AN EVALUATION OF PLASTIC AND ALUMINUM MULCHES IN RELATION TO SOIL TEMPERATURES, WEED CONTROL PRACTICES, AND THE YIELD OF MUSKMELONS AND TOMATOES

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AN EVALUATION OF PLASTIC AND ALUMINUM MULCHES IN RELATION TO SOIL TEMPERATURES, WEED CONTROL PRACTICES, AND THE YIELD OF MUSKMELONS AND TOMATOES

By

JERALD WAYNE RIEKELS

AN ABSTRACT

Submitted to the College of Agriculture, Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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JERALD WAYNE RIEKELS ABSTRACT

The effects of clear, black, and aluminum coated polyethylene films on soil and air temperatures were measured with thermocouples placed at depths of one and four inches in the soil and four inches above the surface of the films. Temperatures were recorded for forty-five days during July, August, September, and October with unshaded plots during warm and cold weather, shaded plots, and plots with windbreaks. Moisture levels in four plots were increased by watering, and one moist plot and a dry plot were covered with black plastic. The use of windbreaks and shading was of little value as the temperature relationships between the plots were essentially the same as those observed for unshaded plots.

Clear plastic resulted in the warmest soil temperatures during the day with maximum increases in soil temperature that averaged 13.5°F and 8.9°F greater than the temperatures of bare soil at depths of one and four inches, respectively. The lowest soil temperatures during the warmest part of the day occurred under aluminum mulch and averaged 1.8°F lower than bare soil at one inch and 0.7°F lower at four inches.

The daytime soil temperatures under black plastic were warmer than those of bare soil but were not as warm as those under clear plastic. Black plastic over moist soil resulted in temperature increases that averaged 10.6°F greater than bare soil temperatures at one inch and 7.0°F greater at four inches. The dry soil under black plastic did not become as warm as the moist soil under black plastic as the average temperature increases were only 8.2°F and 5.4°F over bare soil temperatures at the respective depths of one and four inches.

The soil temperatures during the night under all the films were approximately the same and averaged about 5°F warmer than bare soil at both depths. The average air temperatures above the plastic films for twenty-four hours were 0.7°F warmer than those above bare soil while the temperatures above aluminum averaged 1.0°F higher than those above bare soil during the six-hour period before noon, but the average was 0.6°F cooler for the rest of the day.

Additional soil temperature measurements were made at one and one-half inch depths in soil in flats. The flats were covered with various plastic films, and soil temperatures were recorded with the films in direct contact with the soil and with a one-inch air space between the films and the soil. The results showed that soil temperatures under films in direct contact with the soil averaged 3°F to 5°F higher than those obtained with an air space below the film.

Mulching experiments were conducted to determine the effects of black plastic, hot tents, and chemical weed control used with black plastic on the yields of muskmelons and tomatoes. Muskmelons and tomatoes showed definite responses to plastic mulching which can be partially attributed to the higher soil temperatures under black plastic. An experiment with seven varieties of muskmelons showed that Spartan Rock responded the most to black plastic, and Honey Rock and Michigan Honey Rock responded the least. Delicious, Harvest Queen, Burpee Hybrid, and Harpers Hybrid showed intermediate responses to black plastic.

The use of hot tents with direct seeding produced definite increases in the yield of muskmelons. Melons seeded with cultivation and covered with hot tents resulted in yields that were equivalent to those obtained from transplanting melon plants through plastic. Hot tents used with melons seeded through plastic produced the highest yields.

The use of simazine pellets and spray at two pounds per acre between the rows of black plastic did not markedly affect the yields of muskmelons and tomatoes even though some plants were injured by the chemical.

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INTRODUCTION

One of the primary purposes of mulching is to regulate the temperature of the soil. Different mulching materials have varied effects on soil temperature. Materials that reflect solar radiation reduce the absorption of heat by the mulched soil. Other materials absorb or transmit solar energy which tends to increase soil temperatures above those of unmulched soil. Mulches that warm the soil can be used to improve the growth of warm season crops in cool climates or during cool weather. A mulch that cools the soil can be used in hot climates to lower the soil temperature for a more favorable production of cool season crops.

In this study the influence of various films as mulches on soil and air temperature relationships were evaluated. Transparent, black, and aluminum coated transparent polyethylene films were utilized to measure the effect of transmission, absorption, and reflection of solar energy on the underlying soil.

Additional experiments were conducted with black polyethylene to determine its effect on crop yields. Weed control chemicals were applied between rows of black plastic to investigate the effect of such chemicals upon the crop and to determine if cultivation can be entirely eliminated from a mulched field.

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REVIEW OF LITERATURE

Many factors are responsible for changes in soil temperature. Bouyoucos (1916) listed these factors in two separate categories: intrinsic and external. Intrinsic factors are related to soil physical properties, including specific heat, heat conductivity, radiation, water content, evaporation of water, concentration of the soil solution, topographic position, and condition of the surface. External factors such as air temperature, sunshine, wind velocity, barometric pressure, and rainfall are meteorological.

Soil color affects the absorption of heat, but radiation is affected more by the moisture content of the soil (Bouyoucos, 1913). Bouyoucos (1916) further stated that white surfaced sandy soils reflected heat and were cooler than dark colored soils with the exception of peat which has a high moisture content and is cooled by evaporation. He also found that all soils, when covered with a layer of sand, warmed up the same. He suggested covering the soil with a layer of dark material to increase the rate of warming in the spring.

The application of such a covering layer of material to the soil surface is defined as mulching by Rowe-Dutton (1957). A wide range of materials can be used as mulches which generally consist of natural substances, such as plant residues, peat, manure, stones, straw, and sawdust, or manufactured materials such as asphalt paper, glass wool, aluminum foil, bituminous emulsion, and polyethylene plastic. Mulching conserves moisture, controls weeds, provides winter protection, and regulates soil temperatures. Rowe-Dutton states that mulching with straw or sawdust tends to reduce daily soil temperature fluctuation. Dark colored mulches, such as asphalt paper and black polyethylene, tend to increase soil temperatures during sunny periods by absorbing solar radiation.

Smith (1927 and 1931) conducted soil temperature studies with perforated and nonperforated black and gray paper. He found that soil covered with nonperforated black paper attained the highest average temperatures, between 5°F and 7°F higher than those in cultivated soil. Soil temperatures under the perforated black paper were slightly above those of cultivated soil. The nonperforated gray paper resulted in temperatures just below those of cultivated soil, and the perforated gray paper gave the lowest temperatures.

Makarevskii, as cited by Jacks et al (1955), found that the soil temperature under acetyl cellulose, bitumen, and black paper was greater than that of cultivated soil. Under white paper the soil temperature was lower than in cultivated soil during the day and higher during the night. The temperature differences between mulched and unmulched soils was smallest under white paper and greatest under acetyl cellulose film.

Flint (1928), Magruder (1930), and Stewart et al (1930) all report that black paper mulch increased soil temperatures with the greatest differences occurring on bright sunny days. Flint stated that black paper increased the soil temperature as much as 10°F on sunny days and 3°F without solar radiation. Magruder found the daily mean temperature of soil mulched with black paper to be 6.5°F greater than the temperatures of unmulched soil. Stewart et al found that the warmest months produced the greatest differences between mulched and unmulched soil. The mulched soil showed differences that were 12-15°F greater during the day and 4-5°F greater at night. The corresponding differences during the coldest months were 5-8°F and 2-4°F. During periods of heavy rains the differences were not evident.

Shaw (1926) reported that covering the soil with black paper hastened the rate of warming and retarded the rate of cooling. A narrower range occurred between the maximum and minimum temperatures to give a more uniform soil temperature which was slightly higher under the black paper.

Honma et al (1959) studied muck soil temperatures beneath black polyethylene mulch at a depth of five inches and found that the average soil temperature was 2.5°F higher under the black polyethylene than in bare soil. The maximum and minimum soil temperatures were reached four and eight hours, respectively, after the maximum and minimum air temperatures. The mean soil temperatures for sunny days three inches below the soil surface of bare and covered mineral soils were several degrees higher during the night with covered soils than with bare soils, but the day temperatures of covered soils were lower than those of bare soils. The soil temperature underneath a black plastic hood, which was eight inches above the soil surface, was 5°F lower than that of bare soil while intermediate temperatures occurred beneath black, aluminum, and white polyethylene in that order.

Heslip (1959), studying temperature effects of mulching, found that temperatures at two inches generally exceeded those at a four-inch depth. Black plastic increased the soil temperature an average of 5°F above cultivated soil at the two-inch depth and 3°F at the four-inch depth. Aluminum mulched soil warmed up similarly to cultivated soil but stayed warm longer, and the soil tended to warm up and cool more slowly than air temperature but did not become as low.

Gliniecki (1959) reported that black polyethylene raised soil temperatures above those of unmulched soil while white film produced lower soil temperatures than normal due to reflected sunlight. Aluminum film tended to be similar to white film. Clear film resulted in temperatures at least 2°F higher than black film and had better heat storage.

Voth and Bringhurst (1959) found a high average temperature under clear polyethylene and a low average temperature under black polyethylene with the greatest differences occurring in February, March, and April. During this time soils covered with black plastic had lower temperatures at a three-inch depth than bare soil, but in June and July black plastic resulted in higher temperatures. Also, black and clear films showed the smallest differences at this time.

Clarkson (1959) showed that median and average soil temperatures are higher with black polyethylene mulch than with unmulched soil and found that black film increases heat accumulation during the early part of the growing season. Downes et al (1959) reported that temperatures under both aluminum and black plastic mulches at a depth of four to five inches were 3-5°F higher than under cultivated soil.

Honma et al (1959) found that temperatures one-fourth inch above black plastic averaged 1°F warmer than those above bare muck soil between four and six o'clock in the morning. After sunrise the air temperature above these two surfaces rose more rapidly than the air temperature twelve inches above the soil. In another experiment, temperatures measured one-half inch above bare mineral soil and the various plastic mulches showed no differences during the early morning hours. At noon temperatures were 3.6°F higher over aluminum, 1.1°F higher over black plastic, and 7.6°F lower over the black hood than over bare soil.

Rowe-Dutton (1957) stated that the purpose of any cultural operation is to increase yields, earliness, or quality of the crops by modifying environmental conditions. Many workers have claimed these benefits from mulching, but others have reported undesirable effects. Emerson (1903) listed crops that responded favorably to mulching, but Shaw (1926) reported adverse results from beans, milo, and potatoes mulched with black paper. Flint (1928) found that mulching with paper increased the yield of twelve crops over a four-year period. Edmond (1929) reported increased yields and earliness with six crops. He stated that mulching was best on warm season crops. Magruder (1930) found that black asphalt paper mulch gave off a soluble substance that depressed plant growth. However, he also stated that mulching with black paper increased the rate and percent of germination and early growth to give earlier maturity and larger early yields. Nineteen vegetables responded favorably to mulching and were larger, cleaner, and better in quality. Smith (1931) found that nonperforated black paper gave the highest yields and best growth of two indicator crops while the poorest results were obtained on unmulched soil.

Carolus and Downes (1958) and Carolus (1959) found that mulching with black polyethylene resulted in greater total yields and a greater percentage of the yield harvested early. The greatest response to mulching was obtained from muskmelons and squash while tomatoes, pepper, and eggplant gave favorable results but to a lesser extent. Heslip (1959) reported that black plastic mulch increased the yields of cucumbers 28 percent, tomatoes 31 percent, squash 58 percent, and muskmelons 81 percent above those of cultivated soil. The cucurbits tended to respond more to mulching than tomatoes.

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Muskmelons gave the best response on plastic four feet wide, but tomatoes produced satisfactory results on plastic three feet wide.

Downes *et al* (1959) reported a 41 percent increase in total yield of peppers mulched with black plastic over cultivated peppers. Voth and Bringhurst (1959) found that total and early yields of strawberries were increased with clear polyethylene mulch but not with black polyethylene mulch. Emmert (1957) reported that aluminum plastic gave the best results as black plastic became too warm and injured seed germination.

Clarkson (1959) states that yield increases are not the result of the plastic material but are due to the influence of the plastic on the soils, microclimate, and diseases. Carolus (1959) and Heslip (1959) reported that increased yields from mulching are the result of conserving soil moisture, increasing soil temperature, protecting the surface roots, and increasing aeration of the soil surface. These factors produce more benefits from mulching through increased nutrient availability and the stimulation of microorganisms to increase nitrification (Flint, 1928). Weed control and reduced cultivation are other benefits of mulching that aid in preserving soil moisture and fertility (Edmond, 1929).

Ries (1957) reported that herbicides and shallow cultivation used for weed control in pickling cucumbers resulted in yields equal to those obtained with black plastic mulching.

He stated that black plastic had no additional advantage except to keep the soil undisturbed.

METHODS AND MATERIALS

Temperature Studies

Temperature measurements were made in 1959 at the Hydrologic Research Station at East Lansing on a Hillsdale fine sandy loam soil. A Brown Electronik sixteen point strip chart temperature recorder was used to provide a continuous twenty-four hour record of temperatures. Fifteen thermocouples were placed at depths of one and four inches in the soil and four inches in the air above the surface of each of five plots, and the other thermocouple was placed two and one-half feet above the soil to record the air temperature of the area.

Each thermocouple recorded one temperature reading every four minutes for a total of 15 readings per hour or 360 readings per day. The experiment was conducted for forty-five days under varying conditions providing a total of 259,200 temperature readings for all sixteen thermocouples. One average reading was selected for each hour, a total of 17,280 values, and used in compiling the data reported in this study.

Moisture blocks were placed at a depth of four inches in the plots and four of the plots were watered thoroughly to raise the moisture content of the soil. Moisture readings were taken approximately once a day during July and August but were recorded less frequently in September and October. Dalapon was spread on the plots to prevent the growth of quackgrass, and simazine was applied later to control broadleaf weeds. A snow fence was placed around the entire area in an attempt to reduce the air movement over the plots.

Sheets of polyethylene film, approximately four feet square, were placed on four of the five plots in the following manner:

1. Black polyethylene on dry soil.
2. A control plot of moist bare soil.
3. Clear polyethylene on moist soil.
4. Black polyethylene on moist soil.
5. Aluminum coated polyethylene on moist soil.

Temperatures were recorded under four different conditions consisting of direct exposure during warm and cold weather, shading, and placing windbreaks around each plot. Temperatures were recorded as follows:

July 22-27	Warm weather exposure
July 28-August 2	Shading
August 2-9	Warm weather exposure
August 10-16	Shading
September 1-10	Windbreaks
October 11-12, 16-22	Cold weather exposure

The plots were shaded by mounting a single layer of cheesecloth approximately twelve inches above the surface of each plot. The reduction in sunlight intensity with cheesecloth as measured with a foot-candle meter between 1:00 and 2:30 p.m. was approximately twenty-five percent or

2,200 foot-candles. The windbreaks consisted of sheets of clear polyethylene that were supported approximately two and one-half feet high around the border of each plot.

The days during which the temperatures were recorded were classified as clear, partly cloudy, or cloudy. Pyrheliometer readings in gram-calories per square centimeter of horizontal surface, supplied by the Hydrologic Research Station, were used in making this classification. Records from the Lansing weather bureau provided information as to the amount of sky cover, hours of sunlight, and the percent of possible sunlight and were also used in classifying the daily weather conditions.

In another experiment, the effects of different plastic covers on soil temperature were measured with the films in direct contact with the soil and one inch above the soil surface. Clear, black, clear on black, and green polyethylene films were placed over flats containing soil at two levels, and thermocouples were placed at a depth of one and one-half inches in the soil. The experiment was started in a greenhouse during the winter months of 1960 and moved outside in May to eliminate the effect of shading in the greenhouse.

Muskmelon Yield Tests

Mulching experiments were conducted in 1959 on the horticultural farm at East Lansing. The effects of black plastic mulch on muskmelon yields were compared with yields from cultivated plots. The plastic was laid with a tractor mounted attachment on soil which had been previously fertilized and disced. The melons were harvested as they ripened and records were kept of the number and weight of marketable fruit.

Banded muskmelon plants were set in the field on June 3 in plots consisting of six hills, of two plants each, spaced at five-foot intervals in rows six feet apart. Harvest was started on August 12 and continued through September 18.

Muskmelon Variety Test: Cultivation was compared with four-foot black plastic mulch in this experiment which consisted of two replications of the following varieties:

1. Delicious
2. Harvest Queen
3. Honey Rock
4. Burpee Hybrid
5. Harpers Hybrid
6. Spartan Rock
7. Michigan Honey Rock

Muskmelon Seeding and Transplant Test: Two replications of the varieties, Delicious and Harvest Queen were used in comparing the following treatments:

1. Banded plants - cultivated.
2. Banded plants - black plastic.
3. Seeded - cultivated.
4. Seeded thru black plastic.
5. Seeded - cultivated with hot tents.
6. Seeded thru black plastic with hot tents.

Seeding was done on May 12 for the treatments with hot tents and on May 22 for the other seeded treatments.

Chemical Weed Control

Experiments were conducted with tomatoes and muskmelons utilizing weed control chemicals on plots mulched with black polyethylene. Fifty percent wettable simazine and four percent granular simazine were applied as a spray and as pellets at the rate of two pounds per acre.

Muskmelons: Three replications of Delicious and Honey Rock varieties were planted on June 10. Plots consisted of seven hills spaced at five-foot intervals with rows six feet apart. The following treatments were compared:

1. Cultivated.
2. Four-foot black plastic.
3. Four-foot black plastic and sprayed simazine.
4. Four-foot black plastic and pelleted simazine.

The fruits were harvested from August 12 through September 11.

Tomatoes: Two replications of Fireball and Moreton Hybrid tomatoes were planted on May 30. The plots were thirty feet long and five feet apart consisting of twelve Fireball plants at two-foot intervals or ten Moreton Hybrid plants at two and one-half foot intervals. Comparisors were made between the following treatments:

1. Cultivated.
2. Three-foot black plastic.
3. Four-foot black plastic.
4. Three-foot black plastic and sprayed simazine.
5. Four-foot black plastic and sprayed simazine.

6. Three-foot black plastic and pelleted simazine.

7. Four-foot black plastic and pelleted simazine.

The tomatoes were harvested from July 17 through September 18.

RESULTS

The Influence of Film Mulches on Temperature

Soil Temperature: The effects of plastic and aluminum mulches on soil temperature for unshaded plots during clear warm weather are presented in Figure 1 as the hourly averages in degrees F for July 26 and 27 and August 5 and 6. The warmest temperatures at the one-inch depth were under clear plastic during the daytime between 10:00 a.m. and 7:00 p.m. and under aluminum during the early morning hours between 1:00 a.m. and 8:00 a.m. The coolest soil temperatures at both depths occurred in bare soil at night and under the aluminum during the day. Black plastic over moist soil produced the warmest day temperatures at four inches in the soil while the soil under clear plastic tended to be slightly warmer at night. The greatest temperature fluctuations occurred under the clear plastic at one inch and in the moistened soil under black plastic at four inches. The most uniform temperatures were maintained under the aluminum at both depths in the soil.

The minimum and maximum soil temperatures occurred from 6:00 to 7:00 a.m. and 3:00 to 4:00 p.m. at the one-inch depth, and from 7:00 to 8:00 a.m. and 4:00 to 5:00 p.m. at the four-inch depth, respectively. The magnitude of the differences in soil temperature under mulches at these maximum and minimum points as compared with the uncovered soil are indicated below:

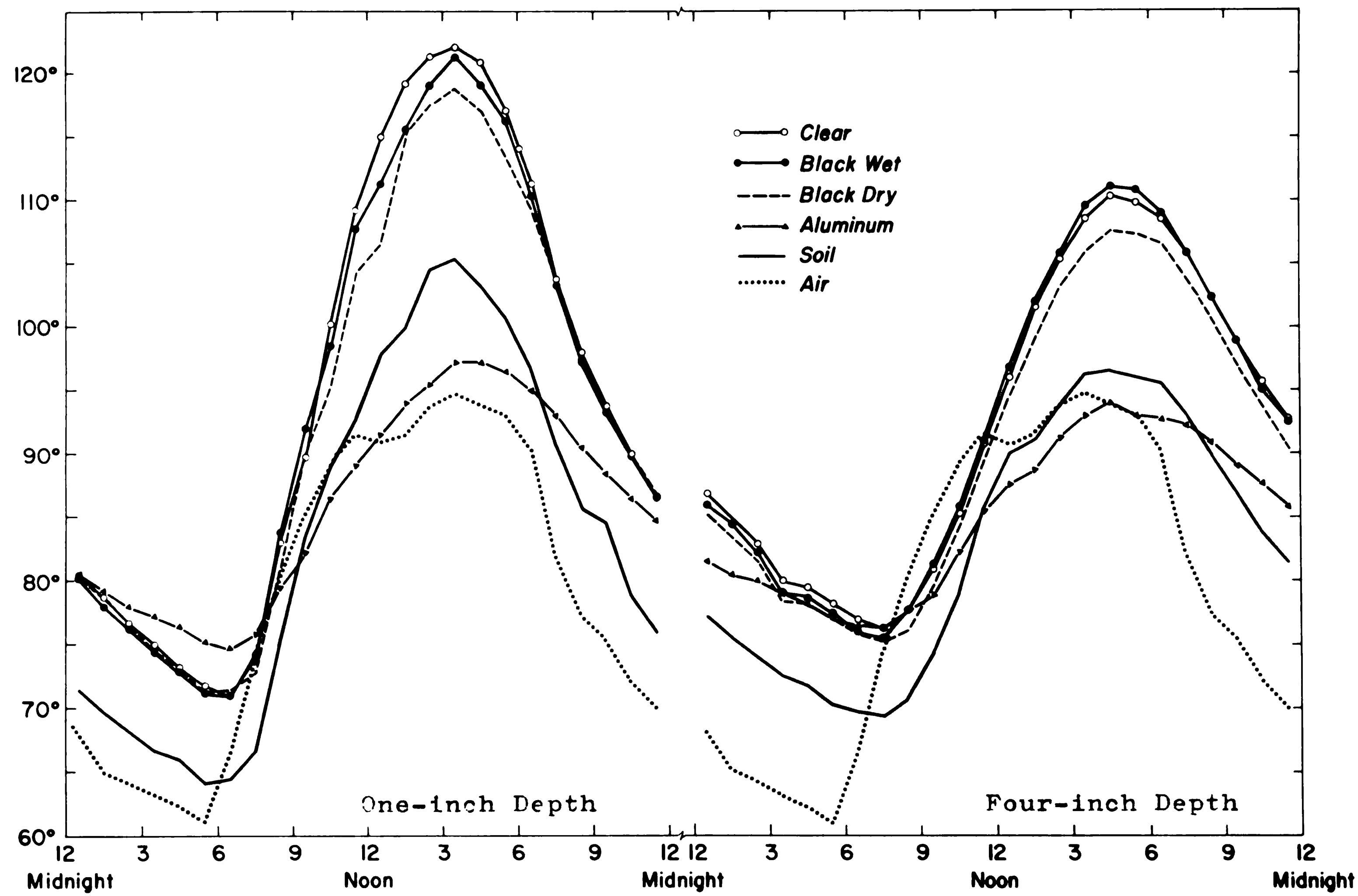

Figure 1. The average effect of various films on soil temperatures during four clear days with unshaded plots. (Hourly averages in degrees F). Average solar radiation for 24 hours - 631.1 gram-calories per square centimeter.

	Maximum		Minimum	
	1-inch	4-inches	1-inch	4-inches
Bare Soil Temperature:	105.3°	96.5°	64.5°	69.5°
Clear:	+16.7°	+13.8°	+6.5°	+6.8°
Black-Wet:	+16.0°	+14.5°	+6.5°	+6.0°
Black-Dry:	+13.5°	+11.0°	+7.0°	+5.8°
Aluminum:	-8.0°	-2.5°	+10.3°	+6.8°

Tables I and II present the average temperatures recorded from unshaded plots during warm weather for partly-cloudy days on July 22, 24, and 25 and August 4 and 9 and for cloudy days on July 23 and August 3, 7, and 8. The results are the averages of the temperatures obtained during six-hour intervals throughout the day. The relationship between the various soil temperatures are the same as those presented in Figure 1 except that the warmest temperatures at the four-inch depth occur under the clear plastic instead of in the moist soil under the black plastic. The temperature differences between the various plots tended to decrease as the amount of solar radiation decreased.

Figure 2 presents the hourly averages in degrees F obtained from shading the plots during clear days on July 31 and August 1, 2, and 14. A single thickness of cheesecloth which reduced the light intensity approximately 2,200 foot-candles, or 25 percent, was used to simulate the effect of a plant growing on the plastic. The reduction in light intensity was not great enough to exert much influence as

TABLE I

The Average Effect of Various Films on Soil Temperatures During Five Partly-cloudy Days* with Unshaded Plots. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil			
			Black Dry	Black Wet	Clear Wet	Alum. Wet
			One-inch depth			
Mid. to 6 a.m.	66.2	69.2	+5.8	+5.3	+6.4	+6.6
6 a.m. to Noon	77.5	77.9	+5.2	+5.9	+6.7	+1.2
Noon to 6 p.m.	86.3	91.8	+11.4	+13.0	+15.5	-2.0
6 p.m. to Mid.	73.2	79.2	+10.5	+10.5	+11.1	+5.4
			Four-inch depth			
Mid. to 6 a.m.	66.2	73.0	+5.6	+5.7	+7.0	+4.2
6 a.m. to Noon	77.5	74.8	+4.6	+4.8	+5.3	+2.8
Noon to 6 p.m.	86.3	87.8	+6.6	+7.5	+8.9	-0.5
6 p.m. to Mid.	73.2	82.6	+9.0	+9.8	+10.8	+2.5

*Average solar radiation for 24 hours - 476.9 gram-calories per square centimeter.

TABLE II

The Average Effect of Various Films on Soil Temperatures During Four Cloudy Days* with Unshaded Plots. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil			
			Black Dry	Black Wet	Clear Wet	Alum. Wet
			One-inch depth			
Mid. to 6 a.m.	68.2	71.9	+7.0	+6.6	+7.7	+6.6
6 a.m. to Noon	73.3	75.4	+4.2	+4.8	+6.1	+2.0
Noon to 6 p.m.	75.6	81.6	+4.7	+5.3	+8.0	-1.0
6 p.m. to Mid.	69.1	73.9	+4.9	+5.0	+6.1	+2.8
			Four-inch depth			
Mid. to 6 a.m.	68.2	76.0	+6.6	+6.7	+8.0	+4.1
6 a.m. to Noon	73.3	74.9	+4.3	+4.6	+6.2	+2.9
Noon to 6 p.m.	75.6	79.9	+3.8	+4.3	+6.4	+0.2
6 p.m. to Mid.	69.1	76.8	+4.5	+4.9	+6.5	+1.2

*Average solar radiation for 24 hours - 208.7 gram-calories per square centimeter.

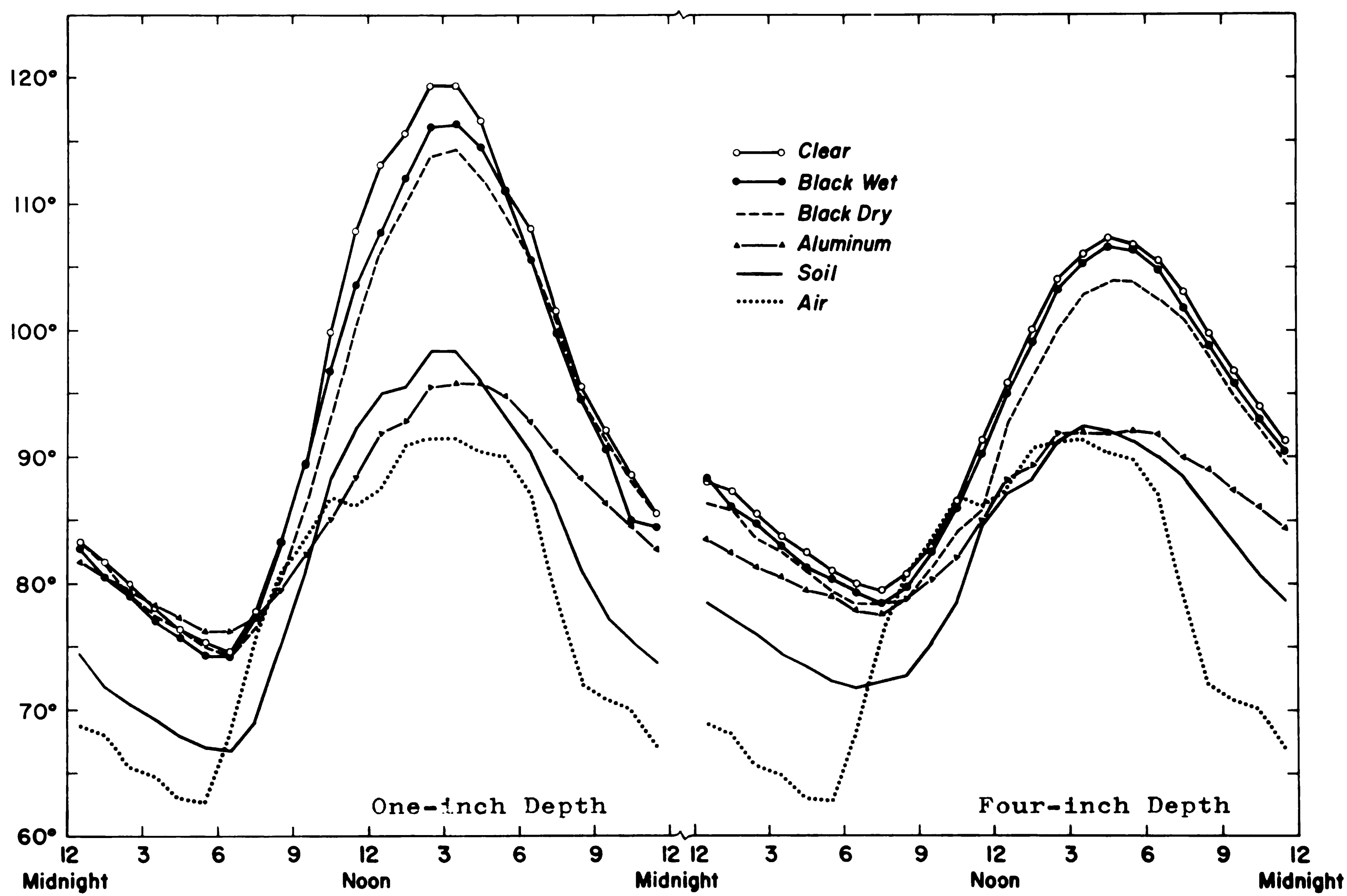

Figure 2. The average effect of various films on soil temperatures during four clear days with shaded plots. (Hourly averages in degrees F). Average solar radiation for 24 hours - 670.1 gram-calories per square centimeter.

the relationships between the plots are essentially the same as in Figure 1 except that at the four-inch depth the soil under the clear plastic was the warmest during the entire twenty-four hour period.

The soil temperature differences at the maximum and minimum points with shade are presented below using the temperatures of bare soil as reference points:

	Maximum		Minimum	
	1-inch	4-inches	1-inch	4-inches
Bare Soil Temperature:	98.3°	92.0°	66.8°	71.3°
Clear:	+21.0°	+15.3°	+7.7°	+8.2°
Black-Wet:	+18.0°	+14.5°	+7.5°	+7.2°
Black-Dry:	+16.0°	+11.8°	+7.5°	+7.2°
Aluminum:	-2.5°	-0.2°	+9.5°	+6.2°

These differences, as compared with those of Figure 1, are larger for the three plastic films and smaller for the aluminum. This would indicate that shading had more influence on the temperature of bare soil than on covered soil.

The soil temperatures of the shaded plots during eight partly-cloudy days are shown in Table III as the averages of six-hour intervals for July 28, 29, and 30 and August 10, 11, 12, 13, and 15. The temperature differences between the plots are smaller than those occurring during clear weather and except for the soil under clear plastic, which averaged warmest during the eight day period at both depths, the relationships are the same as those presented in Figure 2 for clear days.

TABLE III

The Average Effect of Various Films on Soil Temperatures During Eight Partly-cloudy Days* with Shaded Plots. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil: Black Dry	Black Wet	Clear Wet	Alum. Wet
One-inch depth						
Mid. to 6 a.m.	71.9	74.1	+6.3	+6.5	+7.1	+5.9
6 a.m. to Noon	81.2	80.5	+3.9	+6.3	+7.2	+0.7
Noon to 6 p.m.	91.3	94.9	+9.0	+12.2	+14.4	-3.0
6 p.m. to Mid.	79.5	83.8	+8.0	+8.6	+9.7	+3.2
Four-inch depth						
Mid. to 6 a.m.	71.9	77.1	+6.2	+7.1	+8.0	+4.1
6 a.m. to Noon	81.2	77.8	+4.1	+4.7	+5.7	+2.4
Noon to 6 p.m.	91.3	90.2	+6.0	+8.0	+8.7	-1.4
6 p.m. to Mid.	79.5	85.7	+7.3	+8.8	+10.0	+1.3

*Average solar radiation for 24 hours - 479.2 gram-calories per square centimeter.

The effects of shading on soil temperature cannot be directly compared with that from unshaded plots as the temperatures were recorded on different days. The differences between Figures 1 and 2 indicate that shading reduced temperatures as the solar energy was greater when the plots were shaded; but the air temperature was lower during this time also, and the lower temperatures in Figure 2 may have been due to the lower air temperature and not the reduced light intensity. Tables I and III show a similar effect as the soil temperatures with shading are greater than in unshaded plots even though solar radiation was approximately the same for both periods.

Windbreaks were placed around each plot to permit a more accurate measurement of the air temperature above each film, but the recorded differences were neither consistent nor great enough to be of any importance. The average hourly soil temperatures obtained by placing windbreaks around the plots are shown in Figure 3 for six clear days on September 3, 4, 5, 6, 7, and 8. The soil temperatures in the different plots are related in the same manner as in Figures 1 and 2. The maximum soil temperatures at the one-inch depth were reached between 2:00 and 3:00 p.m. which is one hour earlier than those for shaded and unshaded plots. The daytime differences in the soil temperatures beneath the clear and black films tended to be greater than those recorded under shaded or unshaded conditions. These differences, as they

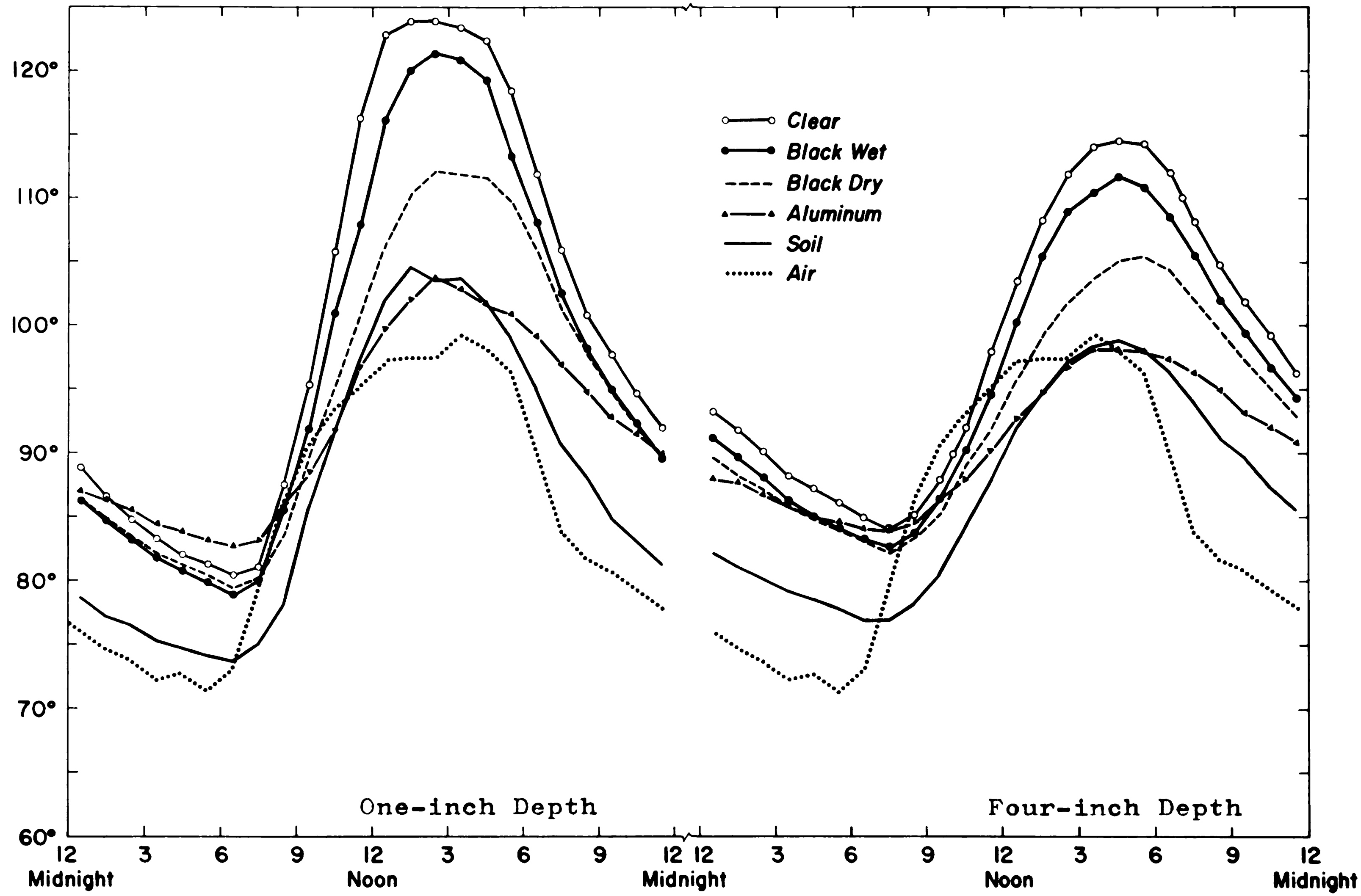

Figure 3. The average effect of various films on soil temperatures during six clear days for plots with windbreaks. (Hourly averages in degrees F). Average solar radiation for 24 hours - 536.8 gram-calories per square centimeter.

occur at the maximum and minimum points, are related to bare soil temperatures as follows:

	Maximum		Minimum	
	1-inch	4-inches	1-inch	4-inches
Bare Soil Temperature:	103.5°	98.8°	73.7°	77.0°
Clear:	+20.3°	+15.7°	+6.8°	+7.2°
Black-Wet:	+17.8°	+12.9°	+5.1°	+6.8°
Black-Dry:	+8.5°	+6.4°	+5.8°	+5.3°
Aluminum:	+0.2°	-0.6°	+9.0°	+7.0°

Table IV presents the average soil temperatures as they were recorded with a windbreak around each plot during partly-cloudy weather on September 1, 2, 9, and 10. The table shows the aluminum covered soil to be slightly warmer than bare soil; whereas, the reverse occurred with shaded and unshaded plots. Clear plastic resulted in the warmest temperatures throughout the entire day. The temperature differences and fluctuations were not as great during partly-cloudy weather, but the relationships are similar to those occurring in clear weather.

The data in Tables V, VI, and VII are the average soil temperatures of unshaded plots during cold weather for clear days on October 18, 19, and 20, partly-cloudy days on October 11, 16, 21, and 22, and cloudy days on October 12 and 17. The results, when compared with Figure 1 and Tables I and II, indicate that the various covers have the same relative effects on soil temperature in both cold and warm

TABLE IV

The Average Effect of Various Films on Soil Temperatures During Four Partly-cloudy Days* for Plots with Windbreaks. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil: Black Dry	Black Wet	Clear Wet	Alum. Wet
			One-inch depth			
Mid. to 6 a.m.	75.2	79.5	+6.1	+5.6	+7.6	+6.6
6 a.m. to Noon	80.2	82.2	+4.6	+6.8	+10.0	+3.7
Noon to 6 p.m.	87.0	93.2	+8.2	+11.4	+17.4	+0.4
6 p.m. to Mid.	76.7	80.8	+8.7	+8.6	+11.8	+6.3
			Four-inch depth			
Mid. to 6 a.m.	75.2	83.1	+5.5	+5.9	+7.4	+5.0
6 a.m. to Noon	80.2	81.4	+4.7	+5.5	+7.4	+4.1
Noon to 6 p.m.	87.0	90.6	+5.4	+8.0	+11.6	+0.6
6 p.m. to Mid.	76.7	84.4	+7.7	+8.7	+11.7	+3.8

*Average solar radiation for 24 hours - 370.1 gram-calories per square centimeter.

TABLE V

The Average Effect of Various Films on Soil Temperatures During Three Clear Days* with Unshaded Plots in Cold Weather. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil Black Dry	Black Wet	Clear Wet	Alum. Wet
			One-inch depth			
Mid. to 6 a.m.	44.1	45.0	+6.8	+5.0	+4.0	+9.6
6 a.m. to Noon	55.0	50.5	+5.0	+4.6	+4.8	+6.8
Noon to 6 p.m.	65.4	68.7	+4.5	+4.8	+8.0	+0.9
6 p.m. to Mid.	48.3	52.0	+8.0	+5.9	+6.4	+8.5
			Four-inch depth			
Mid. to 6 a.m.	44.1	50.1	+2.5	+1.8	+0.6	+5.1
6 a.m. to Noon	55.0	51.9	+3.1	+1.9	+1.3	+5.0
Noon to 6 p.m.	65.4	65.6	+2.8	+3.0	+5.0	+0.5
6 p.m. to Mid.	48.3	57.8	+3.8	+2.8	+3.7	+3.9

*Average solar radiation for 24 hours - 365.6 gram-calories per square centimeter.

TABLE VI

The Average Effect of Various Films on Soil Temperatures During Four Partly-cloudy Days* with Unshaded Plots in Cold Weather. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil			
			Black Dry	Black Wet	Clear Wet	Alum. Wet
			One-inch depth			
Mid. to 6 a.m.	39.3	44.2	+6.5	+4.4	+4.5	+8.5
6 a.m. to Noon	51.4	51.5	+3.4	+3.2	+4.0	+4.0
Noon to 6 p.m.	64.2	67.5	+3.2	+3.7	+6.6	-0.4
6 p.m. to Mid.	51.2	54.9	+6.6	+4.8	+5.5	+6.2
			Four-inch depth			
Mid. to 6 a.m.	39.3	50.2	+4.6	+2.7	+3.0	+5.5
6 a.m. to Noon	51.4	51.4	+3.2	+2.0	+2.5	+4.3
Noon to 6 p.m.	64.2	65.3	+2.2	+2.3	+4.2	-0.1
6 p.m. to Mid.	51.2	59.5	+3.9	+3.3	+4.2	+2.9

*Average solar radiation for 24 hours - 262.3 gram-calories per square centimeter.

TABLE VII

The Average Effect of Various Films on Soil Temperatures During Two Cloudy Days* with Unshaded Plots in Cold Weather. (Averages for Six-hour Periods in Degrees F)

Time	Air	Bare Soil	Differences from Bare Soil: Black Dry	Black Wet	Clear Wet	Alum. Wet
			One-inch depth			
Mid. to 6 a.m.	50.8	53.6	+5.2	+3.9	+4.1	+5.6
6 a.m. to Noon	52.0	54.7	+4.4	+3.7	+3.8	+4.2
Noon to 6 p.m.	54.7	59.4	+4.4	+3.7	+4.8	+2.6
6 p.m. to Mid.	47.7	51.8	+6.2	+5.1	+5.1	+6.6
			Four-inch depth			
Mid. to 6 a.m.	50.8	56.7	+3.7	+3.0	+3.0	+3.5
6 a.m. to Noon	52.0	56.4	+3.3	+2.9	+2.5	+3.1
Noon to 6 p.m.	54.7	59.2	+3.3	+3.0	+3.0	+1.8
6 p.m. to Mid.	47.7	55.9	+2.8	+2.7	+2.4	+2.3

*Average solar radiation for 24 hours - 134.5 gram-calories per square centimeter.

weather. Aluminum caused the greatest difference by keeping the soil warmest throughout most of the night at both soil depths. Cloudy weather resulted in similar soil temperatures beneath the various covers, but all films produced warmer soil temperatures than were recorded in bare soil for the entire day.

Figure 4 summarizes the average hourly soil temperatures obtained under all conditions for forty-five days. At both depths the soil under clear plastic was warmer than the moist soil under black plastic during the day. The next highest day temperatures were in the dry soil under black plastic. The next in order was the bare soil followed by the soil under aluminum.

The early morning soil temperatures at one inch were warmest under aluminum and coolest in bare soil. The dry soil beneath the black film is similar to that under clear film, but both soils were warmer than the moist soil under the black film. The early morning temperatures at four inches were warmest in the soil beneath clear plastic and coolest in bare soil. The black and aluminum covers resulted in similar soil temperatures with the aluminum covered soil slightly lower than that under the two black films between midnight and 5:00 a.m. The greatest and smallest soil temperature fluctuations occurred beneath the clear and aluminum films, respectively.

The average minimum and maximum soil temperatures during

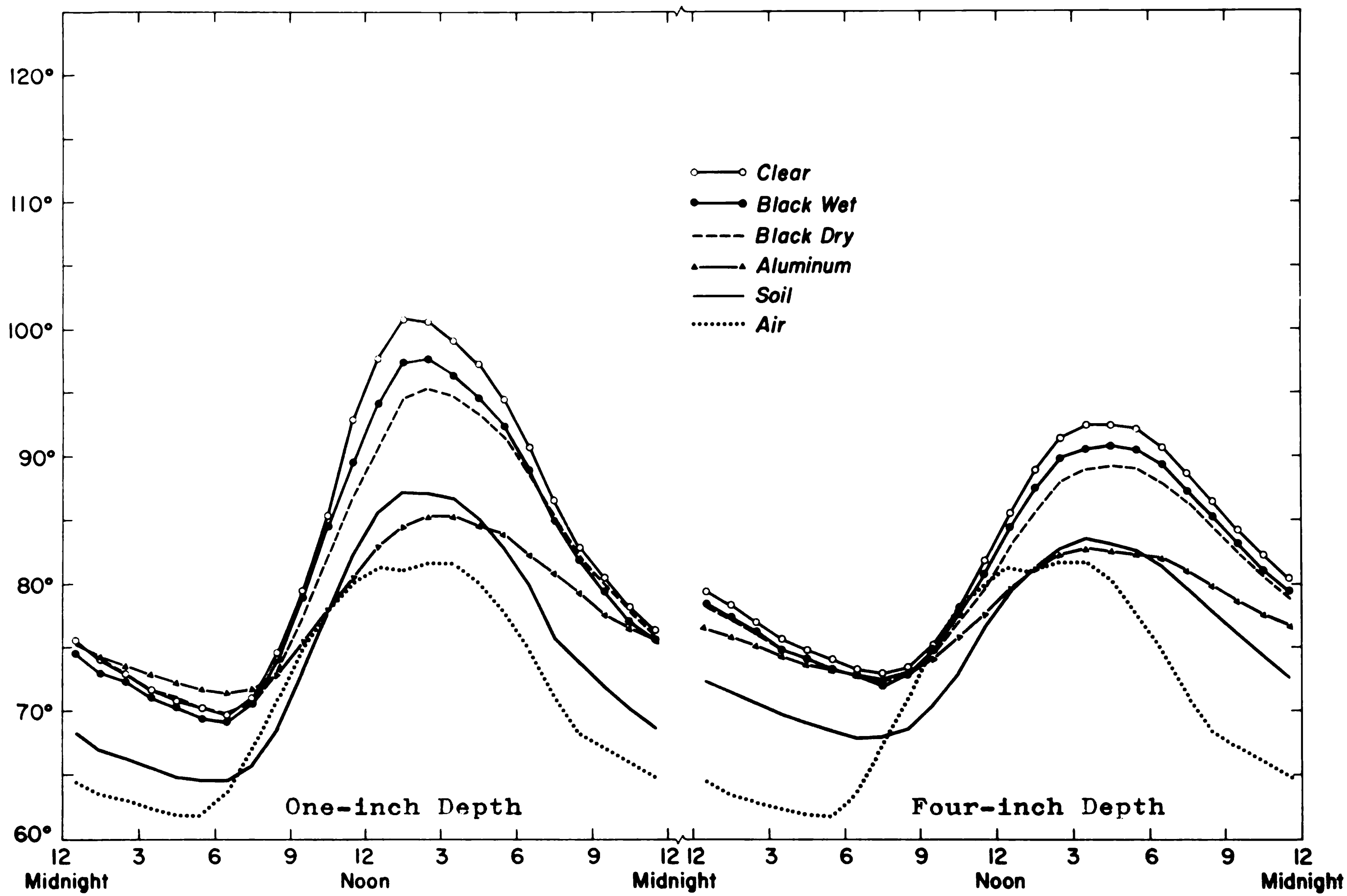

Figure 4. The average effect of various films on soil temperatures during forty-five days. (Hourly averages in degrees F). Average solar radiation for 24 hours - 451.1 gram-calories per square centimeter.

the forty-five day period occurred from 6:00 to 7:00 a.m. and 2:00 to 3:00 p.m. at the one-inch depth and from 7:00 to 8:00 a.m. and 3:00 to 4:00 p.m. at the four-inch depth, respectively. The soil temperatures at these maximum and minimum points vary from bare soil temperature as follows:

	Maximum		Minimum	
	1-inch	4-inches	1-inch	4-inches
Bare Soil Temperature:	87.1°	83.5°	64.6°	68.0°
Clear:	+13.5°	+8.9°	+5.1°	+5.0°
Black-Wet:	+10.6°	+7.0°	+4.6°	+4.0°
Black-Dry:	+8.2°	+5.4°	+5.4°	+4.4°
Aluminum:	-1.8°	-0.7°	+7.2°	+4.5°

The averages of twenty-four soil moisture readings indicating the percentage of field capacity are presented as follows:

Clear:	93.8	Aluminum:	84.5
Black-Wet:	91.3	Bare Soil:	83.0
Black-Dry:	84.3		

A possible effect of these differences in soil moisture on soil temperatures beneath black plastic is suggested by the data in Figure 4. The soil with the highest moisture content showed a greater fluctuation in temperature throughout the twenty-four hour period and was lower at night and higher in the daytime. The differences were more evident at one inch than at four inches with very little difference occurring during the night at four-inch depths.

Air Temperature: A summary of the air temperatures during the forty-five day period four inches above the different surfaces is presented in Table VIII. The data indicate that temperatures above the black and clear films were between one-half to one degree warmer than those above bare soil and aluminum. The black and clear films both tend to radiate more heat to the air than does bare soil, but this could be the natural result of the warmer soil temperatures under the films. The air temperatures above aluminum were slightly cooler than those above bare soil which shows that less heat escapes from the soil with an aluminum cover. Between 6:00 a.m. and noon the air above aluminum averaged one degree warmer than that above bare soil which could be attributed to the reflection of heat from the surface of the film.

Soil Temperature as Affected by Film Placement: The data in Table IX indicate that the presence of an air space beneath the plastic films will result in lower soil temperatures than when the film is in direct contact with the soil. The clear plastic and transparent green plastic produced the warmest soil temperatures while the soil temperatures under the translucent green plastic were slightly cooler. The soil temperatures under the black plastic and the combination of clear on black were cooler than under the green plastic but were warmer than bare soil. The transparent green and clear plastics had similar effects on soil temperature as did the black and the clear on black combination. The clear on black combination tended to increase the soil temperature when the films were in contact with the soil surface.

TABLE VIII

Average Air Temperatures Four Inches Above Various Films. (Averages in Degrees F During a Forty-five Day* Period at Six-hour Intervals)

Time	Air	Bare Soil	Differences from Bare Soil Black Dry	Black Wet	Clear Wet	Alum. Wet
Mid. to 6 a.m.	62.8	62.2	+0.7	+0.6	+0.7	-0.2
6 a.m. to Noon	72.4	71.0	+0.9	+1.3	+0.7	+1.0
Noon to 6 p.m.	80.6	80.9	+0.7	+0.5	+0.4	-0.3
6 p.m. to Mid.	68.7	67.9	+0.9	+0.4	+0.5	-0.7
Averages	71.1	70.5	+0.8	+0.7	+0.6	-0.1

*Average solar radiation for 24 hours - 451.1 gram-calories per square centimeter.

TABLE IX

The Effects of Various Plastic Films on Soil Temperatures at One and One-half Inch Depths.

Type of Film	With Air Space	Direct Contact	With Air Space**
Outdoor Measurements			
Bare Soil (24)*	87.4	87.4	- -
Black (12)	+2.0	+8.3	- -
Clear on Black (12)	+2.0	+11.7	- -
Translucent Green (12)	+9.1	+14.9	- -
Transparent Green (12)	+17.6	+18.6	- -
Clear (12)	+15.4	+19.4	- -
Average	+9.2	+14.6	
Greenhouse Measurements			
Bare Soil	- -	- -	72.7
Black (5)*	73.0	75.8	72.5
Translucent Green (5)	75.2	77.5	76.8
Transparent Green (5)	76.0	79.5	79.3
Average	74.7	77.6	

*Number of readings averaged.

**Average of seven readings made with dial thermometers.

The Influence of Black Plastic on Muskmelon Production

Variety Test: The effects of mulching and cultivation on the yields of seven different muskmelon varieties is shown in Table X. Mulching with black plastic resulted in a total yield of 780 bushels per acre which is significantly greater than the 497 bushels per acre obtained with cultivation. There was no significant differential variety effect from treatment. Spartan Rock showed the greatest response to mulching with an increased yield of 95 percent while Michigan Honey Rock responded the least with a 21 percent increase.

The number of melons per plot was significantly greater in the mulched plots, but the size of the fruit was approximately the same. Spartan Rock and Michigan Honey Rock showed the largest and smallest respective increases in the number of melons produced.

Seeding With Hot Tents and Transplanting Test: Table XI shows the effect of using black plastic mulch and hot tents with direct seeding and plants. All treatments except that of melons seeded thru plastic produced yields that were significantly greater than those obtained from melons seeded with cultivation. Melons seeded through plastic and covered with hot tents produced the highest yield of 835 bushels per acre which was significantly greater than the yields obtained from melons transplanted with cultivation and melons seeded through plastic. Mulching with black plastic resulted in

TABLE X

Effect of Black Plastic Mulch on the Yield of Melon Varieties.
(Marketable Yields in 50 Pound Bushels per Acre)

Varieties	Plastic			Cultivated		
	Yield	Number /Plot	Weight /Fruit*	Yield	Number /Plot	Weight /Fruit*
Delicious	884	56	3.29	478	30	3.35
Harvest Queen	697	40	3.64	472	26	3.83
Honey Rock	618	40	3.19	454	33	2.89
Burpee Hybrid	1,056	58	3.76	680	38	3.72
Harpers Hybrid	994	60	3.45	620	41	3.13
Spartan Rock	707	69	2.13	363	36	2.04
Michigan Honey Rock	509	34	3.09	421	29	3.05
Average	780	51	3.22	497	33	3.15

*Weight in pounds

	Average Yield	Average Number
L.S.D. .05	109 bu.	8
L.S.D. .01	152 bu.	11

TABLE XI

Effect of Black Plastic Mulch and Hot Tents on Seeded and Transplanted Melons.
(Marketable Yields in 50 Pound Bushels per Acre)

Treatment	Delicious			Harvest Queen			Average		
	Yield	Number /Plot	Weight /Fruit*	Yield	Number /Plot	Weight /Fruit*	Yield	Number /Plot	Weight /Fruit*
Plants with Cultivation	681	41	3.47	600	35	3.59	640	38	3.84
Plants on Plastic	971	62	3.21	626	36	3.64	798	49	3.51
Seeded with Cultivation	472	28	3.48	442	24	3.80	457	26	3.84
Seeded thru Plastic	662	42	3.26	578	34	3.51	620	38	3.38
Seeded with Cultivation + Hot Tents	847	58	2.99	620	34	3.77	733	46	3.38
Seeded thru Plastic + Hot Tents	952	63	3.12	719	38	3.91	835	50	3.52

*Weight in pounds

	Average Yield	Average Number
L.S.D. .05	183 bu.	13
L.S.D. .01	258 bu.	19

melon yield increases of 163 bushels with direct seeding, 158 bushels with plants, and 102 bushels with direct seeding and hot tents. The yield of 733 bushels per acre obtained from the melons seeded with cultivation and covered with hot tents was essentially the same as the 798 bushels per acre harvested from the melons transplanted on plastic. A similar relationship occurred between the 640 bushels per acre obtained from melons transplanted with cultivation and the 620 bushels per acre produced from melons seeded through plastic.

The treatments producing the largest yields also produced the largest number of melons per plot, but the largest fruit occurred on the plots with the smallest number of melons and the lowest yields. This indicates that yield increases are primarily due to increases in the number of fruit and not the size of the fruit.

Both varieties had the lowest yields on plots with direct seeding and cultivation, but the highest yields were obtained from melons planted with plastic for Delicious and from direct seeding with plastic and hot tents for Harvest Queen. Delicious showed more response to the various treatments than Harvest Queen.

<u>The Influence of Chemical Weed Control on Muskmelons and Tomatoes Mulched with Black Plastic</u>

<u>Muskmelons:</u> Muskmelon yields of 547, 470, and 449 bushels per acre, as shown in Table XII, were obtained from plastic, plastic with granular simazine, and plastic with sprayed

TABLE XII

Effect of Black Plastic and Chemical Weed Control on the Yield of Two Melon Varieties. (Marketable Yields in 50 Pound Bushels per Acre)

Treatment	Honey Rock Yield	Honey Rock Number /Plot	Honey Rock Weight /Fruit*	Delicious Yield	Delicious Number /Plot	Delicious Weight /Fruit*	Average Yield	Average Number /Plot	Average Weight /Fruit*
Cultivated	223	21	2.52	297	22	3.26	260	22	2.86
Plastic	459	38	2.93	635	46	3.30	547	42	3.11
Plastic with Simazine Spray	399	35	2.75	499	36	3.31	449	36	3.01
Plastic with Granular Simazine	434	34	3.10	506	35	3.45	470	34	3.30

*Weight in pounds

	Average Yield	Average Number
L.S.D. .05	178 bu.	6
L.S.D. .01	248 bu.	8

simazine, respectively, all of which were significantly greater than yields from the cultivated plots. Black plastic resulted in yields that were larger than those obtained from black plastic with simazine, and larger yields were also obtained with granular simazine than with sprayed simazine. The lower yields that occurred with the use of simazine could be attributed to the washing of treated soil into the holes with the plants which resulted in severe injury in a few cases. The yield reduction that occurred with sprayed simazine may have been caused by injury to the melon plants during the application of the chemical.

The largest yields were obtained with the treatments producing the largest number of melons per plot except for the pelleted treatment which produced fewer melons than the spray treatment. However, the fruit size was the largest in the pelleted treatment and resulted in the increase in yield over the spray treatment. The large fruit size with the pelleted treatment was consistent for both varieties which indicates that the pellets may have increased the size of the melons. Delicious responded more to the various treatments than Honey Rock, but both varieties showed the highest yields on plots with black plastic and the lowest yields on cultivated plots.

<u>Tomatoes:</u> Table XIII indicates that plastic mulch significantly increased the early and total yields and numbers of tomatoes. The four-foot plastic resulted in yields that

TABLE XIII

Effect of Black Plastic and Chemical Weed Control on the Average Yield of Fireball and Moreton Hybrid Tomatoes. (Marketable Yields in 56 Pound Bushels per Acre)

		Average Yield	Average Number /Plot
Early Yield (July 17 to Aug. 12)			
Cultivated		156	106
3 ft. Plastic		282	191
4 ft. Plastic		284	193
3 ft. Plastic + Simazine		278	193
4 ft. Plastic + Simazine		284	205
	L.S.D. .05	32 bu.	24
	L.S.D. .01	43 bu.	33
Total Yield (July 17 to Sept. 18)			
Cultivated		547	378
3 ft. Plastic		980	628
4 ft. Plastic		1,066	688
3 ft. Plastic + Simazine		1,010	612
4 ft. Plastic + Simazine		1,081	713
	L.S.D. .05	160 bu.	65
	L.S.D. .01	216 bu.	88

were slightly greater than those obtained from plots with three-foot plastic. The treatments producing the largest yields also resulted in the largest number of melons per plot, and the size of the fruit was approximately the same for all treatments which indicates that yield increases are the result of increases in the number of fruit produced. Both varieties showed approximately the same relative response to the various treatments except that Fireball showed a slightly greater response to mulching than did Moreton Hybrid.

The use of simazine with black plastic had no effect on the early yield of the tomatoes but resulted in slight increases in the total yield that were not significant. These increases in total yield on the chemically treated plots might have been greater but some plants were severely injured by the simazine which was washed into the holes with the plants.

DISCUSSION

The data obtained in these studies indicate that covering the soil with a plastic or aluminum mulch will result in distinct changes in soil temperatures. Mulches that tend to increase the soil temperature in cool climates make conditions more favorable for warm weather crops and increase earliness while mulches that reduce soil temperatures are important in warm climates in the production of cool season crops (Rowe-Dutton, 1957).

The warmest soil temperatures in this study were measured under clear plastic and are similar to those reported by Voth and Bringhurst (1959) and Gliniecki (1959). The soil temperatures under black plastic were also warmer than those of bare soil and agree with the results obtained by Heslip (1959), Gliniecki (1959), and Clarkson (1959), but are contrary to those reported by Honma et al (1959) for mineral soils and by Voth and Bringhurst (1959). Aluminum mulches resulted in soil temperatures that were approximately the same as or lower than bare soil temperatures during the day and warmer than bare soil at night. Heslip (1959) obtained similar results in soil mulched with aluminum. These results indicate that clear and black plastic would be most useful as mulches in cool climates with warm-season crops while aluminum mulches might be more effective in warm climates with cool season crops.

The differences observed in the air temperature above the plastic films are similar to those recorded by Honma et al

(1959) as both studies showed that temperatures above the films are slightly greater than those above bare soil. The temperatures in this study were recorded four inches above the surface of the films. Greater differences probably occurred closer to the films.

Soil temperatures measured under various films in direct contact with the soil surface and with an air space between the film and the soil surface indicate that a film should be laid in direct contact with the soil to obtain the warmest soil temperatures. These conditions can be attained by smoothing the soil surface before applying the film and then stretching the film tightly over the surface while it is being laid. Paper mulches tear easily and cannot be pulled or stretched as tight to the soil as plastic mulches. This indicates that more air space occurs under paper mulches and the resulting soil temperatures would tend to be lower than those under plastic mulches.

The use of black plastic and aluminum mulches with various warm-season crops in Michigan has resulted in larger early and total yields, and such increases can be partly attributed to the warmer soil temperatures that were attained with these mulches (Carolus and Downes, 1958, and Heslip, 1959). The effect of increasing soil temperatures on the growth of tomato plants was investigated by Tiessen (1956) who found that increasing the soil temperature from 46°F to 70°F resulted in large increases in plant growth. He also observed that there was a larger number of flowers and fruit on the plants grown at the higher soil temperatures than on plants grown at lower temperatures. Roberts (1953) reported similar results obtained by increasing the soil temperature of strawberry plants from 45°F to 75°F. These observations indicate that the increase in soil temperatures obtained with black plastic could be a very important contributing factor to the higher yields and better plant growth.

The effect of increases in soil temperature on the absorption of water was studied by Schroeder (1939). He found that an increase in root temperature of cucumbers caused an increase in the rate of absorption of water by the plant and reduced wilting. He attributed the increase in absorption to the reduced viscosity of water and colloidal cellular material and to the increased metabolic activity which occurs at the higher temperatures. Such an increase in the rate of absorption will not prevent a plant from wilting if conditions are such that the rate of transpiration exceeds the rate of absorption, but the increased absorption will reduce any injury from wilting and result in a quicker recovery.

Short periods of wilting will occur in many plants in the late afternoon as a result of a temporary excess in the rate of transpiration over that of absorption. The stomates of a plant generally close during wilting which results in a reduction of photosynthesis. The combined effect of these occurrences may be sufficient to decrease the growth and yield of the plant.

The higher crop yields that have been obtained from black plastic can be attributed to the increase in soil temperature which increases the rate of absorption of water and prevents the plant from wilting. The yield increases that occur with plastic mulch are due mainly to increases in the number of fruit and not the size of the fruit. Such results may be due to the improved absorption of water by the plant which may result in the development of more flowers and definitely in greater fruit set.

Mulching with black polyethylene has resulted in definite yield increases with muskmelons and tomatoes (Carolus and Downes, 1958, and Heslip, 1959). Similar results have been observed in the various mulching experiments conducted in this investigation. The results obtained with the different melon varieties are comparable to those reported by Heslip (1959). The greatest increases were obtained with Spartan Rock in both studies while Honey Rock and Michigan Honey Rock showed the least response. These differences indicate that Honey Rock and Michigan Honey Rock may be more adapted to the climate in Michigan and receive less benefit from mulching with black plastic than Spartan Rock.

Muskmelons covered with hot tents showed large increases in yield as compared to those without hot tents. Heslip (1959) also reported yield increases on muskmelons covered with hot tents, but the differences were not as great as those observed in this study. Melons seeded through black plastic and covered with hot tents resulted in the highest yields, however, this practice could be costly.

Melons transplanted on plastic produced the second highest yields which were approximately the same as those obtained from melons seeded with hot tents and cultivated. The cost considerations between these two treatments are quite complicated as the expense of raising plants to be transplanted with the plastic may exceed the cost of seeding, cultivating, and using hot tents; but the reverse can also be true as these expenses tend to vary from year to year. The yields of melons seeded thru plastic and of melons transplanted and cultivated were also similar and the costs of these treatments would determine which practice to employ. However, one of the above practices may be economic as the yields obtained from seeding with cultivation tended to be the lowest.

The use of chemical weed control between the rows of mulched tomatoes and muskmelons did not affect the yield of either crop significantly. Such results indicate that chemical weed control in combination with black plastic would be practical only when the cost of such a practice is less than mechanical weed control and there is no injury or significant reductions in crop yield.

SUMMARY AND CONCLUSIONS

The effects of various films on soil and air temperatures were recorded at depths of one and four inches in the soil and four inches above the films during forty-five days in July, August, September, and October in 1959. The temperatures as affected by clear, black, and aluminum coated polyethylene were compared with those of bare soil.

Clear plastic resulted in the warmest soil temperatures during the day at both one and four inches in the soil. The maximum increases in soil temperature under the clear plastic averaged 13.5°F and 8.9°F greater than the temperatures of bare soil at depths of one inch and four inches, respectively.

The daytime soil temperatures under black plastic were warmer than those of bare soil but were not as warm as those under clear plastic. The black plastic over moist soil resulted in temperature increases that averaged 10.6°F greater than bare soil temperatures at one inch and 7.0°F greater at four inches. The dry soil under black plastic did not become as warm as the moist soil under black plastic as the average temperature increases were only 8.2°F and 5.4°F over bare soil temperatures at the respective depths of one and four inches.

The lowest soil temperatures during the warmest part of the day occurred under aluminum mulch and averaged 1.8°F lower than the temperature of bare soil at the one-inch depth and 0.7°F lower at four inches.

The soil temperatures under all the films were approximately the same during the night and averaged about 5°F warmer than bare soil at both depths.

The average air temperatures above the plastic films were 0.7°F warmer than those above bare soil. The air temperatures above the aluminum averaged 1.0°F higher than those above bare soil during the six-hour period before noon, but the average temperature throughout the rest of the day was 0.6°F cooler.

The effects of various plastic covers on soil temperatures were also measured at one and one-half inch depths with the films in direct contact with the soil surface and one inch above the surface. The results showed that soil temperatures under films in direct contact with the soil surface averaged from 3°F to 5°F higher than soil temperatures under films with an air space between the film and the soil surface.

Mulching experiments were conducted in 1959 to measure the effects of black plastic, hot tents, and chemical weed control used with black plastic on the yields of muskmelons and tomatoes.

Muskmelons and tomatoes showed definite responses to plastic mulching. The results indicated that fruit size was not influenced by plastic mulch and that increases in yield are primarily due to increases in the number of fruit produced.

The use of hot tents produced definite increases in the yield of muskmelons. Melons seeded with cultivation and covered with hot tents resulted in yields that were equivalent to those obtained from melons transplanted on plastic. Hot tents used on plastic with direct seeding produced the highest yields.

The use of simazine pellets and spray between the rows of black plastic did not markedly affect the yields of muskmelons and tomatoes even though some plants were seriously injured by the chemical.

The results obtained in these studies seem to warrant the following conclusions:

1. Black plastic and clear plastic mulches increase soil temperatures throughout the entire day.

2. Clear plastic results in warmer daytime soil temperatures than black plastic.

3. Aluminum mulches result in the least fluctuation in soil temperature and tend to keep the soil cool during the warmest part of the day.

4. The higher soil temperatures obtained with black plastic are important contributing factors to the higher yields and better plant growth.

5. The yield increases obtained with plastic mulch are primarily due to increases in the number of fruit produced.

6. The use of hot tents result in yield increases of seeded muskmelons.

7. The use of chemical weed control with black plastic

did not affect the yields of tomatoes and muskmelons and can be recommended for use with these crops providing the chemicals have been approved for use by the Food and Drug Administration.

LITERATURE CITED

Bouyoucos, G. J. 1913. An investigation of soil temperature and some of the most important factors influencing it. Mich. Agr. Exp. Sta. Tech. Bul. 17: 1-196.

________________. 1916. Soil temperature. Mich. Agr. Exp. Sta. Tech. Bul. 26: 1-133.

Carolus, R. L. 1959. Now northern growers can grow vine crops at a profit. Amer. Veg. Grower. March.

_______________, and J. D. Downes. 1958. Studies on muskmelon and tomato responses to polyethylene mulching. Mich. Agr. Exp. Sta. Quart. Bul. 40: 770-785.

Clarkson, V. A. 1959. Soil temperatures and nitrogen level as affected by polyethylene mulches. Paper presented at Southern Region of Amer. Soc. Hort. Sci.

Downes, J. D., R. Heslip, and S. Honma. 1959. Effect of polyethylene mulches, starter solution, and kind of transplant on yields of sweet peppers. Mich. Agr. Exp. Sta. Quart. Bul. 41: 641-647.

Edmond, J. D. 1929. Mulch paper for vegetable crops is tested. Mich. Agr. Exp. Sta. Quart. Bul. 11: 115-117.

Emerson, R. A. 1903. Experiments in mulching garden vegetables. Neb. Agr. Exp. Sta. Bul. 80. 26 pp.

Emmert, E. M. 1957. Black polyethylene for mulching vegetables. Proc. Amer. Soc. Hort. Sci. 69: 464-469.

Flint, L. H. 1928. Crop-plant stimulation with paper mulch. U. S. Dept. Agr. Tech. Bul. 75: 1-20.

Gliniecki, V. I. 1959. Evaluating polyethylene films for agriculture. Down to Earth 15 (3): 7-9.

Heslip, R. P. 1959. The influence of mulching on several vegetable crops with special reference to black polyethylene. M. S. Thesis. Michigan State University.

Honma, S., F. McArdle, J. Carew, and D. H. Dewey. 1959. Soil and air temperature as affected by polyethylene film mulches. Mich. Agr. Exp. Sta. Quart. Bul. 41: 834-842.

Jacks, G. V., D. Brind, and Robert Smith. 1955. Mulching. Commonwealth Bureau of Soil Science. Tech. Com. No. 49.

Magruder, Roy. 1930. Paper mulch for the vegetable garden. Ohio Agr. Exp. Sta. Bul. 447.

Ries, S. K. 1957. Chemical and cultural methods of controlling weeds in pickling cucumbers. Mich. Agr. Exp. Sta. Quart. Bul. 40: 503-514.

Roberts, A. N. 1953. Growth and composition of the strawberry plant in relation to root temperature. Ph. D. Thesis. Michigan State University.

Rowe-Dutton, Patricia. 1957. The mulching of vegetables. Commonwealth Bureau of Hort. and Plant Crops. Tech. Com. No. 24.

Schroeder, R. A. 1939. The effect of root temperature upon the absorption of water by the cucumber. Univ. of Mo. Agr. Exp. Sta. Res. Bul. 309.

Shaw, Charles F. 1926. The effect of a paper mulch on soil temperature. Cal. Agr. Exp. Sta. Hilgardia 1: 341-364.

Smith, Alfred. 1927. Effect of mulches on soil temperatures during the warmest weeks in July, 1925. Cal. Agr. Exp. Sta. Hilgardia 2: 385-397.

_______________. 1931. Effect of paper mulches on soil temperature, soil moisture, and yields of certain crops. Cal. Agr. Exp. Sta. Hilgardia 6: 159-201.

Stewart, G. R., E. C. Thomas, and John Horner. 1926. Some effects of paper mulching on Hawaiian soils. Soil Science 22 (1): 37-59.

Tiessen, Herman. 1956. The effects of high analysis soluble fertilizers as interrelated with environmental conditions and cultural practices on the growth and yield of vegetables with special reference to the tomato. Ph. D. Thesis. Michigan State University.

Voth, Victor, and R. S. Bringhurst. 1959. Polyethylene over strawberries. California Agriculture 13 (5): 5-14.