A STUDY OF FACTORS AFFECTING ELECTRIC SOIL STERILIZATION

by

GUSTAVUS HOFFMEYER STEWART

B. S. in Agricultural Engineering

Clemson, 1935

A thesis Submitted to the Graduate Committee

in partial fulfillment of the requirements

for the degree of

M A S T E R O F S C I E N C E

in

Agricultural Engineering

Virginia Polytechnic Institute

JUNE 1938

Approved:

Course Adviser	Dean of Agriculture

A STUDY OF FACTORS AFFECTING ELECTRIC SOIL STERILIZATION

CONTENTS

LIST OF ILLUSTRATIONS

ACKNOWLEDGEMENTS

The author is deeply grateful to the Departments of Agricultural Engineering and Plant Pathology who made possible the opportunity of carrying out this investigation.

He is also indebted to the following men who freely gave of their time and advice: Professor P. B. Potter, Course Adviser; Professor E. T. Swink, Supervisor of Project; Dr. S. A. Wingard;

; and .

The author also wishes to thank for the loan of equipment which added materially in conducting the investigation.

A STUDY OF FACTORS AFFECTING ELECTRIC SOIL STERILIZATION

Introduction

The sterilization of soil is becoming a common practice throughout the country, chiefly because of the greenhouse industry, market gardeners, and florists near large cities. As practically every square foot of soil in greenhouses, hotbeds, cold frames, flats, and pots is kept in production during the winter at considerable expense and effort, it is necessary to control destructive plant enemies such as nematodes, damping off and insect life of various kinds.

Soil may be sterilized by three different methods: steam, chemicals, and dry heat. Steam is the most common method, but it is not available to many growers. Chemicals are used to some extent, but they have their limitations. Dry heat is considered the most effective disinfectant for sterilization. It is used extensively for the sterilization of tobacco beds, being produced from large fires built on the seed bed.

Due to the rapid expansion of rural electrification within the past decade with the increasing availability and economy of electric current, the sterilization of soil with electricity is receiving considerable attention. Two types of portable electric sterilizers have recently been developed to convert electric energy into heat for controlling seed bed diseases. The first of these was advocated by the New York Power and Light Company, Albany, New York. It consisted of an insulated metal box of one cubic yard capacity with 15 heating elements in 1/2-inch metal pipes extending across the box and placed to produce uniform heating. The box, which is mounted on legs, has a hinged top and bottom. The infected soil is shoveled into the top of the box and, after sterilization, is removed by dropping the hinged bottom. The second type was proposed by the Puget Sound Power and Light Company of Seattle, Washington. The current is passed through the soil and the resistance which the soil offers to the flow of current causes the soil and soil moisture to be heated. The soil is added and removed as in the first type.

Much information is needed regarding the use of electricity as a source of heat for soil sterilization. Greenhousemen are continually confronted with the problem of selecting the proper method of sterilizing soil. The small operator is not usually equipped with live steam for sterilization but he does have electricity available. If he is equipped with sufficient information concerning the factors involved, he can take care of his soil sterilization needs with electricity. Therefore, a study of electricity as a source of heat for soil sterilization has been undertaken in an effort to make electric soil sterilization practical and efficient.

SCOPE OF INVESTIGATION

This investigation includes a study of factors affecting electric soil sterilization under actual greenhouse conditions where steam is available. The soil used for testing was taken from various greenhouse benches being infested with a number of common pathogenes, including bacteria, nematodes, black root rot, and weed seeds.

The data compiled from various tests includes records of both room and soil temperatures, watt-meter records of power demand, kilowatt hour records of power consumption, ammeter records of current, and summarized records of plant growth in various samples of sterilized soil which received different treatments during sterilization.

Comparative tests were run on both types of sterilizers for determining the most economical, practical, and efficient method of sterilization.

The portable resistance sterilizer was given a practical test by sterilizing soil in an electric hotbed located where steam was not available.

OBJECTIVES

With the above facts in mind, this investigation was planned around the following objectives:

1. To determine the cost of operation and the efficiency of two types of sterilizers under identical operating conditions.
2. To evaluate the factors of temperature, time, and soil moisture.
3. Selection of the most practical and efficient method of electric soil sterilization that can be recommended to greenhousemen, market gardeners, and florists.

EQUIPMENT

The following equipment was used in carrying out this research project: heating element sterilizer, resistance sterilizer, recording thermometer, recording ammeter, voltmeter, watt-meter, kilowatt-hour meter, and eight mercury thermometers.

Heating Element Sterilizer - This sterilizer resembles a large box of 5 cubic foot capacity mounted on legs. The top and bottom of the box are hinged to make loading and unloading easy. Four 500-watt strip heaters enclosed in tin shields extend across the box and are placed to produce uniform heating throughout the soil. The front of the box has holes located at points through which mercury thermometers can be thrust to observe the various temperatures in different parts of the sterilizer.

Resistance Sterilizer - The external appearance of the resistance sterilizer is identical to that of the heating element sterilizer. Two 24-inch by 30-inch electrodes are placed horizontally in the box, one on the top and one on the bottom. These electrodes are connected to opposite sides of a 230-volt circuit.

A simple safety device in the form of an extension to the arm of an enclosed knife switch opens the switch before the lid can be raised.

Resistance Test Sterilizer - A small resistance soil sterilizer of 1/4 cubic foot capacity was designed and built for experimental purposes only. The electrodes were spaced vertically and the plate

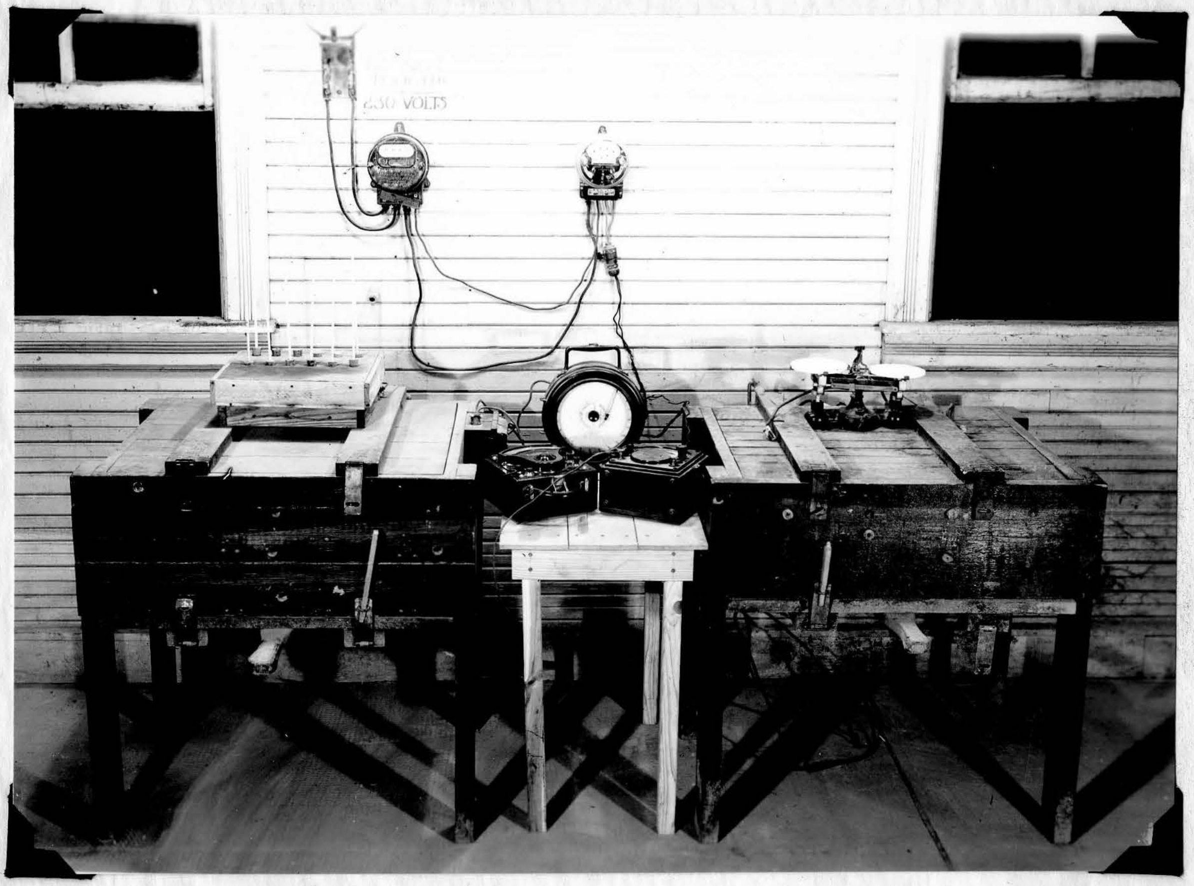


Figure 1. Layout of equipment used for taking data on electric soil sterilizers.

Figure 2. Heating element sterilizer showing location of heaters. This sterilizer has a capacity of 5 cubic feet and a constant demand of 2000 watts.

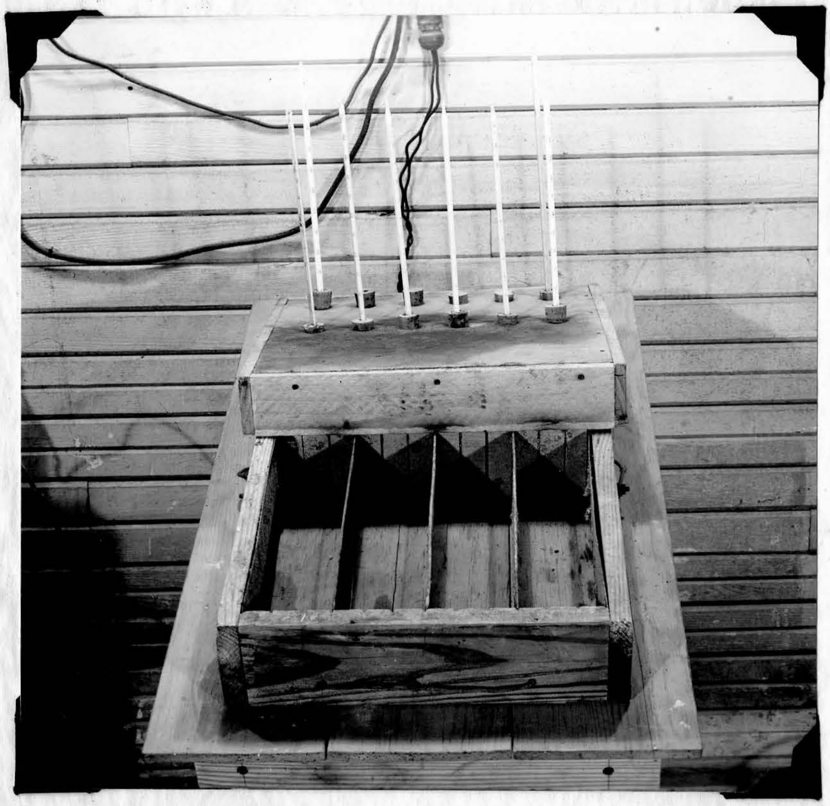


Figure 3. Resistance test sterilizer showing electrodes spaced 3 inches apart. The plate spacing may be varied from 1 to 12 inches by inserting additional plates in grooves.

spacing could be varied from 1 to 12 inches. Holes were put in the top at points through which mercury thermometers could be thrust for taking temperature readings.

The temperature rise of the soil mass was recorded on charts of a Bristol's recording thermometer. As the current was flowing through the soil in the resistance sterilizer, it was necessary to insert a large test tube in a hole drilled in the side of the sterilizer to insulate the thermometer bulb from the soil. This instrument was set to record temperatures within the zone of 60 and 180 degrees Fahrenheit which covered the range used in this investigation.

A General Electric recording ammeter was used to record the variations in current during each test.

A Sangama Electric watt-hour meter which measures energy in terms of the nearest hundredth of a kilowatt hour was used in all experiments where energy was recorded.

A voltmeter and watt-meter was used to check the line voltage and power demand respectively.

PROCEDURE

The electric soil sterilizers used in this investigation were built in the agricultural engineering laboratory by J. L. Calhoun, a graduate student, in 1935. The small resistance test sterilizer was recently designed and built to be operated for experimental purposes only.

The sandy loam soil used for testing was taken from various greenhouse benches being infested with a number of common greenhouse pathogenes; weed seeds, black root rot,* and nematodes.** This soil was sprinkled and allowed to stand over-night to get an even distribution of moisture throughout the soil mass. The next morning this soil was carefully screened and both sterilizers were filled with the same quantity of soil by weight. The sterilizers were then operated until uniform temperatures of arbitrarily chosen values were obtained before the soil was dumped. During this time, data was recorded from readings taken with the voltmeter, ammeter, kilowatt hour meter, and mercury thermometers equally spaced throughout the soil mass.

In order to test the practicability of the portable electric sterilizer, a resistance sterilizer was placed in a 6 ft. by 6 ft. electric hotbed (Figure 4). The sterilizer was filled with soil from the outside, heated to a minimum temperature of 70 degrees Centigrade

---

* A plant disease which causes the root system to rot off.

** A small organism which attracts roots of most common plants resulting in the formation of galls in the last stages. The root system of the plant completely disappears and the plant withers away (Figure 6).

Figure 4. Portable resistance sterilizer used for sterilizing soil in electric hotbeds.

and dumped directly into the bed. Two sterilizers of soil was sufficient to fill the bed to a depth of 6 inches.

Temperature of the soil mass in each sterilizer was recorded on charts of a Bristol recording thermometer. The pointer was set back 70 degreen Fahrenheit to record the maximum temperature. It was necessary to insulate the thermometer bulb from the soil in the resistance sterilizer by placing a test tube in a hole drilled in the center of one end and inserting the bulb in this test tube.

The energy consumption was measured with two kilowatt-hour meters. One meter was calibrated to hundredths of a kilowatt-hour and the other meter was used as a check on the first.

Samples of soil sterilized by both methods were placed in sterilized pots. These pots were sterilized with steam to be sure that all harmful organisms were absent.

All samples were seeded in yellow mamouth tobacco and the plant growth of each was checked to determine the most efficient method. Tobacco was chosen because the controlling of nematodes on tobacco roots is a serious problem now facing the south.

RESULTS

The following tables show the results of this investigation:

Table 1. Typical data sheet for heating element sterilizer, showing time, current, energy, voltage, and temperatures in different parts of the soil.

Table 2. Typical data sheet for resistance sterilizer showing the heating time, demand, energy consumption, and temperatures in different parts of the soil.

Table 3. Approximate kilowatt-hours required to raise one cubic foot of sandy loam soil through certain temperature ranges.

Table 4. Summary of test data on electricity consumption with various plate spacings.

Table 5. The effect of temperature and time upon efficiency of sterilization.

Table 6. Length of time required for sterilization.

Table 1. Typical Data Sheet for Heating Element Sterilizer, Showing Time, Current, Energy, Voltage, and Temperatures in Different Parts of the Soil

(Sandy Loam Soil, Moisture Content 25%, Room Temperature 16° C)

	Thermometer Readings Degrees C					Readings				
	T_1	T_2	T_3	T_4	T_5	Meter	Volt-Meter	Ammeter	Watt meter	Remarks
1:00 P.M.	16	15	15	14	16	57.6	231	8.85	2080	
1:10 "	16	15	15	15	16	58.0	231	8.8	2040	
1:20 "	16.2	15.5	15.5	15	17	58.25	231	8.75	2020	
1:30 "	16.5	16	17	15.5	21	58.5	233	8.75	2045	
1:40 "	19	18	20.5	18	27	58.85	230	8.75	2000	#5 Sweating
1:45 "	19.5	19	22.5	20	31	59	230	8.6	2000	
1:50 "	20.5	20.5	26	20.5	32	59.15	229	8.6	1980	#3 Sweating
1:55 "	22	22	27.5	24	34	59.25	230	8.6	2000	
2:00 "	22	24	30	25	40	59.5	232	8.7	2040	#4 Sweating
2:05 "	24	26	33	27	45	59.7	233	8.78	2020	
2:10 "	25.5	28	35	30	45	59.95	230	8.6	2010	
2:15 "	25.5	30	37	33	46	60	236	8.7	2045	
2:20 "	28	32	40	35	47	60.15	232	8.7	2040	
2:25 "	30	34	43	37	50	60.25	231	8.65	2020	
2:30 "	32	36	45	39	52	60.5	232	8.65	2010	
2:35 "	34	38	48	42	55	60.7	230	8.6	2000	
2:40 "	36	42	51	45	57	61	230	8.6	2000	
2:45 "	37	43	53	46	59	61.25	231	8.6	2010	
2:50 "	45	47	57	50	61	61.5	231	8.6	2010	
2:55 "	49	50	59	52	62	61.6	231	8.7	2010	
3:00 "	50	52	61	54	64	61.7	231	8.7	2010	
3:05 "	58	54	63	56	66	61.85	231	8.6	2010	
3:10 "	51	56	65	59	67	61.95	230	8.6	2010	
3:15 "	52	59	67	60	69	62	233	8.7	2040	
3:20 "	55	60	69	62	70	62.1	233	8.7	2040	Current Off
3:27 "	56	66	72	65	72					
3:32 "	59	67	74	68	73					
3:37 "	60	68	75	69	73					
3:42 "	61	67	76	69	72					
3:50 "	62	72	76	70	70					
3:59 "	62	70	75.5	70	68					
4:07 "	61	70	75	70	66					
5:36 "	59	71	67	67	56					

Table 2. Typical Data Sheet for Resistance Sterilizer Showing the Heating Time, Energy, and Temperatures in Different Parts of the Soil

(2 Inch Electrode Spacing, Sandy Loam Soil, Room Temperature 22° C)

Time	T_1	T_2	T_3	T_4	T_5	T_6	Watts	Meter	Remarks
10.57	22	22	22	22	22.5	22	450	9.645	
10.59	27	22	29.5	27	27	29	510	9.66	
11.02	34	23	43	34	37	38	650	9.69	
11.04	42	23.5	59	46.5	50	49	740	9.71	
11.06	49	25.5	75	52	63	59	840	9.74	# 3 steaming
11.08	55	28.5	88.5	58	75	69	910	9.765	# 5 steaming
11.10	62	31	97	63	99.5	80	990	9.795	# 6 steaming
11.12	70	35	97	66	97	90	940	9.83	# 2 & 4 not
11.14	79	41	97	70	85	91	700	9.87	Making good
11.16	93	48	97	73	85	82	560	9.88	Contact
11.18	95	55	97	75	82	79	400	9.90	Heating slowly
11.22	93	63	96	76	77	75.5	230	9.92	
11.26	87	67	93	76	75	72	130	9.93	
11.29	82	70	89.5	75	73	69.5	100	9.935	Current off

THE COST OF OPERATION AND THE EFFICIENCY OF TWO TYPES OF STERILIZERS UNDER IDENTICAL OPERATING CONDITIONS

It is rather difficult to determine the cost of operation because many variables enter which change with each test run. Therefore, the data from 150 test runs has been summarized in Table 3. The kilowatt-hours per cubic foot for various temperatures rises are given in this table.

Table 3. Approximate Kilowatt-Hours Required to Raise One Cubic Foot of Sandy Loam Soil Through Certain Temperature Ranges

Initial Soil Temp. Degrees Cent.	Final Temperature in Degrees Centigrade 50	55	60	65	70	75
			Heating Element Sterilizer			
15	.80	.92	1.02	1.12	1.21	1.32
21	.68	.80	.90	.98	1.08	1.20
25	.56	.68	.78	.86	.97	1.08
			Resistance Sterilizer			
15	.73	.84	.95	1.02	1.15	1.26
20	.63	.73	.84	.95	1.02	1.11
25	.52	.63	.73	.84	.95	1.02

The resistance sterilizer appears to be a little more economical than the heating element and under ordinary conditions soil can be safely sterilized with a consumption of from 1 to 1.5 kilowatt-hours per cubic foot by either method of sterilization. If power is available at a 2 cent rate, it would cost approximately 2 to 3 cents per cubic foot. As a cubic foot of soil will fill four 2-gallon crocks, it would cost a maximum of .37 cents a crock. This compares favorably with steam in cost, being much cheaper for the small operator who does not have steam available.

The resistance sterilizer is more efficient than the heating element sterilizer because the heat input is direct. In the heating element sterilizer heat is lost in transmission from the heatdrs to the soil and much heat is stored in the heaters which is dissipated into the surrounding air when the soil is dumped.

Resistance test sterilizer - The electrodes of this sterilizer were varied from 2 to 6 inches apart to determine if the plate spacing had any affect on the energy consumption. The soil for each test was weighed carefully so that the same quantity of soil was heated during each test. The summarized data for these tests are shown in the table below.

Table 4. Summary of Test Data on Electricity Consumption with Various Plate Spacings (Average of ten runs for each spacing)

Plate Spacing	2"	3"	4"	6"
KWH	.215	.22	.225	.215
Time	18 min.	20 min.	17 min.	36 min.
Temp. rise	49° C	$52\frac{1}{2}$° C	$52\frac{1}{2}$	48
Watt-range	642-1504	460-1300	460-1400	220-480
KWH cu. ft.	.86	.88	.90	.86

EVALUATION OF THE FACTORS OF TEMPERATURE, TIME AND SOIL MOISTURE

Temperature:

It was very essential to know the lowest safe sterilization temperature at which soil should be sterilized in order to know the minimum temperature at which the current could be turned off. This temperature was found to be 65 degrees Centigrade but 70 degrees Centigrade was chosen so as to allow a small safety factor. This was accomplished in the following way: soil infested with both nematodes and black root rot was heated to various temperatures by both methods. Samples of all test runs were placed in sterilized pots and seeded in tobacco. The results of the growth of these plants as summarized in Table 5 indicate that a minimum temperature of 70 degrees Centigrade for ten minutes is sufficient to kill both nematodes and black root rot.

Uniformity of heating - The soil temperatures in various parts of both sterilizers were found to be within reasonable limits.

In the resistance sterilizer, the temperature variation between maximum and minimum is approximately 20° Centigrade. Figure 9 gives temperature curves for the soil in the small test sterilizer. The low temperature curve represents the low point of the sterilizer taken near the corner. This was due to the heat losses near the corners and edges. However, after the power was cut off this low temperature continued to rise, finally becoming equal to that of the main body of the soil. This low temperature was due partly to poor contact in the

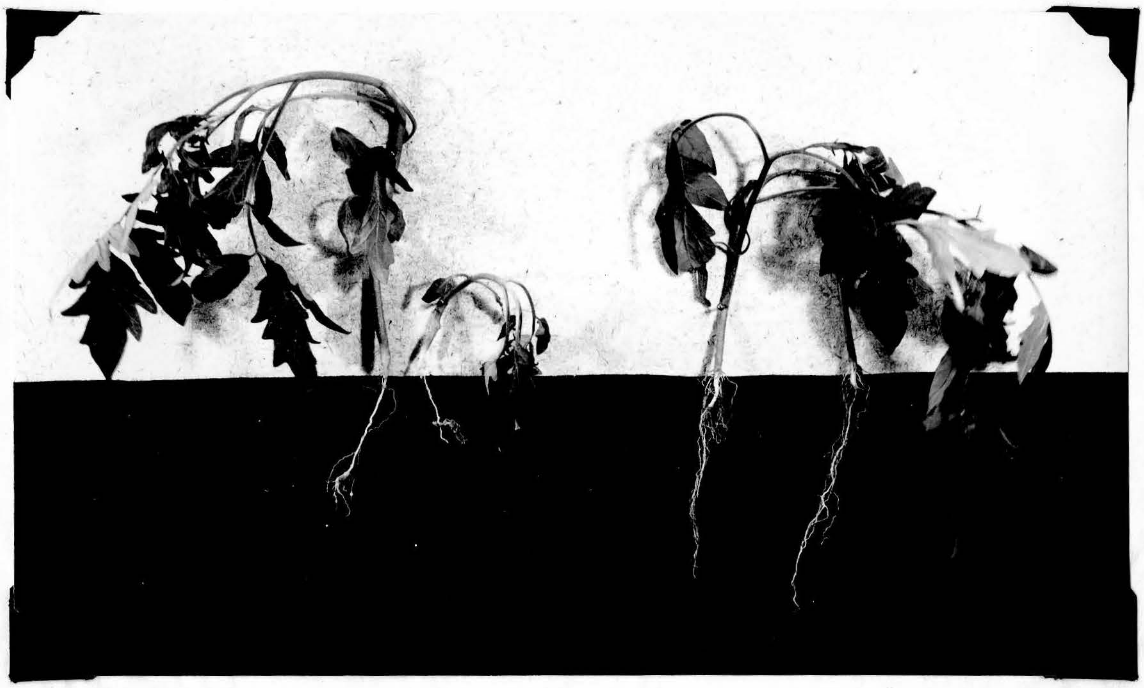
Table 5.- The Effect of Temperature and Time Upon Efficiency of Sterilization

(Growing Period - Dec. 11, 1937 to Mar. 7, 1938)

Pot No.	Temp. C°	Time Sterilizing	Time After Sterilizing	Nematodes	Root	Kind Plant	Height Plant	Remarks
14	44	1 hr.23 m	Dumped	Severe	-	Tomato	15"	Unsuccessful
14A	45	1 hr.40 m	Dumped	Severe	-	Tomato	4"-12"	Unsuccessful
10A	46	3 hr.30 m	Dumped	Heavy	Bad	Tobac.	-	Unsuccessful
9	47	18 hrs.	Dumped	None	-	Tomato	15"	Successful
12	50	1 hr.37 m	Dumped	Severe	-	Tomato	7"-12"	Unsuccessful
14B	50	1 hr.52 m	Dumped	Severe	-	Tomato	3"-11"	Unsuccessful
15	50	1 hr.41 m	Dumped	Bad	-	Tobac.	-	Unsuccessful
6	51	1 hr. 2 m	17 hrs.	None	-	Tomato	9"-33"	Successful
10B	52	4 hr.41 m	Dumped	Heavy	Bad	Tobac.	-	Unsuccessful
7	54	5 hr.30 m	21 hrs.	None	-	Tomato	14"-21"	Successful
10C	54	5 hr.30 m	Dumped	Trace	None	Tobac.	-	Unsuccessful
15A	55	1 hr.51 m	Dumped	Many	-	Tobac.	-	Unsuccessful
10D	58	19 hrs.	Dumped	Few	None	Tobac.	-	Unsuccessful
11	59	1 hr.40 m	Dumped	Light	-	Tomato	10"-14	Unsuccessful
14C	60	2 hr. 5 m	Dumped	Light	-	Tomato	6"-8"	Unsuccessful
15B	60	2 hr. 6 m	Dumped	Light	-	Tobac.	-	Unsuccessful
11A	64	2 hr. 5 m	3 hrs.	None	-	Tomato	12"-16	Successful
14D	65	2 hr.15 m	Dumped	None	-	Tomato	7"-12"	Successful
15C	65	2 hr.13 m	Dumped	None	-	Tobac.	6"-17"	Successful
14E	69	2 hr.30 m	Dumped	None	-	Tomato	12"-12	Successful
15D	70	2 hr.25 m	Dumped	None	-	Tobac.	0	Successful
Check - Root Rot Soil					Bad			
Check - Nematodes Soil				Heavy				

Controlling Black Root Rot

Figure 5. Showing the contrast between tobacco plants grown in the unsterilized check pot front center and the sterilized pots.



Unsterilized Sterilized

Controlling Nematodes

Figure 6. The root system of plants grown in unsterilized soil compared with the roots of plants grown in sterilized soil. Note the nematodes on the roots of the plants at the left.

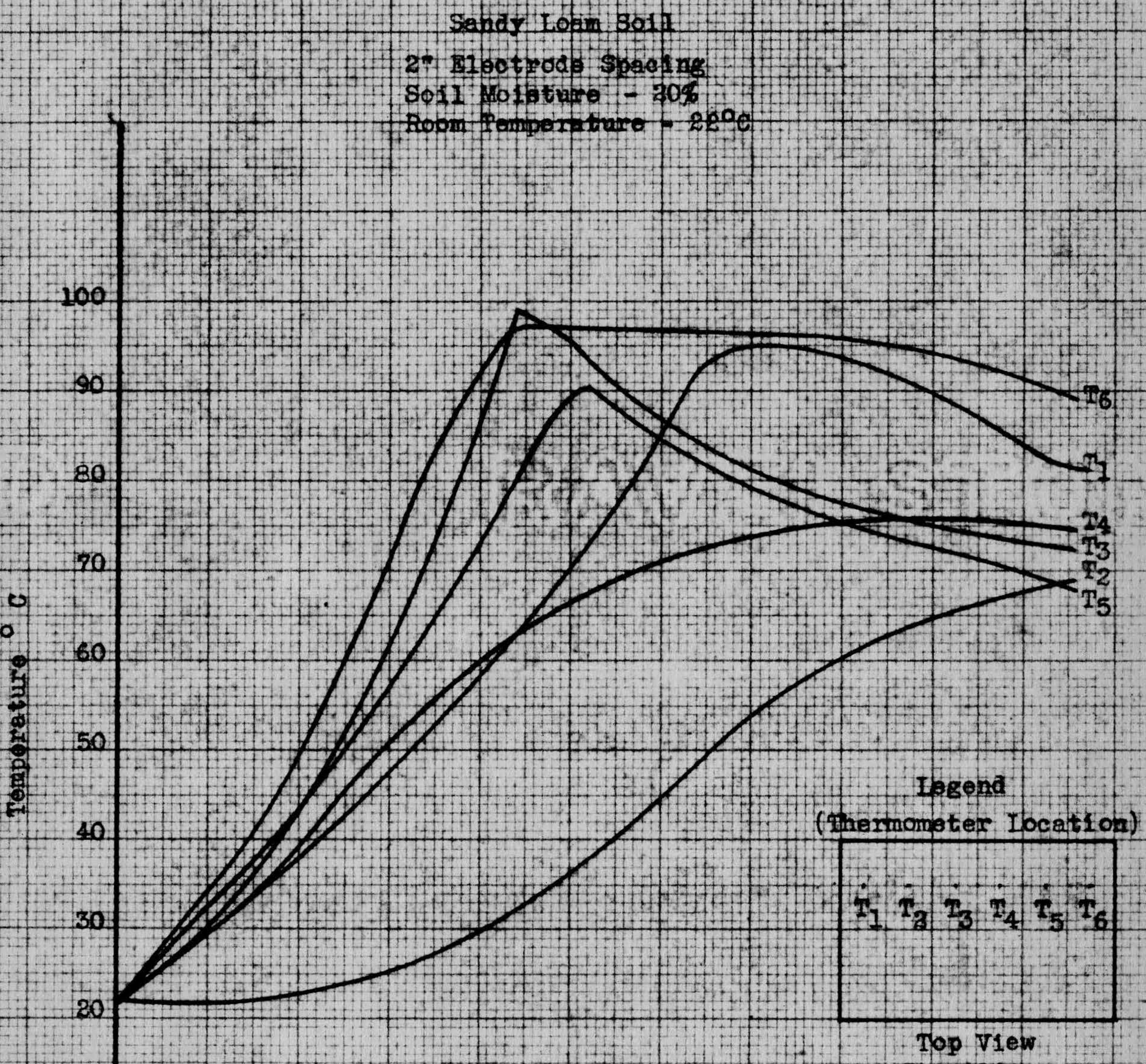
Healthy Plants Grown in Sterilized Soil

Figure 7. Flat of soil heated to 70°C for one hour in the heating element sterilizer. Compare with check flat of unsterilized soil below.

Plants Grown in Check Flat of Unsterilized Soil

Figure 8. Showing the grass, oxyalis, and snapdragons growing among the tobacco plants.

Fig. 9 . Soil Sterilization in the Resistance Sterilizer Showing Variation in Temperatures Midway Between Electrodes.



corners. The high temperature curves begin to fall immediately after the peak is reached throughout the soil mass, after which the fall is gradual.

The temperature variations in various parts of the sterilizer can be partially overcome by observing the following points:

1. Covering the sterilizer with a canvas was found very helpful in checking radiation. When the sterilizer is to be operated in the open on a cool windy day it is impossible to get a temperature rise without this because the heat loss will be greater than the heat input. For this reason, the better the sterilizer is insulated, the better is the chance of preventing the corners from lagging behind. If the sterilizer is to remain loaded for several hours after the current is off, the canvas will help hold a uniform temperature.

2. A uniform moisture content is desirable because dry soil is a poor conductor of electricity. If the moisture content is uneven, more current will flow through the part highest in moisture content, thereby heating it while the dryer portion lags by several degrees and may never reach a desired sterilization temperature.

3. The corners have a tendency to lag behind the main body of soil. This can be overcome by packing the soil in the corners, sprinkling the corners, or eliminating the corners by building a cylindrical sterilizer with horizontal electrodes.

4. It is very essential to have good contact between the electrodes and soil if a uniform temperature is to be obtained;

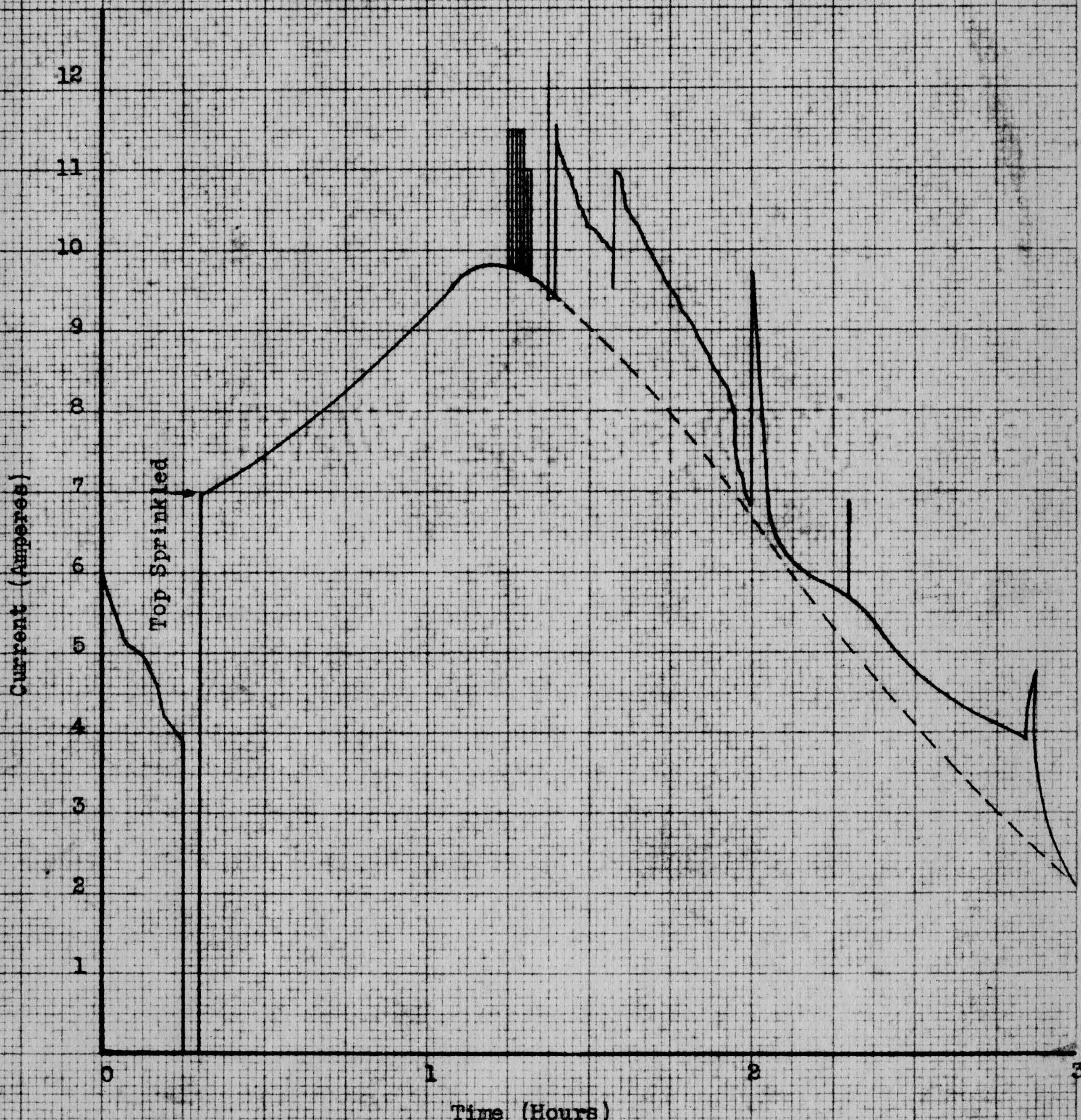
otherwise, the temperature rise will take place between the parts of the soil and electrodes which are making contact. Good contact can be obtained by the addition of weight to the cover of the sterilizer. Evidence of this is clearly shown in Figure 10. A weight of 50 pounds per sterilizer was found to be sufficient.

5. Lumps give a very uneven temperature rise because the moisture content in the lump is not the same as the surrounding soil and the electrode contact is very poor. A minute air gap tends to interfere with the passage of the current and retards heating. Therefore, it is very desirable that all soil be screened before sterilizing.

In the heating element sterilizer it is rather difficult to get a uniform temperature distribution. When water is heated, the solution in contact with the heating surface becomes less dense with temperature rise and moves to the top while the heavier colder water replaces it and the process is continued. Thus, the water is heated by convection, conduction and radiation.

Unfortunately, soil does not behave this way when heated. Soil being a solid, is dependent upon conduction and radiation for heat transfer. This results in an almost impossibility of securing a uniform temperature distribution throughout the soil mass. The soil near the heaters reaches an extreme temperature, burning out all organic matter and killing beneficial bacteria. The conduction properties of soil are very poor but can be made fairly satisfactory with the proper moisture content. Figure 11 gives the minimum temperature curves

Figure 10. Soil Sterilization in Resistance Sterilizer Showing Effect Additional Pressure on Electrodes has on Demand Due to Better Contact.



between the heaters. The maximum temperatures were too high to record with the thermometers available.

The temperature differential is great enough to give an 8° C to 10° C temperature rise in the minimum parts of the sterilizer after the current is cut off. This will result in a saving of energy if it is closely watched by the operator.

Curve No. 5 represents a point in the lower right corner. Note the quick temperature rise and fall. Curve No. 1 represents a corner near the top with the lid cracked. The heat loss was considerable at this point. The other curves represent points in the front center of the sterilizer.

Time:

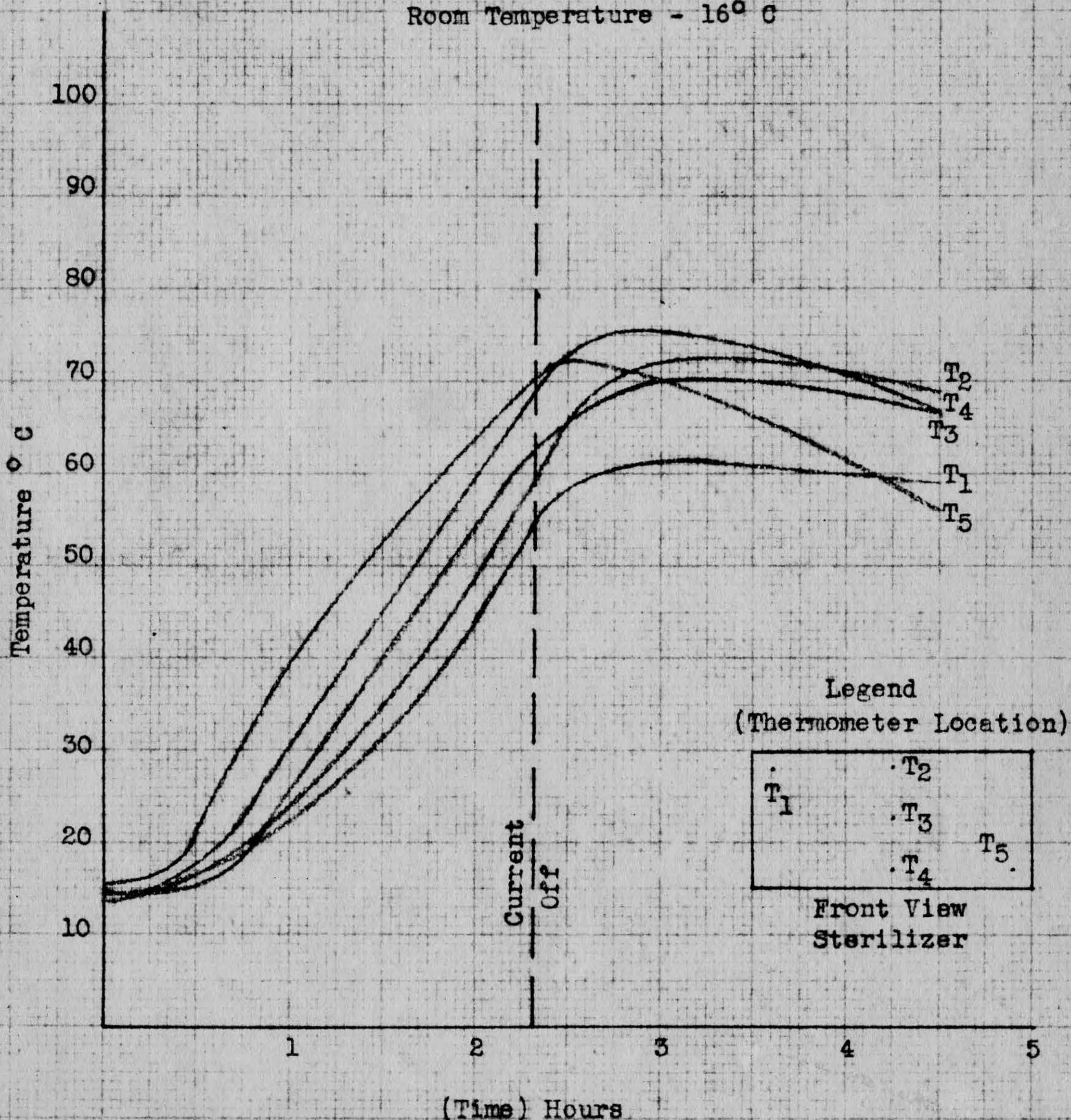
Tests run on both sterilizers show that it is necessary to maintain a soil temperature of 70° C for a minimum length of 10 minutes to efficiently sterilize soil. If lower temperatures are to be used, the length of time required to eliminate nematodes is much longer. The table below gives the results of tests in which the soil remained in sterilizer for a period after the current was cut off.

Table 6. Length of Time Required for Electric Soil Sterilization

Final Temperature Degrees Centigrade	Time Sterilizing	Time After Sterilizing
50	1 hr.	17 hrs.
55	4 hrs.	12 hrs.
60	3 hrs.	9 hrs.
65	2 hrs.	3 hrs.
70	30 min.	10 min.

Figure 11. Soil Sterilization in Heating Element Sterilizer Showing Variation in Minimum Temperatures Between the Heaters.

Sandy Loam Soil
Moisture Content - 25%
Room Temperature - 16° C



It is not practical to let the soil remain in sterilizer for many hours because the amount of soil that could be sterilized in a given time would be very small.

The length of time required to elevate soil through certain temperature ranges with the resistance sterilizer varies with the power demand, moisture content, soil type, and temperature rise of soil. Therefore, it is rather difficult to state any definite period required to sterilize a given quantity of soil. The time required can be estimated if the initial demand is known by substituting in the formula below.

$$\text{Time (Hours)} = \frac{\text{Kilowatt hours per cu. ft. (Table 3) X Vol. Box (cu.ft.)}}{\text{1.5 X Kilowatt demand (initial)}}$$

Example: Given - Sterilizer capacity - 5 cu. ft.
Initial demand - .8 k. w.
Initial soil temperature - 20° C
Desired soil temperature - 70° C
To Find - Time required in hours

$$\text{Time} = \frac{1.02 \text{ X } 5}{1.5 \text{ x } .8} = 4.25 \text{ hours}$$

The time required to elevate sandy loam soil through 50° C with the heating element sterilizer is almost constant, the moisture content making the variations in the different tests. A formula has been worked out by Cornell University Agricultural Experiment Station for estimating the time required for sterilization. This is illustrated in the formula and example below:

$$\text{Time (Hours)} = \frac{\text{Kilowatt-hours per cu.ft. (Table 3) X Vol. Box (cu.ft.)}}{\text{Kilowatt capacity of heaters}}$$

Example: Given - Sterilizer capacity - 5 cu. ft.
Kilowatt capacity of heaters - 2.0 k.w.
Initial soil temperature - 21° C
Desired soil temperature - 70° C

$$\text{Time} = \frac{1.08 \times 5}{2} = 2.7 \text{ hours}$$

Moisture Content:

A certain initial moisture content (20 - 30%) was found to be essential for the satisfactory operation of both types of sterilizers although for different reasons in each.

A certain initial soil moisture is essential in the resistance sterilizer to give electrical conductivity. Sandy loam soil with various moisture contents was tested to find the relation between the proper moisture content and time. It can be shown that by the addition of a small amount of water the sterilizing time can be cut in half. The relationship that soil moisture has on demand and time is illustrated in Figure 12. With an initial moisture content of 15 percent it was next to impossible to reach a sterilization temperature. The reason for this is very interesting. When the sterilizer is started, the kilowatt demand rises steadily, increasing the temperature until the boiling point is reached. As the point of contact between the electrodes is always a little hotter than the main soil mass, naturally steaming occurs at this point first. This immediately dries out the soil, breaking the contact and results in the demand dropping lower than the original start. In some measure, this is a safety feature, automatically turning off the power without overheating the soil. However, if the moisture content of sandy loam soil is below 15 percent, this drying out of soil will cut the sterilizer off before heating has taken place. Figure 12 shows the proper moisture content to be between 20 and 30 percent for sandy loam soil. This is usually soil with the proper moisture contents for planting. Sandy loam soils with moisture contents above 30 percent are dangerous because the wiring system is likely to be overloaded.

Due to the increase in demand with increase in moisture content, the length of time required for sterilization is greatly shortened. Figure 13 illustrates the affect various moisture contents have on the temperature and time. The length of time required for sterilization can be cut in half by doubling the moisture content.

A certain initial soil moisture is required for the heating element sterilizer to give thermal conductivity. Dry soil is a good insulator and without the proper moisture the heater will burn the soil to a point where all organic matter and beneficial bacteria are destroyed without the main body reaching a safe sterilization temperature. The soil is then in worse shape than before sterilization. The water holding capacity is reduced to a minimum and the remaining harmful bacteria can thrive with their enemies absent in the heated area.

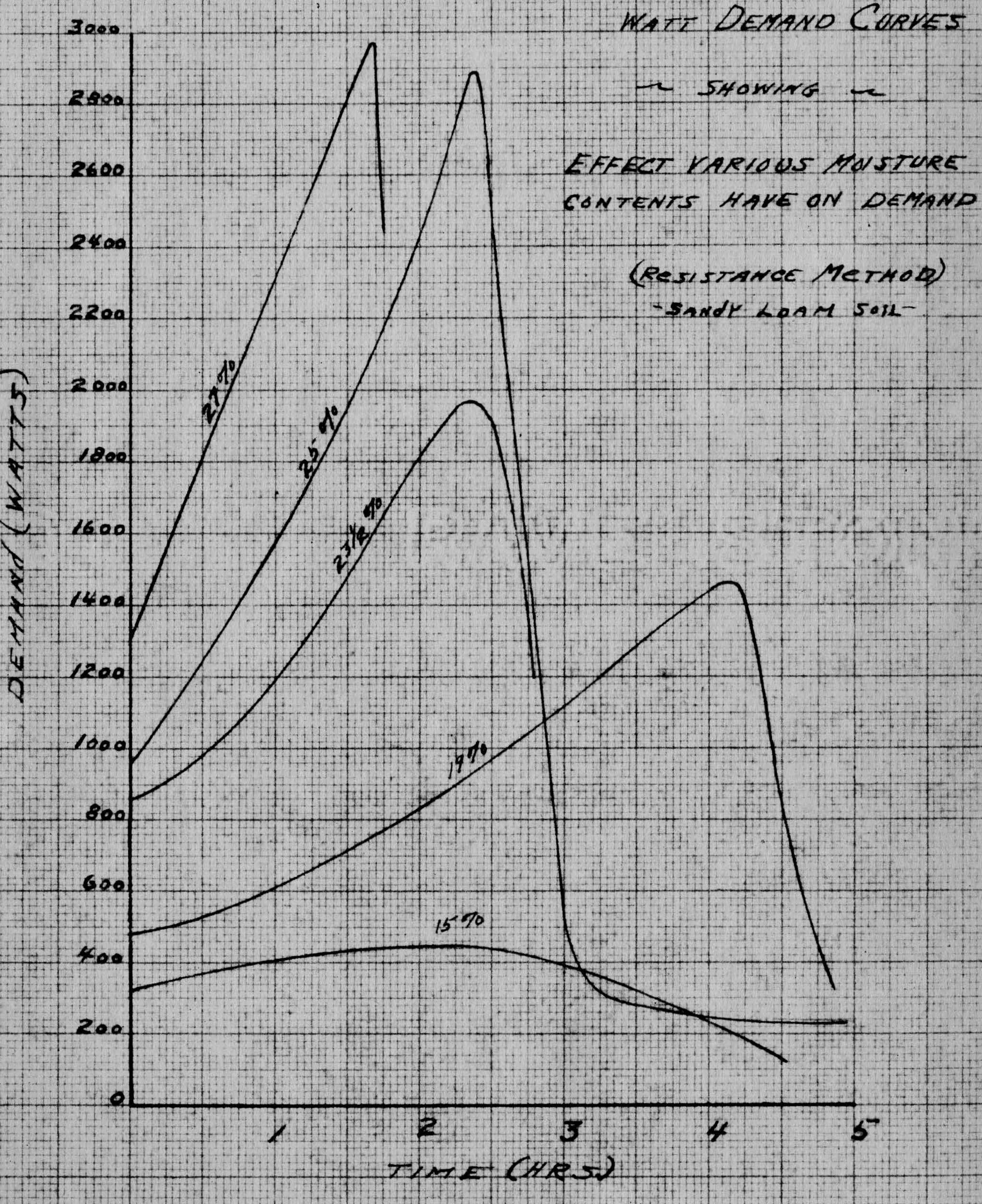

WATT DEMAND CURVES
~ SHOWING ~
EFFECT VARIOUS MOISTURE CONTENTS HAVE ON DEMAND
(RESISTANCE METHOD)
-SANDY LOAM SOIL-
DEMAND (WATTS)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
27%
25%
23½%
19%
15%
1
2
3
4
5
TIME (HRS.)

FIGURE 12

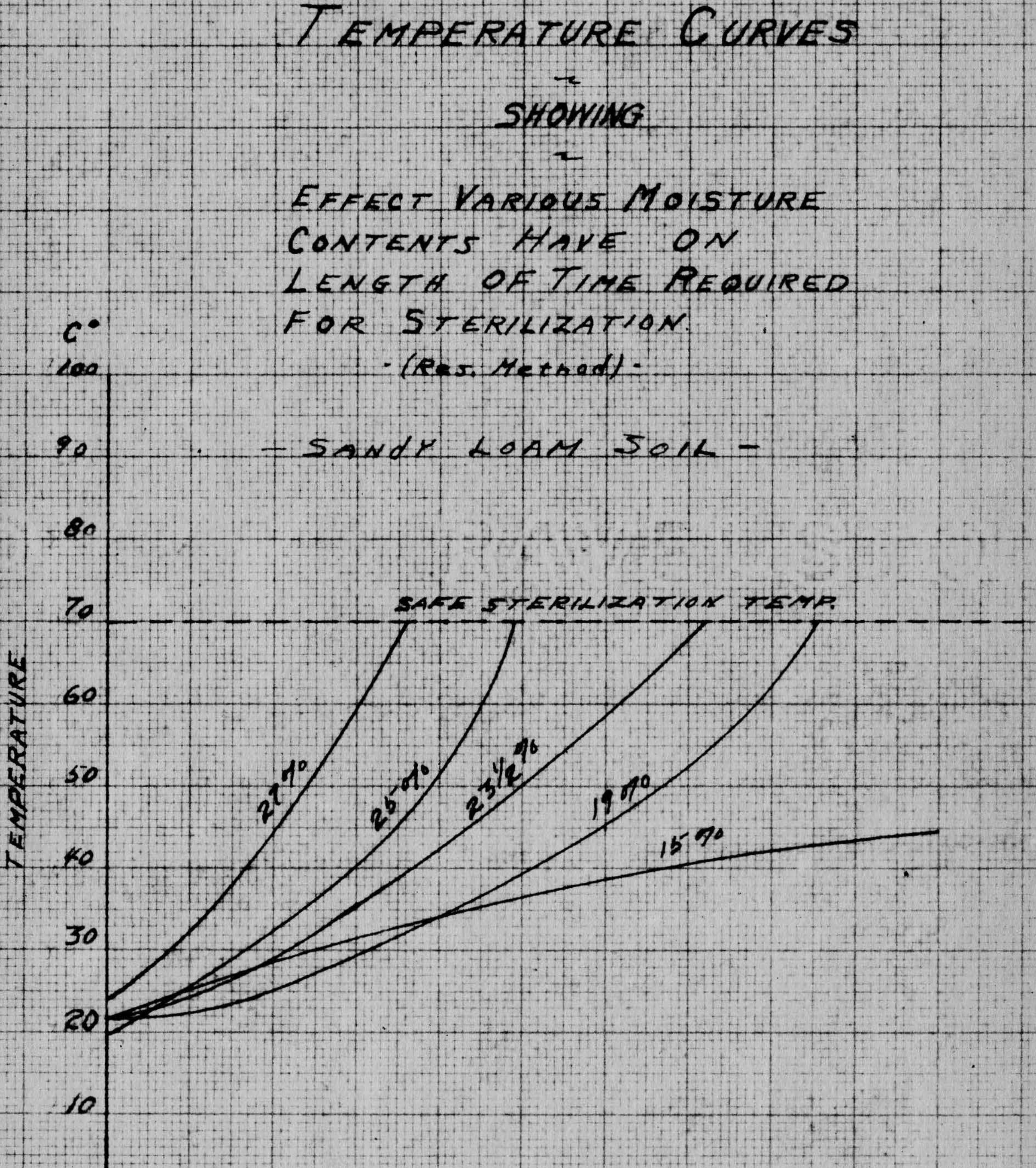

TEMPERATURE CURVES
SHOWING
EFFECT VARIOUS MOISTURE CONTENTS HAVE ON LENGTH OF TIME REQUIRED FOR STERILIZATION.
·(Res. Method)·
– SANDY LOAM SOIL –
SAFE STERILIZATION TEMP.
C°
100
90
80
70
60
50
40
30
20
10
0
TEMPERATURE
27%
25%
23 1/2%
19%
15%
1
2
3
4
5
HOURS

FIGURE 13

SELECTION OF THE MOST PRACTICAL AND EFFICIENT METHOD OF SOIL STERILIZATION THAT CAN BE RECOMMENDED TO GREENHOUSEMEN, MARKET GARDENERS, FLORISTS

It is essential that a good sterilizing method possesses certain important qualities of operation. The following requirements are listed in the order of their importance: (1) Capability of producing a uniform temperature throughout the soils mass; (2) Safety of operation; (3) Simplicity of operation; (4) Well insulated for heat and electricity; (5) Constant electrical demand; (6) Comparatively cheap to operate; (7) Reasonable in forst cost; (8) Light in weight.

Both types of sterilizers have advantages and disadvantages which may be listed as follows:

The Resistance Sterilizer has the advantages of (1) uniform temperature distribution throughout the soil mass; (2) Lower operating cost; (3) Simple construction; (4) Lower first cost; and (5) Light weight.

It has disadvantages as follows: (1) Power demand varies with moisture content, temperature rise, soil type, time and organic matter in soil; (2) Hazard of electric shock; (3) Contact between plates difficult to maintain; (4) Proper moisture ~~for~~ content necessary to prevent cutting off.

The Heating Element Sterilizer has the advantages of (1) Constant demand; (2) Less dangerous; (3) Simplicity of operation; (4) Moisture content of soils a minor factor in operation.

It has disadvantages as follows: (1) Extreme variation in soil temperature; (2) Higher first cost; (3) Heavier.

If the advantages and disadvantages of both sterilizers are carefully weighed, according to the qualifications, the author believes that the heating element sterilizer would be favored for its great safety and simplicity of operation.

Cautions:

1. Figure 14 shows the relation between the power curves of the two sterilizers. The final demand of the resistance sterilizer is always two to three times the initial demand. It is very essential that the wiring system be of large enough capacity to take care of this variable load. The average greenhouseman should, therefore, consult his local power company before making this installation.

2. The danger from electric shock is very great with the resistance sterilizer although a safety device is installed to prevent the operator from coming in contact with the live electrodes. One should be very careful that the legs are insulated from the ground and that they are kept dry because wet wood ceases to be an insulator. Never touch wood of sterilizer while standing on ground when current is on.

3. Never try to sterilize soil in the plant bed because the neutral wire of the transformer is usually grounded which results in a direct short.

SHOWING THE RELATION BETWEEN POWER CURVES OF RESISTANCE AND HEATING ELEMENT STERILIZERS

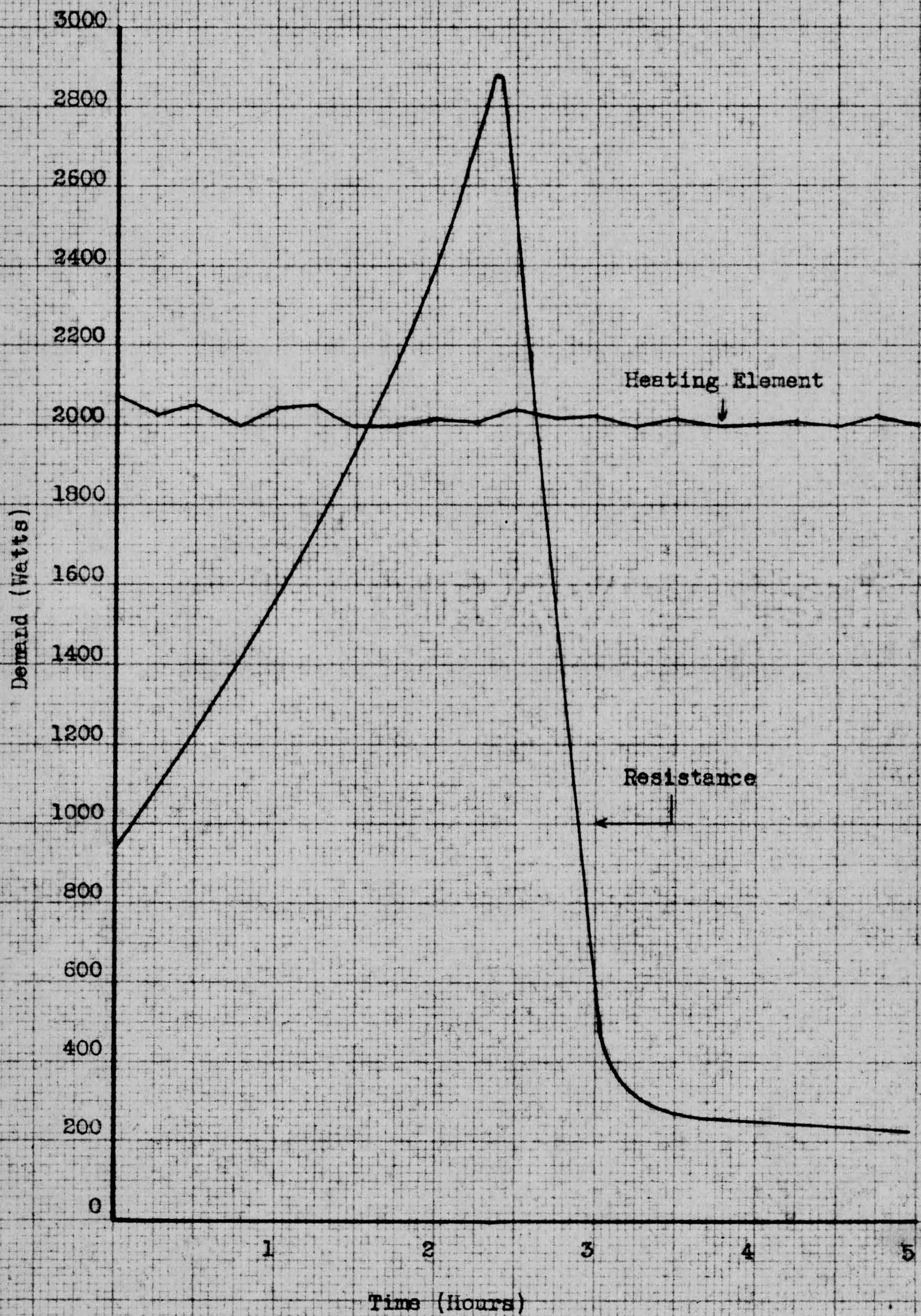


Figure 14

CONCLUSIONS

The author believes that from this rather broad study of factors affecting electric soil sterilization the fundamental results of this report are as complete as could be devised within the time; that some of the results are of great importance and warrant definite conclusions; that some results are probably only possible trends and need to be verified by more extensive data on these phases of the problem; that while some of the results seem quite definite, they vary slightly from published material on this subject. The following conclusions are listed in the order of the objectives of this report:

1. A 50°C rise in temperature (20°C- 70°C) requires from 1 to 1.5 kilowatt-hours per cubic foot.

2. The resistance sterilizer is more economical on power consumption than the heating element sterilizer because of the direct heat input to the soil.

3. A saving in power consumption can be had with the heating element sterilizer by cutting the switch when the temperature is 10°C below the desired soil temperature.

4. Changing the plate spacing in the resistance sterilizer does not affect the power consumption.

5. Evidence is shown in this report that a temperature of 70°C is sufficient to kill all plant seed, nematodes and black root rot.

6. Good heat insulation is essential to obtain a uniform temperature near the edges and corners of both sterilizers.

7. A uniform moisture content is essential in the resistance sterilizer to give uniform conductivity, thereby producing uniform heating.

8. Soil in corners of resistance sterilizer should be tamped lightly to prevent temperature here from lagging behind temperature of main body.

9. All soil should be screened to eliminate air gaps when sterilizing with resistance sterilizer.

10. Weight should be added to the top of the resistance sterilizer to make and maintain good soil contact.

11. If more time is employed, soil can be efficiently sterilized at a lower temperature with a saving of current.

12. A temperature of 70°C must be maintained for at least 10 minutes to effectively sterilize soil.

13. An initial moisture content of from 20 to 30 percent is necessary to sterilize sandy loam soil by either method.

14. The length of time required for sterilization by the resistance method varies directly with the moisture content.

15. A large variety of variables effect the operation of the resistance sterilizer and the author is of the opinion that its use is limited to research work where the operator is thoroughly familiar with electricity.

BIBLIOGRAPHY

Blauser, I. P. Sterilizing Soil with Electricity - Ohio State University, Agricultural Engineering Department, Mimeographed paper No. 15: 1-9, 1934.

Carney, Lawrence B. Electric Soil Sterilization, Agricultural Engineering, 13:95-96, 1932.

Horsfall, James G. Pasteurizing Soil Electrically to Control Damping Off, New York State Agricultural Experiment Station, Bul. 651: 1-8, 1935.

Krewatch, A. V. & Kable, Geo. W. Electric Soil Sterilization - Nat. Rural Electric Project, College Park, Maryland, Rept. No. M-15 (Mimeographed), P. 1-12, 1933.

Scott, J. C. Sterilizing Soil with Electricity - Puget Sound Power and Light Company, Mimeographed leaflet, P. 1-3, September 7, 1932.

Tavernetti, J. R. Characteristics of the Resistance Type Soil Sterilizer - Agricultural Engineering, 16: 271-274, 1935.