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AGRICULTURAL EXPERIMENT STATION

METHODS OF SUPPLYING ELECTRIC HEAT TO HOTBEDS

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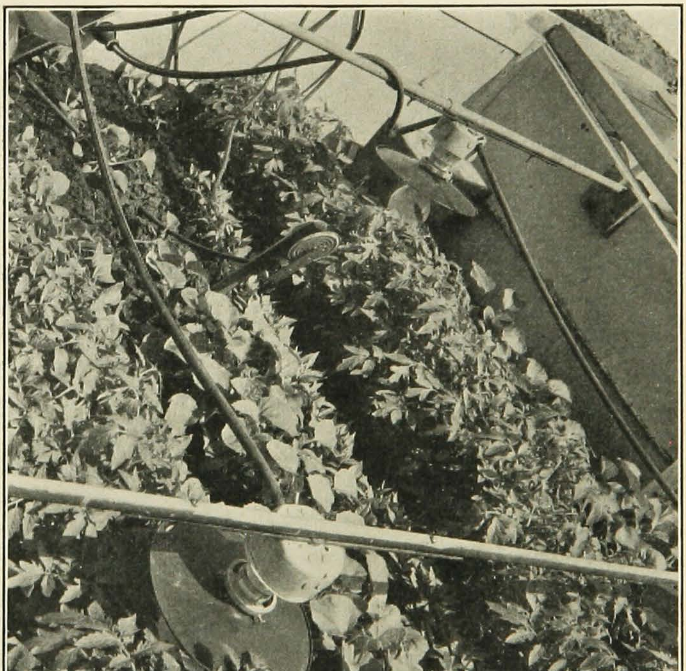

UNIVERSITY FARM, ST. PAUL

SUMMARY

Comparison of four methods of heating hotbeds electrically indicates that any of them will provide sufficient heat even in very cold weather. The use of current, however, is markedly increased by lower outside temperatures.

Radish and lettuce plants grown during the period from February 8 to March 20 attained the largest size in sections that were supplied with artificial light. But the current used was greater than that used in the other two.

The current required to raise the air temperature of the frames a certain number of degrees above the outside temperature was less in the two frames that had no electric lights. This is not an entirely satisfactory comparison, because light may often be the limiting factor in plant growth.

The spring experiment covered the period between March 21 and April 30. The amount of current required for germination of the four crops planted was less in the frames where heat was applied in the soil.

The growth of the plants was best in the sections equipped with lights. By weighing a number of plants it was possible to determine the amount of current required to produce a unit of growth. The lighted beds gave the smallest figures for all crops except peppers. This crop responded about the same to all treatments.

The second experiment again demonstrated the important effect of outside temperature on the consumption of current.

Three growers of vegetable plants furnished certain observations which chiefly show that heating with cable is satisfactory and not expensive. Costs from the three show an average of approximately 95 cents per sash for 31 days.

METHODS OF SUPPLYING ELECTRIC HEAT TO HOTBEDS

T. M. CURRENCE

In the last decade there has been a gradual increase of interest in the use of electricity for heating hotbeds. This interest was greatly stimulated recently by the development of a heating element that can be placed directly in the soil, thereby simplifying installation and reducing first cost. Considerable experimental work has been reported by state experiment stations and various commercial organizations. Further study, however, appears to be needed, with the general objective of reducing installation and operating costs. This bulletin outlines results of an experiment with four electrical heating combinations and suggests the possibility of combining a heating method with one for lighting.

LITERATURE ON ELECTRIC HOTBEDS

Garver and Vincent (1), of Washington State College, were among the first to publish results on heating hotbeds electrically. Their conclusions indicate that operating an electrically equipped bed for a season would cost $5.89 per sash; for a manure bed the cost would be $5.33. These figures are based on the assumption that the electric equipment would wear out in three years. Manure was estimated to cost $12 per cord and electric current 3 cents per kilowatt hour. The figures do not include the cost of labor. This is an important item, as electricity requires a minimum amount of care and eliminates the tedious process of preparing manure for the beds. Also the equipment in use for electric hotbeds should be usable for longer than three years.

Parks (2), of the Missouri experiment station, in a publication covering a large amount of work on the use of electricity for heating hotbeds, draws the following general conclusions:

1. Ordinarily, it is economical to substitute electricity for manure in hotbeds when the cost of trucking and labor is considered.

2. Operating costs on electric hotbeds vary with the season, the crop grown, the insulation, and the method of handling the bed. In general, 100 to 250 kilowatt hours are sufficient to heat a 6 x 12 bed for one season.

3. Under Missouri conditions a cable immersed in the soil will perform essentially the same as heaters placed in an oven-type compartment underneath the soil.

4. A 6 x 12 hotbed frame can be electrified for about $5.00.
5. It is safe and easy to operate.

Nixon (3), of Cornell University, has written general instructions on the use and installation of electric hotbeds. He considers that 25 to 40 kilowatt hours per sash will be the average consumption per season if the seeds are planted March 15. Nixon recommends, also, an installation that will permit turning off a part of the current during the milder weather of late spring. Kable (4), of the National Rural Electric Project at College Park, Maryland, has written on experimental work with electric hotbeds and has summarized the results and general recommendations of others on the subject. Included in Kable's report is a comparison of results obtained by overhead vs. bottom heat. While he thinks the question unsettled, he considers that bottom heat is generally the more satisfactory. In a later report Kable and Krewatch (5) describe an experiment in which favorable results were obtained by placing the heating element on the surface of the soil.

EXPERIMENTAL WORK AT UNIVERSITY FARM

For the experiment at University Farm, an eight-sash frame was constructed in the fall of 1931 on a southern exposure, over coarse gravelly soil. The frame was built entirely above ground and lined with an insulating material. This was covered with a waterproofing compound. The construction was of one-inch pine boards raised on the north side to give a six-inch slope. The outside of the frame was covered with roofing paper. Partitions to divide the frame into four equal areas of two sashes each were constructed and insulated. A different method of heating each of these four beds formed the basis for the experiment and are described. The four beds with systems of heating are illustrated by Figures 1, 2, 3, and 4.

Section A. West end of frame. Heated and illuminated by four 100-watt Mazda lamps attached to a cross piece of one-half inch pipe about 12 inches above the soil. Lamps were equipped with six-inch shallow cone reflectors.

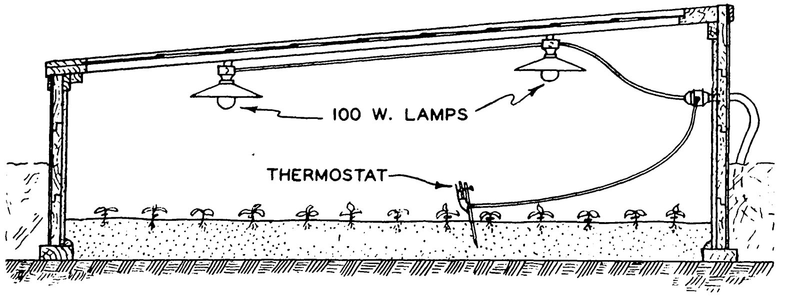

Fig. 1. Method for Combining Heat and Light in Section A

Section B. One hundred twenty feet of General Electric hotbed cable placed in the soil used approximately 200 watts of heat. An additional 200 watts were used by four 50-watt Mazda lamps suspended in the same way as in Section A.

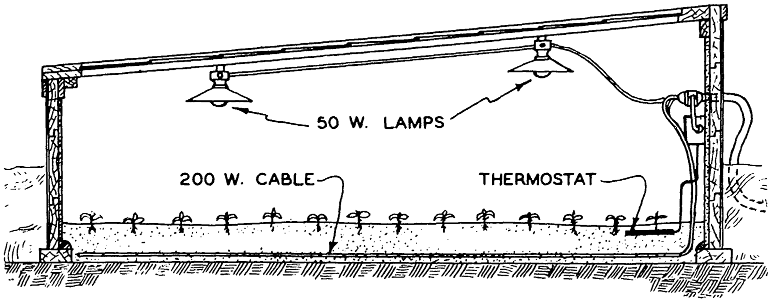

Fig. 2. Method for Combining Heat and Light in Section B

Section C. Sixty feet of General Electric hotbed cable placed six inches below the surface of the soil. This amount of cable delivers approximately 400 watts. This bed was equipped with a second 60-foot length of cable in order to produce more heat in severe weather, but the need of extra heat did not arise during the course of the experiment.

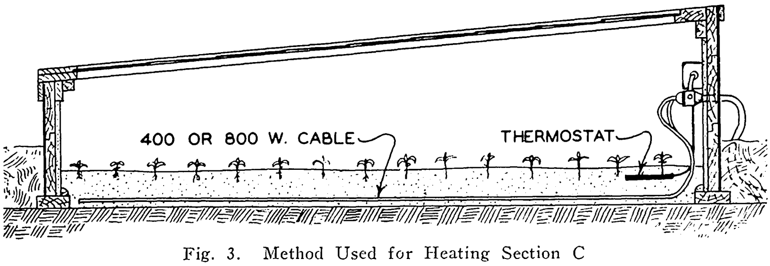

Fig. 3. Method Used for Heating Section C
The second 60-foot unit of cable in the frame was never used.

Section D. Sixty feet of General Electric hotbed cable attached to inside walls of the frame.

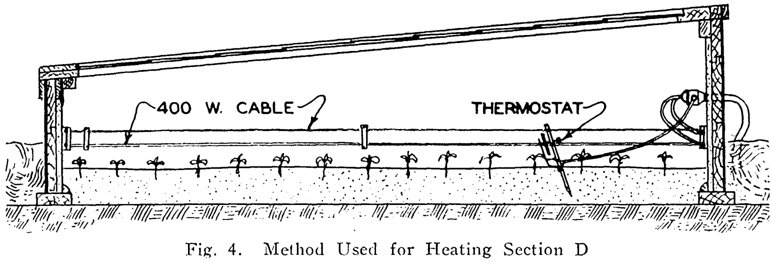

Fig. 4. Method Used for Heating Section D

The sections were all equipped with electric meters and with thermostats to regulate the temperature. The work was divided into two periods, the details of which will be considered separately. The period from February 8 to March 14 will be discussed under the heading "Winter Experiment." From March 21 to April 30 covers the period "Spring Experiment."

Winter Experiment

On February 8, 1932, lettuce and radish seeds were sown in the four sections. These were drilled in alternate rows spaced about six inches apart. An attempt was made to adjust all thermostats in such a way that the air temperature would range from 50 to 55 degrees, Fahrenheit, but the sunshine and the difficulties of making all the thermostats operate at the same temperature caused the heat of the beds to fluctuate.

Table 1

Daily Use of Current, in Kilowatt Hours, for Thirty Days During the Winter Experiment

Date	Section A kwh.	Section B kwh.	Section C kwh.	Section D kwh.
Feb. 11	6	6	4	5
12	6	6	4	5
13	7	8	4	6
14	9	10	6	8
15	8	9	5	6
16	8	8	5	6
17	8	7	10	8
18	7	8	6	6
19	8	7	5	6
20	2	7	6	5
21	6	9	4	5
22	2	7	6	6
23	8	10	7	9
24	4	7	4	4
25	5	7	3	4
26	7	8	3	4
27	5	5	3	3
28	4	5	3	4
29	5	5	1	3
March 1	4	6	3	2
2	2	9	6	2
3	8	6	6	5
4	7	7	5	4
5	7	8	6	6
6	5	9	7	8
7	5	8	7	7
8	8	8	7	8
9	9	9	8	7
10	8	9	7	8
11	7	7	5	6
Total for 30 days	185	225	156	166
Kwh. per sash per day	3.08	3.75	2.60	2.78
At 3 cents per kwh. per bed	$5.55	$6.75	$4.68	$4.98
At 3 cents per kwh. per sash	2.78	3.38	2.34	2.49
Av. cost per day per sash	$0.092	$0.113	$0.078	$0.083

Altho this was a preliminary study and was conducted in colder weather than that in which hotbeds are ordinarily operated, certain recorded data may be of interest.

In Table 1 are shown the daily consumption of current and the comparative cost of each section for 30 days. The differences in cost are not great but probably have some significance. Figure 5 is a presentation of data on the amount of current used in relation to the outside temperature.

This diagram is included for the primary purpose of showing details, and it is therefore thought desirable to present the same data in a more summarized form. This has been done in Table 2, in which the weekly averages for outside temperatures are shown and also the current used, by weeks. From these data it is clearly apparent that outside temperatures have an important bearing on the consumption of current. All beds show an increase for the period from March 7 to 14, when there was a week of very cold weather.

Table 2

Current Used in Relation to Outside Temperatures for the Five Weeks of the Experiment

Date	Section A kwh.	Section B kwh.	Section C kwh.	Section D kwh.	Average outside temperature, degrees F.
Feb. 8-15	49	52	32	42	17.4
Feb. 15-22	47	55	41	42	19.0
Feb. 22-29	35	49	29	34	25.8
Feb. 29-March 7	38	51	34	30	26.8
March 7-14	51	57	48	50	7.9

The outside temperature for the whole period of the experiment averaged 19.7 degrees F. The air temperature inside the structure averaged 65.5, 61.0, 59.9, and 62.3 for the four beds A, B, C, and D, respectively. To compare the heating efficiency of the four treatments, an index, or ratio, has been calculated. The degrees difference between average outside temperatures and average inside temperatures when divided into the total number of kilowatt hours used gives the number of kilowatt hours for each degree rise in temperature. The figures calculated in this way are as follows:

Section	A	B	C	D
Ratio	5.98	6.37	4.58	4.65

The fact that C and D gave almost identical figures is of some interest, because only air temperatures are considered. Apparently the loss in heating the soil is compensated for by a more favorable distribution of the heating element. If records of soil temperatures were available it is probable that C would show a still greater efficiency.

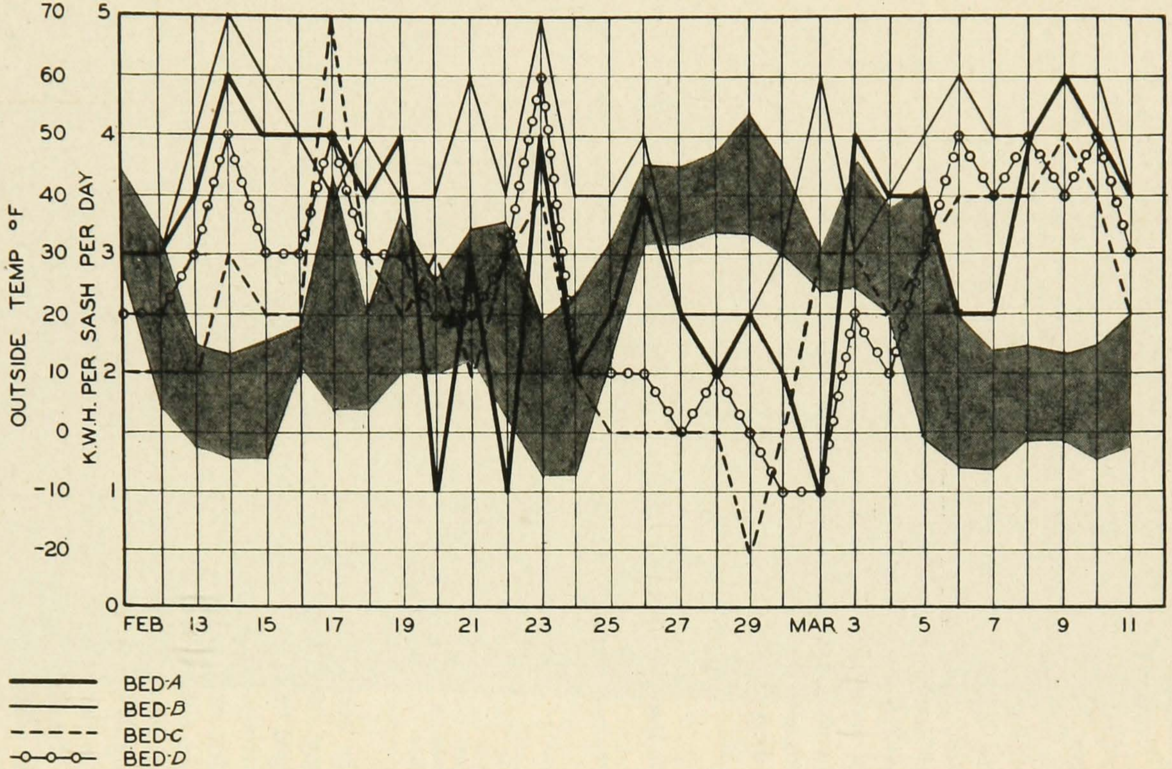

Fig. 5. Effect of Outside Temperature on Amount of Electricity Required to Heat the Sections
The shaded area shows the maximum and minimum readings for outside temperatures.

Altho Beds C and D show an advantage in the comparison, it is not necessarily true that they are the most efficient for plant growing. Light is an important factor in plant growth and Beds A and B were equipped to provide both light and heat. This phase of the problem will be discussed in connection with a later experiment.

Figure 6 is a photographic comparison of plants from the four beds. The picture was made on March 2, approximately three weeks after planting the seed. For commercial use the crops had no value, but the comparative sizes are of interest for showing the rates of growth. The largest plants of both crops were grown in Section A. The lights undoubtedly had a stimulating effect on the growth, as the temperature in this section averaged more than three degrees lower than in any of the others at the time the photograph was made.

The data and observations resulting from this preliminary study provide certain tentative conclusions which may be stated as follows:

1. On an occasion in which the outside temperature dropped to 15 degrees below zero, the lowest temperature in any of the frames was 38 degrees above. At this time the sash were covered with a felt mat of approximately one-half inch thickness. From this it may be concluded that any of the heating methods will protect plants from freezing if reasonable care is used in covering the sash and in the construction of the frame.

2. Section D, with a coil above ground, used less current than any other section and produced better plants than did Section C.

3. Section A produced rank growth that was somewhat uneven. This unevenness could probably be overcome by a better distribution of the lights.

4. The combination of bottom heat and overhead light was expensive to operate but the plants in this bed made good growth.

5. Considerable difficulty was experienced in regulating moisture conditions in Section C. When ventilation was reduced to a minimum in cold weather, moisture condensing on the glass tended to keep the soil surface wet. If properly ventilated, the soil rapidly dried out and baked and also current was wasted. Perhaps unfavorable moisture conditions resulted in the poor growth of the plants in this section.

Spring Experiment

On March 20, seeds of four different crops were sown in the hotbeds—two rows each of muskmelons, tomatoes, eggplants, and peppers. Thermographic records were taken of the soil and air temperatures in each section. The air temperatures were taken two inches above the surface in the northwest corner of each section, the bulbs being shaded from direct sunlight. The soil temperatures were recorded in the center of the beds approximately one inch below the surface. Care

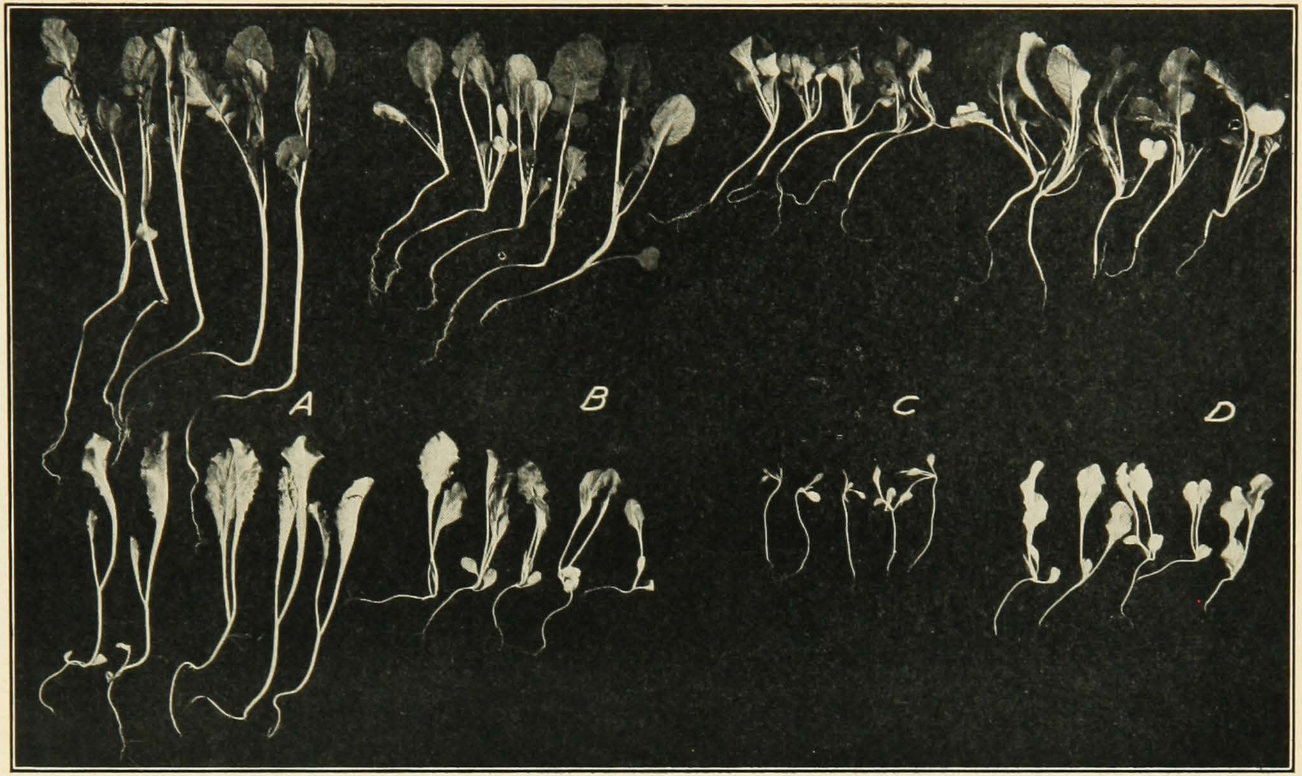

Fig. 6. Representative Radish and Lettuce Plants from the Four Sections
(Photographed March 2)

was taken to place the thermograph bulbs between coils instead of directly over them. During the first three weeks the thermostats were adjusted to connect the circuit as near as possible at 63 degrees. After April 15, the adjustment was made lower in an attempt to operate the frames as economically as possible and to take full advantage of the heat from the sun. The temperature desired in this instance was 50 degrees. Previous to April 6, felt mats were used to cover the sash at night and were left on if the days were cloudy. On that day the use of mats was discontinued and extra sash were used instead. They were simply laid on top of the original sash, thereby no light or heat from the sun was lost in the early morning or late evening hours, as when the mats were used.

Records of outside temperatures were taken in the shade, and the daily consumption of electricity for each bed was recorded. Weekly photographs were made of representative plants, and on April 30 representative plants of each crop were weighed. Thus it is possible to compare several factors in relation to each other for the four treatments.

Table 3 presents a summary of certain data. The days required to germinate the different crops are given. The quickest germination was generally found to be the cheapest, as indicated by the figures on current required. Tomatoes germinated slowest in Section D but the current used was slightly less than for any of the others. For the other three crops, one or the other of the sections with soil heat was cheapest. It seems that for germinating such crops as melons, egg-plants, and peppers soil heat is desirable. The temperatures maintained during this experiment were probably too low to get best results on peppers.

Table 3

Comparisons of Time and Kilowatt Hours Required for Germination and of Current Consumed in Producing a Unit of Plant Growth

		Section A	Section B	Section C	Section D
Tomatoes	Days to germinate	7	6	6	8
	Kwh. required	35.8	36.0	32.5	30.0
	Size of plants (individuals) Apr. 30	5.4±.349	6.4±.291	4.1±.317	3.3±.294
	Kwh. per gram of plants	21.1	22.5	28.5	26.7
Melons	Days to germinate	8	6	6	10
	Kwh. required	39.1	36.0	32.5	38.8
	Size of plants (individuals) Apr. 30	5.0±.190	7.2±.252	2.4±.153	0.9±.034
	Kwh. per gram of plants	22.8	20.0	48.7	97.7
Eggplants	Days to germinate	10	8	9	15
	Kwh. required	49.3	40.7	40.5	66.2
	Size of plants (5 plants), Apr. 30	5.3±.436	6.0±.380	3.3±.139	2.8±.163
	Kwh. per gram of plants	21.5	24.0	35.4	31.4
Peppers	Days to germinate	16	12	13	17
	Kwh. required	81.0	69.1	72.9	69.6
	Size of plants (5 plants) Apr. 30	2.2±.072	2.5±.083	2.1±.089	1.5±.053
	Kwh. per gram of plants	51.8	57.6	55.7	58.7

The size of the tomato and melon plants is the average obtained by weighing 50 plants of each from each fo the beds. The weights for the peppers and eggplants were obtained by weighing 20 samples of 5 plants each, because single plants were too small to be weighed accurately on the balance used. All plants made the best growth in Sec-

Fig. 7. Tomato Plants from the Four Sections (Photographed April 30)

tion B, which had the combination of lights and soil heat. Also it used the greatest amount of current. Section D, which used the least current, produced the smallest plants in all cases. However, a more accurate method of comparing the results is to consider the amount of current required to produce a unit of growth in the different sections.

These data are given in the table, and were obtained by dividing the total current used by the mean weights of the plants. It is apparent that the two beds with lights stand out favorably when compared in this way. Undoubtedly the lights had a stimulating effect on growth and aided in maintaining a favorable temperature. It should be pointed out

Fig. 8. Melon Plants from the Four Sections (Photographed April 30)

that, altho the records were taken on April 30, the differences in the size of the plants were established by April 15. During the last two weeks of the experiment, practically no current was used. If the treatments had been operating during this two weeks the differences in the size of the plants might have been greater.

These calculations were not made for the winter experiment but the largest plants were grown in Bed A and it is possible that similar results would have been obtained. In fact, one would expect best results from the artificial lights under conditions of reduced natural illumination.

Fig. 9. Eggplant Plants from the Four Sections (Photographed April 30)

The figures in Table 4 show the soil and air temperatures in connection with the range for each and in relation to outside temperatures and the amount of current required. As would be expected, the highest soil temperatures occur in the beds having bottom heat. The greatest fluctuations in soil temperature occurred in Bed C. This may have been due to a difference in the thermostats. The air temperatures averaged about the same in all the frames, particularly after April 15, when the thermostats were set to operate at a lower temperature. The current used up to April 15 may seem excessive and costly and undoubtedly a saving could have been made in this respect if it had been attempted. This will be indicated later when the results obtained by growers are discussed.

Table 4

Inside and Outside Temperatures, Degrees F., in Relation to Kilowatt Hours Consumed

Week		Section A	Section B	Section C	Section D	Outside
March 22	Average soil temperature	56.3	67.0	68.0	58.0	
to	Range	10.0	10.0	25.0	17.0	
March 28	Average air temperature........	64.0	64.0	62.0	66.0	31.7
	Range	38.0	53.0	51.0	45.0	40.0
	Average soil and air temperature	60.1	65.5	65.0	62.0	
	Kwh. required	35.8	40.7	35.3	27.4	
March 29	Average soil temperature	57.9	68.0	70.0	56.0	
to	Range	10.0	15.0	16.0	14.0	
April 4	Average air temperature	66.0	65.0	61.0	68.0	35.6
	Range	30.0	41.0	39.0	39.0	38.0
	Average soil and air temperature	61.9	66.5	65.5	62.0	
	Kwh. required	36.1	44.2	44.0	30.5	
April 5	Average soil temperature	58.4	67.6	70.2	57.2	
to	Range	11.0	9.0	31.0	20.0	
April 11	Average air temperature.........	71.0	71.2	68.4	71.2	44.4
	Range	49.0	46.0	49.0	46.0	31.0
	Average soil and air temperature	64.7	69.4	69.3	64.2	
	Kwh. required	27.1	25.2	24.4	20.8	
April 12	Average soil temperature........	64.0	71.8	72.5	64.2	
to	Range	15.0	15.0	27.0	23.0	
April 18	Average air temperature.........	76.5	76.9	75.1	77.9	44.5
	Range	63.0	57.0	66.0	60.0	43.0
	Average soil and air temperature	70.2	74.3	73.8	71.0	
	Kwh. required	13.5	23.7	13.1	9.4	
April 19	Average soil temperature.......	62.6	65.0	65.7	64.6	
to	Range	17.0	23.0	28.0	26.0	
April 25	Average air temperature........	74.1	78.6	73.4	75.6	53.1
	Range	62.0	62.0	60.0	64.0	47.0
	Average soil and air temperature	68.3	71.8	68.5	70.1	
	Kwh. required	2.0	0.0	0.0	0.0	
April 26	Average soil temperature........	57.2	55.8	59.3	56.3	
to	Range	15.0	14.0	27.0	20.0	
April 30	Average air temperature	68.0	66.1	67.2	68.7	44.1
	Range	67.0	69.0	70.0	72.0	40.0
	Average soil and air temperature	62.6	60.9	63.2	62.5	
	Kwh. required	6.4	0.0	0.0	0.0	

Figures 7 to 11 show the comparative size of the plants on April 30. Differences in size were established soon after germination in much the same order as they appear in these photographs. From the illustrations it is clear that the largest plants for all crops except tomatoes grew in Section B. Section A produced good stocky tomato plants and fairly

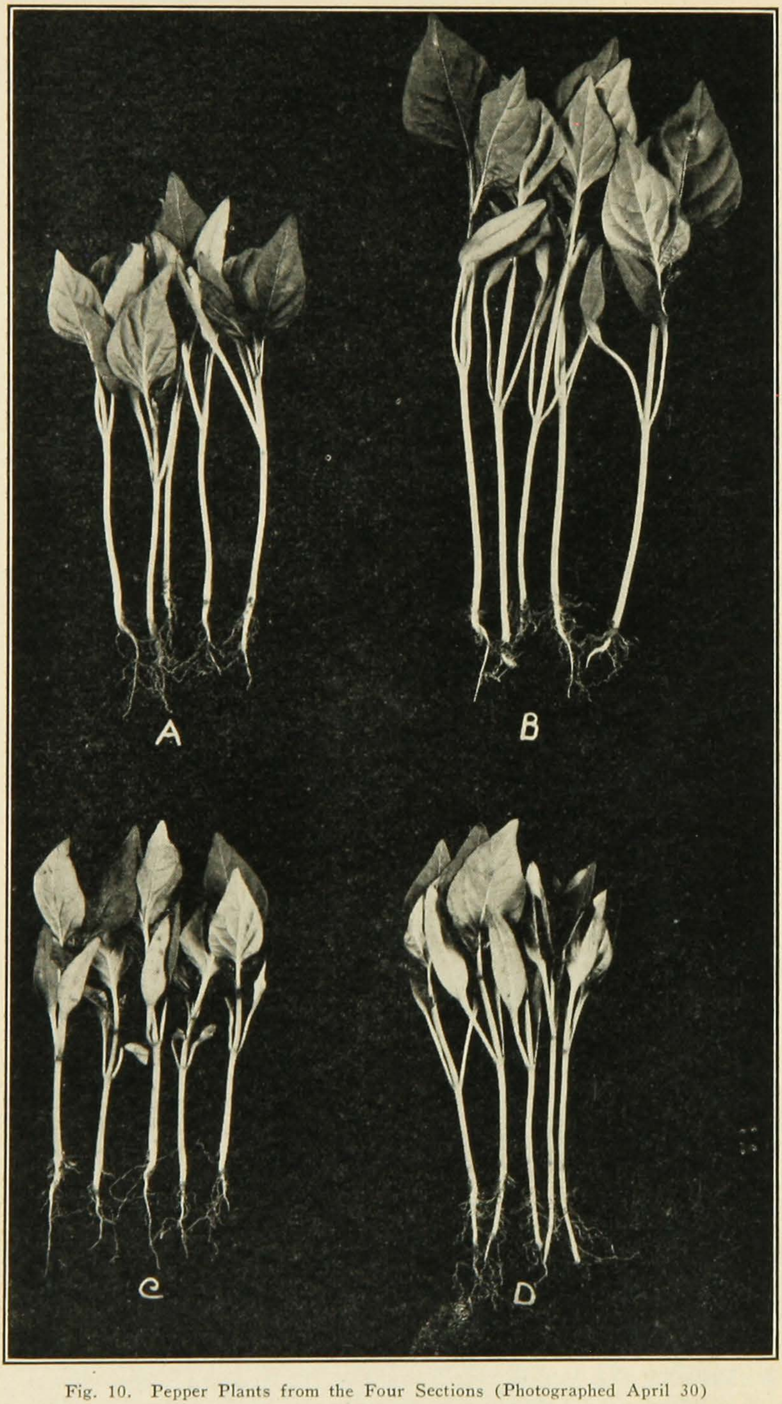

Fig. 10. Pepper Plants from the Four Sections (Photographed April 30)

good plants of all the crops except peppers. The combination of soil heat and artificial light seemed best suited for peppers. The melon plants grown in A and B were large but were somewhat spindling and appeared to be more tender than those growing in the other two frames. Root systems developed in the different beds were not compared other than by the photographs and by rather superficial observations at the time of removing the plants from the soil. No outstanding differences could be noted except that the smaller plants seemed generally to show a larger root system in proportion to the amount of top. Whether or not this could be demonstrated by careful weighings is not known.

COMMERCIAL TRIALS

Three vegetable growers in the vicinity of Minneapolis and St. Paul used electrically heated hotbeds in the spring of 1932. They have kindly furnished certain records and observations that may be of interest to other growers.

Mr. Edward Pieper equipped a four-sash bed (12 x 6 feet) with two lengths of 60-foot General Electric hotbed cable placed about four inches below the surface of the soil. The bed was seeded to peppers on February 23 and the plants came through the ground in nine days. A soil temperature of 65 to 75 degrees was maintained until the plants were approximately one inch in height. At this stage the temperature was lowered to vary from 45 to 55 degrees.

During the first two weeks of this trial the weather was unusually cold, but satisfactory temperatures were easily maintained in the bed. In fact, after three weeks the growth became so rank that it was necessary to lower the temperature in order to prevent the plants from growing too large. The time of seeding was about the same as Mr. Pieper ordinarily uses for his manure-heated beds. He considers that a saving of two weeks could have been made by using the electric heat.

The current used for the first 31 days in the whole frame was 120 kilowatt hours, or 30 kilowatt hours per sash.

At the cost of three cents per kilowatt hour, which was the rate paid by Mr. Pieper, the total is $3.60, or 90 cents per sash.

The results were entirely satisfactory to this grower and he plans a larger installation in the near future.

F. W. Bennis, of Hopkins, Minnesota, installed electric heat in a six-sash bed (18 x 6 feet). Two 60-foot lengths of General Electric hotbed cable were used and were laid on the surface of the soil. Peppers, tomatoes, and cabbages were seeded in flats and the flats placed on the cable. Germination of peppers and tomatoes required about eight days. The stand was fair, but somewhat uneven. A temperature of 60 to 65 degrees was maintained until the plants were about one inch in height and was then reduced to 50 to 55 degrees.

The seeding was done March 16 to 19 and the plants were transplanted on or before April 14. At the end of the 26 days, 179 kilowatt hours had been used, or practically 30 kilowatt hours per sash. The cost was 90 cents per sash for current used.

A further opportunity to observe the effect of cold weather on current used was furnished in this case. The current was turned on March 14, two days before seeding. A severe cold spell occurred during the following week with temperatures going below zero at times. On March 21, 92 kilowatt hours had been used but the proper temperatures inside the bed had been maintained without difficulty. Obviously this week of cold weather had an important effect on the total current used and gives an idea as to the current required under adverse weather conditions.

B. W. Faber, of Robbinsdale, Minnesota, installed two 60-foot lengths of the General Electric cable in a six-sash bed. The cable was attached to the sides of the frame. As the soil was frozen when put into the beds, about one week was required to thaw it and get it prepared for planting. The current was turned on March 14 and pepper, tomato, and onion seeds were planted on March 20. Germination occurred about 14 days after seeding. Altho the trial was not entirely satisfactory, a good crop of all the plants was grown. Mr. Faber considers that cheaper results would have been obtained if the cable had been put in the soil. He expects to use a combination of soil and air heat in the future. The current used up to April 13 by the six sashes was 211 kilowatt hours, at a total expense of $6.48. This would have been considerably reduced if it had not been necessary to thaw the soil during a period of unusually cold weather.

Considering the results obtained by these three men it seems practical to use electricity for heating hotbeds under their conditions and the fact that all of them plan further installations indicates that they are satisfied with their results.

GENERAL CONSIDERATIONS

Each of the four methods of heating used in the experiment appears to have certain advantages and disadvantages and the type to be recommended for commercial use is a matter depending largely on the use the grower intends to make of it. Apparently, underneath heat should be most economical for germinating seeds in general. For rapid growth after germination and particularly in cloudy weather the lights will have an advantage for most crops. The combination of lights and soil heat will be adapted to a wider range of conditions. This combination used considerably the most current in our trials but was not the most expensive considering the plants produced. It is possible that better results would be obtained if the bottom heat were turned off as soon as germination occurs leaving the 200 watts to be obtained only through the lights. By using 25-watt light bulbs and placing them four to a sash, a better distribution of heat and light would be obtained. This should eliminate the uneven growth that was experienced during this study.

It is thought by some that light has an important function in preventing damping off. During this experiment, damping off was not prevalent, therefore this phase of the subject was not studied. If such a control measure can be satisfactorily demonstrated it will be a factor worthy of consideration.

The use of lights probably would be desirable for a bed of less than 6 x 6 feet in size. As reducing the watts of heat necessitates lengthening the cable, a heating capacity of 200 watts would require a cable 120 feet long. Obviously this length would be cumbersome to install in a small area. Home gardeners and amateur flower growers appear to be considerably interested in electric hotbeds of about one sash in size. It is believed that lights or a combination of lights and cable attached to the same circuit would meet their heating requirements.

ACKNOWLEDGMENT

The writer is indebted to the Northern States Power Company for providing and installing the electrical equipment used for the work. John M. Larson, of the rural sales department of the company, furnished diagrams 1, 2, 3, 4, and 5 and offered suggestions on various phases of the study. H. B. White and L. W. Neubauer, of the Division of Agricultural Engineering, co-operated in recording the soil and air temperatures during April.

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