THE EFFECT OF DIFFERENT TYPES OF HEATERS USED SINGLY AND IN COMBINATION FOR FREEZE PROTECTION

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ABSTRACT

We used four different types of heaters, separately and in combination, to protect citrus trees less than 6 years old and in areas less than 1 acre. These heaters included two types which burn propane gas and two types of relatively new solid-fuel heaters.

Our results indicate that some types of heaters can be used together more effectively than others, depending on conditions and the situation. Propane gas heaters alone provided adequate increases in temperature in our study. Such heaters can be supplemented effectively with solid-fuel types of heaters. One type of solid-fuel heater was as effective as propane...
Figure 2.—Propane gas II heater.

Figure 3.—Two solid-fuel type III heaters in combination with three solid-fuel type IV heaters. Type III heaters are 3 ft. from the tree trunks and one each at the N and NW aspects. Type IV heaters are 1 ft. from the tree trunks and one each at the NW, NE and S aspects.
gas heaters, and also was the least affected by shifts in wind direction.

We think the under-the-tree type of solid-fuel heaters warrants further research for cold protection, especially if improvements are made to allow better control of burning rate and heat output.

INTRODUCTION

Within the past 5 years a variety of heaters to protect citrus trees from freeze injury have been suggested. Last year, we reported (5) on the use of two types of heaters which burn propane gas. We used propane heaters this past winter and included relatively new under-the-tree type of heaters which burn solid fuel. These solid-fuel heaters initially gained attention in Texas (2, 3) and have since been considered for use in Florida and also California (4).

This report describes some of the performance characteristics of propane gas and solid-fuel heaters, used singly and in combination to protect young citrus trees in the winter of 1965-66.

METHODS AND PROCEDURES

Study area—Investigations were in a citrus orchard larger than 10 acres used as an experimental fruiting out area. Trees were various selections of citrus hybrids 5-year-old and spaced 5 ft. apart in rows extending east and west. Rows were spaced 20 ft. apart north and south. Height of trees averaged 9 ft. above ground level.

The various heating trials used 4 plots, 4 rows of 25 trees per plot. Study plots measured 80 by 120 ft. and were in a straight line east and west. Buffer strips 40 ft. wide separated plots from each other. Specific types of heaters were assigned randomly to plots. A heating trial included three heated plots and one unheated plot, as a control.

Description of heaters—Work was concentrated on two types of heaters which burn propane gas and two types which burn solid fuel.

Heater I—propane gas (Fig. 1): Fifty-two heaters were used in a 0.16 acre plot of 100 trees, or one heater at every other tree, or 10 feet between heaters in an east and west direction. Heaters were placed on the north side of trees, 5 ft. from the trunks.

Heater II—propane gas type (Fig. 2): A total of 100 heaters were used, or one heater per tree. Heaters were placed on the north side of the trees, 5 ft. from the trunks.

Heater III—solid fuel (Fig. 3): Two heaters were used per tree except when used to supplement other heaters of a different type. Then only one heater per tree was used. Heaters were placed north of the trees and 3 ft. from the trunks.

Heater IV—solid fuel (Fig. 3): We used three heaters per tree, placing one heater each NW, NE and S of the trees, 1 ft. from the trunks.

The heaters are essentially bunsen burner-type units with a metal disk attached to the top. Solid steel disks have replaced the perforated disks which were first used but found to be unsatisfactory because of excessive warping under prolonged intense heating. A horizontal metal pipe, few inches above ground level, connected each burner to a gas line extending vertically downward to approximately 30 inches below ground level. Vertical lines led to one of four main laterals, each with a separate hand valve. Line pressure was fixed at 12 psi. Laterals were connected to a main line from a 70-gal-per hr. vaporizer supplied with fuel from two 1,000 gallon tanks.

Heater output is about 50,000 BTU per heater per hr. with an estimated 20% radiant and 80% convective heat.

Heater II—propane gas type (Fig. 2): A total of 100 heaters were used, or one heater per tree. Heaters were placed on the north side of the trees, 5 ft. from the trunks.

The heaters have burners enclosed by rectangular metal casings, open at one end. Copper pig tails allow some flexibility in spacing and final positioning. Metal tripods support the heaters about 12 inches above ground level. Each heater has a separate hand valve. Installation is similar to that of heater I. Operating gas pressure was fixed at 5 psi at the main gas line connected to the vaporizer.

Total heat output is about 50,000 BTU per heater per hr. and is essentially 100% convective heat.

Heater III—solid fuel (Fig. 3): Two heaters were used per tree except when used to supplement other heaters of a different type. Then only one heater per tree was used. Heaters were placed north of the trees and 3 ft. from the trunks.

The heaters are galvanized steel pans 12 inches wide, 17 inches long, and 2½ inches high which are filled with petroleum wax. A wick of rock wool is in the center of each pan and each end is covered with a moveable metal lid. These heaters will burn approximately 10 hr. and heat output averages about 22,000 BTU per heater per hr. These heaters emit essentially 100% convective heat.

Heater IV—solid fuel (Fig. 3): We used three heaters per tree, placing one heater each NW, NE and S of the trees, 1 ft. from the trunks.
The heaters are primarily a mixture of petroleum coke plus unknown ingredients. Each heater is made up of two 1-lb. bricks (2 X 4 1/2 X 8 inches) pressed together and comes wrapped in paper and sealed in polyethylene bags. These heaters burn about 4 hr. BTU output is unknown. Both radiant and convective heat are emitted.

Instrumentation

Thermocouples detected changes in temperature in both heated and unheated areas. Five trees served as sample points in each of the four plots. All of the trees were in the same east-west row and each of the five trees per plot represented one sample point at the extreme west edge of the plot: one between the center and the west edge, one at the center, one between the center and the east edge, and one at the extreme east edge of the plot. Each sample point was represented by one thermocouple attached to the underside of a leaf approximately in the center of the canopy of the tree. In addition, one thermocouple per plot was attached to the underside of a leaf located at the top of one of the five trees. Thermocouples were 24-gauge copper-constantin, connected to a 24-point potentiometer. Print time was every 2 minutes, and overall accuracy was calibrated to ±0.5° F.

Thermometers, accurate to ±1.0° F, indicated changes in temperature around the lower portion of the trunk of trees heated by solid-fuel III heaters. Thermometers were attached vertically to the trunk and at different levels above ground.

A portable thermistor probe was used to spot-check temperatures inside fruit (Fig. 4).

Heating trials and heaters used—Two major trials were conducted: nights of January 27-28 and 30-31, 1966. The first freeze night was characterized by a wind which averaged less than 5 mph and the direction shifted often. At 1 A.M. the wind was from the NW, and shortly thereafter shifted frequently to the WNW, W, and WSW. It was SW at dawn, and then became SE. Calmer, more stable conditions prevailed during the night of January 30-31, the worst freeze of the season. Wind, consistently from the N or NW, averaged less than 1 mph for the entire night.

Study plot treatments for the nights of January 27-28 included propane gas type I heaters supplemented with solid-fuel type III heaters; propane gas type II supplemented with solid-fuel type IV; solid-fuel type III supplemented with solid-fuel type IV; and one unheated plot.

Treatments of the nights of January 30-31 included propane gas type I heaters supplemented with solid-fuel type III heaters; propane gas type II heaters by themselves; solid-fuel type IV heaters supplemented with solid-fuel type III heaters; and one unheated plot.

Results and Discussion

Temperature increases during the freeze of the night of January 27-28 were greatest in areas heated by propane gas II and solid-fuel III heaters. Temperatures were increased as much as 9° F above ambient (Fig. 5). Increases of about 4.5° F are indicated for propane gas I heaters which were the fewest per unit area. Overall results are similar to those reported last year (5).

Figure 4.—A portable thermistor probe unit used to indicate temperatures inside oranges on tree heated by solid-fuel III heaters.
The somewhat excessive variation in the temperature increases, especially noticeable for propane gas II heaters, is attributed mostly to the frequent shifts in wind direction that occurred that night. The lesser effect of shifting wind on the other type of heaters probably resulted from the proximity of the other heaters to the ground level; they were therefore less exposed to wind. In addition, some of the heat output of propane I heaters is radiant heat, which is less affected than convective heat by wind. Others (6) have reported that solid-fuel heaters placed beneath trees are less affected by wind than are gas type heaters.

Differences in temperature increases between different heaters used singly and in combination are not readily evident because of the large variation in the data. However, indications are that three solid-fuel IV heaters per tree added less than an average increase of 1°F to temperatures produced by other types of heaters; whereas, the temperature increased averaged 2.6°F when one solid-fuel III heater was added per tree to the propane gas I heaters. This represents approximately an increase of 53% of the 4.9°F average temperature increase indicated before solid-fuel III heaters were added.

In contrast to the preceding the effect of adding other types of heaters to those already burning was very evident during the worst freeze of the year, January 30-31, 1966 (Fig. 6). Undoubtedly, this is due in large part to the calmer and more stable wind condition that prevailed during the night. Propane gas heaters alone provided adequate increases in temperature, 6-12°F above unheated controls. The lighting of one solid-fuel III heater per tree, alongside trees already being heated by propane gas I heaters, increased temperature from 8-10°F to 18-20°F above unheated controls. Such temperature increases were much in excess of what

![Figure 5](image-url)

Figure 5.—Average temperature increase in the center of mid-canopies of citrus trees heated by different types of heaters used January 27-28, 1966: (1) three solid-fuel type IV heaters per tree were added to trees already heated by propane gas type II heaters; (2) one solid-fuel type III heater per tree was added to trees already heated by propane gas type I heaters; and (3) three solid-fuel type IV heaters per tree were added to trees already heated by two solid-fuel type III heaters per tree.
seemed to be required. Similar results were obtained when solid-fuel III heaters were lighted alongside of trees already being heated by solid-fuel IV heaters. Solid-fuel IV heaters alone increased temperatures less than an average of 2°F above ambient; whereas the addition of one solid-fuel III heater per tree increased temperatures more than 800%, or from an average difference of 1.6°F without type III, to 14.9°F above ambient with type III. The effectiveness of solid-fuel III heaters was indicated also by temperatures inside fruit. Oranges, directly above and about 3 ft. from solid-fuel III heaters, were 42°F or about 10°F higher than 31.8°F indicated inside unheated oranges nearby.

Other heating trials indicated the relative ineffectiveness of solid-fuel IV heaters to increase temperatures in the center of tree canopies. Temperatures in the center of tree canopies averaged less than 4°F above ambient; and no increase of temperature was indicated at the top of trees (Fig. 7).

Other workers (3) have reported results better than ours for solid-fuel type IV. They used larger blocks, a greater total number per heating trials, and heated areas much larger than...
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Their results from a 7-acre area, with 1,200 lb. of fuel per acre, indicated that temperatures within the canopies of trees were increased on the average of 5.6° F at the 5 ft. level and 4.4° F at the 10 ft. level. Also, the average mass effect was 4.7° F over a 5 hr. period. Apparently, this heater is better suited for large mass type of heating than it is for heating small areas or widely scattered individual trees.

Solid-fuel IV heaters increased temperatures considerably around the main trunks of trees. Thermometers indicated temperatures as much as 28° F above ambient 2 hr. after the heaters were lighted and at 2 and 6 inches above ground (Fig. 8). Temperatures subsequently decreased rapidly. The calculated percent of effectiveness, based on areas under the curve of Figure 8 and using 2 hr. as 100%, indicated that heaters were losing effectiveness at a rate of about 22.5% per hr. Thus there was only about 10% effectiveness 6 hr. after the heaters were lighted (Fig. 9). Loss of effectiveness is partly attributed to the ash which accumulates on the surfaces of the fuel as it burns. The ash apparently interferes with emission or radiant heat, and the amount of convective heat must be too small to offset the loss of radiant heat.

A similar loss of effectiveness (Fig. 10) was measured at the automatic climate station (Fig. 11). One thermocouple had been embedded 1 inch into the trunk of each of two trees, 1 ft. above ground level. Trees were 30 feet apart. One solid-fuel type IV heater was placed 1 ft. away from the trunk of one of the trees. The heater was lighted during one of the freeze nights. Peak temperature occurred 2 hr. after the heater was lighted. The temperature of the heated tree trunk was 18° F higher than the unheated tree trunk. Thereafter, the temperature difference rapidly decreased between the heated and unheated tree. The heated tree trunk was only 2° F higher than the unheated tree trunk 6 hr. after the heater was lighted. These results are similar to those indicated by thermometers attached to the surfaces of the

![Figure 7.—Average temperature of citrus trees heated by three solid-fuel type IV heaters per tree.](image-url)
trunk. Overall protection is considerably less than that indicated with soil banks (5), but some of the unfavorable features of soil banks in certain cases may justify the use of heaters as a reasonable substitute in the protection of tree trunks.

LITERATURE CITED

Figure 8.—Average temperature increase in °F indicated by thermometers attached vertically to trunks of citrus trees heated by three solid-fuel type IV heaters per tree. Heaters spaced 3 ft. from the tree trunk, and one each at NW, NE and S aspects. Measurements taken at 2, 6, 12, 18 and 24 inches above ground and 2, 4, 5 and 6 hr. after heaters were lighted.
Figure 9.—Calculated percent effectiveness of solid-fuel type IV heaters 2, 4, 5 and 6 hr. after heaters were lighted. Calculations based on areas under the curves of Figure 6 and 2 hr. arbitrarily selected as 100%.

Figure 10.—Temperature increase indicated by thermocouple embedded 1 inch into the wood of a citrus tree trunk, and 1 ft above ground level. Thermocouple embedded on the S aspect and tree trunk heated by one solid-fuel type IV heater 1 ft from the trunk and on the S aspect.

Figure 11.—Automatic climate station and local radio communications used in cold protection work.
AUTOMATIC MONITORING AND RECORDING OF CLIMATE FACTORS IN CITRUS GROVES

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Abstract

Improved methods of measuring and recording climatological data in relation to plant behavior are needed. Consequently, an automatic electronic data sampler-recorder was engineered and constructed for future studies.

The instrument is essentially a transistorized audio amplifier made to measure and record minute changes in climate. These changes are converted into electrical signals by detecting devices which, in turn, are presented to the instrument in proper sequence by a mechanical selector switch.

After being properly processed and compared with a standardizing voltage, the resultant information is punched out on computer paper tape. The tape information can be read directly, decoded by a special typewriter, or inserted into a computer for direct statistical analysis.

Information gathered to date indicates that the instrument will assist in improving the recording of the microclimate in a citrus grove or elsewhere, when climatological data is needed to interpret physiological reactions of plants.

Introduction

The need for increased use of automation in studies of climate in citrus groves became evident during a 5-year study of microclimate in citrus areas of Florida, Texas and California (1). Various factors such as temperature, radiation, humidity, wind and rain were sampled and recorded on both strip and disc type charts. This vast accumulation of data had to be transcribed manually for statistical processing. After transcribing, the data had to be prepared manually for statistical analysis by computer facilities. Both chores were extremely timeconsuming and provided undue opportunity for error. A method of sampling and recording which would shorten sampling time and be directly applicable to computer processing seemed desirable, if further study in citrus grove climate was to be pursued.

With the advent of transistor and miniaturized electronic components, a data sampler and recorder that would accommodate the factors sampled in citrus grove climate studies seemed possible. Inquiries were made at the U.S. Weather Bureau, and weather instrument engineering firms were consulted as to the feasibility of an automatic electronic climate monitoring system (2). After a consensus of opinion, a contract was let for engineering and construction of an instrument that would sample information from more than 20 positions in a citrus grove, and which would record the information, at specific time intervals, on a tape that could be read visually, decoded with an automatic typewriter, or analyzed directly by computer. This report describes the instrument and also presents a sample of the data recorded.

General Description

Physical size and weight

The unit is built on an aluminum chassis which measures 17" X 13" X 4". A panel attached to the chassis acts as a support for relays, motors and tape punch. The panel is 18" high and 19" wide (Fig. 1). The overall weight is 25 lb. It can be lifted and carried by one