour. Reasonable operating costs for oranges are apparently about $1.20 per acre per hour as an average for the season. This figure is based on an average fuel consumption of twenty gallons of oil per acre per hour and includes costs of refilling. The cost for deciduous fruits, assuming an oil consumption of fifteen gallons per acre per hour, will be about $1.15 in the northern part of the state where oil costs more than in southern California.

Total Costs.—The total yearly cost of orchard heating is made up of the annual overhead charge plus the cost of operations for the season. From the data presented above it may readily be seen that marked variation in orchard heating costs may be expected even in a given locality. By exercising good judgment and foresight there is ample opportunity for the fruit growers to materially reduce their costs of heating. Community oil storage close at hand may eliminate the necessity of providing storage facilities in the orchard. If the heaters are stored full of oil under the trees the costs of handling and of filling and emptying may be materially reduced. The purchase at low prices of used equipment may markedly lower the overhead cost.

COMMON MISTAKES MADE BY GROWERS IN CONDUCTING HEATING OPERATIONS

Orchard heating is an operation the success of which depends largely upon the personal efficiency of the grower who undertakes it. Whenever the personal equation enters so largely into any operation mistakes and failures are inevitable. Some of the mistakes would be amusing were it not for the disastrous consequences resulting from them. Some of the more common causes of failure are discussed in this section.

Insufficient Equipment.—There is a tendency on the part of many growers to equip on the basis of average rather than of extreme conditions. During a survey made recently, a frequent statement made by growers was that fruit had been lost through failure to provide a sufficient number of fires. A very common mistake is the failure to provide extra protection around the borders of the orchard.

Inadequate Knowledge of Temperatures.—Fuel may be wasted or fruit lost through inadequate knowledge of orchard temperatures. Every year some growers are found who have no thermometers at all, who start firing when neighbors do or when they are called out by some protective organization. Others place dependence on inaccurate thermometers. It is believed that the inaccuracy of thermometers used a few years ago was largely responsible for the frequent failures which attended heating operations at that time. Many growers have the thermometers hidden in trees where it is difficult if not impossible to find them on a dark night. Sometimes fruit is lost after sunrise because the heaters are extinguished too soon. Heating should continue until a check thermometer outside of the heated area shows a definite rise in temperature.

Torches Improperly Prepared.—Crops have been lost because of inability to light heaters with torches stored from the previous season and not refilled. The evaporation of the lighter fractions of the torch fuel left them partially filled with fuel unsatisfactory for firing. Torches should be freshly filled each season with the proper mixture and then tested before they are needed.

Heaters Improperly Assembled.—Heaters will not burn properly unless the bowl covers are on tight. Growers often report that heaters go out after lighting. A common cause of this trouble is improper placing of the down draft tube or plate in heaters which have this attachment. Several growers were found trying to operate the ''Supply Company'' type of heater with the draft plate missing. Tubes or plates should be placed so as to carry the pilot flame toward the center of the heater and keep it concentrated on the surface of the oil as the oil level drops in the bowl.

Other Mistakes.—Failure to remove soot from the stacks or to refill the heaters after a few hours' burning may make lighting very difficult. On the other hand, if the heaters are cleaned too thoroughly, especially in the draft parts, or are filled too full of oil they will be difficult to light and many of them will go out unless given special attention in lighting. Regulating tall and medium stack heaters too soon after lighting will cause many of them to go out or to burn unsatisfactorily. The failure to keep the stack covers on tight and all openings closed permits rain water to get into the oil. This causes frothing and sometimes explosion of the heaters. Many growers have been greatly delayed in their lighting operations the first dangerous night of the season because the draft covers and regulating hole covers had been stuck shut with fresh paint. On wet nights these heater parts are sometimes frozen and can be opened only with special tools or by thawing them out with burning torch fuel. Attempts to kick the drafts open generally result in bent parts which make regulating difficult.

The delegation of responsibility for heating operations to incompetent foremen has been a common cause for failure. This highly important and very expensive orchard operation requires intelligent supervision and careful organization before the danger season. It should not be undertaken by persons unwilling to undergo the inconvenience and hard work necessary to insure success.

COMMUNITY ORGANIZATION FOR ORCHARD PROTECTION

Some of the aspects of community interest in orchard heating have been referred to in a previous section. In certain communities as a result of the awakening of the business interests to the recognition of the relation of orchard heating to the prosperity of the district, arrangements have been made to assist growers in financing the purchase of heating equipment and groups of growers have been given aid in providing facilities for storing oil. A large capacity community storage tank is shown in figure 14.

There are other types of community cooperation, however, which have done much to promote orchard heating and to assist citrus fruit growers in protecting their crops. Among these the oldest and perhaps the most helpful are the cooperative frost warning organizations, of which the Pomona Valley Frost Protective Association is one of the most widely known. Organizations of this type of which there are a considerable number, have greatly reduced the risks of orchard heating and the needless consumption of oil by maintaining a reliable frost patrol system, which keeps in close touch with temperature conditions throughout the district and warns the individual grower by telephone shortly before the time when lighting of the heaters should commence. They generally work in close cooperation with the Fruit Frost Service of the Weather Bureau and thereby have the assurance that their service is based on authoritative weather forecasts. The work of these organizations is now supplemented by radio broadcasting from Los Angeles and Oakland of the Weather Bureau minimum temperature predictions for the different fruit producing communities. These predictions are for the "key stations," which are selected as being typical cold spots in the various communities.

The organization referred to has been particularly active in promoting and assisting in investigational work concerning orchard heating and has been directly responsible for much of the progress made in the heating methods and equipment of citrus fruit orchards. In this connection it should be mentioned that among the first studies and tests of orchard heating made in California were those undertaken by the Riverside Horticultural Society more than thirty years ago.

Fig. 14.—Large community oil storage tank.

Frost warning organizations are financed in various ways, one of the commonest being pro-rating the expense to the different packing associations in the district served, in proportion to the number of cars shipped by each. There is still a considerable field for expansion in cooperative frost protection work of this type.

Another type of cooperative organization concerned with problems relating to orchard heating is that of the oil purchasing and storage associations. Some of these represent cooperation within a given packing association or between different packing associations within a district exchange, while others are entirely separate from the marketing organizations and are organized on the stock issuance basis. In the case of the former, the local packing association or the district exchange owns the storage and distribution facilities and the oil is purchased through the subsidiary purchasing corporation of the central marketing agency. All costs are pro-rated to the grower on the basis of a charge for oil determined at the close of the season's operations. In the latter type of organization all facilities are owned by the corporation, its purchases of oil made in the open market, and the costs pro-rated to the members on the basis of the amount of oil consumed by each. In order to minimize disputes over the return of oil by members of oil storage organizations it is believed that weighing the oil on delivery and again on the return of what is left at the end of the season with a system of dockage for dirty oil is to be preferred over other systems which have been used.

It appears not at all unlikely that cooperation in orchard heating will receive further extension among citrus fruit growers in such matters as the delivery of oil to the growers, the filling and refilling of heaters, and perhaps even in their operation.

Organizations of the types above noted have done much to place orchard heating on the sound basis that it now occupies in the citrus industry of California. For, in addition to the functions for which they were formed, they have fostered and assisted in much needed investigational work, have aided in securing the important frost forecasting service of the Weather Bureau, and have done much to acquaint the residents of the towns and cities in the citrus districts with the importance of orchard heating as a practice which, although dirty, laborious, and objectionable alike to both grower and city resident, is necessary for the prosperity of each.

LABORATORY TESTS OF ORCHARD HEATERS[11]

In a study of heaters made by A. H. Hoffman in 1927 the most important makes of heaters were tested in the laboratory. The following questions comprise part of the objectives of the study:

1. What are the characteristic burning or fuel consumption rates of the different heaters?
2. How efficiently do they convert fuel into heat?
3. What per cent of the heat is lost by radiation?
4. How fast do the hot gases rise from the stacks of the heaters?
5. How much smoke is produced by each heater?

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[11] Subsequent to the preparation of Bulletin 398, of which this publication is a revision, A. H. Hoffman, Associate Agricultural Engineer in the Experiment Station conducted a laboratory study of orchard heaters, the results of which were reported in Bulletin 442. All of the most important makes were studied. A summary of the results which are of most practical value to growers is given in this section.

6. What characteristics are necessary in a satisfactory fuel for orchard heating?

The heaters studied are shown in figure 15.

From the utility standpoint the burning, or fuel consumption rates, are of the utmost importance, since to produce heat in large quantities is the prime requirement. The heat produced equals the number of pounds of fuel burned times the heat content per pound, assuming complete combustion. The heat content of a fuel is generally expressed in British thermal units (abbreviated B.t.u.) per pound. Its value is about 20,000 for oil, 16,000 for coke, and 13,000 for coal.

Fig. 15.—Names of the heaters tested: 1. Pomona. 2. Kittle. 3. Scheu Jumbo Cone Louvre. 4. Scheu Baby Cone Louvre. 5. Scheu Double Stack. 6. Bolton. 6s. Bolton (with spider). 7. Troutman. 8. Canco. 8s Canco (with spider). 9. Diamond. 10A. Dunn (10 in the illustration). 10C. Dunn (with 30-inch stack; not shown). 11A. Citrus, 9-gal. low stack. 11B. Citrus, 9-gal. medium stack. 11C. Citrus, 9-gal. high stack. 12A. Citrus, 6-gal. low stack. 12B. Citrus 6-gal. medium stack. 12C. Citrus, 6-gal. high stack. 13 Karr. 14 Jessen (large). 15 Jessen (medium). 16. Jessen (small). 17. Low Delivery. 18. Baby Double Stack. 19. Citrus Gas Flame. (From Agr. Exp. Sta. Bul. 442.)

A study of characteristic burning rates demonstrated the need for frequent regulation of oil heaters, and frequent re-fueling of solid-fuel heaters. If this is not done the rate of heat production decreases rapidly, as shown in figure 16. The rates at which several solid-fuel heaters produced heat when lighted, at once regulated and not

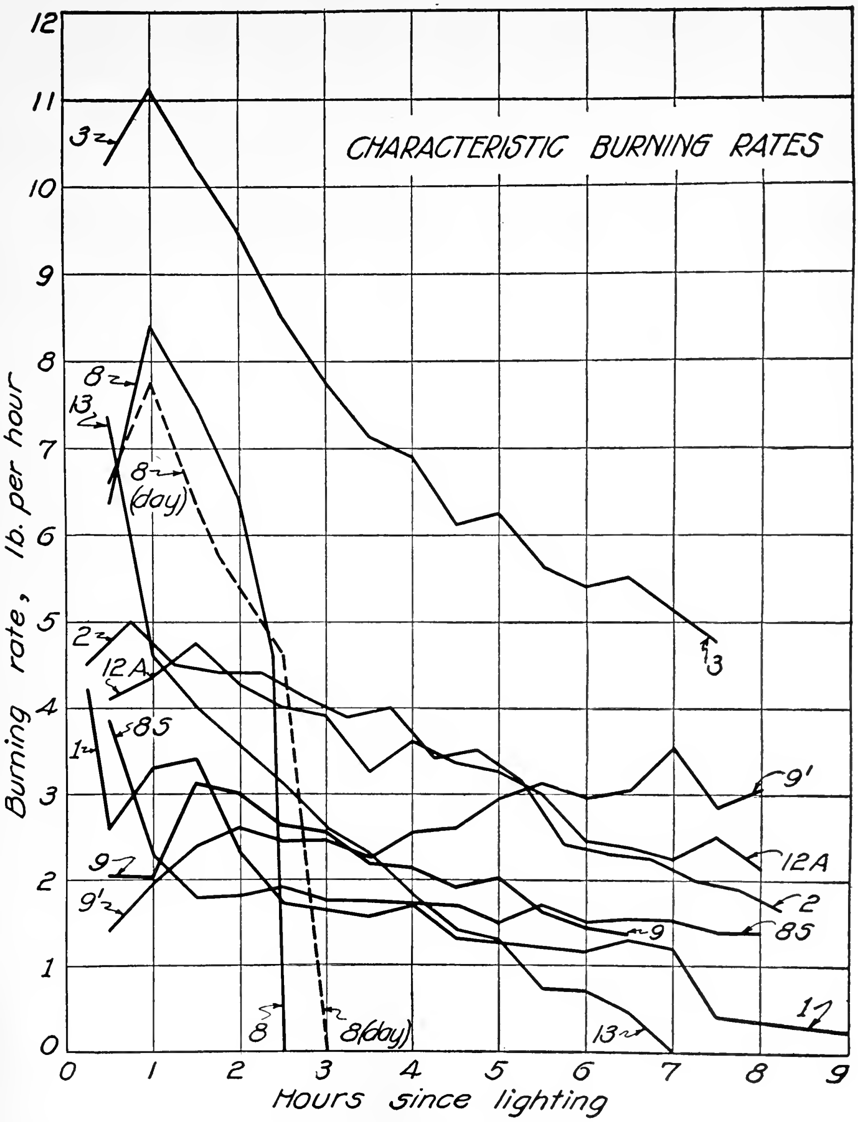

Fig. 16.—Characteristic burning rates. Each curve, except "8" and "8 (day)," is the record of a single test on the heater of the corresponding number. The fuel reservoirs were full at lighting. The only draft adjustments, if any, were made immediately after lighting. All briquet heaters were top lighted. The deviations from smooth curves are due principally to wind variations. Briquet type heaters vary more than the oil burners (curves, 1, 9, 9′, and 13). Curve 9′ shows a typical case of imperfect lighting (heater No. 9). The dotted line curve "8 (day)" is the average of three tests run in daytime and shows how higher air temperature slows the burning rate. Curve "8" is the average of 4 tests all run at night. See figure 15 for identification of heaters.

re-regulated, is shown in table 18, in the column headed, ''Heat in fuel, B.t.u. per hr.'' Table 19 shows data for oil burning heaters at two or more draft settings for each, and indicates how the rate of heat production may be controlled in heaters of this type.

To find out how efficiently the several heaters converted fuel into heat it was necessary to analyze the hot gases arising from them to find the per cent of carbon monoxide gas and to determine the weight of smoke (carbon) per unit volume of the hot gases. The amount of carbon monoxide was in no case found to be greater than five-hundredths of one per cent. The heat loss represented by the unburned carbon in the smoke of some of the smokiest heaters was only about one-tenth of one per cent of the heat value of the fuel used. We must conclude therefore that *the fuel-to-heat conversion efficiency of all the heaters tested was practically 100 per cent.* That is to say, the heaters tested got out of the fuel used practically all the heat there was in it. This takes no account of fuel left unburned in the reservoirs, or else assumes that the drafts in distilling-type heaters are opened sufficiently at the last to burn out completely the asphaltic residues. This could not usually be done without damage to the heaters. The most effective portion of the heat is that in the hot gases (products of combustion) rising from the stacks of the heaters. Some of that portion of the heat which is in radiant form may be lost without influencing temperature in the orchard. The study indicated that these losses were of minor importance. Tables 18 and 19 show that in all cases the heat radiated above the horizontal plane was less than 5 per cent of the total.

This table also shows that the variation in velocity of the hot gases from the stack ranged from less than 2½ to 14 feet per second. It is not believed that this range of hot gas velocities results in any material difference in the actual efficiency in heaters under orchard conditions. It is not considered good practice to force the fuel consumption of the oil heaters studied to a greater rate than one gallon of oil per heater per hour.

In practically all the heaters clearer burning was obtained at low burning rates, than at high as shown in tables 18 and 19. Nearly all oil burning heaters smoked badly when burned at maximum capacity. A comparative study of all the heaters tested indicated that in some cases a very slight difference in design apparently caused a large difference in smokiness. While absolute smoklessness under all conditions seems not feasible under present conditions of available fuel and equipment, still a great improvement could be made by the elimination, especially in thickly settled districts, of the lard-pail and all other open type heaters; by redesign of some of the other heaters; by more care in the production of the fuels used; and especially by more care on the part of the user to regulate more frequently and to avoid burning at too high rates. In justice to the user it should be added that poorly designed or constructed heater covers sometimes make it impossible to regulate the burning rate.

Oils, being higher in heat content per pound, are more effective than solid fuels. The oils sold for orchard heating differ considerably in characteristics that affect their suitability. Oils that leave large asphaltic residues on burning are less desirable both for distilling and for non-distilling type heaters. High sulphur content is objectionable. High viscosity or rapid increase in vicosity when temperature decreases, make an oil unsuitable for non-distilling type heaters.

The accumulation of heavy residues in the reservoirs of distilling-type heaters and in the burners of the non-distilling type has been a frequent cause of trouble. In extreme cases the heaters would operate very unsatisfactorily or could scarcely be made to burn at all. It seems that these asphaltic residues are not necessarily merely the asphalt that was present in the original oil, but are probably produced by what the oil chemist calls ''cracking of the molecules'' of oil when heated. The heat to which the oil in the reservoir is subjected may ''crack'' or change some of the oil into two new kinds of oil, one that vaporizes easily and therefore burns readily, and one that is very heavy and hard to vaporize and hence is liable to fail to mix with the oxygen of the air and so be left unburned. Some oils will ''crack'' much more readily than others. Table 20 shows the variations in typical orchard heater fuels with respect to the points enumerated above.

TABLE 18

SUMMARY OF NIGHT TESTS, BRIQUET BURNING HEATERS

No.	Name	Time since lighting		Fuel charge, (approx.) pounds	Fuel		Heat in fuel,* B.t.u. per hr.	Heat radiated[a]		Maximum upward velocity[b], ft. per second	Temperature of gas[b], degrees F.	Temperature surface,‡ degrees F.	Smoke, pound per 1000 cu. ft. of gas
		Hr.	Min.		No.	Pounds per hour		B.t.u. per hr.	Per cent				
1	Pomona	0	45	15	3	2.18	29,356			3.6	600		Trace
		1	15	14	3	2.20	29,625						Trace
		2	15	10	3	1.80	24,239						
		2	45	9	3	2.04	27,471						
		4	10	8	3	1.68	22,623	1,013	4.5				
9	Diamond	0	40	13	3	3.44	46,323	1,564	3.4	4.4	860	556, 575, 50	Trace
		1	40	10	3	2.50	33,665	1,326	4.1	3.5	665	418, 560, 60	Clear
13	Karr	0	35	34	3	4.13	55,615	1,633	2.9	4.4	1,030	732, 50, 50	Trace
		2	35	27	3	3.75	50,496	1,697	3.4	Less than 2.5	317	248, 334, 589	Trace
14	Jessen, large	0	50	29	4	1.63	26,377	406	1.5				
		1	30	28	4	1.50	24,273	579	2.4				
		2	30	26	4	4.63	74,923			Less than 2.5	494	378, 356, 197	0.0053
		5	45	18	4	2.75	44,501	1,529	3.4				
		0	32	28	3	2.88	38,782	1,024	2.6	Less than 2.5†	490	690, 352, 50	0.0124
		3	30	19	3	2.86	38,513			Less than 2.5†	477		Trace
15	Jessen, medium	1	25	24	4	1.38	22,331	400	1.8				
		4	53	18	4	1.80	29,128			Less than 2.5	335	422, 476, 360	Clear
		5	42	16	4	2.04	33,011	1,089	3.3				
16	Jessen, small	0	50	19	4	1.42	22,978	267	1.2				
		1	25	18	4	2.60	42,073	474	1.1				
		5	05	13	4	1.08	17,477			Less than 2.5	627	453, 615, 489	Clear
		5	43	12	4	1.14	18,447	631	3.4				

* Practically equal to heat delivered per hour.

[a] Only that part above horizontal plane through radiation center of heater.

[b] Measured at top of stack.

† When regular lid was in place. With lid off, 4.6 maximum.

‡ Temperatures are top, middle and bottom, respectively.

TABLE 19

SUMMARY OF NIGHT TESTS, OIL BURNING HEATERS

No.	Name and type of heater	Fuel charge, pounds, (approx.)	Fuel		Heat in fuel,* B.t.u. per hr.	Heat radiated[a]		Maximum upward velocity,† ft. per second	Temperature gas, degrees F.	Temperature of surface, degrees F.			Smoke, pound per 1000 cu. ft. of gas
			No.	Pounds per hr.		B.t.u. per hr.	Per cent			Top	Mid.	Bot.	
2	Kittle, non-distilling	55	2	7.13	140,803	4,894	3.5	Less than 2.5	850	589	658	1,071	.0124
		51	2	5.25	103,677	2,641	2.5	Less than 2.5	834	467	547	800	.0107
		47	2	3.25	64,181	926	1.4	Less than 2.5	512	248	292	422	Trace
17	Low delivery, non-distilling	35	2	3.25	69,118	899	1.3	Less than 2.5	690	206	249	414	Trace
		33	2	1.25	24,685	267	1.1	Less than 2.5	290	59	77	150	Trace
3	Scheu, Jumbo Cone Louvre, distilling	29	2	10.75	212,291			10.0	1,435				.0133
		23	2	5.5	108,614			7.5	1,071				Clear
		59	1	10.63	209,943	9,470	4.62	When 18″ square deflector was used, radiation fell to 3.85%					
		54	1	10.38	205,035			11.0	1,302	715	830	978	.0195
		34	1	3.82	75,379	2,111	2.8	8.8	792				Trace
		35	3	14.88	303,329	10,715	3.5	10.3	1,287				.0231
		27	3	6.75	137,599	5,127	3.7	9.2	884				Clear
4	Scheu, Baby Cone Louvre, distilling	56	2	7.09	139,947	5,598	4.0	11.0	1,255				.0280
		48	2	3.82	75,339	2,411	3.2	8.7	816	283	325	400	Trace
		56	1	4.64‡	91,640‡				1,285	530	580	700	
		32	3	6.88	140,249	4,987	3.6						
		20	3	4.25	86,636	2,305	2.7						
5	Scheu, double stack, distilling	39	1	11.51	227,224	9,089	4.0	5.6	839	547			.0200
		32	1	8.00	158,000	5,885	3.7	5.3	834				.0213
		33	1	4.25	83,938	2,167	2.6	4.8	769	467			.0133
													Trace
		42	2	4.88	96,370			7.0	1,217				.0089
		38	2	3.38	66,748			6.8	1,244				Trace

* Practically equal to heat delivered per hour.

[a] Only that part above horizontal plane through radiation center of heater.

† Measured at top of stack.

‡ Averages for 7¼ hours.

TABLE 19—(*Continued*)

No.	Name and type of heater	Fuel charge, pounds, (approx.)	Fuel		Heat in fuel,* B.t.u. per hr.	Heat radiated[a]		Maximum upward velocity,† ft. per second	Temperature gas, degrees F.	Temperature of surface, degrees F.			Smoke, pound per 1000 cu. ft. of gas
			No.	Pounds per hr.		B.t.u. per hr.	Per cent			Top	Mid.	Bot.	
6	Bolton, lard pail, distilling	9	2	5.32	105,059	4,060	3.9	4.2	1,069	......	......	......	.0302
6s	Bolton, lard pail, distilling (spider)	10	2	1.6	31,597	1,738	5.5	3.3	817	......	......	......	.0258
7	Troutman, modified lard pail, distilling	6	1	1.88	37,130	1,564	4.2	3.7	833	......	......	......	.0267
		8	2	2.00	39,496	......	......	4.8	1,019	......	......	......	.0320
8	Canco, lard pail, distilling	7	1	4.88	96,380	4,761	4.9	4.0	1,062	......	......	......	.0262
8s	Canco, lard pail, distilling (spider)	5	1	1.50	29,625	626	2.1	2.7	645	......	......	......	.0142
8	Canco, lard pail, distilling	12	2	5.96	117,698	......	......	5.1	1,039	......	......	......	.0302
8s	Canco, lard pail, distilling (spider)	8	2	3.28	64,773	......	......	3.2	702	......	......	......	.0204
10A	Dunn, distilling	41	2	6.00	118,488	4,605	3.9	7.9	1,445	837	930	......	.0213
		35	2	3.00	59,244	2,044	3.5	7.1	1,070	689	792	......	.0240
10C	Dunn, 30-in, stack added, distilling	35	2	7.50	148,110	6,035	4.1	11.9	1,175	733	1,005	1,029	.0329
		31	2	4.25	83,929	2,984	3.6	9.9	783	466	618	987	.0293
11A	Citrus, 9-gal., low stack, distilling	40	1	9.38	185,255	6,621	3.6	5.5	1,036	745	......	......	.0204
		36	1	7.88	155,630	4,199	2.7	5.1	1,045	415	......	......	.0231
		51	2	10.25	202,417	7,785	3.8	5.6	1,165	732	......	......	.0293
		46	2	5.63	111,181	4,356	3.9	5.3	1,157	724	......	......	.0142
11B	Citrus, 9-gal., medium stack, distilling	31	1	13.00	256,750	10,021	3.9	7.6	1,157	690	475	......	.0222
		25	1	9.00	177,750	6,744	3.8	7.5	1,122	900	835	......	.0204
		42	2	8.25	162,921	7,605	4.7	7.3	1,191	892	858	......	.0249
		38	2	5.25	103,677	2,230	2.2	6.7	1,261	875	775	......	Trace

* Practically equal to heat delivered per hour.

[a] Only that part above horizontal plane through radiation center of heater.

† Measured at top of stack.

TABLE 19—(*Concluded*)

No.	Name and type of heater	Fuel charge, pounds, (approx.)	Fuel		Heat in fuel,* B.t.u. per hr.	Heat radiated[a]		Maximum upward velocity,† ft. per second	Temperature gas, degrees F.	Temperature of surface, degrees F.			Smoke, pound per 1000 cu. ft. of gas
			No.	Pounds per hr.		B.t.u. per hr.	Per cent			Top	Mid.	Bot.	
11C	Citrus, 9-gal., high stack, distilling.....	16	1	7.75	153,063	3,128	2.0	12.9	1,374	645	733	758	.0160
		8	1	3.26	64,385	1,031	1.6	10.1	792	334	316	307	Clear
		35	2	13.50	266,598	8,144	3.1	12.3	1,069	732	775	900	.0142
12A	Citrus, 6-gal., low stack, distilling........	25	1	8.00	158,000	6,418	4.1	4.8	1,029	....	....	....	.0213
		23	1	4.42	87,295	2,994	3.4	4.7	1,113	....	....	....	.0160
12B	Citrus, 6-gal., medium stack, distilling	21	1	9.26	132,885	7,632	4.2	7.9	1,234	....	....	....	.0258
		19	1	4.96	97,960	3,522	3.6	8.1	1,183	....	....	....	.0204
12C	Citrus, 6-gal., high stack, distilling......	13	1	6.68	131,930	3,702	2.8	11.5	1,144	....	....	....	.0142
18	Baby double stack, distilling............	14	2	4.38	86,496	3,279	3.8	4.3	1,090	283	85	68	Trace
		11	2	1.22	24,093	622	2.6	4.6	880	188	111	77	Clear
19	Citrus, gas flame, distilling..............	40	2	5.38	106,244	3,674	3.5	4.6	860	387	163	163	Trace .0124
		37	2	2.25	44,433	909	2.0	3.3	840	248	133	124	Clear
		23	2	3.94	77,807	....	....	....	....	....	....	....	Trace

* Practically equal to heat delivered per hour.

[a] Only that part above horizontal plane through radiation center of heater.

† Measured at top of stack.

TABLE 20

ORCHARD HEATER FUELS

Fuel No.	Source and season bought	Specific gravity, Baum* (at 60° F.)	Viscosity, seconds, Saybolt		B.t.u. per lb.	Sulphur, per cent	Residue (Calif. test), per cent
			20° F.	32° F.			
Oil 1	Citrus Exp. Sta., Riverside, 1925–1926	32.5	81	67	19,750	0.24	6.83
Oil 2	Union "Stove Oil," Davis, 1926	34.4	48	45	19,748	1.31*	0.201
Oil 3	Standard Oil Co., "27+," Winters, 1926	27.5	105	78	20,385	0.47	0.206
Oil 4	Richfield, "No. 2 straw distillate," 1927	36.1			19,723	0.31	0.144
Oil 15	General Petroleum Co., Covina, 1926–1927	32.6					2.80
Oil 16–17	Run of 1926-1927, sold to Cooperative Citrus Growers, Covina	32.5					2.83
Oil 18	Calpet, Fillmore Refinery, 1926–1927	27.4					3.36
Briquet 1	"Diamond" (coal dust), Pacific Coast Coal Co., Los Angeles, 1925–1926				13,046	0.84	
Briquet 2	Carbon, Fernholtz Machinery Co., Los Angeles, 1925–1926				16,315	0.46	
Briquet 3	"Diamond" (coal dust), 1926–1927				13,466	1.06	
Briquet 4	Coke, Shell Co., Los Angeles, 1926–1927				16.182	0.41	

* Determined by sulphur bomb method. The values for the other fuels were obtained by the bomb calorimeter method.

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