RADIANT HEAT — SOME GENERAL PROPERTIES AND ITS PRODUCTION BY FOUR TYPES OF GROVE HEATERS

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ABSTRACT

Radiant heat travels by "line of sight" and obeys the law of inverse squares. That is, areas at two and three units distance, respectively, from a heat source would receive 1/4 and 1/9 as much radiant heat as an area one unit distance from the heat source. These facts should be considered in the spacing and placing of grove heaters.

Four types of heaters: the return stack, jumbo cone, Spot, and a prototype heater were tested. The first two were conventional oil burning heaters adapted for use in a central fuel distribution system, while the latter two were expressly designed for use in a central distribution system. The prototype heater produced the greatest amount of radiant heat by a considerable margin. The return stack was second, the jumbo cone a close third, and the Spot fourth. The radiant heat produced by the return stack (and by the prototype and jumbo cone heaters) was mostly as radiation from the heated stacks. Flames emanating from the cooler stacks of the Spot heaters were responsible for most of their radiant heat output.

INTRODUCTION

There has been much interest in radiant heat production by different types of grove heaters. Interest in grove heating systems with fuel piped to the heaters has been revived, spurred by rising production costs and labor shortages. Particularly encouraging are some central heating systems which have largely overcome the disadvantages of the early "pipeline heating systems" used in California and described by Schoonover, *et al.* (4). First consider some facts about radiant heat. Then, how radiant heat is produced by different heaters, and how one may make the most effective use of it.

Heat waves comprise the long wave or infra-red portion of the electro-magnetic spectrum. They travel by "line of sight" and behave in every respect in the same manner as visible light except that infra-red radiation is invisible to the human eye. One can use the anology to light in the following manner: Imagine a beam of light which passes through a small square hole and illuminates a square area one foot from the light. At a distance of 2 feet the beam of light will illuminate an area 4 times as large as the first but since it is the same light, at only 1/4 the intensity per unit area. At 3 feet it will illuminate nine units of area at 1/9 the intensity per unit area, as demonstrated in Figure 1. It can be said that radiant heat obeys the "Law of Inverse Squares," expressed as follows:

$$I = \frac{1}{(d)^2}$$

where I = the intensity of radiation

and d = the distance from the heat source.

Let the intensity of radiation 1 foot from the source = 1

Then, if the distance (d) — 2 feet

$$I = \frac{1}{(2)^2} = \frac{1}{4}$$

and when d = 3 feet

$$I = \frac{1}{(3)^2} = \frac{1}{9}$$

Now, suppose one wishes to know the intensity of radiation at less than 1 foot from the source, say 1/2 foot:

$$I = \frac{1}{(\frac{1}{2})^2} = \frac{1}{\frac{1}{4}} = 4$$

So at 1/2 foot from the source the intensity is increased to 4 times that at 1 foot and at 2 feet from the source it is only 1/4 that at 1 foot. This elementary physical principle has important application to grove heating. In general, the

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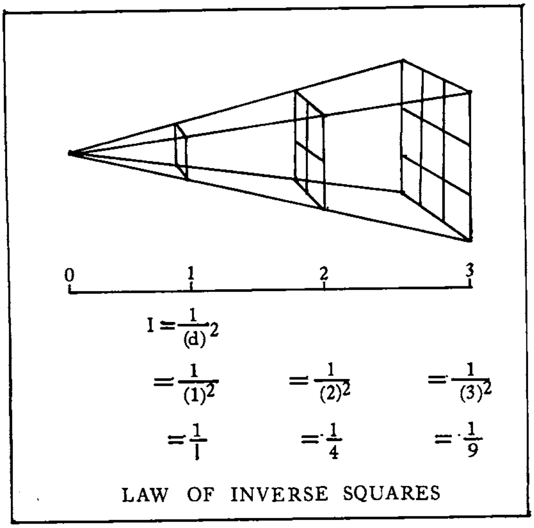

Figure 1.

temperature of a leaf is determined by the radiant heat from the heater. There are 3 ways to increase the radiant heat the leaf receives from the heater: (1) Increase the temperature of the heater stack; (2) Decrease the distance from the stack to the leaf, and (3) Increase the area of the radiating surface. The latter can only be done by using more heaters or a heater with a larger radiating surface. By increasing the heater stack temperature 200°F almost 50% more radiant heat will strike the leaf.

Placement of heaters can be very important. Examples of placement are shown in Figures 2 and 3. The trees are assumed to be spaced 25′ x 25′ and 18′ in diameter. The shaded portion represents the area that can be heated effectively by radiation. The area of effective radiational heating extends outward about 11 to 12 feet from each heater. In Figure 2 the heaters are placed in the open spaces and the area of effective radiational heating is calculated as about 25 ft^2 per tree, or 100 ft^2 for the 4 trees receiving the heating. The complete circle is 380 ft^2 in area so 280 ft^2 of possible radiant heat is wasted or 26% of the available radiant heat is utilized. Now, if the heaters are placed in the rows a larger area can be radiantly heated (Figure 3). The effective area is 76.4 ft^2 per tree, or 153 ft^2 for 2 trees, and 45% of the available radiant heat is utilized. Thus, placing the heaters in the rows makes it possible to increase the heated area by 53%. These figures apply to the plane of the heater. The portion of the tree above the level

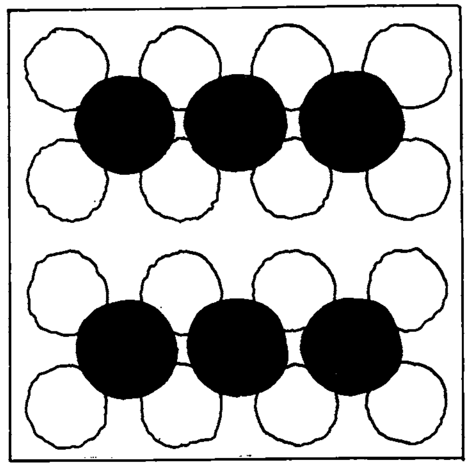

Figure 2. Radiant heat distribution with heaters placed in open spaces.

of the heater receives less radiant heat .(To digress a bit, it can be pointed out that even with the best heaters more than half of the radiant heat is wasted. Thus, it is a challenge to design a more efficient heating system.)

What about the unheated portions of the trees? The heated area could be doubled by placing heaters in every row. At best this would increase the area heated to about 60%. This would double the cost of heaters and possibly fuel, which would not be economically feasible. The maximum amount of radiant heat produced by stack heaters is only about 30% of their total output; the remainder is mainly convective heat from the heated gases (2). (A neglegible amount

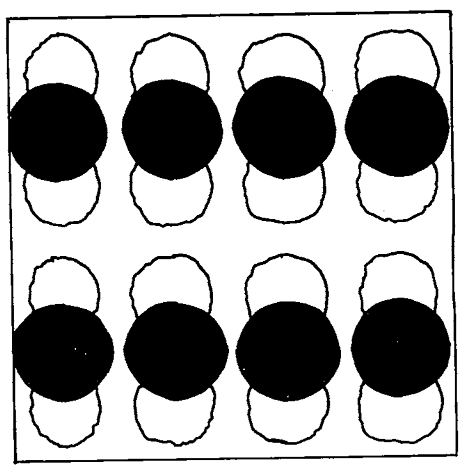

Figure 3. Radiant heat distribution with heaters placed in the rows.

of heat is produced by conduction.) Therefore the objective should be to utilize the best combination of radiant and convective heat. Placing the heaters by the trees in alternate rows would accomplish this.

Figure 4 is a 3-dimensional picture of the distribution of heat around a citrus tree. Gerber has shown that due to temperature variations at different parts of the heater stacks, the area of effective radiant heat distribution around a stack heater does not describe a perfect hemisphere, and the shape of the area varies somewhat with the type of heater (2). For the purpose of this discussion, however, it will be assumed that the area is a hemisphere. This will simplify calculations and the error in any case will be small. Figure 4 shows that only about 1/6 of the tree can be heated by radiation while convective heat, shown by the arrows, is distributed to heat the remainder of the tree.

Materials and Methods

In order to determine the radiant heating effect of different types of heaters an experiment was performed with several heaters and small metal plates. Thermocouples were attached to each plate, which was painted black to absorb radiant heat. A heater was placed in the center of a level, open area and at each of 4 quadrants, at distances of 5 1/2, 11, and 22 feet from the heater a 3 inch^2 black metal plate was positioned at a height of 4 feet. The plates were *mounted* vertically with the blackened surfaces facing the heater. Similar 3 inch squares of fresh citrus leaves with thermocouples attached were placed perpendicular to the incident radiation at the same distance from the heater. A control thermocouple was exposed at a distance of 300 feet east of the test area. The test layout is shown in figure 5.

The purpose of the leaf temperature measurements was to make the results of the tests as realistic as possible. The temperatures recorded on the blackened plates served as a measure of the radiant heating of the heaters while the leaf temperatures indicated how much of this radiant heat was absorbed by the leaves. Temperatures were taken of heated and unheated leaves and black plates. The change in temperature due to heating of both leaves and black plates was then calculated. The radio of the change in leaf temperature to the change in black plate temperature was considered an index of the radiant heat absorptivity of the leaves. This experiment was designed so that the radiant energy absorptivity of the leaves might be determined. There are 2 causes for the lesser absorption of heat by the leaf as compared to the black plates: One is due to the color and physical characteristics of the leaf, and the other is the angle of the leaf in respect to the incident radiation.

Four types of grove heaters, (1) the jumbo cone, (2) return stack, (3) spot, and (4) proto-

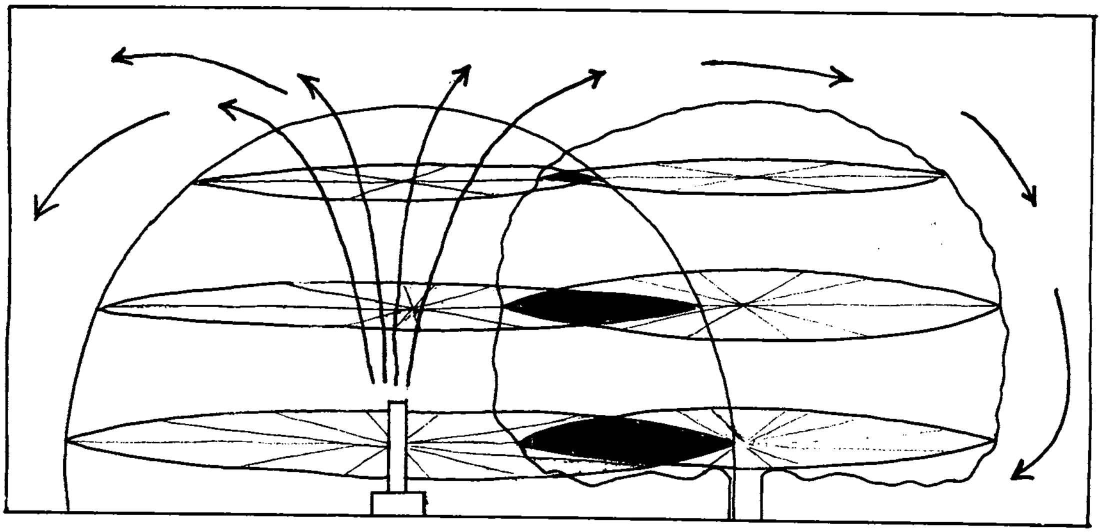

Figure 4. A 3-dimensional picture of heat distribution around a citrus tree.

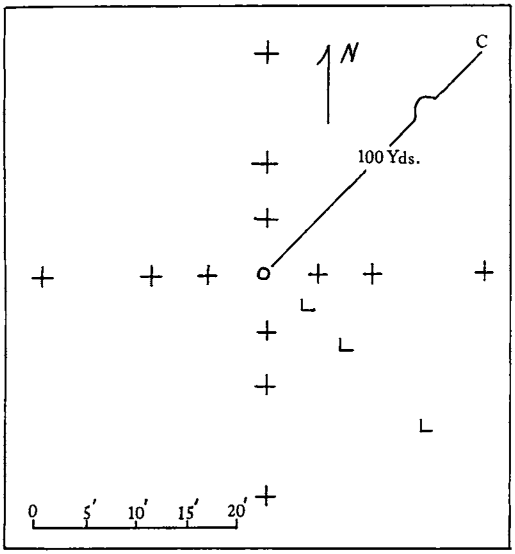

Figure 5. Test layout
+—Thermocouples attached to blackened plates
L—Thermocouples attached to leaves
C—Control thermocouple
O—Heater

type were used to determine the effective radiant heat output at various distances from the heaters and at different operating pressures. The first 3 heaters were production models modified for use in an oil burning central fuel distribution system by the substitution of a special cap and a nozzle for the standard cap. The burning rate of the modified heaters was controlled entirely by varying the fuel line pressure as the special cap had only fixed vents. The spot and prototpye heaters are designed to be used in central heating systems. The tests were conducted on clear, calm nights. Only 1 heater was operated in each test. This eliminated the possibility that convective heat would be a factor in the results. Each heater was lit and operated at its full range of pressures, 30 minutes at each pressure setting. Temperature data was recorded by an L&N 24 point recorder. The fuel consumption of the jumbo cone, return stack, and spot heaters was determined during the experiment. It was impossible to determine the fuel consumption of the prototype heaters in the same manner so data from a previous experiment was used for comparative purposes (1). The jumbo cone and return stock heaters were tested at 40, 60, 80, and 100 psi and the spot heaters at 80, 100, and 150 psi. The prototype heaters, the only true

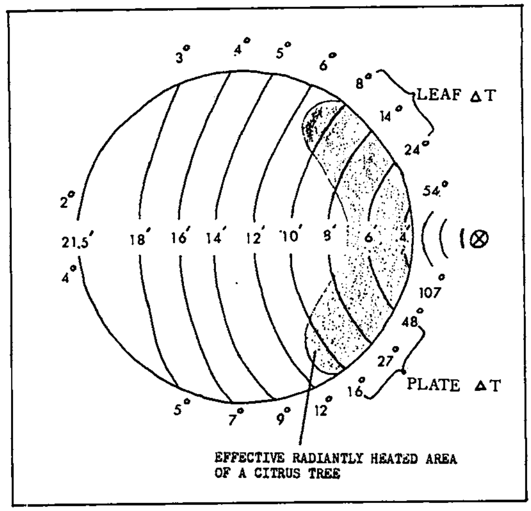

Figure 6. Temperature distribution (△T) around a modified Jumbo Cone heater at 60 PSI.

low-pressure system, were tested at 10, 15, 20, 25, 30, and 40 psi.

Results and Discussion

Figures 6 ,7, 8, and 9 show the distribution of radiant heat from the 4 types of heaters. The term Δ T used in the figures is defined as the temperature differential in the leaves and plates produced by radiant heating. The figures through the center of the drawings indicate the distances

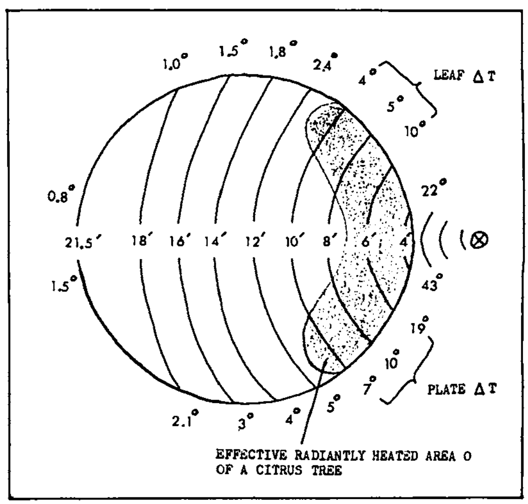

Figure 7. Temperature distribution (Δ T) around a modified Return Stack heater at 60 PSI.

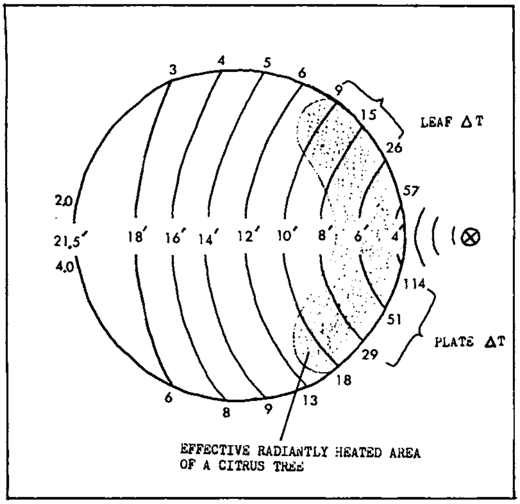

Figure 8. Temperature distribution (△T around a Spot heater at 60 SPI.

from the heater. The return stock was the most efficient of the 3 standard heaters and the jumbo cone was a close second. Both of these heaters performed well at 40 and 60 psi. The radiant heat output of both heaters increased when the pressure was increased from 40 to 60 psi, then it dropped slightly at 80 psi. There was a further decline at 100 psi so 60 psi was the most efficient operating pressure. At the present time it is unknown why the radiant heat output dropped off at 80 and 100 psi. The radiant heat from the

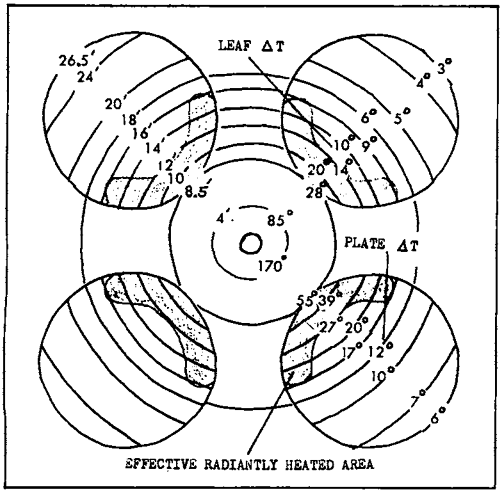

Figure 9. Temperature distribution (△T) around a Prototype heater at 30 PSI.

jumbo cone and return stack heaters is produced primarily by the heated stacks and is proportional to the stack temperatures. However, some radiant heat is produced by flames coming out of the stacks at the higher operating pressures. In the case of the spot heaters, flames emanate from the stacks at all operating pressures and extend as high as 6 feet above the stacks when burning at 150 psi. The flames are a major source of radiant heat of the spot heaters and this is why increased pressure increased the radiant heating effect. Some radiant heat comes from the stacks but these remain relatively cool.

In the jumbo cone and return stack heaters the fuel is burned primarily in the stacks while in the spot heater much combustion is above the stacks. These 3 types burn atomized fuel while the prototype burns vaporized fuel. The fuel is vaporized in a spiral of stainless steel tubing which is quickly pre-heated during the lighting process by the burning of the mixture of diesel

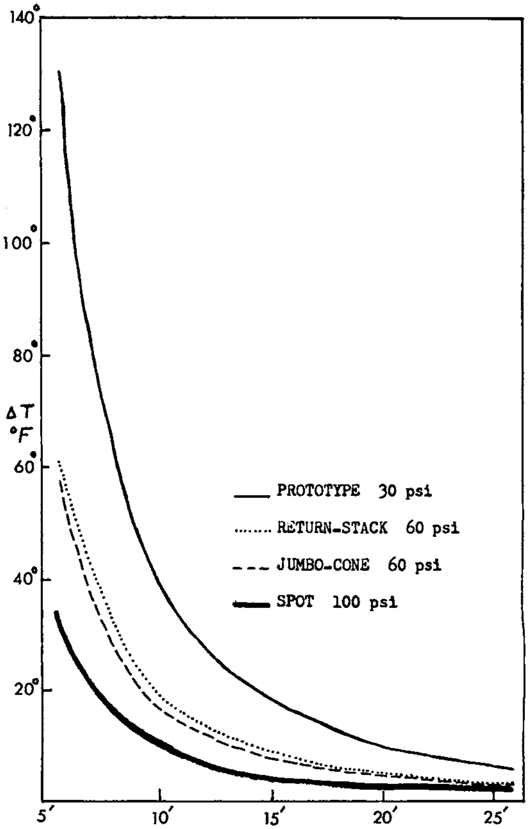

Figure 10. Maximum radiant heat output of the 4 heaters tested.

Table 1. A Summary of the Performance Characteristics of the 4 Heaters Tested

Heater	Jumbo Cone	Return Stack	Spot	Prototype
Type	Conventional, modified for heating system.	Conventional, modified for heating system.	Designed for heating system.	Designed for heating system.
Fuel	#2 Diesel	#2 Diesel	#2 Diesel	#2 Diesel
Type of Burner	Atomizing	Atomizing	Atomizing	Vaporizing
Fuel Consumption at: 40 psi	.67 gal/hr	.67 gal/hr		
60 psi	.81 gal/hr	.81 gal/hr		
80 psi	.93 gal/hr	.93 gal/hr	.86 gal/hr	
100 psi			.94 gal/hr	
150 psi			1.20 gal/hr	
30 psi				1.39 gal/hr
Air Pollution Factor	virtually smokeless	virtually smokeless	Nearly smokeless except some smoke at 150 psi	virtually smokeless
Ease of Lighting	fair	fair	excellent	fair
Leaf and plate* T produced 6' from heater at: 30 psi				77/109
60 psi	34/48	36/51		
100 psi			20/28	

* (leaf/plate)

oil and gasoline from the flambeau torch. The spot heater was the easiest to light of the 4 types. It could be lit by dropping a lighted match down the stack. The prototype heater produced the greatest amount of radiant heat by a considerable margin (Figure 10). This was mostly due to the large radiating surface presented by the 55 gallon oil drum that served as a jacket for the heater. The prototype burned 1.39 gallons of fuel per hour at 30 psi, which was the highest fuel consumption of the 4 heaters tested. (See Table 1) It was the only heater that could heat 4 trees when placed in the open space. It fact, the heat from the prototype was so intense that it would scorch the leaves if placed between the rows. It was found to produce a temperature of 325° at 2 1/2 feet, the distance from the heater to outer edge of the trees when the heater was placed in the rows. Figure 10 and Table 1 give a quick comparison of the performance of the 4 types of heaters.

The change in leaf temperatures shown in Figures 6, 7, 8, and 9 are not the actual temperature changes as recorded on leaf mounts. The leaf mount temperature changes were only 71% of the temperature changes shown by the black plates, indicating a difference between absorptivity of leaves and black plates. (See Table 1). Further, it was considered that not all of the leaves of a citrus tree are turned in such a way as to be normal (purpendicular) to the radiation from a heater. Some leaves are turned edgewise and receive practically no direct radiation although they may receive some radiation reflected by other leaves. It was assumed that the average leaf was inclined at a 45° angle or in a plane halfway between the horizontal and the vertical. If leaves have only 71% of the absorptivity of black plates and only 71% of the incident radiant heat is effective due to the 45° inclination of the leaves, then a change in temperature of only 50% (71% of 71%) of the change in the temperature of the black plates is to be expected. This loss in heating effectiveness is shown by the Figures (Δ T leaves) on Figures 6, 7, 8, and 9.

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IRRIGATION REQUIREMENTS OF CITRUS GROWN ON LAKEWOOD FINE SAND

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Abstract

'Pineapple' orange trees growing on Lakewood fine sand were maintained at 3 soil moisture and 2 fertility levels. Tree growth and fruit production were influenced by irrigation treatments but not by fertilizer treatments. Fruit quality was affected by fertilizer but not by irrigation treatments.

This study would indicate trees growing on Lakewood fine sand require more frequent irrigation than those growing on other well-drained soils.

Introduction

Lakewood soils are described as excessively drained, thick acid sands (5). The surface soils consist of nearly white sand to depths of 10 to 24 inches underlain by brownish-yellow or reddish-yellow sands. The Lakewood soils are low in organic matter and mineral nutrients and generally are not suitable for cultivated crops. However, when irrigation was available, citrus and other subtropical fruits and improved pasture have been grown successfully under good management.

Most citrus irrigation investigations have been conducted on Lakeland fine sand (2, 3, 7). No irrigation research data are available on Lakewood fine sand. Growers who have irrigation facilities use them liberally. It is not uncommon for growers to irrigate twice as frequently and using twice as much water on Lakewood fine sand as would be applied to other soils.

An experiment was initiated in 1965 to obtain information on the irrigation requirements of citrus planted to Lakewood fine sand with emphasis on the influence of water on tree growth, fruit production, and fruit quality. This paper summarizes the results obtained from 1965 to 1968.

Materials and Methods

This study was conducted at Camp Cloverleaf near Lake Placid, Florida, in a 5-acre grove equipped with permanent overhead irrigation. The trees, 'Pineapple' orange on rough lemon rootstock, were planted in 1957. The topography of the land sloped toward the lake. The soil is predominantly Lakewood fine sand except for a corner along the lake where the soil resembled a Leon series. There were wide variations in tree size in the block with the trees closer to the lake being much smaller than trees on higher ground. Part of the difference in tree size was possibly due to past irrigation practices. The trees on higher ground usually received twice as much irrigation as those in the lower area. This is shown in the 1965 irrigation (Table 1). Irrigation Treatments I and II included most of the trees on higher ground and Treatment III covered most of the trees closer to the lake.

The block was divided into 7 plots of about 40 trees each, but the treatments were not replicated. Treatments were designed to determine if tree size and fruit production could be equalized through liberal use of irrigation and fertilization. Treatments outlined in Table 1 included