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INFLUENCE OF WATER MULCHES ON SOIL TEMPERATURES AND SWEET CORN AND GREEN BEAN PRODUCTION

S. A. BOWERS

United States Department of Agriculture[1]

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The relation between soil temperature and crop production has been studied extensively. Such studies resulted in a wide acceptance of plastic mulches, asphalt mulches and other practices designed to favorably alter the crop environment.

Favorable qualities attributed to plastic mulches are suppression of weed growth, reduction of evaporation, and elevation of soil temperatures early in the season. Experimental evidence indicates the existence of optimum soil temperature ranges for maximum crop production. Wort (11), working under greenhouse conditions, found maximum vegetive production with Marquis wheat occurred at a soil temperature of 72° F. Yamaguchi, *et al.* (12), working with potatoes in the greenhouse, reported that maximum foliar growth was in the soil temperature range of 70 to 75° F.; the optimum temperature range for tuber formation was 60 to 75° F.

Allmaras *et al.* (1) estimated that for field conditions the optimum soil temperature for corn dry matter production was 81.3° F. Willis *et al.* (10) found the most favorable soil temperature at a four-inch depth for corn growth was about 75° F. Mack *et al.* (4) found that the dry weight of snap bean plants increased as the soil temperature was increased from 54° F. to 78° F.

With plastic mulches, and also on normal soils, soil temperature later in the season may exceed the optimum range and be detrimental to crop production. For example, in the unpublished data of Hanks and Bowers[2] soil temperatures of 150° F. at one-cm. depth and 100° F. at 16-cm. depth were recorded under a clear plastic mulch.

The data of Curcio and Petty (2) concerning the transmission of radiant energy through water suggest that water mulches, i.e., layers of water contained in polyethylene envelopes, might confine the soil temperatures to a more constant optimum range. By applying their data to Moon's (6) solar energy distribution curve, it can be calculated that at normal incidence a 10-cm. water mulch will absorb approximately 35 per cent of the energy in the direct solar beam, thereby decreasing the radiant energy reaching the soil.

Due to the high specific heat capacity of water, one would expect water mulches to act as a heat sink during the day and a heat source at night. Assuming a bulk density of 1.3 g./cm.^{3}, and a moisture content of 0.2 g./cm.^{3}, the heat capacity of soil is 0.46 cal./cm.^{3} °C. On a volumetric basis, for equal amounts of heat, the soil will change 2.2° C. for every 1° C. change in the water mulch. Thus, by restricting the energy gain or loss by soils, one could expect water mulches to dampen the diurnal fluctuations in soil temperatures and prevent temperature extremes. The water mulch restricts energy loss by absorbing all longwave radiation from the soil and reradiating at a lower temperature. The energy reradiated is a function of temperature as indicated by the Stefan-Boltzman law, $R = \sigma T^4$, where R is the rate of energy loss per unit area, σ is the Stefan-Boltzman

[1] Contribution from the Northwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, Kimberly, Idaho; Idaho Agricultural Experiment Station cooperating. The author is a research soil scientist (Physics), Northwest Branch, Snake River Conservation Research Center, Kimberly, Idaho.

[2] Hanks, R. J. and Bowers, S. A. Unpublished data from the 1958 Annual Research Report, United States Department of Agriculture, Agricultural Research Service, Soil and Water Conservation Research Division, Western Soil and Water Management Research Branch, Manhattan, Kansas.

constant, and T is the temperature of the water in °K.

A small-scale preliminary test, under non-cropped conditions, in September, 1964 showed that water mulches do alter the soil temperatures. Soil temperatures under the water mulch showed less fluctuation. As compared to check treatments, their maximum soil temperatures at a one-cm. depth were lower; their minimum temperatures were higher. At a 10-cm. depth, both their maximum and minimum temperatures were higher. In addition, these temperatures appeared more in line with reported optimum soil temperatures for crop growth. Since these preliminary results indicated a possibility of establishing and maintaining a soil temperature environment more favorable for crop production, this experiment was initiated in the summer of 1965 to determine the response of heat-sensitive crops to water mulches.

PROCEDURE

The experimental field design was a randomized complete block with four replicates. Golden Beauty sweet corn and Garden Green bush beans, both garden varieties, were the crops selected. Treatments with each vegetable were as follows: (*a*) 10-cm. water layer contained within a 6-mil clear polyethylene bag; (*b*) Conventional 6-mil clear polyethylene mulch; (*c*) Check.

Figure 1 shows the installation of the various treatments early in the season. These plots were 11′ x 12′ in size and diked to prevent runoff. Detailed soil moisture data was available only from July 30 to September 8. On July 30 access tubing was installed in two replicates and moisture measured to a three-foot depth with a neutron meter. Flood irrigation was used; water was added by a garden hose connected to a water meter. The time and amount of water added to each plot was based on meter readings. With both beans and corn the available water in the top three feet was not allowed to drop below 60 per cent. The planting date was June 2, 1965. Prior to planting, all plots were preirrigated. Between June 2 and June 30 all plots received the same amount of water, approximately three inches.

FIG. 1. Water mulch, plastic mulch treatments applied to green bean plots.

The planting rates for corn and beans resulted in 51,000 and 57,000 plants per acre respectively. This excessive corn population resulted from an arithmetic miscalculation; the error was not realized in time to make the appropriate adjustments. A two-foot row spacing was used; 100 lbs. N/acre was disked into each plot. Despite the excessive corn population, there was no visual evidence of nitrogen deficiency.

Soil temperatures were measured with copper-constantan thermocouples connected to a 24-point temperature strip chart recorder. In three of the replications thermocouples were placed in the center of each plot at both the 1- and 10-cm. depths and approximately 12 inches on each side from the nearest plant stalks. In addition, thermocouples were placed within each of the water mulches at approximately three cm. above the soil surface. Temperatures were measured every six minutes throughout the entire day. Temperatures under corn were recorded on seven different days: June 12, 14, 26, 27, July 24, 25, and August 8, 1965. With beans, temperatures were measured only on August 6 and September 17, 1965.

In addition to the 1965 results, a portion of the preliminary testing of 1964 is reported in this paper. This preliminary part consisted of one plot each of four different treatments; statistical inferences are not possible. Plot sizes were 12′ x 12′. The treatments were as follows: (a) constant 10-cm. water mulch; (b) water mulch emptied at 6:00 AM and refilled at 2:00 PM; (c) water mulch refilled at 6:00 AM and emptied at 2:00 PM; (d) bare soil. The purpose of this simplified experiment was to determine whether soil temperature could be altered at will by manipulation of the water layer level. The one-cm. soil temperatures approached their minimum and maximum values at 6:00 AM and 2:00 PM, respectively. Thermocouples were installed at 1-cm. and 10-cm. depths on all plots. Also, heat flow disks were placed at a depth of ⅛ inch.

In addition, a Thornthwaite[a] miniature net radiometer, suspended from a long, counterbalanced ¼-inch pipe, was placed at approximately 30 inches above the center of the water mulched plot and the bare plot. The two output signals were continuously recorded on a single-point strip chart recorder equipped with a stepping switch.

[a] Trade names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product named by the United States Department of Agriculture.

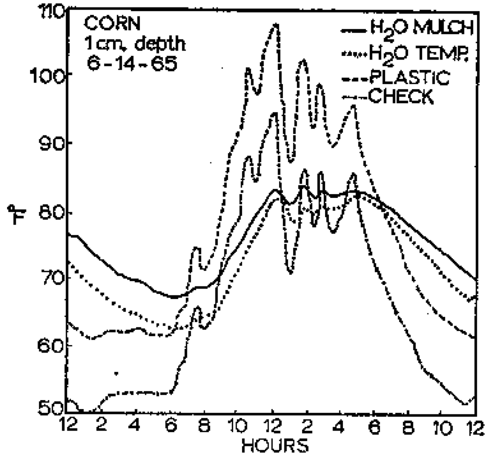

FIG. 2. Average soil temperatures at 1-cm. depth. H_2O temperature refers to the temperature within the water mulch.

RESULTS AND DISCUSSION

On June 14 the corn development was approximately 20 cm. high. Practically, this was equivalent to no crop cover. The soil temperature curves for this date, and all other days on which temperatures were measured, are the average of three replicates. The damping effect of water mulches on the one-cm. soil temperatures is shown in figure 2. Water mulches caused warmer nighttime temperatures and lower daytime temperatures; in addition, they damped the magnitude of the temperature fluctuations resulting from intermittent cloud cover during the daylight hours. The maximum temperature under the water mulch treatment was 24° F. less than that under the plastic and 11° F. less than the check; the minimum temperatures were higher by 6° F. and 17° F., respectively. Figure 3 shows the 10-cm. soil temperatures on this same day. Contrary to what one might anticipate, at no time during the day did the 10-cm soil temperature of the check plots exceed that of the water mulch; in comparison to the check, this indicates a heat buildup on water mulch plots. This phenomena

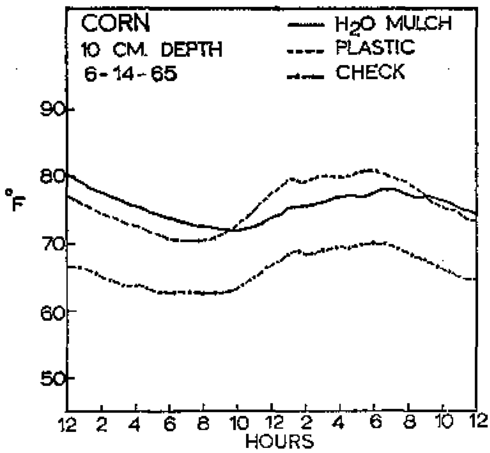

FIG. 3. Average soil temperatures at 10-cm. depth.

may possibly be due to greater evaporation from the checks resulting in less available energy for soil heating. The soil moisture status for the day under discussion was not determined. If, however, evaporation caused substantial differences in soil moisture content, one could anticipate differences in thermal conductivity (3, 7, 8). Depending on the temperature gradients, the water mulched plots, with their higher moisture contents, could conduct greater amounts of heat to lower levels. Another possible contributing factor to this heat buildup was the lower daytime temperatures of the water mulch resulting in less heat loss to the atmosphere by convection and longwave radiation.

As indicated previously, the emitted longwave radiation is a function of the temperature as described by the Stefan-Boltzman law, $R = \sigma T^4$. Obviously, the water mulch during the daytime would radiate less energy. These temperature trends agree with the results of a short preliminary test in September, 1964 for noncropped surfaces.

Figures 4 and 5 show the soil temperatures under a corn canopy on July 24, 1965. On this date, vegetative growth and shading was near maximum. As before, the water mulch damped the one-cm. soil temperatures (fig. 4). The maximum one-cm. temperature beneath the water mulch was 23° F. less than the check and 12° F. less than the plastic; the minimum temperature was 14° F. and 7° F. higher than that of the check and plastic treatments respectively.

It is of interest to compare the one-cm. temperature trends of July 24 with those of June 14. On June 14, under noncropped conditions, the plastic treatment generated higher daytime temperatures than the check. This probably is the result of a greater evaporation rate from the check and the thermal characteristics of the mulch; i.e., its greenhouse effect and the insulating effect of the air layer between mulch and soil. Conversely, under a full canopy on July 24, the daytime temperatures on the check treatments were higher than the plastic. Possibly this change in temperature trend is due to differences in cover. The check canopy at its fullest was rather sparse as com-

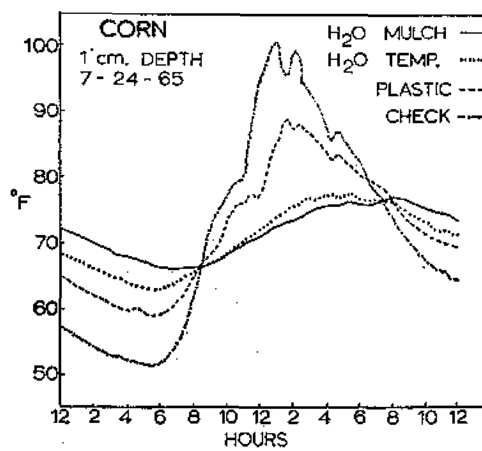

FIG. 4. Average soil temperatures at 1-cm. depth.

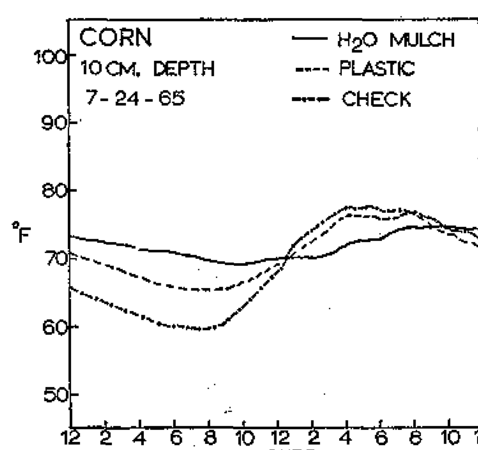

FIG. 5. Average soil temperatures at 10-cm. depth.

pared to the plastic, and numerous voids were evident. A visual assessment of the amount of crop cover placed them in the following order: Water mulch > plastic > check. Apparently, greater amounts of solar radiation were incident on the check surface than on the plastic as a result of its more sparse cover. In addition, a dryer check soil surface could have caused part of this effect.

Figure 5 shows the 10-cm. soil temperatures under full crop cover. Contrary to the events of June 14, the water mulch treatments had lower temperatures after 12:00 noon than did the check treatment. This comparative change in temperature trend is probably again a function of differences in cover. The check was simply subjected to a greater heat load.

The maximum and minimum temperatures for the seven days of measurement with corn are shown in table 1. These temperatures at

TABLE 1

Daily maximum and minimum soil temperatures in °F. under a sweet corn crop

Treatment	Date, 1965	*10 cm.* Watch Mulch			Plastic Mulch			Check		
		1	2	3	1	2	3	1	2	3
Maximum temperatures, 1-cm.	6/12	105	101	100	113	116	139	101	109	103
	6/14	86	83	84	102	106	114	93	100	93
	6/26	69	69	69	63	60	63	55	54	64
	6/27	94	89	89	102	100	104	87	87	90
	7/24	77	79	75	86	107	86	99	111	96
	7/25	77	76	74	77	79	78	78	84	81
	8/8	74	77	74	82	91	81	80	86	80
Average		82.0			92.8			87.8		
Minimum temperatures, 1-cm.	6/12	75	75	76	70	69	67	58	57	58
	6/14	67	67	68	62	61	60	51	48	50
	6/26	56	56	55	54	51	55	48	47	48
	6/27	52	53	52	48	45	49	39	37	41
	7/24	66	67	66	59	61	58	53	51	51
	7/25	69	70	69	65	66	64	62	61	59
	8/8	67	69	68	64	64	64	56	55	57
Average		64.9			59.8			51.8		
Maximum temperatures, 10-cm.	6/12	89	88	89	92	91	92	78	78	79
	6/14	80	80	80	81	80	81	70	70	70
	6/26	73	73	73	68	68	69	61	60	59
	6/27	79	76	77	83	78	79	69	67	68
	7/24	74	75	73	75	81	73	81	78	73
	7/25	73	75	73	73	75	73	73	72	70
	8/8	72	74	72	75	76	74	72	70	70
Average		77.0			78.0			70.9		
Minimum temperatures, 10-cm.	6/12	79	79	79	76	76	76	69	69	68
	6/14	71	72	73	70	71	71	63	62	61
	6/26	62	63	62	58	59	59	53	52	52
	6/27	58	59	59	55	55	56	49	49	48
	7/24	69	69	69	64	67	65	61	60	58
	7/25	70	72	71	67	71	68	66	66	63
	8/8	68	70	69	66	67	66	60	60	61
Average		68.7			65.9			59.5		

both the one-cm. and 10-cm. soil depths were subjected to an analysis of variance, the associated "F" test, and Duncan's multiple range test.

The maximum temperature trends are not entirely clear. At the one-cm. depth, maximum temperatures under the water mulch were significantly lower than under the plastic (5 per cent level), but not significantly lower than the check. Here again check temperatures may have been reduced by evaporation. Graphically, however, and on the basis of means, water mulches do appear to dampen the one-cm. maximum temperatures. At the 10-cm. soil depth, the water mulch maximum temperatures were not significantly different from those of the plastic, but were significantly higher than the check (1 per cent level). A plot of daily average maximum temperatures versus time, for both one-cm. and 10-cm. depths, showed no consistent trend; temperature crossovers for all treatments existed. One can only speculate as to reasons for lack of consistent maximum temperature trends. Primarily, maximum temperatures are a function of the daytime conditions since this is when the maximum heat load arrives. (It is recognized, however, that residual effects from previous days will exert modifying influences.) Factors that alter this incoming heat load, such as intermittent cloud cover, changes in voids in crop cover in respect to thermocouple placement because of wind movement, changes in zenith angle, and in evaporation, can generate great variability in maximum temperature. In addition, the treatments displayed differential response to changes in heat load, such as the damping characteristic of water mulches. The installation in each plot of several thermocouples in parallel, as suggested by Tanner (9) might have resulted in the recording of more representative temperatures by averaging out the possible effects of thermocouple site anomalies.

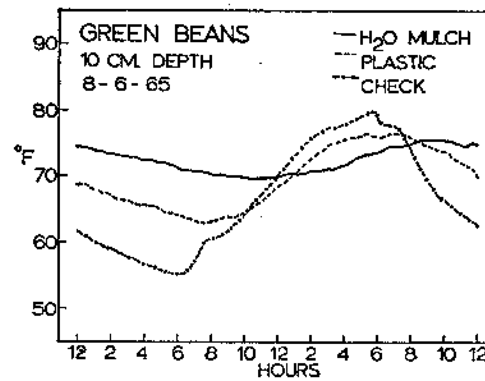

Fig. 7. Average soil temperatures at 10-cm. depth.

With minimum temperatures, the trends were consistent at both the one-cm. and 10-cm. levels. The plot of average minimum temperature versus times resulted in no temperature crossovers; for each of the seven days the minimum temperatures were in the following order: Water mulch > plastic > check. At both depths the water mulch treatments had significantly higher (1 per cent level) minimum temperatures than either the plastic or check treatments.

There were insufficient temperature data with green beans to warrant any statistical interpretation. However, figs. 6 to 9 do show the soil temperatures under beans on two days of vastly different climatic conditions. On August 6, 1965, the maximum air temperature was 85 F. and the minimum was 48° F. (figures 6 and 7); the sky was generally clear. The crop cover was full. At both the one-cm. and 10-cm. soil depths, the damping effect of the water mulch treatment is evident. The trends are identical to those found under a full corn canopy.

On September 17, 1965, unusual weather conditions existed; a snow storm, equivalent to 0.4 inches precipitation, occurred. The maximum air temperature was 43° F.; the minimum was 29° F. Snowfall began at 5:30 AM

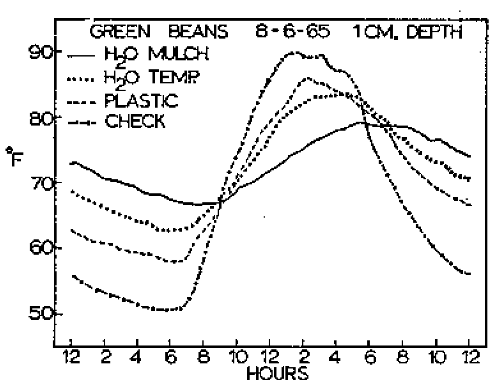

Fig. 6. Average soil temperatures at 1-cm. depth. H_2O temperature refers to the temperature within the water mulch.

and stopped at 10:00 AM. The resulting soil temperatures clearly demonstrate the superiority of water mulches as protection against cold temperatures (figs. 8 and 9). At both soil depths the minimum water mulch soil temperatures were 7 to 8° F. higher than the check, and about 5° F. higher than the plastic. On the afternoon of September 17, 1965, skies cleared and the snow melted. That evening temperatures dropped; a low of 24° F. air temperature was recorded early the following morning. The one-cm. soil minimum temperatures were 32.0° F. on the check plots, 36.7° F. on the plastic, and 40.7° F. on the water mulch plots. On the check and plastic plots, the bean plants were frozen to the soil line; on the water mulch plots they were frozen down to water level, approximately four inches high. Below that level the plants were not harmed; initiation of new foliage and flowering continued. Small quantities of fresh beans were available two weeks after the freeze. The physical setup of the water mulches should afford excellent protection for emerging seedlings early in the spring. Possibly water mulches of other geometries could be designed to afford even greater protection to the plant.

The damping effect of water mulches is undoubtedly a function of the high specific heat capacity of water. As indicated previously, the water mulch can absorb twice as much energy as a moist soil layer of the same depth with no greater change in temperature. Similarly, it can lose the same energy as the soil layer with half the temperature change. The rate of heat loss or gain, by either radiative, convective, or conductive means, between a soil and its environment is a function of the temperature gradient. Because of water's high specific heat capacity, the gradient between the soil and its immediate environment, the water mulch, is smaller; thus the heat loss from the soil is relatively small. During the evening hours, with the exception of conduction from the soil to the plant, all heat loss from the soil would be gained by the water mulch. Because of the range of soil temperature, all radiative energy loss from the soil would be longwave and this is absorbed by the water.

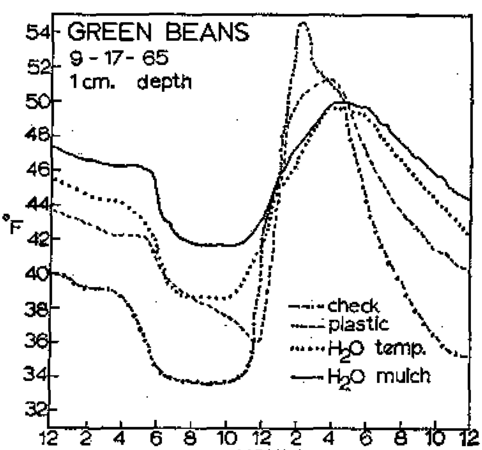

FIG. 8. Average soil temperatures at 1-cm. depth. H_2O temperature refers to temperature within the water mulch.

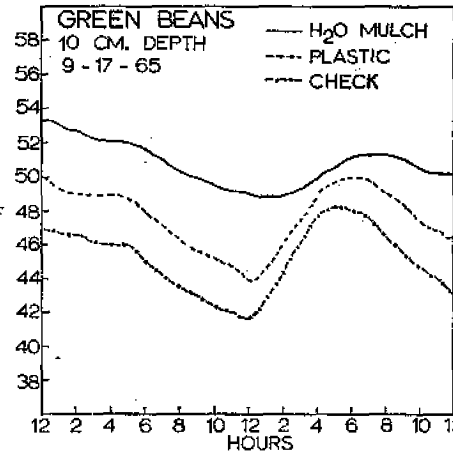

FIG. 9. Average soil temperatures at 10-cm. depth.

The method of heat gain during the daylight hours for water-mulched soils is somewhat different from that of heat loss. The water layer is heated during the day primarily by the absorption of radiant energy. Energy is then transmitted to the soil both by heat conduction and infrared radiative transfer; this is the reverse of the soil heat loss procedure. However, the soil is heated by an additional method. Again, the data of Curcio and Petty (2) indicate a 10-cm. water layer will transmit considerable radiant energy of wavelengths less than 1.2 μ. This energy is absorbed at the soil surface and degraded to heat. It appears the water mulches are more effective in heat storage than the other treatments. Net radiation measurements on single plots for six days in

September, 1964 showed that the average absorption by a 10-cm. water mulch was 151 ly./day (24 hours) as compared with 116 ly./day by a bare plot. This difference in net radiation can probably be attributed to less longwave reradiation from the water mulch due to its lower daytime temperature.

Figure 10 shows the one-cm. soil temperature for September 24, 1965. When water was removed at 6:00 AM, the remaining empty bag acted as a conventional plastic mulch, as is indicated by the steep positive slope and high soil temperature. The addition of water at 2:00 PM caused a rapid decrease in temperature. The one-cm. soil temperature dropped from 114° F. to 73° F. within one hour; most of this change occurred during the first 20 minutes. From 3:00 PM to 5:00 PM the temperature increased slowly due to heating of the water layer. After 5:00 PM the temperature curve ran parallel to that of the constant 10-cm. water mulch, indicating its water mulch characteristics were restored.

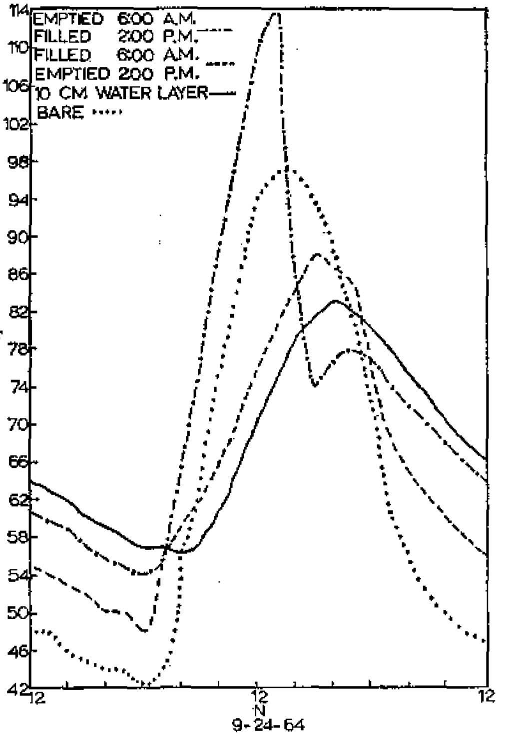

FIG. 10. Soil temperatures at 1-cm. depth. Polyethylene bags were filled or emptied at time indicated.

The addition of water at a temperature of approximately 60° F. to the empty bag at 6:00 AM resulted in a rapid 10° F. rise in 1-cm. temperatures; at this time in the morning the water was considerably warmer than the soil. This treatment assumed the characteristics of a water mulch until 2:00 PM. At 2:00 PM the water layer was removed; the 1-cm. soil temperatures continued to rise until 4:00 PM. Apparently, the influence of conventional plastic mulch dominated from 2:00 PM throughout the remainder of the day.

Some effects of changing treatment were observable at the 10-cm. depth. The most obvious difference was an unusual phase shift resulting from emptying the bag at 6:00 AM and refilling at 2:00 PM. In other portions of this experiment phase, shifts generated by the treatment usually followed or just barely preceded the check treatment. Here, however, the phase shift preceded the check by 3 hours. This was caused by the addition of the cold water resulting in a reversal of heat flow prior to the time the 10-cm. temperatures would normally achieve their maximum temperatures. The data obtained from soil heat flow disks indicated a downward heat flow upon the addition of water at 6:00 AM; a large upward flow of soil heat was observed on filling the mulch at 2:00 PM with cool water.

The most noticeable influence of the various treatments on the two crops was that of vegetative growth. Water mulches induced an early, more vigorous growth. This early lead was maintained throughout the season. As previously indicated, with both corn and beans the water mulch plots had tall and very dense canopies; the check plots were sparse; the plastic treatment had canopies intermediate to the other two.

Tasseling was initiated on the water mulch and plastic treated plots at the same time; tasseling on the check plots lagged behind the other treatments by approximately 3 to ½ days. This is similar to the effect observed by Mederski and Jones (5), who noted that on soils heated by electric cables corn tasseled five days earlier than on unheated soils.

The formation of corn ears was based on the initiation of silking. Starting on July 26, 1965 and continuing over a two-week period, the water mulch plots, based on a cumulative count, were two days ahead of the plastic and eight days ahead of the check in ear formation.

Harvest followed a similar trend. Since both the corn and beans were garden varieties, several pickings were needed to complete the harvest. The corn water-mulch plots had heavier and earlier yields; the check plots yielded slightly more at the last pickings (figure 11). Statistical analysis of the total corn yields showed that the water-mulch and plastic yields were significantly larger than those of the check, but not significantly different from one another. The attribute of water mulches hastening maturity could be important to vegetable production where prices are often dependent on earliness to market.

The average yield of green beans by individual pickings is shown in fig. 12. As with sweet corn, the water mulch treatment resulted in earlier, heavier yields. The total cumulative

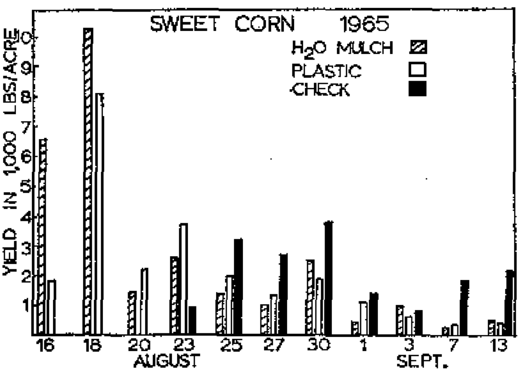

FIG. 11. Average sweet corn yield for individual pickings.

TABLE 2

Correlation coefficients and "t" values for corn yields versus the seven-day average, maximum, minimum, and mean soil temperatures at the 1- and 10-cm. depths on nine individual plots

Soil Temperature and Soil Depth	r	t
Maximum temperature		
1 cm.	−0.36	1.02
10 cm.	0.81	3.69*
Minimum temperature		
1 cm.	0.81	3.69*
10 cm.	0.87	4.69*
Mean temperature		
1 cm.	0.62	2.08
10 cm.	0.86	4.45*

* Significant at 1 per cent level.

yields of the water mulch and plastic treatments were significantly different from those of the check, but not from one another. However, up to and including the seventh picking, the water mulch yields were significantly different from those of the check, but not from one another. However, up to and including the seventh picking, the water mulch yields were significantly greater than those of the plastic.

One tends to think of the response of heat-sensitive crops in terms of either maximum, mean, or optimum temperatures. Table 2 shows the correlation coefficients of corn yields versus various temperatures for the nine individual plots on which temperatures were recorded. These temperatures are the seven day averages on each of the nine plots. In addition, "t" values

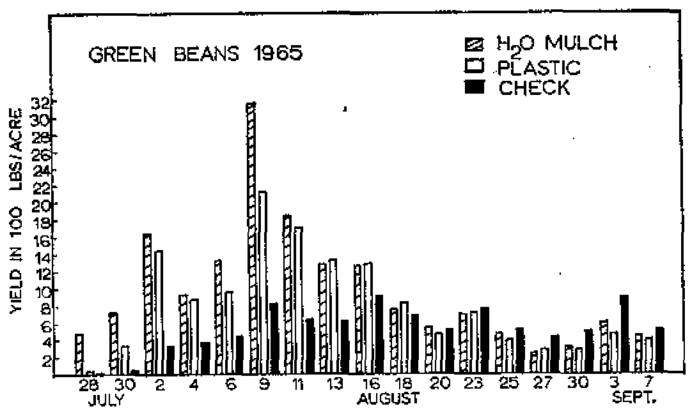

FIG. 12. Average green bean yield for individual pickings.

TABLE 3

Water utilization and efficiency from June 30 to September 8, 1965

Treatment	Sweet Corn			Green Beans		
	HO_2 Mulch	Plastic	Check	H_2O Mulch	Plastic	Check
Water use, inches	13.26	15.49	13.34	13.31	11.14	12.60
Yield, lbs./acre	28,100	24,000	16,600	17,100	14,100	9,300
Efficiency, lbs./acre-inch	2,119	1,549	1,244	1,285	1,266	738
H_2O	1,628*			988*		

* Efficiency when water mulch is included.

are shown to test the significance of the correlation coefficients.

Table 2 shows that yields are more closely correlated with minimum temperatures. Similarly, the temperatures at 10 cm., both maximum and minimum, were more closely correlated to yields than those at one cm. This probably results from less variability in 10-cm. temperatures due to damping and also a probable greater root concentration at this depth. The highest correlation, $r = 0.87$, was for minimum temperatures at the 10 cm. depth.

Table 3 shows water use by both corn and beans from June 30 to September 8, 1965. The water used is the difference between volumetric soil moisture contents on June 30 and September 8, plus the sum of the precipitation and irrigation during this period. While the inches of water used by each treatment show no consistent trend, the water use efficiency, i.e., pounds produced per acre-inch of water used, indicates that with corn the water mulch was superior to the other treatments; with beans it was just as efficient as the plastic treatment. However, when one considers the amount of water required within the water mulch, the efficiency drops; with corn it was equal to the plastic, but with beans less efficient than the plastic treatments. In all cases, both the plastic and water mulch treatments were more efficient than the check.

SUMMARY

Water mulches, i.e., polyethylene bags filled with four inches of water and placed on the soil surface between the crop rows, were tested for their influence on soil temperatures and production of sweet corn and green beans. These mulches, due to their high specific heat capacity, act as a heat sink during the day and a heat source at night. The effect is a dampening of the diurnal fluctuations of soil temperature at 1- and 10-cm. soil depths. Minimum soil temperatures under water mulches at both the 1- and 10-cm. depths were significantly higher on seven test days than on either clear plastic mulch or check treatments.

The effect of water mulches on crop growth was one of early, vigorous growth. Ear formation of corn on the water mulches was 2 days ahead of the plastic treatment and 8 days ahead of the check. With both corn and beans, water mulches resulted in earlier, heavier yields.

Yield of corn was closely correlated with the seven-day average minimum temperature at the 10-cm. depth; $r = 0.87$.

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