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CONTENTS

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THE EFFECT OF A PAPER MULCH ON SOIL TEMPERATURE

BY CHARLES F. SHAW*

INTRODUCTION

Paper mulch is a term applied to a covering of specially prepared paper placed on the surface of the soil for the purpose of modifying soil temperatures, decreasing losses in soil moisture by evaporation and preventing or decreasing the growth of weeds. The paper mulch is extensively used in the Hawaiian Islands on pineapples and to some extent on sugar cane and certain vegetables. Farmers and vegetable growers in California are experimenting with the paper mulch and manufacturers are putting on the market papers specially prepared for this purpose.

There is very little literature bearing directly on this subject. The proceedings of the Annual Short Courses in Pineapple Production at the University of Hawaii[1, 2, 3] contain some discussions of the paper mulch, and a number of papers of a popular nature have been published in the news journals of the Islands. Mr. Charles F. Eckart,[4] the originator and patentee of the method, and the manufacturers of mulching paper, report material benefits from its use, especially in weed control and in increased crop yields. In none of these publications is there any extended discussion of the effects on soil temperature or soil moisture. The Hawaiian Sugar Planters' Experi-

* Acknowledgments are due to Professor J. W. Gilmore, who supervised the planting and supplied all crop data, and to Mr. E. V. Winterer, who cared for the thermographs and made the soil moisture determinations.

ment Station has undertaken some studies of the effects of the paper covering in these regards, but no reports have yet been published. Unpublished data show a material increase in temperature and a considerable reduction in the loss of soil moisture where the paper mulch is used.

EXPERIMENTAL WORK

The experiments herein reported were undertaken to study the effects of the paper mulch on soil temperatures and soil moisture and the correlated effects on growth and development of certain crops. A plot of land about 30 $\times$ 60 ft., on the campus in Berkeley, was prepared by thorough cultivation and the removal of all stones, hard lumps and trash. Three crops were chosen for trial—milo, beans and potatoes—because they represent plants of different vegetative and fruiting habits. A further consideration was that milo is not suited to Berkeley conditions, while beans and potatoes normally do well here. The crops were each planted in three 60-foot rows placed approximately 36 inches apart. After the plants were up and well established, the paper covering was placed on the south half of the tract. The plots were prepared, the crops planted and thermographs installed early in May. The paper covering was laid on May 17, and temperatures were recorded from that date. Observations were continued to August 25 (ten days after the beans were harvested) giving a total record of 100 days.

Paper

Unperforated paper, weighing about 12 lbs. to the 100 square feet and impregnated and coated on both sides with asphaltic material, was used as the mulch cover. This was placed on the ground between the rows after the plants were well up, the paper being fitted tightly against the rows of beans and corn, and around the individual potato plants. The paper was held in place by lath placed along each edge and fastened down by long wire staples thrust into the soil. The potato plot had additional lath crossing the paper strips at intervals. It is necessary that the paper be well fastened down, otherwise it will be pulled loose and blown away by winds. Lumps and stones must be removed as they will cause the paper to break, and give access to the wind, which will tear and blow the paper. The location and layout of the plots, position of thermographs and the method of fastening the paper are shown in figures 1 to 4.

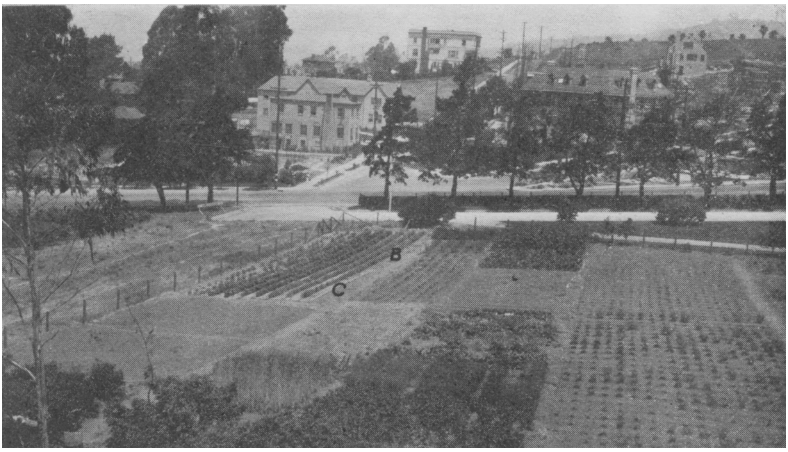

Fig. 1.—Location of covered (C) and bare (B) plots in gardens north of Hilgard Hall. The potatoes are nearest the fence (left), beans in the middle, and milo on the right.

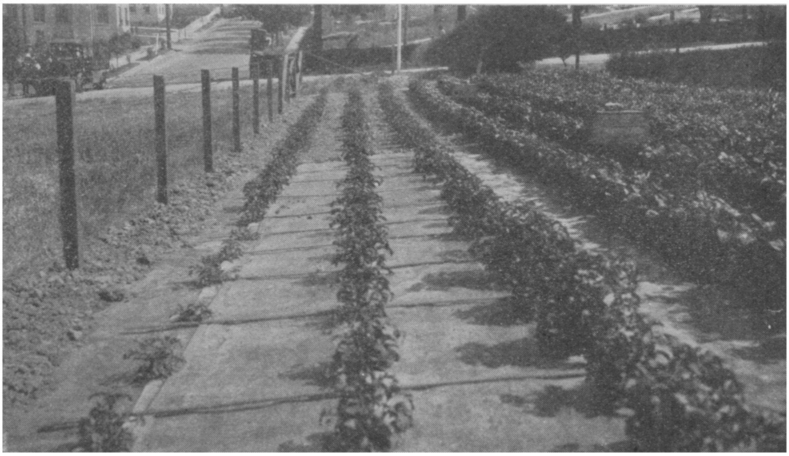

Fig. 2.—Potato plots, June 28, 1924. Note lath on either side of the rows and across middle to hold the paper. Potato results disregarded because of uneven stand due to poor seed and variation in soil.

Fig. 3.—Milo plots, June 28, 1924, from the covered end. Note the lath on either side of the rows to hold the paper. These were fastened by wire staples thrust well into the ground.

Fig. 4.—Milo and bean plots, June 28, 1924, from the bare end. The two thermographs can be seen within the shelters in the bean plots.

Thermometers

Two recording thermographs were used; one recording soil temperature only, the other recording both soil and air temperatures. The thermographs were placed in box shelters, mounted on posts about 18 inches above the soil surface, the thermometer bulb being buried in the soil about four feet north of the shelters, well away from any effect of shading or radiation from the shelter. The bulbs were placed in the soil in a horizontal position with the top of the bulb three inches below the soil surface, the wire tube to the thermograph being covered to a greater depth, and led up to the instrument in a wooden case. The thermographs were inspected daily, and were checked against mercury thermometers at intervals. The resulting records are complete, except for one period when the clock in one instrument was out of order; and another when the recording pen failed to leave its mark during the period of highest temperature.

Weather

The weather conditions throughout the experiment were normal, although the amount of fog was rather low. The Weather Bureau records show that there were 48 clear days, 17 cloudy days and 35 partly cloudy days. There was .07 in. rain on June 9, .01 in. on August 18, and a trace on August 19. During this period the winds were gentle, except on May 29 and 30, when there was a strong wind blowing from the north.

The records of the air temperatures over the plots are somewhat misleading in that the maximum on the bright sunny days is excessively high. This is due to the lack of ventilation in the instrument shelter, and the undue heating by radiation from the box covering. On cloudy days this was not noticeable, and during the night the recorded air temperatures appear to be correct.

Soil Temperatures*

The temperatures of the bare and covered plots and of the air are shown graphically in figures 5 to 11. Figure 12 shows one of the original thermograph sheets, giving the record of the covered plot and of the air for the week beginning June 30.

* Temperatures reported throughout this paper in degrees Fahrenheit.

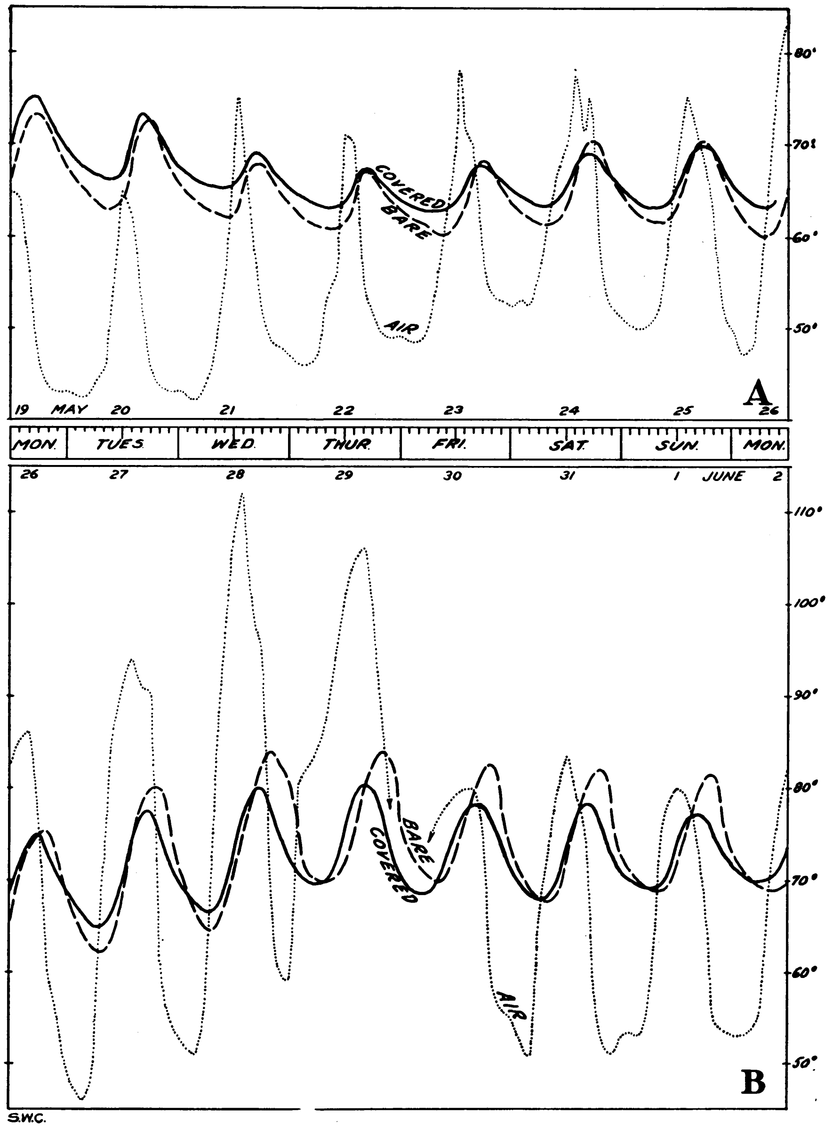

Fig. 5.—Temperature records reproduced from thermograph sheets. A—for week of May 19 to 26. B—for week of May 26 to June 2.

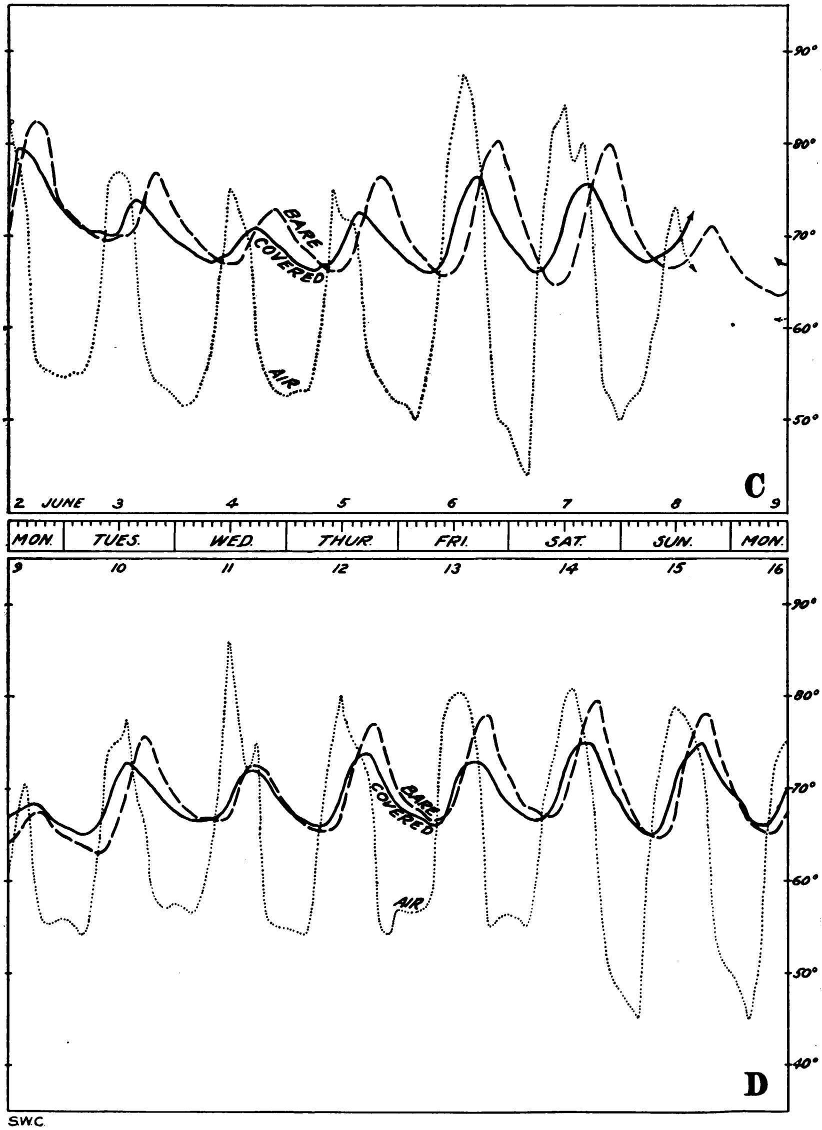

Fig. 6.—Temperature records reproduced from thermograph sheets. C—for week of June 2 to 9. D—for week of June 9 to 16.

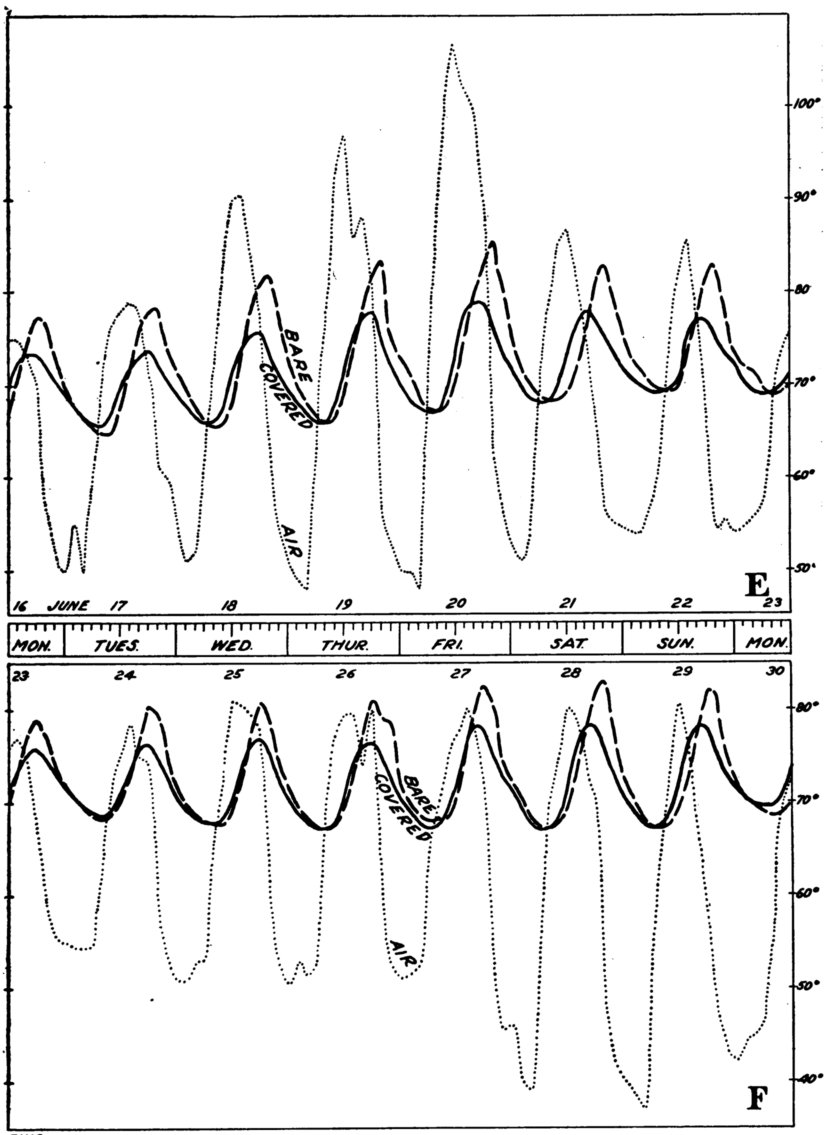

Fig. 7.—Temperature records reproduced from thermograph sheets. E—for week of June 16 to 23. F—for week of June 23 to 30.

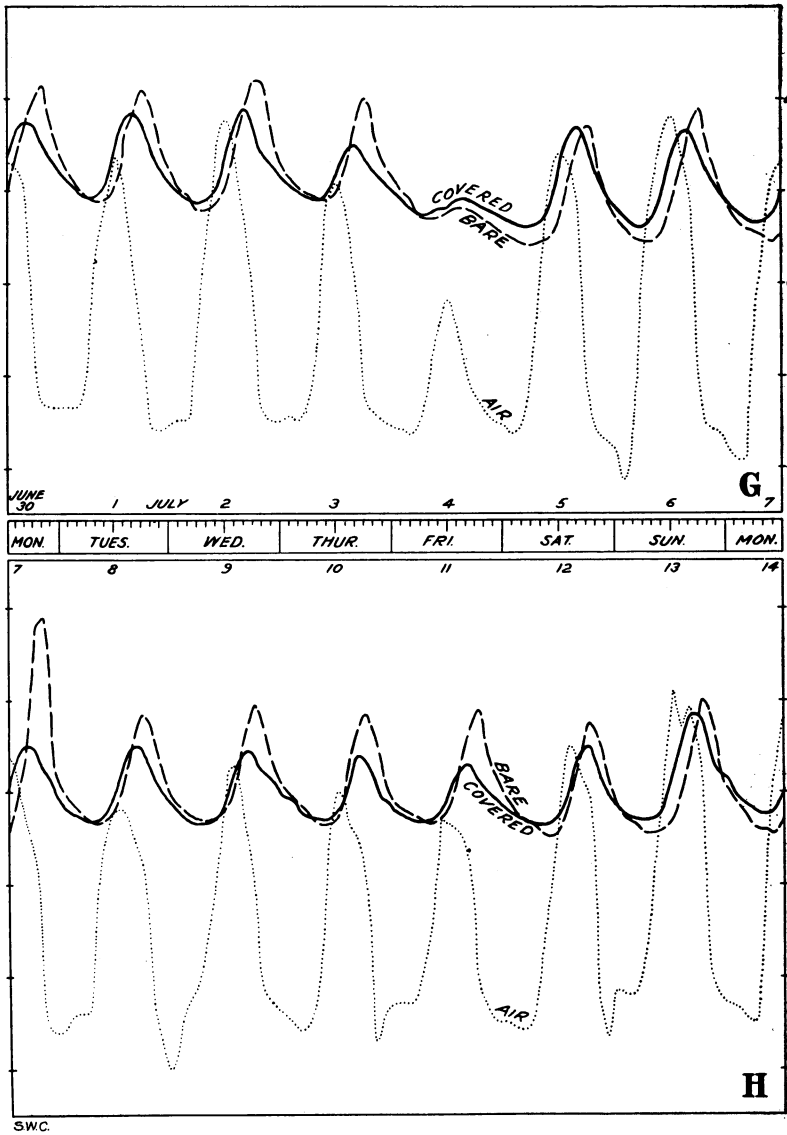

Fig. 8.—Temperature records reproduced from thermograph sheets. G—for week of June 30 to July 7. H—For week of July 7 to 14.

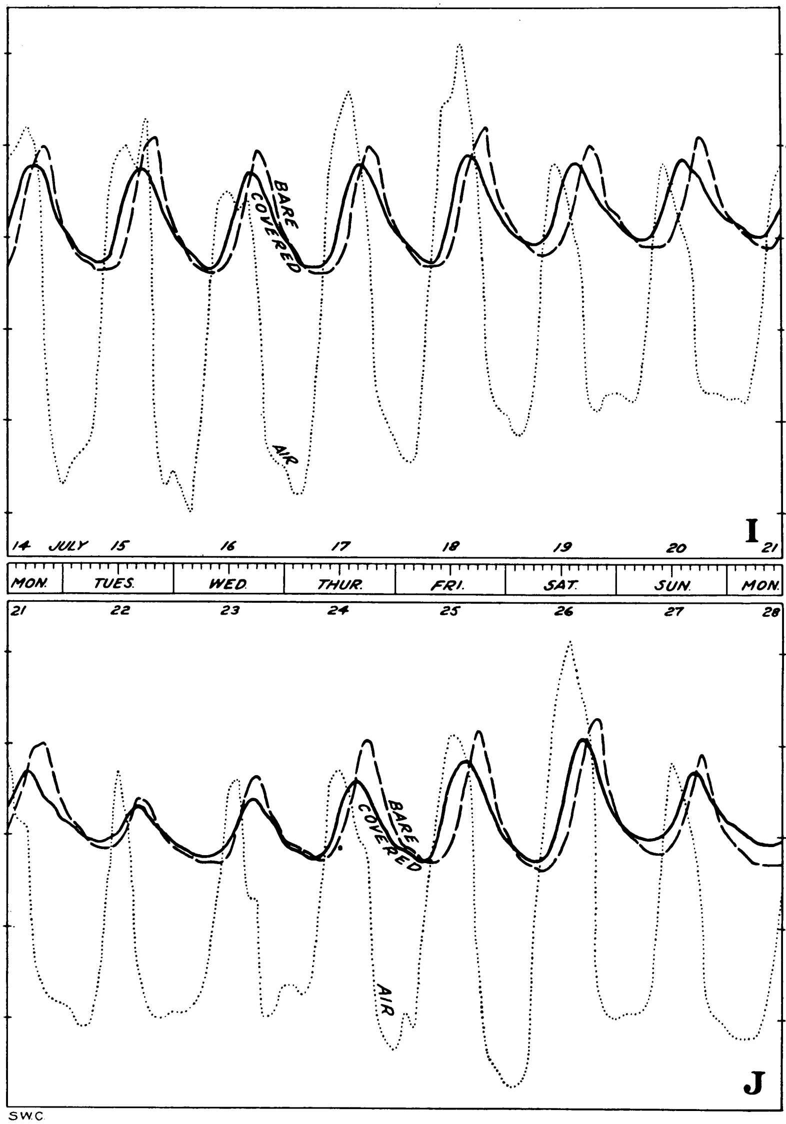

Fig. 9.—Temperature records reproduced from thermograph sheets. I—for week of July 14 to 21. J—for week of July 21 to 28.

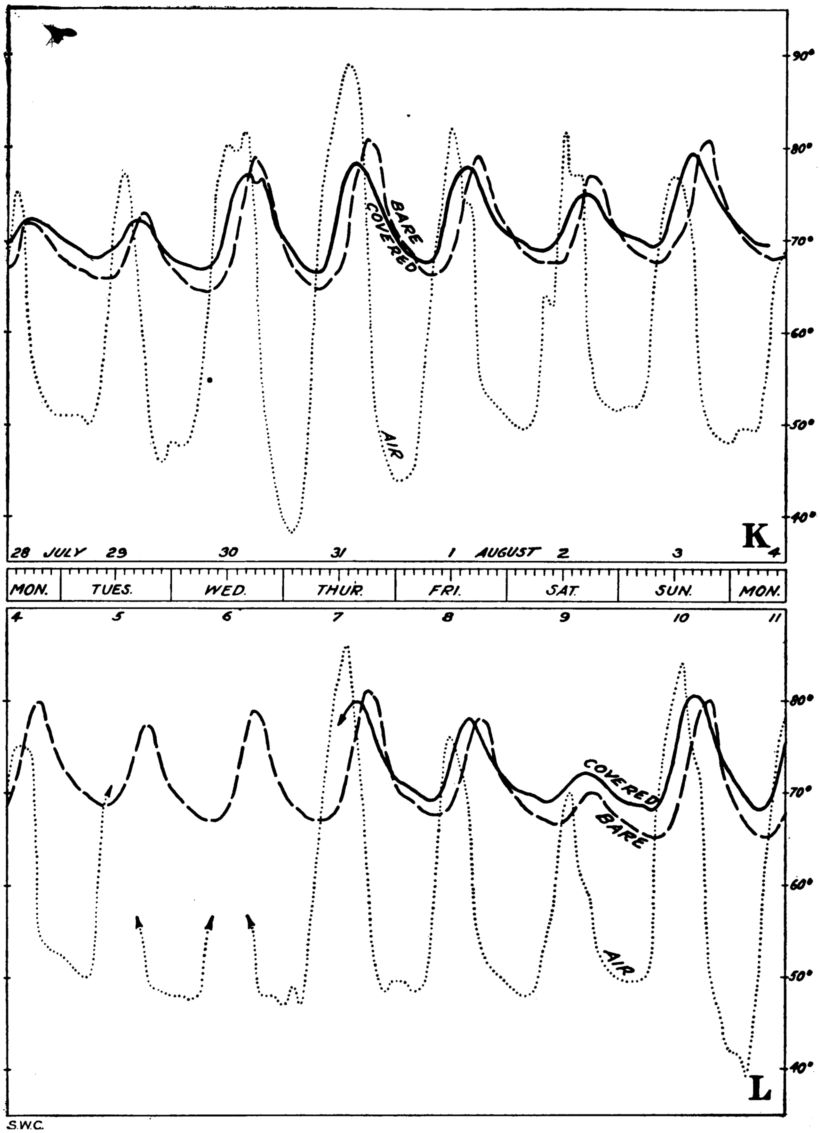

Fig. 10.—Temperature records reproduced from thermograph sheets. K—for week of July 28 to August 4. L—for week of August 4 to 11.

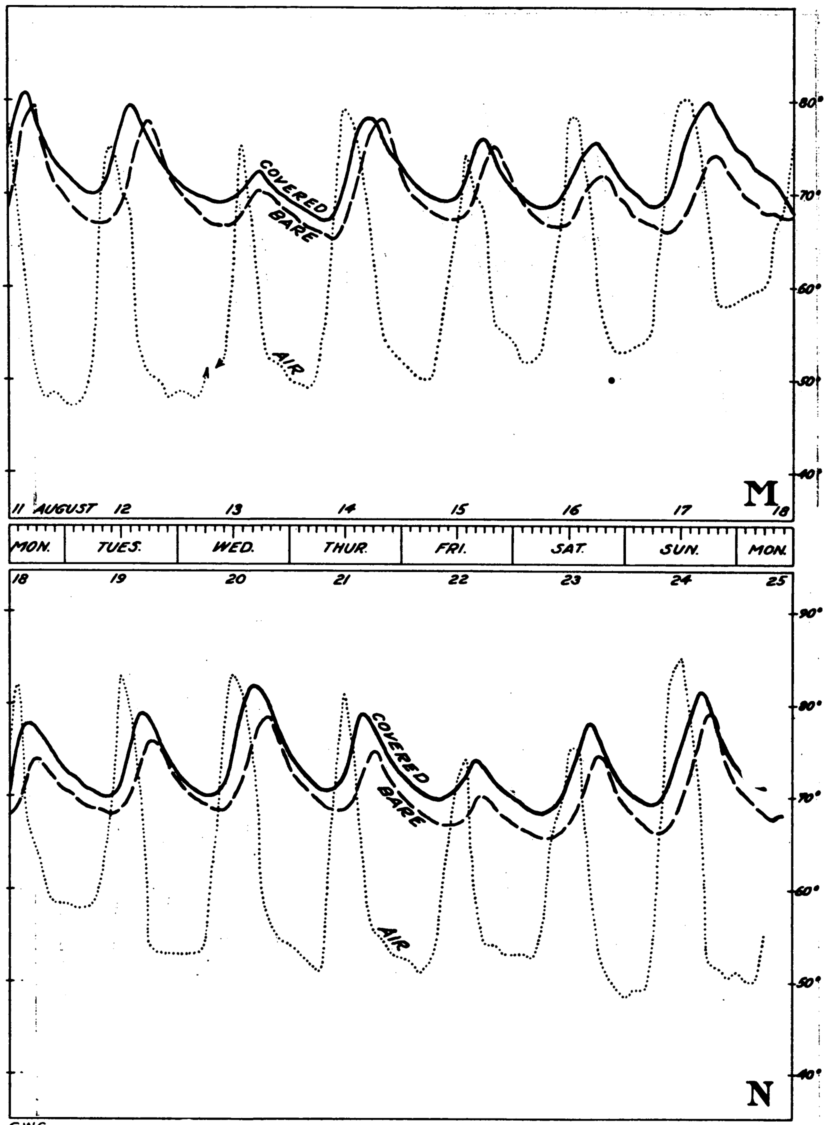

Fig. 11.—Temperature records reproduced from thermograph sheets. M—for week of August 11 to 18. N—for week of August 18 to 25.

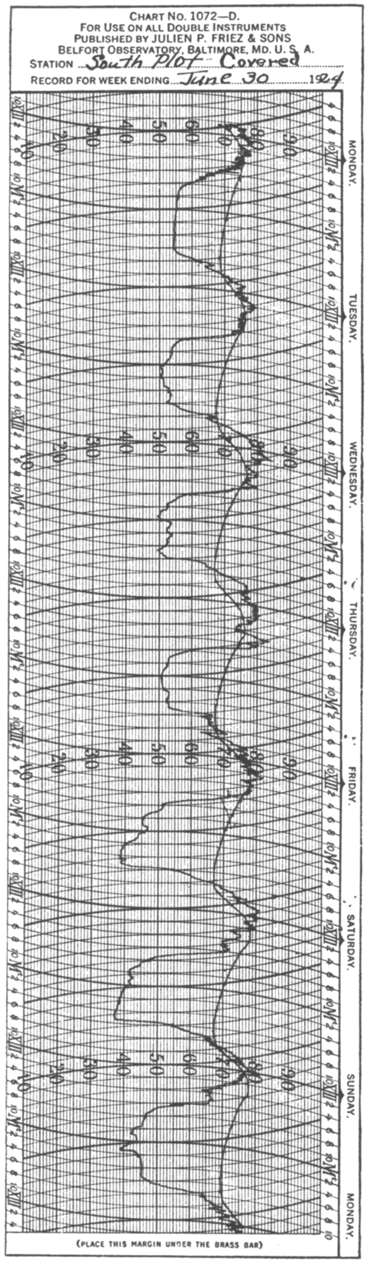

Fig. 12.—Reproduction of original of thermograph record sheet showing temperatures of the covered plot and the air for the week of June 23 to 30.

A study of these records shows the relation of the soil temperatures to that of the air. In a period of rising temperatures, with a relatively long heated period each day, as from May 25 to 29, there is a corresponding rise in both the maximum and minimum soil temperatures. The rise in the soil temperatures, although slow and of small magnitude, is definite. The effect of a single, very cold day is shown by the almost total lack of the usual afternoon rise in soil temperatures on July 4 and August 7. The soils appear to respond more strikingly to the low than to the high temperatures. This may in part be due to the more prolonged periods of low temperatures, as compared with the much briefer period of high. It may also be due in part to the damping influence of the soil depth and a lag due to heating the mass of soil above the bulbs of the thermometers. A study of the temperature records shows that there was no seasonal increase in the temperature of the soil *at this depth,* during the period of the experiment, the average weekly temperatures rising or falling slightly in response to the variations in air temperature.

The rate at which heat penetrates the soil and the effect of the covering is shown by the lag or delay of the maximum or minimum soil temperatures behind those of the air. The thermometer bulbs were covered by three inches of soil which had to be warmed by the absorbed heat before a change could occur. An analysis of the figures shows that in reaching the maximum, the covered soil had a mean lag of about 3 hours 31 minutes, while the bare plot delayed 5 hours 48 minutes after the maximum air temperature had been reached. The covered plot reached its minimum temperature 5 hours 7 minutes after the air, while the minimum of the bare plot was 6 hours 28 minutes behind the air. The total period of cooling of the covered plot, however, averaged 45 minutes longer than that of the bare plot.

The lag of the bare plot behind the covered plot is maintained quite consistently throughout the full period. Figure 13 shows the soil temperatures on two warm days—May 27 and 28—and on two cool days—July 15 and 16. On each of these four days the bare plot was two to three hours behind the covered plot in reaching the maximum temperatures, while the minimum for both plots was reached at approximately the same time each of the four days—about 8 A.M. The average hourly difference in temperature between the covered and bare plots for the full period of the experiment is shown in figure 14. The two plots averaged about the same from midnight to 2 A.M., the covered plot was .38° warmer from 2 to 4 A.M., .75° warmer from 4 to 6 A.M., 1.15° warmer from 6 to 8 A.M., 1.91° warmer from 8 to 10 A.M., 3.05° warmer from 10 to 12 noon, 3.07° warmer from 12 to 2 P.M., 1.11° warmer from 2 to 4 P.M., 1.92° cooler from 4 to 6 P.M., 3.21° cooler from 6 to 8 P.M., 1.51° cooler from 8 to 10 P.M., and .53° cooler from 10 P.M. to midnight.

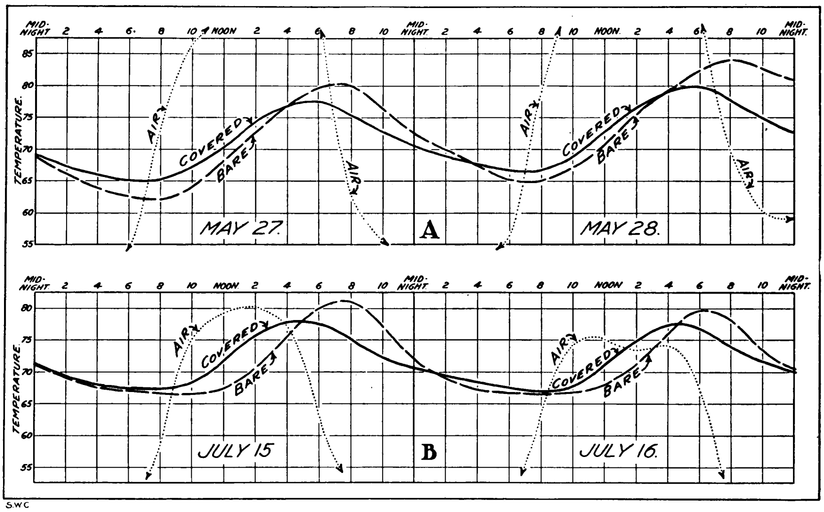

Fig. 13.—Enlarged curves showing temperatures on two warm and two cool days.

A—May 27 and 28 were two warm days, the air maxima being 94° and 112°, while the minima were 46° and 51°.

B—July 15 and 16 were two cool days, the air maxima being 80° and 75°, while the minima were 43° and 40°.

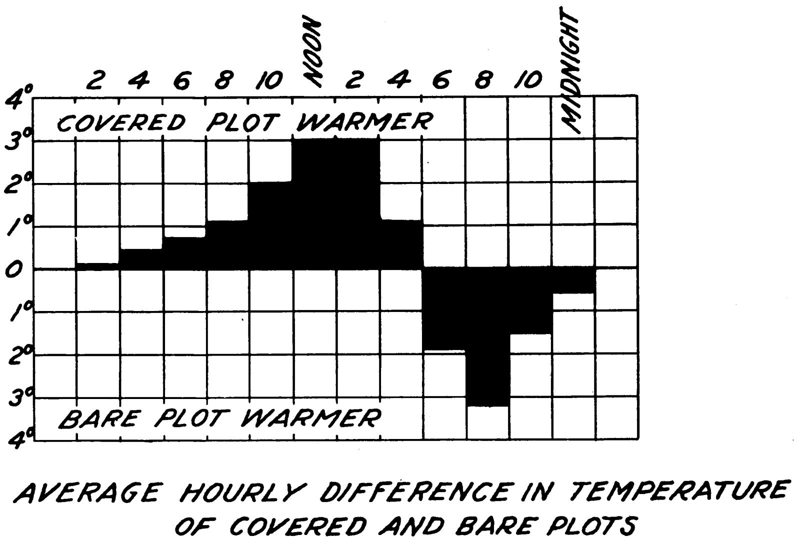

Fig. 14.—The hourly differences in temperature of the bare and covered plots, averaged for the full time of the experiment.

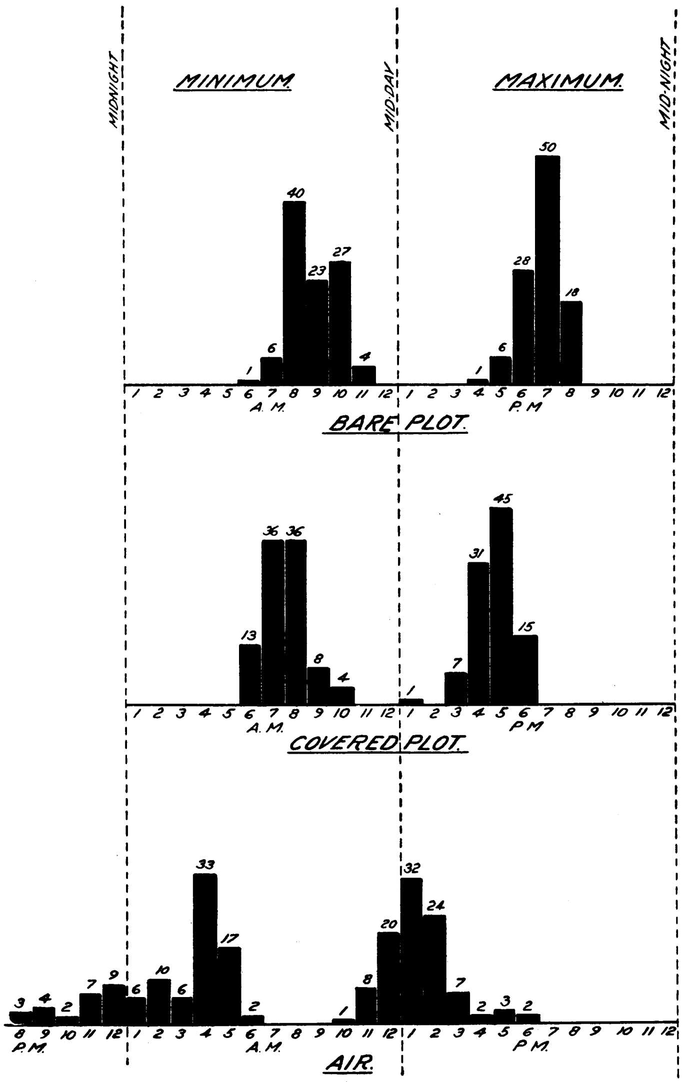

Fig. 15.—Time frequency occurrence of the maximum and minimum temperature of the bare plot, covered plot and the air.

Figure 15 shows the time-frequency occurrence of the minimum and maximum temperatures for the air and the bare and covered plots. Minimum temperatures for the air thermometer occurred irregularly between 8 P.M. and 6 A.M., the mean period being about 2:30 A.M., although the most frequent occurrences were 4 A.M. (1/3 of days) and 5 A.M. (1/6 of days). The covered plot reached its minimum about 7:30 A.M., while the bare plot was coldest about 8:50 A.M. The bare plot lagged about one hour and twenty minutes behind the covered plot in cooling to its minimum daily temperature. On three nights, however, the bare plot reached its minimum one hour earlier than the covered plot, and on sixteen nights they reached this point at the same hour.

Maximum temperatures for the air thermometer occurred irregularly between 10 A.M. and 6 P.M., the mean being about 1 P.M. and the mode lying between 12 and 2 P.M. The bare plot reached its maximum about 6:45 P.M., the mode lying between 6 and 8 P.M., while the covered plot reached its maximum temperature about 4:30 P.M., the mode lying between 4 and 6 P.M. The covered plot reached its maximum two hours before the bare plot.

The soil in both plots was warmer during the night than during the day, but the covered plot maintained a more even temperature with a much narrower range between the daily minima and maxima. The average daily range in temperature was 8.58° for the covered plot, 11.07° for the bare plot, and 31.03° for the air, while the extremes in any day ranged from 3° to 13.5° for the covered plot, from 1° to 19.5° for the bare plot, and from 14° to 61° for the air thermometer. The actual minimum and maximum temperatures reached during the period of the experiment were: Covered plot, 63° and 80°, bare plot, 60° and 84°, air thermometer, 39° and 112°. All the maxima were reached on May 29, but the minima were recorded on different dates.

Need for Continuous Records

In temperature studies where continuous records are not available, soil temperatures are usually read at stated intervals, often only twice or three times a day. If different plots or treatments are being compared, the results may be quite misleading. The lag of one treatment might be much greater than that of another and the time of reaching maximum or minimum temperatures might differ by an hour or more. The need for continuous records in soil temperature work is strikingly brought out by this study.

Thermal Differences

Thermal differences were determined by measuring on each of the original record sheets (by planimeter) the area above the 60° line as a base, and calculating the degree-hours above 60°. As neither plot cooled below 60° at any time during the experiment, there were no negative values. The results are given in table 1, which shows

TABLE 1

Differences in Total Weekly Temperatures of Bare and Covered Plots Determined by Calculating the Total Number of Degree-Hours Above 60° as a Base

Date, week ending	Hours of record	Degree-hours above 60° for the week		Degree-hours difference for week*	Degree-hours difference per hour*
		Covered	Bare		
5/19	72	588	476	+ 112	+1.55
5/26	164	1045	783	+ 262	+1.60
6/2	172	2078	2213	− 135	−0.79
6/9	169	1162	1362	− 200	−1.16
6/16	168	1497	1533	− 36	−0.21
6/23	166	1850	2032	− 182	−1.09
6/30	170	1989	2098	− 109	−0.64
7/7	168	1767	1767	0	0
7/14	167	1634	1717	− 83	−0.50
7/21	169	2031	1945	+ 86	+0.51
7/28	167	1868	1856	+ 13	+0.08
8/4	168	1868	1605	+ 263	+1.56
8/11	170	2042	1828	+ 214	+1.26
8/18	165	1945	1570	+ 375	+2.27
8/25	164	2125	1672	+ 453	+2.76
Total	2419	25,489	24,456	+1033	+ .42

**Note.*—− = Bare plot warmest; + = Covered plot warmest.

that the bare plot was warmer during six weeks, the covered plot warmer during eight weeks, and the two identical one week. The bare plot was consistently warmer from May 26 to July 14, while the covered plot was warmer before and after that period, the difference becoming more marked toward the latter part of the season. There is evidence that this seasonal difference may be due to variations in shading by the growing plants. The thermograph bulbs were placed just west of the middle row of beans, and during mid-season were shaded to considerable extent. When the paper was put in place, the beans had developed but two pairs of leaves, and during the first three weeks there was little shading. By August first the beans were ripening, the leaves curling, and the shading was progressively decreasing. They were harvested on the 15th, and the records show that during the last two weeks—August 11–18 and 18–25, the covered plot showed by far the greatest increase of temperature over the bare plot. The totals show that the covered plot was warmer by 1033 degree-hours above 60° for the full period, or an average of .42 degree-hours per hour. A parallel study of the temperature differences (table not shown in this paper) by two-hour intervals throughout the full period, indicates that the covered plots were warmer during 1400 hours by an average of 2.16 degrees per hour, the bare plots were warmer during 634 hours by an average of 3.29 degrees per hour, while both were the same during 208 hours. The total difference in degrees, divided by the number of hours, shows the covered plot to be warmer by an average of .417 degrees per hour, closely correlating with the results obtained by the planimeter measurements given in table 1.

Soil Moisture

The soil at the beginning of the experiment, on May 16, was moist and in ideal condition for crop growth. It was intended to study the effect of the paper covering on the soil moisture conditions throughout the experiment, but on May 24 the bare plot received an unauthorized irrigation, and on July 23, a broken water line flooded a portion of the covered plot. Soil moisture determinations having been started, were continued at weekly intervals throughout the full period, though it is felt that they may not be indicative of true conditions. These data are given in table 2 and indicate no moisture deficiency throughout the season, although the surface soil of the bare plots had become rather dry by August. As shown in figure 16, which gives the average moisture to a dept of 18 inches, there is a progressive decrease in the amount of water present from the beginning to the end of the experiment. The irrigation of the bare plot in the third week, and the flooding of the covered plot in the twelfth week cause characteristic breaks in the curves. From the data as presented, the paper mulch seems to have decreased the water losses from the upper eighteen inches of soil, the bare plot from the sixth to the tenth weeks containing an average of from .5 per cent to

4 per cent less moisture than that in the bare plots, or, if expressed as percentages of the total moisture present, a loss of from 4 to 20 per cent, a large part undoubtedly coming from the upper six inches. Had it been possible to sample the stony subsoil below 18 inches, this difference would be much reduced.

TABLE 2

SOIL MOISTURE IN BARE AND COVERED PLOTS

(Per cent on dry weight basis.)

Bare Plot

Depth	0–3 inches	3–6 inches	6–9 inches	9–12 inches	12–18 inches	18–24 inches
5/17	21.82%	26.46%	21.70%	20.70%	24.63%	
5/24	22.45	23.50	22.00	20.30	21.62	18.40%
5/31*	18.91	32.10	25.02	20.90	22.21	
6/7	17.53	21.02	22.99	19.44	20.00	19.91
6/14	22.75	21.22	17.91	17.05	20.00	
6/21	14.89	17.25	14.12	18.60	9.11	
6/28	14.27	18.00	16.80	21.88	10.52	5.62
7/7	13.70	15.60	14.00	15.60	11.71	17.71
7/12	6.94	13.19	12.15	13.59		22.80
7/19	12.54	14.10	12.99	10.84	12.40	17.75
7/26	12.28	15.28	14.88	13.45	13.54	16.54
8/2	6.03	13.40	13.71	12.53	17.06	19.33
8/9	8.14	10.15	12.22	12.08	14.25	13.30
8/18	5.32	8.79	14.09	11.32	12.72	16.81

* Plot irrigated by furrow method on afternoon of May 24th.

Covered Plot

Depth	0–3 inches	3–6 inches	6–9 inches	9–12 inches	12–18 inches	18–24 inches
5/17	23.10%	27.50%	24.30%	22.82%	21.72%	
5/24	14.95	23.95	20.50	19.32	18.10	
5/31	21.64	27.84	22.94	18.92	20.95	
6/7	16.25	25.13	22.05	17.83	14.39	
6/14	18.44	22.02	18.69	16.72	17.35	
6/21	15.17	19.20	17.78	15.74	20.35	20.28%
6/28	9.71	28.88	15.39	13.64	17.85	17.62
7/7	10.50	16.32	15.39	12.60	16.97	16.91
7/12	11.28	14.97	15.23	11.72	16.30	17.61
7/19	9.05	14.48	7.88	15.42	14.96	16.84
7/26	8.11	13.62	12.23	10.66	15.62	18.32
7/30*	29.85	31.65	27.00	22.39	21.72	17.51
8/2	34.10	24.25	20.90	23.78	22.49	21.10
8/9	23.40	22.22	19.35	19.70	18.64	14.78
8/18	27.10	21.23	20.15	19.86	19.15	17.95

* Covered plot partially flooded by accident on July 28, sampled on July 30. A dry, compact layer found below 15-inch depth.

The application of the water had no apparent effect on the soil temperature, there being no break or modification of the temperature curves. As the water came from pipes buried in the ground, it probably was close to the temperature of the soil at the time of application.

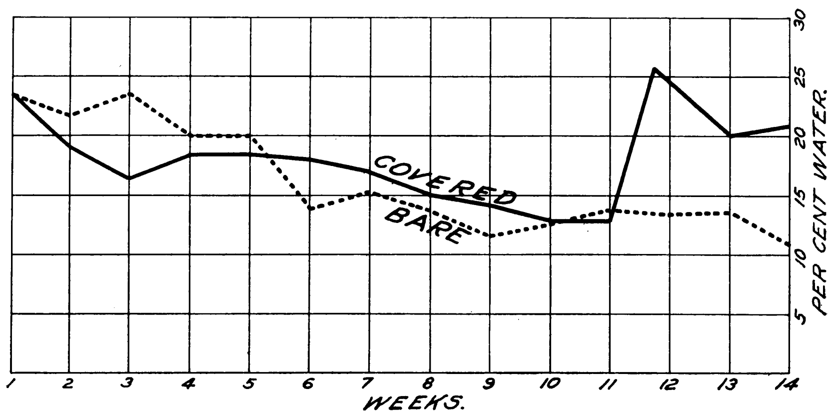

Fig. 16.—The average content of soil moisture to a depth of eighteen inches in the bare and covered plots throughout the experiment.

Crops

The crops planted were beans, milo and potatoes. Beans and potatoes do fairly well in Berkeley, and it was thought that they would give an indication of the response of a seed and a tuber crop to any differences in soil temperature which might result from the mulch. Milo was selected because it does not thrive here, it being thought that if the temperature of the covered plot was higher than that of the bare, the increased heat in this plot might result in better growth and development.

The irrigation on May 24 and the flooding of July 23 altered the crop growth to some extent, particularly that of the milo. The stand and growth of potatoes was so irregular and uneven, owing to poor seed and to soil differences that they were wholly disregarded in estimating the results. During the season the milo on the bare plot appeared a little better than that on the covered plot, but both made short irregular growths, forming heads with but few or no seeds and the evidence regarding this crop is therefore of little value.

On June 7, the beans were coming into bloom on both plots, with those on the bare plot looking somewhat the better. Five bean plants and sixteen milo plants were taken from each plot, care being taken to select uniform and average plants. The stems were cut at the ground surface and were weighed green, then dried and again weighed. The weights are given in table 3.

TABLE 3

WEIGHTS OF PLANTS HARVESTED JUNE 7

		Covered	Bare
5 bean plants	Green weight	505.6 gr.	615.9 gr.
5 bean plants	Dry weight	88.5 gr.	98.5 gr.
16 milo plants	Green weight	173.7 gr.	225.1 gr.
16 milo plants	Dry weight	26.5 gr.	32.4 gr.

On August 7, the beans were at full maturity and turning yellow, a few leaves had fallen and the pods were well ripened. Five plants were again harvested, dried and weighed with the results shown in table 4.

TABLE 4

DRY WEIGHT OF BEANS HARVESTED AUGUST 7

	Covered	Bare
Weight of beans	283.0 gr.	300.0 gr.
Weight of pods	102.0 gr.	118.0 gr.
Weight of plants	215.5 gr.	232.5 gr.
Total dry weight	600.5 gr.	650.5 gr.

The beans were harvested on August 15, and threshed on August 30. A count of 23 plants from each plot showed 506 pods from the covered and 570 from the bare plot or an average of 22 pods and 24.8 pods per plant. The total harvest is given in table 5.

TABLE 5

	Total number of plants	Yield	Equivalent yield per 100 plants
Covered	122	4.2 kg.	3.4425 kg.
Bare	208	8.8 kg.	4.2307 kg.

These various figures show that the beans did considerably better on the bare plot, with the milo giving indications in the same direction. The accidental irrigation may have modified these results somewhat, but as neither plot showed any deficiency of water during the season, the results of growth and yield are considered representative of the effects of the treatment.

The fact that the paper was not perforated, and aeration therefore restricted to some extent, might account for some differences in yield and growth. The papers used in mulching are usually perforated.

CONCLUSIONS

Covering the soil with an asphalt-coated paper increased the mean temperature of the soil by an average of about .42 degree per hour. The covered plots were warmer 62.5 per cent of the time, the bare plots warmer 28.3 per cent of the time, and they were the same about 9 per cent of the time. The covering hastened the time of warming, retarded the rate of cooling, and gave a narrower range between the maximum and minimum temperatures with a resulting more uniform temperature condition. The experiment demonstrates that a paper covering modified the delay or lag in reaching maximum or minimum soil temperature and emphasizes the need for continuous records in any soil temperature studies where differences in treatment or shading may occur.

Soil moisture losses from the upper eighteen inches that were sampled were reduced to an appreciable extent by the paper covering, much of the loss from the bare plot apparently being due to the drying out of the upper six inches. The water present at the end of the experiment was still above the wilting point and there was no moisture deficiency in either plot. Crop yields indicate that the covering is of no benefit to any of the crops grown, the figures actually indicating an adverse effect.

From the results of this experiment, it is evident that while the use of the paper mulch cover may conserve the moisture to some extent, they give no indication that it will favorably affect the growth of crops under such climatic conditions as exist in Berkeley.

SUMMARY

The paper mulch is extensively used in the Hawaiian Islands, and is being tried out in other parts of the United States. An experiment was carried out in Berkeley, using a paper of medium weight as a mulch, with potatoes, milo and beans as crops.

Thermograph bulbs were placed in the soil at the dept of 3 inches below the surface, and continuous records of soil temperatures for the covered and bare plots obtained.

The temperatures show that the *covered* plot lagged about one and one-third hours behind the bare plot in reaching the minimum temperature, while the *bare* plot lagged about two hours behind the covered plot in reaching the maximum.

The average daily range for the covered plot was 8.58°, and for the bare plot was 11.07°. The covered plot averaged about .42 degree per hour warmer than the bare plot. The use of paper gave more uniform and slightly higher soil temperatures.

The soil moisture gradually decreased during the season, except when accidental irrigation increased the supply. The covered plots lost water more slowly than the bare plots but neither showed any deficiency of moisture during the period of the experiment.

The growths of potatoes and of milo were unsatisfactory and the yields were not considered. The beans did considerably better on the bare plot.

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