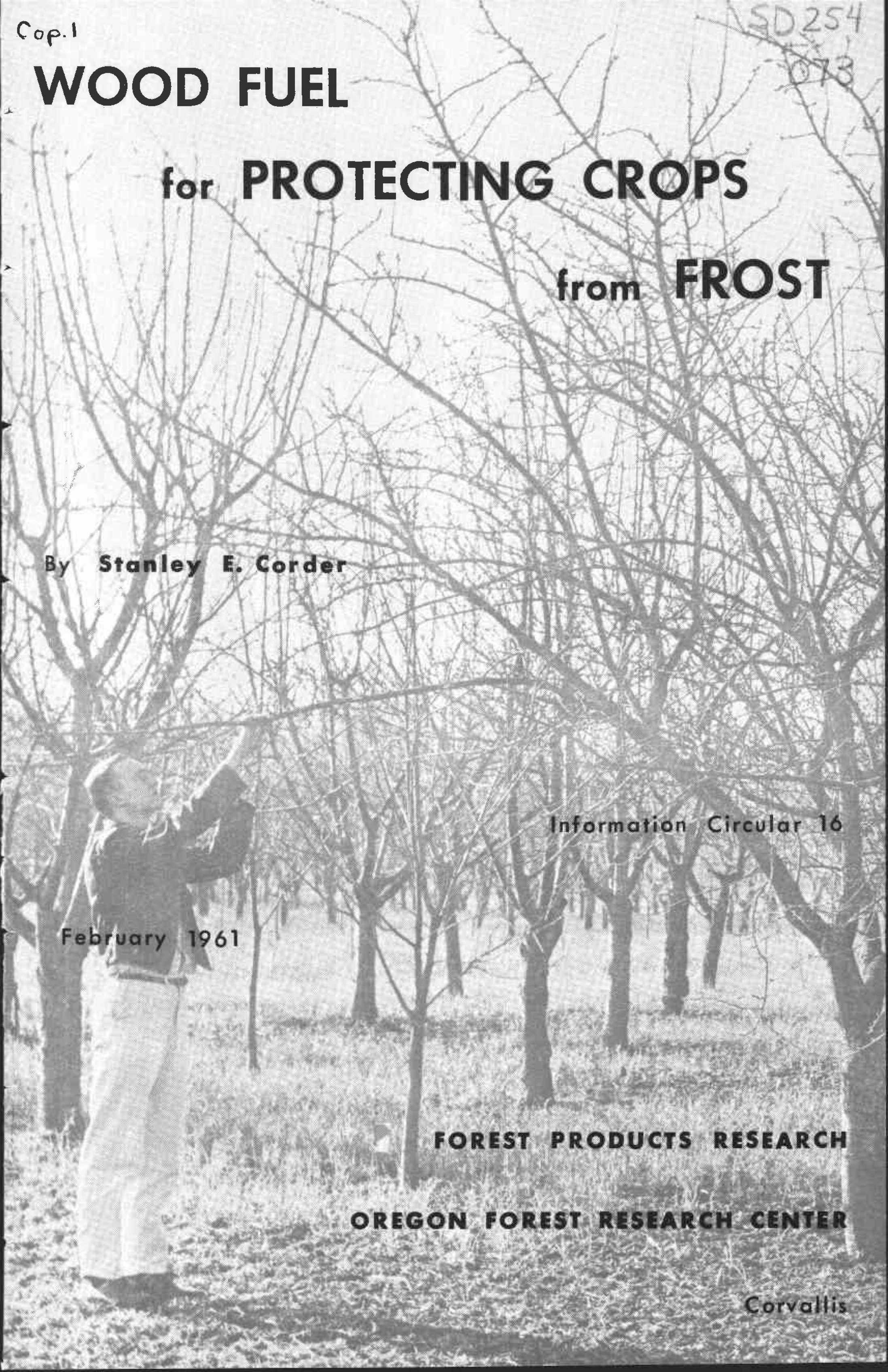
WOOD FUEL for PROTECTING CROPS from FROST



By Stanley E. Corder

Information Circular 16

February 1961

FOREST PRODUCTS RESEARCH

OREGON FOREST RESEARCH CENTER

Corvallis

OREGON FOREST RESEARCH CENTER

Two State programs of research are combined in the Oregon Forest Research Center to improve and expand values from timberlands of the State.

A team of forest scientists is investigating problems in forestry research of growing and protecting the crop, while wood scientists engaged in forest products research endeavor to make the most of the timber produced.

The current report stems from studies of forest products.

Purpose . . .

Fully utilize the resource by:

- developing more by-products from mill and logging residues to use the material burned or left in the woods.
- expanding markets for forest products through advanced treatments, improved drying, and new designs.
- directing the prospective user's attention to available wood and bark supplies, and to species as yet not fully utilized.
- creating new jobs and additional dollar returns by suggesting an increased variety of salable products. New products and growing values can offset rising costs.

Further the interests of forestry and forest products industries within the State.

Current Program . . .

Identify and develop uses for chemicals in wood and bark to provide markets for residues.

Improve pulping of residue materials.

Develop manufacturing techniques to improve products of wood industries.

Extend service life of wood products by improved preserving methods.

Develop and improve methods of seasoning wood to raise quality of wood products.

Create new uses and products for wood.

Evaluate mechanical properties of wood and wood-based materials and structures to increase and improve use of wood.

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ACKNOWLEDGMENTS

Members of the Fruit Growers League at Medford suggested this project and cooperated in all phases. Special gratitude is due Bob and Don Root for their guidance and assistance, as well as for providing orchard for a 10-acre field test.

Tests in one-acre fields were conducted at the Southern Oregon Branch of the Agricultural Experiment Station under direction of John Higdon. Local growers also assisted in these tests. Valuable weather forecasts were supplied by R. D. Church and other personnel of the Medford Station of the U. S. Weather Bureau.

Helpful information and suggestions were given by F. A. Brooks and A. S. Leonard, from the University of California.

Many staff members of the Oregon Forest Research Center gave valuable contributions. John B. Grantham and George Atherton furnished helpful guidance, while Charles Morris, Chyde Perkins, Richard Winn, Robert Magnusson, and Darrel Palmer helped with tests and calculation of results.

SUMMARY

An investigation was made to determine feasibility of burning wood fuel to protect crops against low temperatures. In this report, factors related to protection of crops against frost are reviewed, and experimental results of wood fuels are presented. The most promising applications of wood fuel for protection of crops appeared to be wood briquets burned in cans and slabs and edgings banded in bundles for open burning. In the Rogue River Valley, cost of wood fuels was close to cost of oil. Main advantages of wood fuels were low output of smoke and small investment of capital.

WOOD FUEL FOR PROTECTING CROPS FROM FROST

by

S. E. Corder

INTRODUCTION

Frosts pose an annual threat of damage to crops in many fruit-growing regions. Orchardists in the Rogue River Valley of Oregon normally use about a million gallons of oil each year at a cost of about $150,000 to combat damage by frost. In 1954, a severe frost in the Rogue River Valley resulted in a drop in crop value of four-million dollars. Although protection against frost is expensive, damage to crops can be even more costly.

The Rogue River Valley is also a center of lumber and plywood production. Wood residue developed from these lumber and plywood operations has a potential output of heat equal to 37 million gallons of oil yearly. Since most of this residue is disposed of by incineration, investigation was made to discover methods to utilize some of this wasted residue in the heating of orchards.

Factors affecting formation of frost and methods of protecting crops are reviewed. Various types of residue from sawmills were investigated to discover a fuel and method of burning that would produce heat for a period of about 2 1/2 hours at a rate approximate to burning one gallon of oil an hour. Fuel also would have to be low in cost and output of smoke, easy to light and resistant to weather.

Tests were conducted in cooperation with the Southern Oregon Branch of the Agricultural Experiment Station in orchards at Medford. Tests of radiation were performed at the Oregon Forest Research Center, Corvallis. Experimental procedure is described, and results are illustrated in graphs. Comparison of costs of wood fuels and oil of equivalent heat is included.

Interest has been growing in the use of wood fuels for protection against frost. For example, in 1961, wood briquets were burned in cans in 500 acres of orchards in the Rogue River Valley.

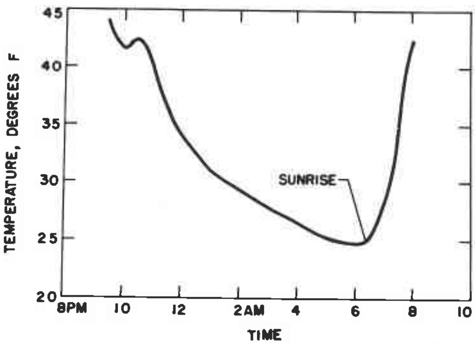
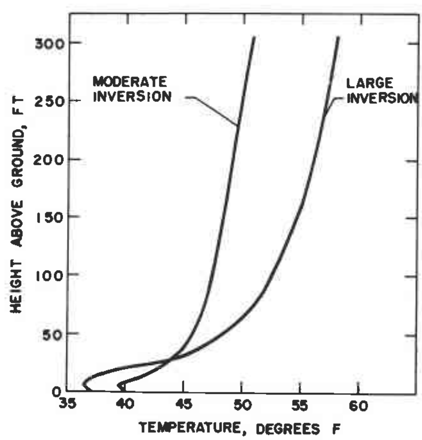


Figure 1. Record of temperature at 10-acre pear orchard, from U. S. Dept. Agric. Farmer's Bulletin No. 1588.

Figure 2. Variation in temperature with height for two nights with different temperature inversions at Riverside, California.



PRINCIPLES FOR PREVENTION OF FROST

Knowledge of atmospheric conditions and their effects upon formation of frost is necessary for the prevention of damage to crops. Methods effective in protecting crops depend upon atmospheric conditions and type of crop. Damage to a crop depends on duration of freezing temperature, stage of development of fruit, kind of fruit, vigor of tree, and weather preceding low temperatures (10)*. Specific recommendations for protection of crops can be obtained from local county extension agents. The United States Weather Bureau maintains a frost-warning service in major fruit-producing regions of the country.

Formation of Frost

Frosts usually occur on calm, clear nights with warmer air existing at increasing heights above ground. At night, the earth's surface radiates heat to cold outer space making ground lower in temperature than surrounding air. Being more dense than warm air, cold air remains near ground (4). Manner of decrease in temperature on a night when protection against frost would be necessary is shown in Figure 1. Freezing temperatures lasted about five hours for the night illustrated.

Sometimes frosts occur when winds transport air from a cold region. When frost is accompanied by wind, protection of crops by heating is difficult. Fortunately, most frosts are caused by loss of heat through radiation, against which orchards may be protected by heating.

Effect of temperature inversion

Increase in temperature of air with height is called inversion since this condition is inverse to that existing during day. Magnitude of inversion is difference in temperature between two levels of air. At night,

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*Numbers in parentheses refer to list of selected references.

temperature of air 50 feet above ground may exceed that of air at ground level by more than 10 F. Magnitude of inversion is an important factor in heating orchards. Kepner (7) has shown that effect of heating is about one-third greater with 20 F inversion than with 5 F inversion, and that heating effect with small inversion is in direct proportion to radiated heat. When large inversion is present, winds above five miles an hour may mix warm, upper air with cool air near ground. This mixing action warms the air near ground, and freezing temperatures will not likely occur. Inversion varies with movement of air, temperature of preceding day, rate of loss of heat by radiation, and conduction characteristics and temperature of soil. Variation in temperature with height for two different conditions of inversion above a citrus orchard in California is shown in Figure 2.

Effect of water vapor

Amount of water vapor present in air is important in two aspects of heating orchards. Water vapor tends to retard loss of heat by radiation by intercepting and reradiating outgoing heat. Water vapor also retards decrease in temperature by adding heat to surrounding air as it condenses to dew or forms frost. The temperature at which water vapor begins to condense is called dew point. Dew point is an indication of amount of water vapor present in air. If dew point is low, damage to crops can occur without formation of frost. There is also greater possibility of damage to crops by frost when dew point is low.

Effect of clouds

Because low, dense clouds intercept and reradiate outgoing radiation from ground, little danger from frost exists when a heavy cloud cover is present. High, thin clouds, however, offer little resistance to radiation and consequent drop in temperature. Early experimentors reasoned that a cover of smoke might retard radiation of heat, but smoke offers little resistance to radiation and the disadvantage of air pollution is great.

Methods of protecting crops against frost may be classed in three categories: conservation of heat, equalization of heat by mixing air, and addition of heat.

Conservation of heat

The well-known "greenhouse" effect offers an effective method of frost protection by covering growing plants with glass. Glass admits most of the sun's radiation, but is practically opaque to the long waves of outgoing radiation. Although greenhouses are effective, their cost is so high that only a few crops of high value can be so protected.

Various schemes of covering plants or trees with canvas, burlap, paper, and similar materials have been tried, but protection was slight and cost was usually prohibitive.

Sprinkling and flooding with water have been tried. Spraying trees with water has proved impractical because of cost and possible damage to trees from weight of ice. Flooding a crop with water will protect it from frost, but cranberries are the only crop with which flooding is practical. Cranberries also have been protected by spraying with water.

Mixing of air

Large power-driven fans or propellers are used to produce artificial wind that mixes cold air near the ground with warmer air above ground. These machines have been installed extensively in California citrus orchards. Under ideal conditions of large temperature inversion and calm atmosphere, temperatures in orchards have been increased as much as 6 F over a limited area (1). When temperature inversion is small, wind machines have little effect. Experiments conducted with a helicopter rotor by Michigan Agricultural Experiment Station (5) showed results similar to those obtained with fans or propellers. Main advantage of wind machines is lack of expense for fuel.

Addition of heat

Of all methods of protecting crops, the most effective and practical for large-scale use is direct heating. Heat from open fires or special orchard heaters is dispersed by both convection and radiation. In convection, hot gases and smoke from fires or heaters mix with air. The warmed air rises until it encounters air of the same temperature--usually at a height less than 100 feet above ground. This height is called the ceiling, and is an indication of magnitude of the temperature inversion. A low ceiling indicates large inversion with considerable heating at tree level. High ceiling indicates small inversion and a problem in heating since much heat will rise above the trees.

Heat also is transmitted from heaters by radiation. Radiation is line-of-sight transfer of heat from a warm surface to a cold surface without heating the air between. In heating orchards, both open flames and hot metal surfaces radiate heat directly to trees, ground, and space. Radiant heat is not affected by wind or inversion, and is especially important when wind or small temperature inversion is present.

Heating for protection of crops has been practiced extensively in citrus orchards in California because of high value of crop and availability and convenience of oil (2, 8, 7). Open-flame oil heaters are effective and low in cost, but their high output of smoke is a major disadvantage. Where smoke is not a problem, open oil heaters still are used.

To minimize output of smoke, special oil heaters have been developed. The return-stack orchard heater was developed at the University of California about 1940. It holds about 10 gallons of oil, burns at a top rate of slightly above one gallon of oil an hour, and costs 7 to 8 dollars. Although reasonably smokeless, the return-stack heater is costly.

Wood has been burned extensively for heating citrus groves in Florida (9). Pine wood is cut to 4-foot lengths, 5 or 6 inches in diameter, and 3 pieces are combined to lay a fire, as shown in Figure 3.

Wood chosen is "fat wood", or "light wood", southern pine impregnated with natural resin because of injury of a tree.

Other solid fuels, such as coal, coke, and carbon briquets, have been burned for protection of crops, but oil is most common now.

Figure 3. Citrus groves in Florida have been heated with wood burned in small piles. Photo courtesy of Dr. A. F. Camp.

Selection of fuel mainly is determined by cost, availability, and labor required for handling fuel and tending fire. In the following comparison are shown the values of heat yielded in complete burning of the fuels. Since oil is burned widely for protection from frost, other fuels are compared to oil as follows:

- Oil for heating orchards yields about 140,000 BTU* a gallon.
- Coal or coke is variable in quality. High-grade coal or coke yields about 13,000 BTU a pound; therefore, one ton of such coal is equivalent to 180 gallons of oil.

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*BTU, quantity of heat required to raise a pound of water 1 F.

- Oven-dried wood has heating value of 8300-9000 BTU a pound. When air-dried to 20 per cent moisture content, Douglas fir and pine contain about 7000 BTU a pound. Wood briquets, if pine or Douglas fir, normally contain about 7 per cent moisture and 8300 BTU a pound. One cord of Douglas fir contains about a ton of dry wood, and is equivalent in heating value to 125 gallons of oil. Twenty pounds of air-dried Douglas fir at 20 per cent moisture content are equivalent to one gallon of oil, and 17 pounds of wood briquets from Douglas fir are equivalent to one gallon of oil.

EXPERIMENTAL

Preliminary tests were performed to investigate types of fuel and methods of burning. Most promising fuels and methods of burning were field tested in orchards and tested for output of radiant heat.

Preliminary Tests

Preliminary tests were performed to determine types of fuel and methods of burning that would satisfy the following requirements: easy ignition, resistance to weather, low cost and low output of smoke, and release of heat equivalent to burning one gallon of oil an hour for a period of about 2 1/2 hours.

Materials

Residue from sawmills, the cheapest wood fuel, is available in many parts of Oregon. Methods were sought to utilize sawdust, planer shavings or slabs and edgings.

A self-contained product, made from wood and requiring no burner, seemed most desirable to growers. Feasibility of producing such a product was investigated.

Wood briquets are the most compact form of wood fuel. Fine wood residue is compressed under high pressures, usually without binder, to form a firm, dense product. Briquets tested were "Pres-to-Logs," the most common briquet on the West Coast. "Pres-to-Logs" are solid cylinders about 4 inches in diameter, 12 inches in length, and 8 pounds in weight. Density of "Pres-to-Logs" is about 80 pounds a cubic foot, over 2 1/2 times the density of most softwoods and about 18 times the density of loose planer shavings from which the briquets are produced.

Tests

Several methods for burning slabs were tested. The most promising method of burning appeared to be in bundles of pieces banded together

Figure 4. Bundles of wood slabs ignited with oil were most promising of all methods tested.

in units about 15 inches in diameter and 20 inches in length (Figure 4). These bundles contained 10-20 pieces of air-dried wood and weighed about 50 pounds. Bundles were placed on end, and a quart of oil was poured over them before ignition.

Open burning of wood briquets was tried before consideration of a simple burner. Five-gallon containers for grease and paint were obtained,used,for about 25 cents each. Holes were punched near base of the cans for draft. About 1/2 pint of oil was poured on briquets before ignition. In Figure 5, briquets are shown burning in a can.

Results

Sawdust and shavings are bulky. Containers of 30 gallons for sawdust and 75 gallons for shavings would be required for a burning period of 2 1/2 hours. Cost of handling and burning such bulky fuel makes its use impractical in orchards.

Preliminary investigation on producing a molded product at competitive cost was discouraging, and investigation was turned to other methods.

The most promising method of burning slabs was in a unit formed by banding pieces together to form a bundle. Bundling accomplished two major objectives: the self-contained units could be burned without burners and handling of fuel was simplified. When placed in a vertical position and started with a quart of oil, bundles burned as self-contained units for about 2 1/2 hours. Bundles fell over after burning was underway, but burning continued and consumed most of the wood. Ignition was the most important factor of successful burning. Amount of starting oil and construction of bundle largely determined ignition and burning. Best ignition was obtained by pouring about a quart of diesel oil over bundles. Voids in bundle to act as chimneys were found to be essential for successful burning. Because of irregular shape of slabs, voids were easily and naturally obtained. Variations in size and shape of material in a bundle caused variation in rate of burning; however, most bundles burned for 2-2 1/2 hours with an average release of heat equivalent to about one gallon of oil an hour. Moisture content of slabs directly from sawmills is high, and air-drying slabs for 2-3 months during summer is required for easy ignition.

Open burning of wood briquets was unsuccessful. Results varied between tests, and rate of burning dropped rapidly during late stages of burning.

The simplest and cheapest burner for briquets appeared to be a can of about 5-gallon size with draft holes punched near the base. A small amount of dirt or gravel placed in bottom of can protected it from direct contact with hot coals. Results for similar lighting procedures yielded similar curves for different tests of rate of burning. A typical curve for

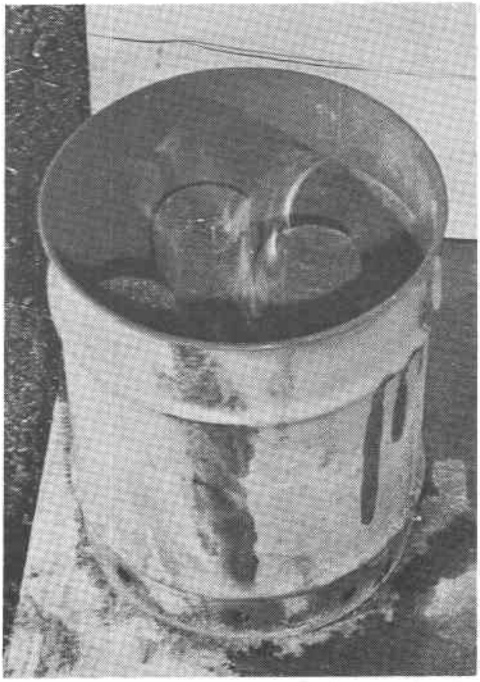


Figure 5. Burning of wood briquets in 5-gallon cans was tested.

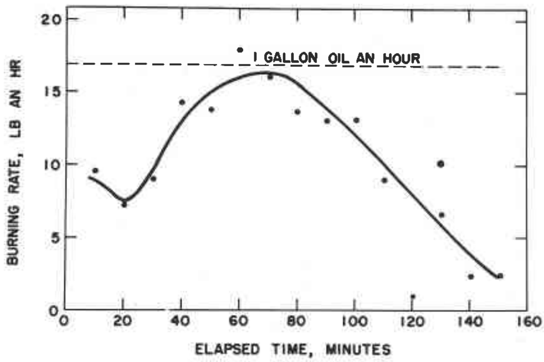


Figure 6. Typical rate of burning of four pine-wood briquets in can with eight 1/2-inch diameter draft holes.

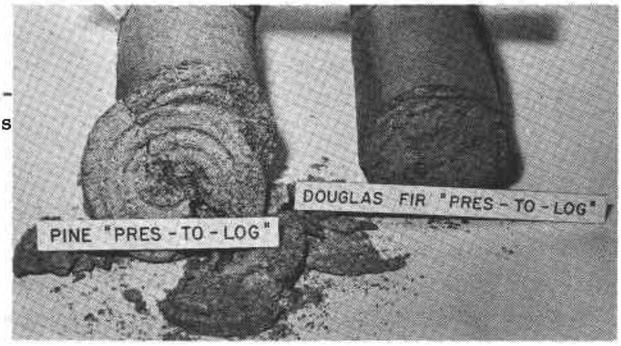
rate of burning is illustrated in Figure 6. Lighting procedure affected rate of burning, and if more than 1/2 pint of oil was used, burning started at high rate, reached its peak sooner and lasted a shorter time than indicated in Figure 6. Maximum rate of burning was reached about one hour after lighting with release of heat nearly equivalent to burning a gallon of oil an hour. Release of heat equivalent to burning over one-half gallon of oil an hour was obtained for 2 hours. Refueling would be required if heating period exceeded 2-2 1/2 hours. Shaking burner at late stage of burning broke-up coals and increased rate of burning.

Difference was noted in rates of burning for briquets made from pine and those made from Douglas fir. Briquets of pine ignited and burned more readily than those of Douglas fir. Similar rates were obtained by adding about a quart of starting oil to the Douglas fir briquets and punching twice the number of draft holes in the burning cans.

Smoke from briquet burning was low, and, although it was not measured, visual observation indicated that smoke would be tolerable.

An undesirable characteristic of wood briquets was their tendency to decompose when exposed to moisture. Even exposure to high humidities would cause them to fall apart. Difference again was found between briquets made from pine and those made from Douglas fir. Briquets of pine and Douglas fir after exposure to 85 per cent relative humidity at 80

Figure 7. Briquets of Douglas fir survived exposure to high humidities for three weeks more successfully than did briquets of pine.



F for 3 weeks, are shown in Figure 7. Briquets of pine expanded and separated, while briquets of Douglas fir appeared to be unaffected. Dipping briquets in hot paraffin for weatherproofing was tried by some fruit growers in Medford. Paraffin improved resistance to weather, but briquets still did not withstand continuous exposure. Briquets of Douglas fir, dipped in paraffin at 200 F for 5 minutes, remained intact when exposed to gentle shower of water for 5-6 days; however, briquets of pine remained intact less than 2 days under same conditions. Paraffin absorbed during 5-minute dip was 0.1-0.2 pounds a log for a cost of 1-2 cents a log. Briquets have been protected successfully in orchards by plastic or asphalt-impregnated bags and plastic sheets.

Tests in Orchards

Three tests were conducted in orchards near Medford to compare heating effects of return-stack oil heaters, open bundles of slabs, and wood briquets burned in cans. Tests were performed in cooperation with the Southern Oregon Branch of the Agricultural Experiment Station and members of the Fruit Growers League of Medford.

Procedure

In the first test, 3 one-acre plots in a pear orchard at the Experiment Station were equipped with return-stack oil heaters, wood briquets in cans, and open bundles of slabs (Figure 8). Oil heaters were burned

Figure 8. Methods of heating orchards tested for comparison were performed on 3 one-acre plots. Return-stack oil heaters, wood briquets in cans, and open bundles of slabs were tested.

with one draft hole open. At 8:10 P.M., 16 oil heaters, cans of briquets and slab bundles were ignited in each plot. At 9:30 P.M., 14 additional cans of briquets and slab bundles, and 13 oil heaters were ignited. An additional 21 cans of briquets and slab bundles were ignited at 10:20 P.M. A wind of 4-5 miles an hour started about 10 P.M., causing increase in temperature in both unheated and heated plots.

At midnight, most fuel of first lighting of briquets and slab bundles had burned; therefore, 35 units of briquets and slabs were still burning. Twenty-nine oil heaters were burning at an estimated rate of three-fourths of a gallon an hour.

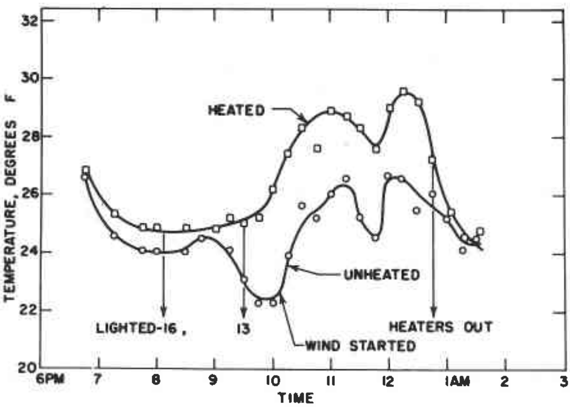
On the night of the second test, the U.S. Weather Bureau indicated that a moderately high ceiling with inversion of about 5 F was present. Actual inversion was not measured. Additional methods of burning were tried, but difficulty of refueling made them impractical.

Object of the third test was to compare increase in temperature caused by burning bundles of slabs with that caused by oil heaters during a night when heating was necessary. Cloud cover kept temperatures above freezing on night selected for test, making heating unnecessary; however; the plot equipped with slabs was tested to determine characteristics of ignition and performance.

Seventeen bundles of slabs were distributed to an acre. Ignition of slabs was accomplished by pouring a quart of diesel oil over each bundle and lighting it with a typical lighting torch. After two hours, bundles had burned to beds of coals. Refueling was accomplished by placing new bundles on beds of coals from previous bundles. All added bundles ignited satisfactorily without addition of oil.

Results

Results of the first field test are illustrated in Figures 9, 10, and 11. Direct comparison of heating effects of the two types of wood burning with heating effects of oil burners is difficult, because more briquet cans and slab bundles than oil heaters were burning toward end of heating period; however, curves do show that about midnight, increase in temperature caused by oil heaters was about 3 F, and increase caused by



Temperature-time relationship for one-acre plot heated by different methods.

Figure 9. Return-stack oil heaters.

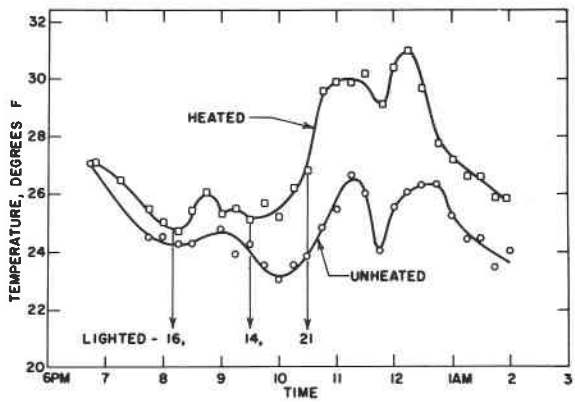


Figure 10. Wood briquets.

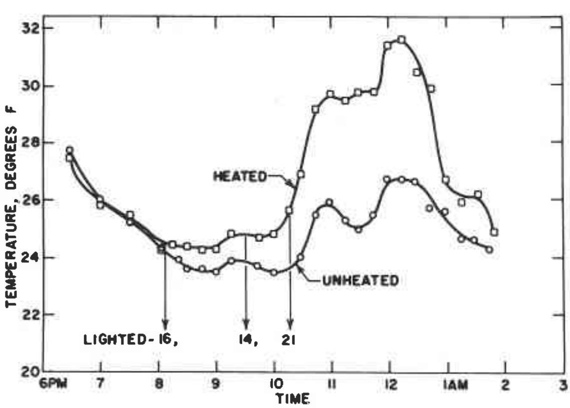


Figure 11. Slab bundles.

wood briquets and slab bundles was 4-5 F.

Results of the second field test are illustrated in Figures 12, 13, and 14. Oil heaters appeared to be most effective, as they increased

Temperature-time relationship for one-acre plots heated by different methods in second test. Thirty-two heaters, cans, or bundles burned with refueling done only in test with wood briquets.

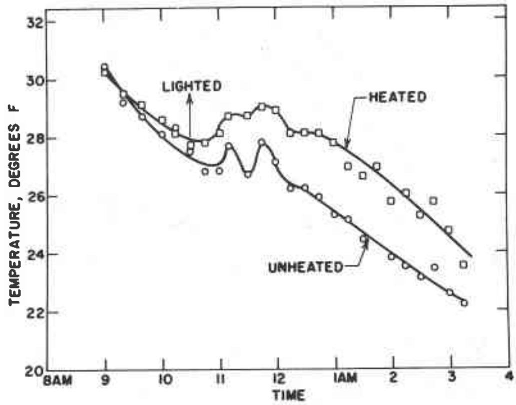


Figure 12. Return-stack oil heaters.

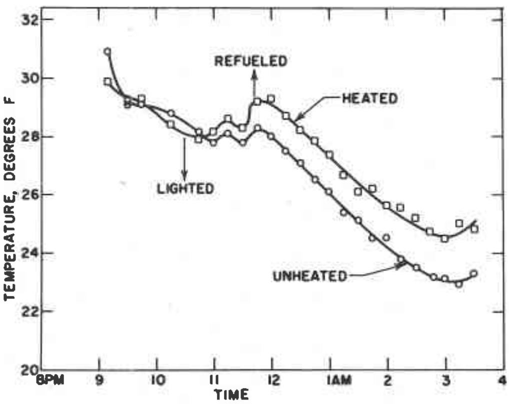


Figure 13. Wood briquets.

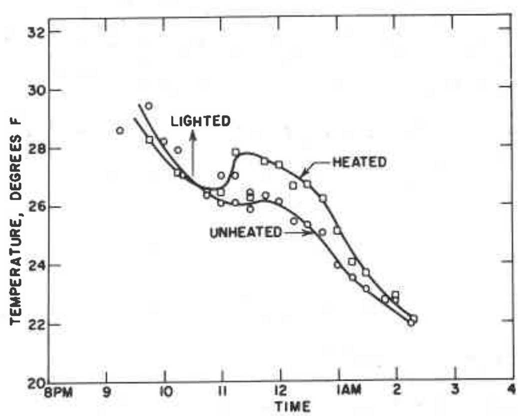


Figure 14. Slab bundles.

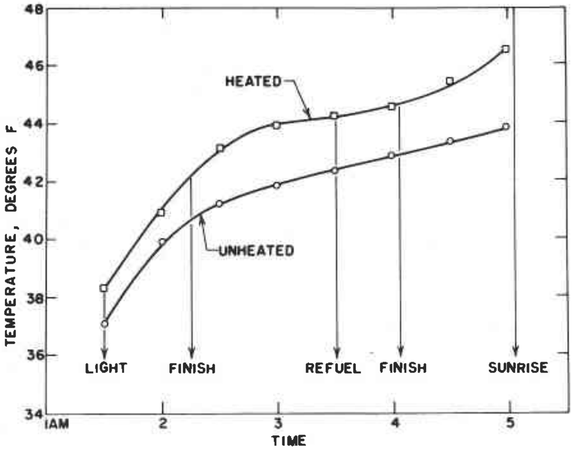


Figure 15. Rise in temperature on 10-acre plot heated with 17 bundles of Douglas fir slabs burning on each acre.

temperature about 2 F. Wood briquets burned in cans, with refueling, caused increase in temperature of 1-1 1/2 F. Increased temperature remained 3 hours after refueling, when most fuel had burned leaving only glowing coals. Burning of slabs caused apparent increase in temperature of about 1 3/4 F one hour after igniting; the increase dropped to 1 F after 2 1/2 hours. Bundles were not refueled, but refueling after 2 1/2 hours would have been necessary if heating had been continued.

Results of the third field test are illustrated in Figure 15. Temperatures shown are averages of 8 readings taken inside the heated plot and 5 taken outside the heated zone. Increase in temperature of 2 F was obtained within 1 hour after ignition. Nine of the 180 bundles required relighting. Some unburned residue remained after burning. Typical remains of two bundles are shown in Figure 16.

Note that weather conditions were not typical for orchard heating: temperature was rising, and the sky was cloudy.

Tests of Radiation

Tests were conducted to compare output of radiant heat of wood briquets, bundles of slabs, and return-stack oil heaters. Tests of radiation were performed at the Oregon Forest Research Center, Corvallis.

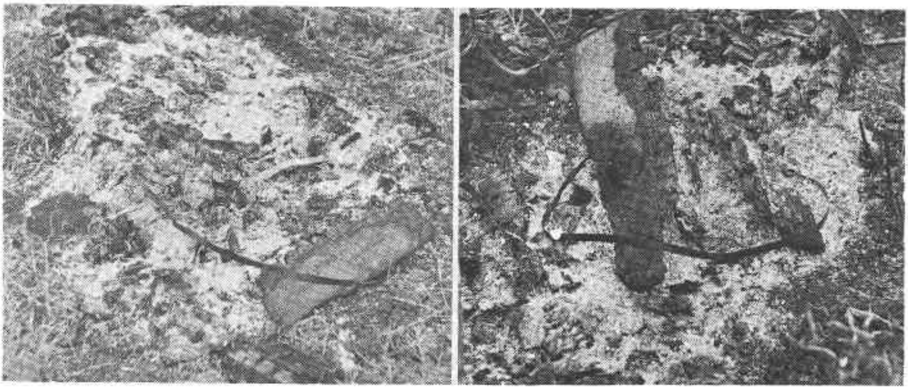


Figure 16. Remains of two bundles of slabs following burning.

Amount of radiant heat is an important factor in orchard heating. Kepner (7) has found that in actual practice, two-thirds of the radiant heat from oil heaters goes to trees and ground, and one-third is lost to space.

Procedure

Heating units were placed in the center of an imaginary sphere, and intensity of radiation during burning was measured at representative points on the sphere. Measurements were taken with an 8-junction silver-bismuth, Eppley thermopile in conjunction with a portable potentiometer.

Results

Comparison of output of radiant heat for the three methods of burning is shown in Figure 17; comparison of distribution of radiant heat is shown in Figure 18.

The return-stack oil heater, burning 1 gallon of oil an hour, produced 39,000 BTU of radiant heat an hour. Since diesel oil has a heating value of about 140,000 BTU a gallon, radiant heat accounted for 28 per cent of the heat available in the fuel. Draft opening of 2 1/2 holes gave a burning rate of 1 gallon oil an hour. During test, rate of burning dropped 16 per cent in one hour. Increasing draft openings as oil level dropped was necessary to obtain steady rate of burning.

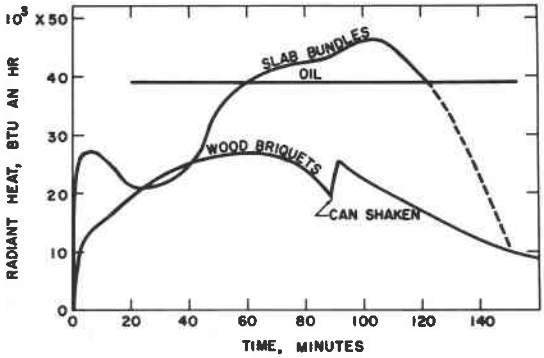


Figure 17. Comparison of radiation from three sources of heat.

Wood briquets in cans gave maximum radiation of about 27,000 BTU an hour at one hour after lighting. After 2 1/2 hours, radiation dropped to 10,000 BTU an hour. Radiant heat accounted for about 23 per cent of the heat available. Similar results from tests on five different burners indicated little difference between burners.

Maximum rate of radiation for bundles of slabs was 45,000 BTU an hour. Radiant heat accounted for about 23 per cent of heat available. Variation was noted in burning of different bundles. The curve illustrated in Figure 18 is considered to be representative, although the bundle chosen burned slower than most bundles tested.

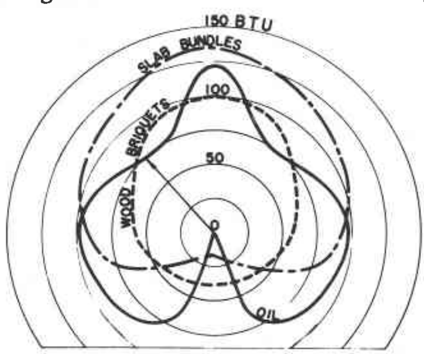


Figure 18. Radiant heat in BTU an hour falling on each square foot of a sphere of 6-foot radius from source of heat, one hour after lighting. For example, note the oil burner radiated no heat directly downward, but did radiate about 75 BTU a square foot in the direction the arrow points.

Percentage of available heat yielded as radiant heat was 23 per cent for bundles of slabs and wood briquets burned in cans compared to 28 per cent for oil heaters. The burner contained about 30 pounds of wood briquets whereas the slab bundle weighed about 50 pounds.

CONSIDERATIONS OF COST

Factors of cost vary between areas, depending on availability and transportation of fuels. Since information was obtained from the Rogue River Valley, comparison is given for that area. Total costs involved in heating an orchard were not analyzed; only costs of fuel and burners were considered. Other costs, such as those for lighting torches and fuel, thermometers, and flashlights, should be about the same for all methods of heating. Cost of labor was not included because of lack of information.

For making comparisons, the following assumptions were made:

- Heating requirement would be equivalent to 350 gallons of oil an acre each season.
- Fuel on hand for one season should be equivalent to twice the heating requirement, that is, 700 gallons of oil an acre.
- Spacing of heaters would be 35 oil heaters an acre and 70 bundles of slabs or burning cans for wood briquets an acre.
- Return-stack oil heaters cost $7.70 each; can burners cost 30 cents each for used cans or 90 cents for new cans.
- Oil costs 15 cents a gallon; wood briquets cost 16 dollars a ton. Bundles of Douglas fir slabs can be obtained for 20-30 cents each.
- Allowance of 10 per cent loss of fuel for wood briquets and 25 per cent for slabs was made for unburned material remaining when burning was finished or no longer necessary.

From the assumptions listed, Table 1 was prepared to show major investment cost--heaters and fuel--and fuel cost for a season. A significant advantage of wood briquets and slab bundles is low investment for burning equipment. Return-stack oil heaters cost $270 an acre, while burners for wood briquets cost $21-65 an acre and slab bundles require no investment for burners.

Table 1. Comparison of Costs of Three Methods of Heating an Acre of Orchard.

Cost	Return-stack oil heaters	Wood briquets in burning cans	Bundles of Douglas fir slabs
	Dollars	Dollars	Dollars
Investment for heaters	270	21-65	0
Investment for fuel	106	112	70-106
Seasonal fuel	53	56	35-53

Fuel costs were about the same for oil and wood briquets. One wood briquet weighs 7.6 pounds, and with an allowance of 10 per cent for loss at late burning stages, one briquet has heat equivalent to 0.4 gallon of oil. Five briquets are necessary to produce heat equivalent to that from 2 gallons of oil. With briquets costing 6 cents each, and allowance of 2 cents for starting oil, 5 briquets and starting oil cost 32 cents compared with 30 cents for 2 gallons of oil. Transportation for 75 miles accounted for about one-third of the cost of briquets. Proximity of manufacture would mean low costs, while longer distances would make wood briquets less competitive.

Cost for slab bundles is difficult to predict, since they are not made commercially. In bulk, unseasoned slabs of Douglas fir were available in the Medford area at cost of 8 cents for material required for a bundle 15 inches in diameter and 20 inches long. Air-dried material cost 12 cents a bundle. Bundles made from unseasoned slabs would have to be air-dried for several months during the summer before use. Indication of cost of bundling slabs by hand with a small jig and steel banding equipment was obtained from making bundles for field tests. Bundles were made by hand at a rate of 13-20 bundles a man-hour. With labor at 2 dollars an hour, cost of bundling by hand was 10-15 cents a bundle. Mechanizing the bundling operation could reduce this cost considerably, perhaps to 5 cents a bundle. Cost of steel strap or wire is about 2 cents a bundle, and a quart of starting oil costs 4 cents. Cost of a slab bundle and starting oil is shown in Table 2.

Table 2. Estimated Cost of a Slab Bundle.

Materials and labor	Cost
	Cents
Unseasoned slabs	8
Bundling	5-15
Steel strap or wire	2
Starting oil (one quart)	4
Total	19-29

Comparative costs of labor were not obtained, but they probably would be greater for wood fuels than for oil, because of heavier weight handled for equivalent heat.

CONCLUSIONS

Heating is the most effective and practical method for protecting crops against damage from low temperatures; however, heating is expensive, and only crops of high value subjected to frequent frosts justify its cost. If heating may be necessary, careful preparations should be made well in advance of need.

The two methods of burning wood fuel that appeared most feasible were the burning of four wood briquets in a simple can with holes at base for draft and open burning of air-dried slabs of Douglas fir that were banded in bundles 15 inches in diameter and 20 inches long. Wood briquets have been burned successfully in cans in about 150 acres of orchards in the Rogue River Valley.

Measurements indicated the proportion of heat emitted as radiation from both wood briquets in burners and open bundles of slabs was about 23 per cent of heat available, compared to 28 per cent for the return-stack oil heater tested. Since slab bundles burned at a higher rate than did wood briquets or oil, these units had the highest output of radiant heat when burning was well established.

Smoke from wood briquets was low, but for slab bundles, smoke was pronounced at early stage of burning. Smoke from wood fuel does not leave a sooty film as does that from simple oil heaters; therefore, smoke from wood fuel was considered to be tolerable.

To obtain heat comparable to that from oil requires about 2 1/2 times as much weight in wood briquets and 3 1/2 times as much weight in slabs. Because of this weight and consequent cost of transportation, wood fuels, to be competitive, must be used near area of production.

Survey of costs of fuel for area near Medford, Oregon, indicated that cost of equivalent heat was about the same for wood briquets and oil;

equivalent heat from bundles of slabs probably would cost slightly less than oil.

Wood briquets must be protected against exposure to inclement weather. Wax coating of briquets was not satisfactory. Some growers have used plastic and asphalt-treated bags to protect briquets in the field. Exposure can be tolerated by slab bundles; however, they should not be positioned vertical until nearly ready for lighting. If placed vertically on wet ground for prolonged time, bundles may be difficult to light. Slabs have high moisture content, and should be air-dried during summer.

Wood fuels do not have controlled rate of burning as do oil heaters; however, heating effect could be regulated by varying the number of units burned simultaneously. Refueling would be required of wood fuels if heating were necessary longer than 2-2 1/2 hours.

Major advantage of wood fuels, in addition to low output of smoke, is that no investment in equipment is required for burning slab bundles, and relatively small investment is needed for burners for wood briquets. Because of this low investment, wood fuels merit special consideration for marginal heating for infrequent frosts and emergency heating for uncommonly low temperatures.

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About 500 acres of pear orchards in the Rogue River Valley are being heated this year by burning wood briquets in cans. Plastic bags keep briquets from decomposing by being exposed to moisture.