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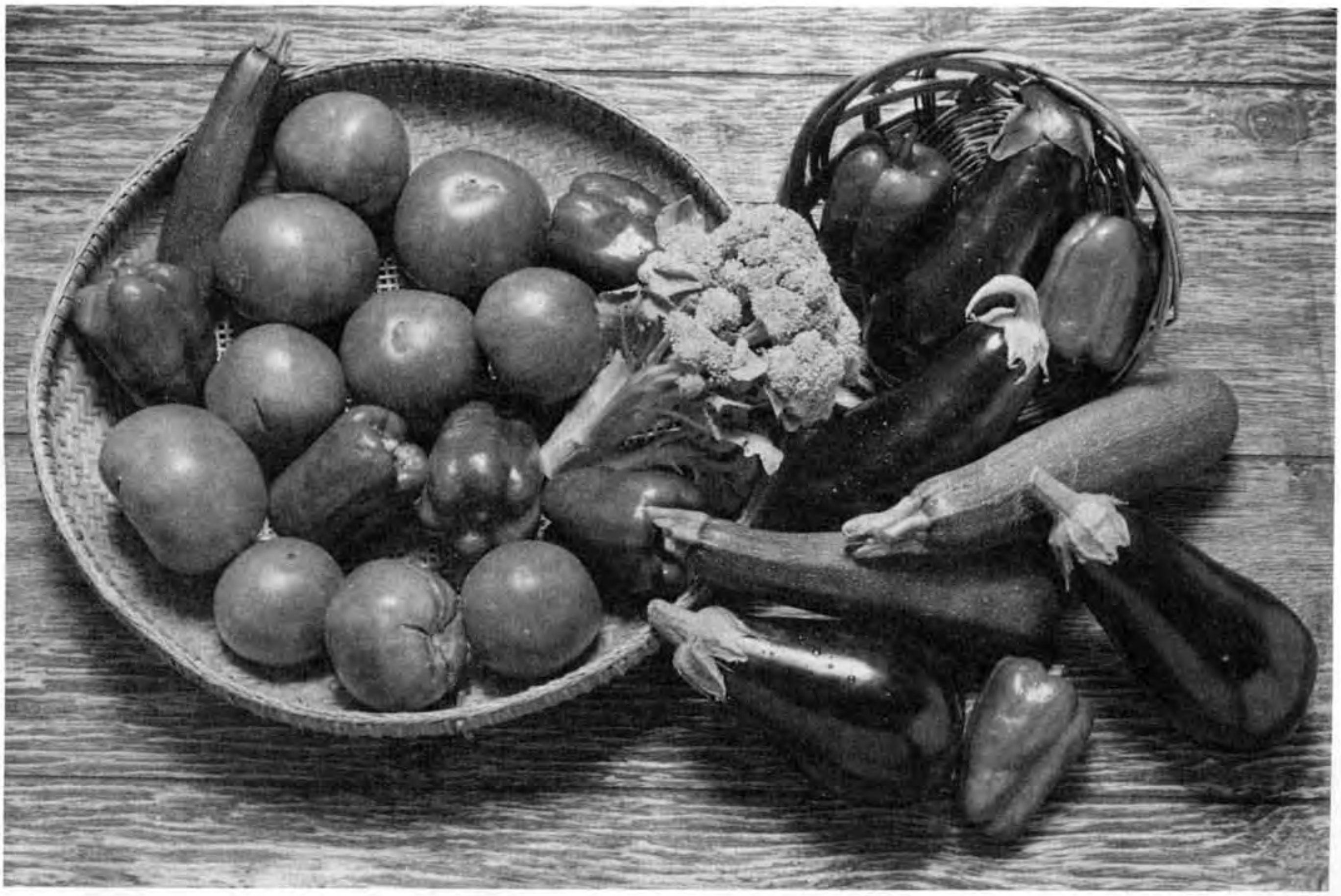
MULCHES: Their Effect on Fruit Set, Timing and Yields of Vegetables

By David E. Hill, Lester Hankin, and George R. Stephens



THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION, NEW HAVEN

MULCHES: their effect on fruit set, timing and yields of vegetables.

David E. Hill, Lester Hankin and George R. Stephens

Home gardeners aspire to grow abundant and early vegetables to supply family needs and also earn the "bragging rights" of the neighborhood. Commercial growers also seek bumper crops, but for them timing is essential: fruit from plants maturing early commands high prices, and plants that mature during short periods of time are adaptable to mechanical harvesting. Both gardeners and commercial growers must contend with drought when rain is inadequate for crops. About one-third of Connecticut's home gardens and perhaps three-fourths of its commercial acres have very sandy or shallow soils whose meager reservoirs of moisture prolong water stress.

Mulches of plant residues have been used for centuries by farmers and gardeners to increase moisture supplies and crop yields. Recently, paper and plastic film have been introduced to modify the soil environment, improve yields (Jacks et al., 1955), and repel insects (George and Kring, 1971; Smith and Webb, 1971). The primary benefit of mulches is to conserve soil moisture by reducing evaporation of water from the soil (Army and Hudspeth, 1960; Lippert et al., 1964; Shales and Sheldrake, 1966) and by suppressing weeds that compete with crops for moisture, light, and nutrients (Emmert, 1975; Flint, 1928).

Depending upon the type, mulches can keep the soil cool or warm it within the root zone (Clarkson, 1960; Honma et al., 1959; Shales and Sheldrake, 1966). The alteration of moisture and temperature under a mulch modifies the microenvironment of the soil surrounding the roots. The bulk density (wt/unit volume) of soil is lowered under mulch (Liptay and Tiessen, 1970), and nitrate concentrations are increased (Black and Greb, 1962; Clarkson, 1960; Knavel and Mohr, 1967). These factors profoundly affect the distribution of roots under a mulch (Isenberg and Odland, 1960; Knavel and Mohr, 1967). From lysimeter data, Waggoner et al. (1960) estimated that mineralization of organic matter by microorganisms in soil under plastic film is greater than in bare soil; but Hankin et al. (1982) showed that temperature differences of 11-14 C (20-25 F) provided by various mulches appeared insufficient to create important differences in populations and biochemical activities of soil bacteria.

Not all crops are expected to respond to a particular mulch in the same manner. Vegetables such as broccoli, cauliflower, and cabbage are regarded as "cool weather" crops; peppers and eggplant are favored by warm weather. Thus, in our experiments from 1978 through 1981 we studied several kinds of mulches and their effects on representative cool and warm weather crops.

Although the yield of a crop is important, earliness and timing are equally important in vegetables. Hence, we measured the change in yield caused by various mulches and also, for some crops, plant synchrony, the timing of crop development from flowering to maturity. These observations show which mulches are the most beneficial for a specific crop.

METHODS AND MATERIALS

All experiments were conducted at the Experiment Station's Lockwood Farm in Mt. Carmel, Hamden, Connecticut from 1978 through 1981. The soils are derived from loamy glacial till and are classified as Yalesville fine sandy loam, and Cheshire fine sandy loam by the Connecticut Cooperative Soil Survey. The most notable characteristic of the Yalesville soils is weakly cemented bedrock at a depth of 50-100 cm (20-40 inches). The Cheshire soil has physical characteristics similar to the Yalesville soil, except it is deeper to bedrock and has a loamy sand substratum. These medium-textured soils have a moderate moisture holding capacity, however, the storage potential in the Yalesville soil is somewhat limited by its shallower depth. The organic matter content of both is 4-6%.

Various mulches were used to create differences in soil temperature, conserve moisture and suppress weeds. Soils were kept cool by raw leaves, grass clippings, and alumnized film that either absorbed solar energy or reflected it. Soils were warmed with black paper, black film, or clear film that transmitted solar energy to the soil.

Treatments varied from year to year and are summarized as follows:

<u>1978 and 1979 -- Broccoli, peppers, eggplant</u>

Plot size:	1.5 x 3 meters (4.9 x 9.8 feet)
Replications:	2
Variety grown:	Broccoli-DeCicco 1978
	Peppers-Yolo Wonder 1978
	Eggplant-Var. unknown 1979
Plants/plot:	4
Spacing within row:	60 cm (24 in)
Mulch materials:	Polyethylene-clear 4-mil thickness
	Polyethylene-black 4-mil thickness
	Raw leaves-75 cm (3 in) depth; mixed oak and maple
Treatments:	Clear film over black film
	Black film
	Clear film over black film over leaves
	Leaves over black film
	Leaves
	Bare soil

Fertilization:	Broccoli	Peppers	Eggplant
		grams (lb)/plot	
Urea (46-0-0)	110 (0.24)	55 (0.12)	110 (0.24)
Triple superphosphate (0-40-0)	115 (0.25)	115 (0.25)	115 (0.25)
Muriate of potash (0-0-60)	80 (0.18)	80 (0.18)	80 (0.18)
Ground limestone	1535 (3.38)	1535 (3.38)	1535 (3.38)

<u>1980 and 1981 -- Eggplant and Zucchini Squash</u>

Plot size:	3 x 3 meters (9.8 x 9.8 feet)
Replications:	5
Variety grown:	Eggplant-Florida No. 10 1980
	Eggplant-Highbush 1981
	Zucchini squash-Italian Vegetable Marrow 1981
Plants/plot:	8
Spacing within x between rows:	
	Eggplant 60 cm (24 in) x 90 cm (36 in)
	Zucchini squash (hills of 2) 120 cm (48 in) x 90 cm (36 in)
Mulch materials:	Polyethylene-clear 4-mil thickness
	Polyethylene-black 4-mil thickness
	Aluminized polyethylene 2-mil thickness
Treatments:	Clear film + herbicide
	Black film

	Aluminized film		
	Bare soil + herbicide		
	Bare soil		
Fertilization:		Eggplant	Zucchini Squash
		grams (lb)/plot	
Urea (46-0-0)		225 (0.5)	150 (0.33)
Triple superphosphate (0-40-0)		225 (0.5)	150 (0.33)
Muriate of potash (0-0-60)		180 (0.4)	125 (0.27)
Ground limestone		3630 (8.0)	3630 (8.0)

1980 -- Tomatoes

Plot size:	1.5 x 3 meters (4.9 x 9.8 feet)
Replications:	4
Variety grown:	Big Boy
Plants/plot:	4
Spacing within x between rows:	60 cm (24 in) x 90 cm (36 in)
Pruning:	4 stems
Mulch materials:	Raw leaves-mixed oak and maple
	Grass clippings
	Biodegradable paper-black
Treatments:	Raw leaves-7.5 cm (3 in) thickness
	Grass clippings-2 5-cm (2-in) applications May & August
	Black paper
	Bare soil
Fertilization:	grams (lb)/plot
10-10-10	680 (1.5)
Ground limestone	1135 (2.5)

1981 -- Tomatoes

Plot size:	3 x 3 meters (9.8 x 9.8 feet)
Replications:	5
Variety grown:	Better Boy VFN
Plants/plot:	8
Spacing within x between rows:	60 cm (24 in) x 90 cm (36 in)
Pruning:	2 plants/plot each 1-stem, 2-stems, 3-stems, unpruned
Mulch materials:	Polyethylene-clear 4-mil thickness
	Polyethylene-black 4-mil thickness
	Grass clippings
Treatments:	Clear film-no herbicide
	Black film
	7.5 cm (3 in) Grass clippings applied after planting in mid May
	7.5 cm (3 in) Grass clippings applied after fruit set on first clusters in late July
	Bare soil
Fertilization:	grams (lb)/plot
10-10-10	680 (1.5)
Ground limestone	1135 (2.5)

All plots were rototilled, limed, and fertilized before mulching. The soils beneath clear plastic films were treated with herbicides to prevent germination of weeds; Dacthal controlled weeds in eggplant, and Prefar controlled weeds in Zucchini squash. Weeds on the bare soil of the control plots without herbicide were removed by hand or scalping with a hoe to minimize root damage. Seedlings of broccoli, peppers, eggplant, Zucchini squash, and tomatoes were planted through slits in the plastic and paper. Grass clippings were added after tomato seedlings were planted or after the first clusters of fruit set. All plots were irrigated as needed. Insects were controlled with recommended insecticides as needed. All vegetables were harvested when they reached marketable size and were weighed in the field.

In 1980 all tomato plants were pruned to 4 stems and tied to stakes. In 1981, the staked tomato plants were pruned to different levels. Of 8 plants in each plot, 2 were pruned to 1 stem, 2 to 2 stems, 2 to 3 stems, and 2 remained unpruned. Suckers from below the soil surface were removed.

Soils were sampled throughout the growing season to measure moisture content. On sunny days throughout the growing season soil temperatures were observed in the early afternoon with thermometers placed at a 10-cm (4-in) depth to measure differences among mulch treatments. In mid June 1980 soil temperatures were measured continuously at a 5-cm (2-in) depth for 48 hours to observe daily fluctuations.

Air temperature near and in the shade of Zucchini squash leaves was also measured continuously for 48 hours in mid June 1980. Unshielded thermocouples (single strand No. 20 AWG copper-constantan, polyvinyl insulation) were suspended from the underside of leaves about 15 cm (6 in) above the mulch or soil surface. The thermocouples were shielded from direct solar radiation by the leaves but were exposed to radiation from the leaves and mulch or soil surface.

In 1981 flowers from randomly selected eggplants in each treatment were tagged throughout the growing season. Size of fruit was recorded at harvest.

During June 10 to July 1, 1980 and 1981, the setting of tomato fruits from the first flower clusters was recorded.

RESULTS AND DISCUSSION

Soil Temperature

The various mulches used in our experiments to conserve moisture and suppress weeds profoundly affected soil temperature. In general clear and black films and black paper warmed the soil while reflective aluminized film, leaves, and grass clippings slowed warming and cooling of the soil.

Table 1 shows the average difference in temperature between mulched and bare soil at a depth of 10 cm (4 in).

Table 1. Average soil temperature differentials beneath various mulches and combinations of mulches compared to bare soil. Measurements were made in early afternoon on sunny days at a 10 cm (4-in) depth.

Mulch	°C(°F) differential from bare soil
Clear film	+6.7 (+12)
Clear film over black film	+4.4 (+8)
Black film	+3.3 (+6)
Black paper	+2.2 (+4)
Aluminized film	-3.3 (-6)
Grass clippings	-5.6 (-10)
Clear film over black film over leaves	-6.1 (-11)
Leaves	-10.0 (-18)
Leaves over black film	-11.1 (-20)

Obviously large variations in soil temperature were produced by mulches, especially early in the season before the mulches were shaded by plants. Once the mulches were partially shaded by the plants, differences in soil temperature narrowed but were still measurable. Figure 1 illustrates temperature fluctuations at a 5-cm (2-in) depth beneath plastic films during 48 hours on June 10-12 when Zucchini squash covered about half the mulch. Clear film transmitted the sun's energy and in early afternoon warmed the soil about 9 C (16 F) more than bare soil. Black film transmitted less energy and the soil warmed only 2 C (4 F) more than bare soil. Most of the radiation is absorbed by the black film and not transmitted to the soil (Waggoner et al. 1960). Aluminized film reflected the sun's energy, and at midday the soil was about 1 C (2 F) cooler than bare soil.

Bare soil cooled about 8 C (14 F) in the afternoon and night following a sunny day, less on cloudy days and after soaking rains. The soil beneath the clear plastic remained warmer than bare soil. Beneath aluminized film the soil neither warmed nor cooled much.

Air Temperature

Energy reflected from the aluminized film or radiated from the lower surface of the leaf warmed the air adjacent to the leaf about 5 C (9 F) compared to air above bare soil (Figure 2). Although black film also warmed the air about 2 C (4 F), clear film did not warm the air during the day. As the plastic mulches became fully shaded by the plants, differences in air temperature beneath the leaves diminished.

At night, the air cooled and the temperature under a squash leaf was 1.5 C (3 F) warmer in plots mulched with clear film than with aluminized film. The greater nighttime temperature above the clear film can be accounted for by radiation of heat stored by day in the soil. In contrast, the aluminized

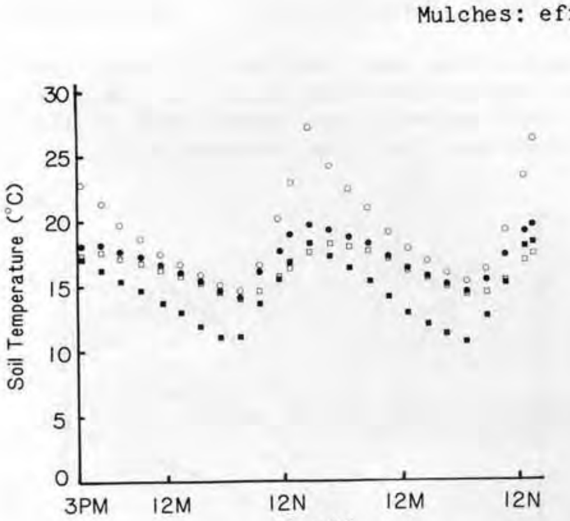


FIGURE 1 Typical soil temperature in mid June, at a depth of 10 cm (4 in.), under various mulches. The 45 - hour period of measurement was cloudless. Treatments are: ○ clear film, ● black film, □ aluminized film, ■ bare soil control.

film limited heat storage by day and released little to the air at night.

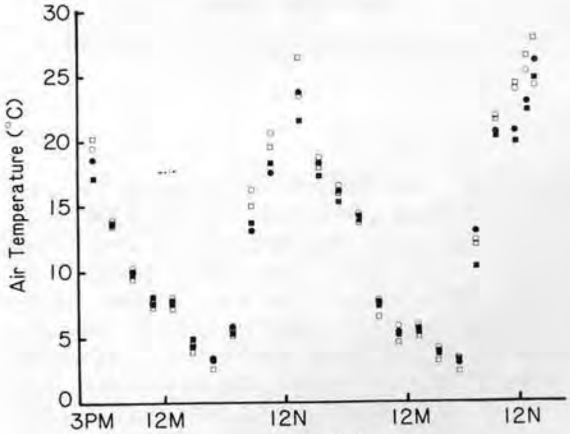


FIGURE 2 Typical air temperature in mid-June taken at a height of 30 cm (12 in.) above various mulches within the canopy of zucchini squash. The 45-hour period of measurement was cloudless. Treatments are : ○ clear film, ● black film, □ aluminized film, ■ bare soil control.

Flowering and Setting of Fruit

Waggoner et al. (1960) showed that increased soil temperature under plastic films promoted roots, flowers and yield of strawberries, a traditional early crop. We examined whether early warming of soil under plastic film benefits crops that mature during the heat of summer when differences in soil temperature under plastic film are lessened by shading of the plants.

In 1981 tomatoes were grown in soil mulched with clear film, black film and grass clippings to maximize differences in soil temperature. In this experiment, a soil temperature difference of almost 14 C (25 F) was achieved between the clear film and the grass mulch.

From June 10 to July 1, 1981, only 1 to 2% of the flowers aborted among the various treatments, indicating that mulch had little effect on fruit set. The nighttime air temperatures averaged 16 C (60 F) or about 4 C (7 F) above normal, however. These temperatures are favorable for fruit set (Splittstoesser, 1979); and the mulches had minimal effect.

We also observed effects of mulches when temperatures were unfavorable. In 1980 we observed the early growth of tomato seedlings and the setting of fruit in the first flower cluster in plots mulched with black paper, raw leaves, and grass clippings. During the setting of fruit in mid June, the tomato plants were 13% taller in plots treated with black paper, 8% taller with leaves, and 6% taller with grass clippings than in bare soil. Thus mulches produced larger plants, especially mulches that warmed the soil.

The flowering and setting of fruit in the first cluster occurred between June 9-24 when the weather was unusually cool and dry. Daytime air temperatures were less than the normal 12 C (53 F) on 13 of 16 days. Night temperatures were often 2-7 C (38-45 F) and the average was about 3 C (6 F) less than normal. These cool temperatures caused 50% or less fruit set in all treatments. Thirty-five (44%) of the eighty flowers in the first clusters on plants in bare soil set fruit; 50% were set and matured with the warming black paper mulch; 43% with leaves that kept the soil cool; and 39% with grass clippings that kept the soil cool. The black paper, which warmed the soil, produced a significant 7-11% increase in fruit set over all other treatments.

How do various mulches affect vegetables that flower and set fruit during the warm summer? Our experiment in 1981 with eggplant, a warm-weather crop, is illuminating. The first flowers appeared in early to mid July. The number of flowers that formed and the percentage setting fruit was greatest in plots greatly warmed by clear film. Fully 87% of the flowers set fruit compared with 70% on bare soil, 70% on plots treated with black film and 78% on plots covered with reflective aluminized film.

Although the increased setting of fruit in plots treated with clear film was significant compared to bare soil and black film, this advantage was lost in late July and August as daytime and nighttime temperatures reached their maximum. During this time, as the plants grew with numerous branches, we observed flowers with thick stalks setting fruit while those on thin stalks aborted. To confirm this observation we measured diameters of each flower stalk on four plants as they broke bud and flowered during the growing season. Table 2 shows the relation between stalk diameter and fruit set.

Table 2. The effect of stalk diameter on the setting of fruit in eggplants.

Stalk diameter mm	% of flowers setting fruit
< 2.5	0
2.5 - 2.9	25
3.0 - 4.0	58
> 4.0	100

The thicker the stalk, the greater the set of fruit. Many flowers of High Bush eggplant were in clusters with one dominant stalk and one or two subordinate stalks. Seldom did more than one fruit set in a cluster. If two formed, neither grew to maturity. The greater early fruit set in plots mulched with clear film may have been due to thicker flower stalks on large plants that responded to increased soil temperatures during the day and warmer air at night (Figure 2).

Timing of Yield

To now we have written of the early flowers and their set. The reason we plant vegetables and fruit, however, is their yield, and we turn now to the course of yield through the season.

<u>Broccoli-1978</u> Although the differences in yields of first-picked heads of broccoli among treatments were not significant, the heads produced in cool soil with leaf mulch were smallest (Figure 3). After 10 weeks the yields diverged as the harvest of secondary sprouts began. The plants in plots with leaf mulch over black film produced superior yields in July and August as the soil remained cool. The yields of broccoli in the soil covered with black film alone, clear film over black film, or clear film over black film over leaf mulch were similar throughout the year, and the data were averaged. The yields from plants in plots with cool soil beneath raw leaves were smallest and even less than from the bare soil.

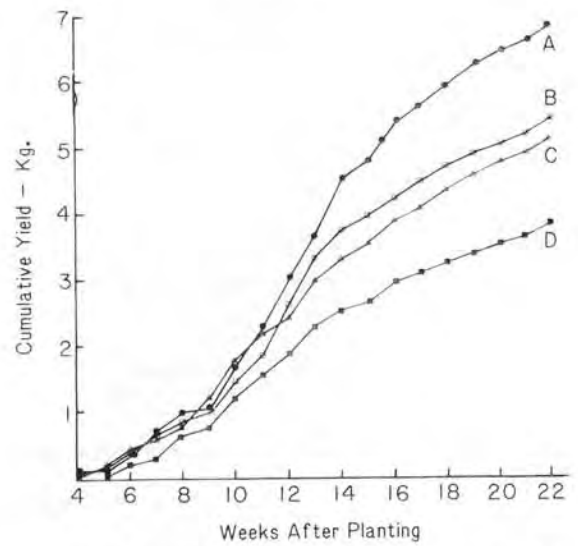


FIGURE 3 Cumulative yield of broccoli from each treatment throughout the 1978 growing season. Treatments are: A - raw leaves over black film, B - average of black film, clear film over black film, clear film over black film over raw leaves, C - bare soil control, D - raw leaves.

<u>Peppers-1978</u> The growth of peppers (Figure 4) shows striking differences. Harvest from plants on the soil warmed with black film began two weeks before the other plots. By the 12th week after planting, when other plants began to yield, nearly 10% of the crop on black film had been harvested. Although the black film maintained its advantage from early yield throughout July and August, the yields of plants in cool soil beneath clear and black film over leaves were outstanding throughout September and until frost killed the plants in mid October. Plants in soil kept cool with raw leaves yielded less than a third of the highest yielding plot and the harvest was delayed until the 14th week after planting, fully 4 weeks after the harvest began from plants in the black film. The total yield on plots with black film, however, was 26% below the maximum yield from plots with cool soil beneath clear and black film over leaves. Peppers on the bare soil yielded as little as those treated with leaves, but the first fruits were harvested two weeks earlier.

<u>Eggplant-1979</u> Harvest of eggplant began

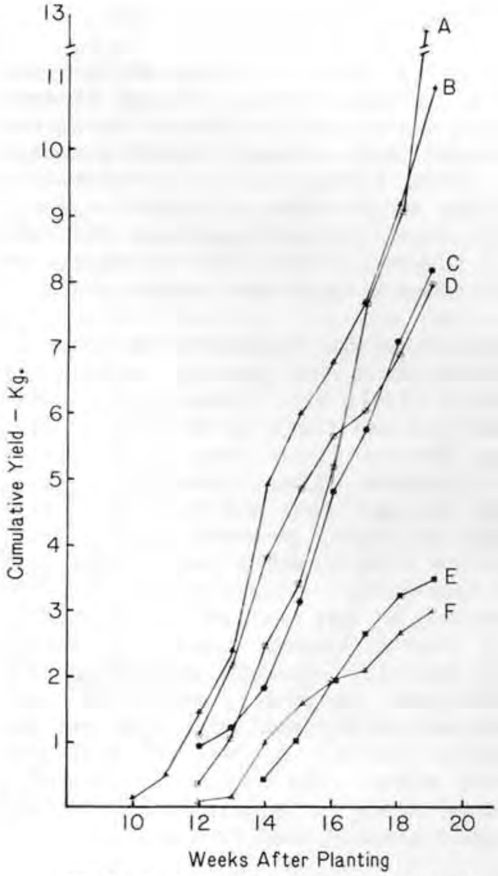


FIGURE 4 Cumulative yield of peppers from each treatment throughout the 1978 growing season. Treatments are: A – clear film over black film over raw leaves, B – black film, C – raw leaves over black film, D – clear film over black film, E – raw leaves, F – bare soil control.

August 2 (11 weeks after planting) in all plots (Figure 5). Thus the warming by the treatments had no effect on the timing of initial yields. By the 13th week, on plots with clear over black film, a warming treatment, yield doubled compared to plots with other mulches and tripled compared to plants on bare soil. This advantage lasted until the 15th week. During September, from the 15th to 19th weeks, production on all plots was markedly reduced. In October (weeks 20 and 21), yields of eggplant on all mulched plots were high, but the greatest yield was on bare soil. Because the fruit matures from flowers in 4 to 5 weeks, the plateau of yield in all plots during September indicates that conditions for flowering and fruit set were unfavorable in August when rainfall was 9.5 cm (3.8 inches) but 80% fell August 11-13. Thus, early August was dry.

Eggplant grows best at 26 C (78 F) day and 20 C (68 F) night temperatures (Splittstoesser, 1979). The minimum temperatures during August 1979 were less than 20 C (68 F) on 20 of 31 days with lows on many nights of 7-15 C (45-59 F). Thus, cool dry weather in August likely caused the poor yields in September.

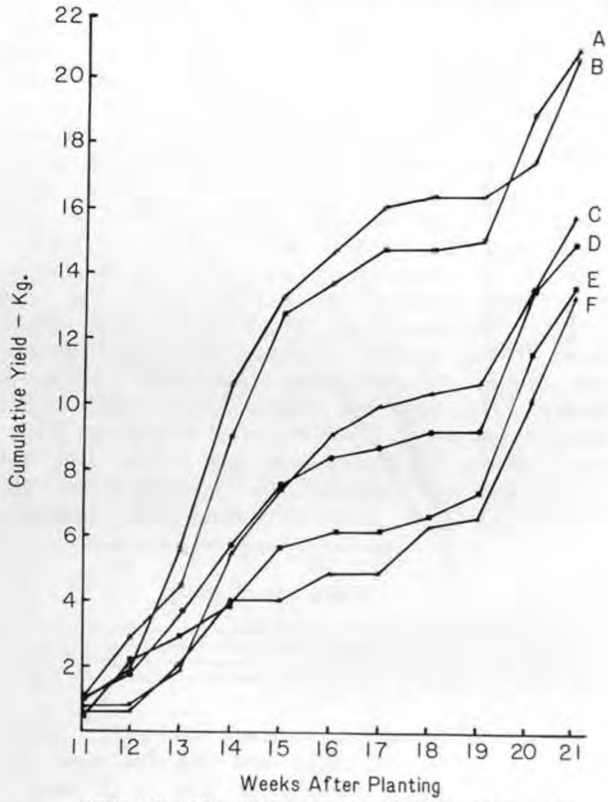


FIGURE 5 Cumulative yield of eggplant from each treatment throughout the 1979 growing season. Treatments are: A – clear film over black film over raw leaves, B – clear film over black film, C – black film, D – raw leaves over black film, E – raw leaves, F – bare soil control.

Eggplant-1980 Variability in soil temperatures in 1980 was achieved by a simpler system than in 1978 or 1979. Clear or black film warmed the soil, while aluminized film kept the soil cool. Weeds under the clear film were controlled with the herbicide Dacthal. Dacthal was also added to plots with bare soil to determine if the herbicide affected yield of eggplant.

Fruit was harvested from all treated plots beginning July 24th, the 9th week after planting; a week earlier than in 1979 (Figure 6). The greatest divergence in yield occurred from the 9th to the 14th week, and then yields paralleled one another for the remainder of the season. Thus the influence of plastic films either warming or keeping the soil cool is more pronounced during late July and August than in September and October when the plants are large and fully shade the underlying plastic.

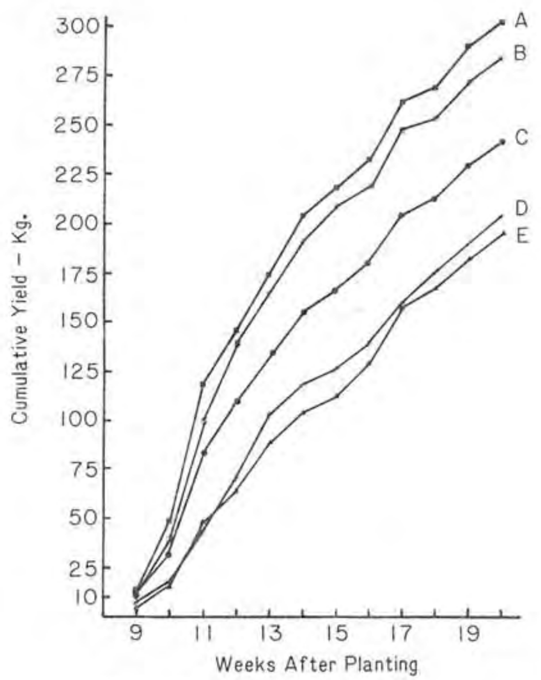


FIGURE 6 Cumulative yield of eggplant from each treatment throughout the 1980 growing season. Treatments are: A – clear film and Dacthal, B – aluminized fil.n, C – black film, D– bare soil control, E – bare soil control and Dacthal

Clear film, which warmed the soil, produced the greatest yield and was followed by aluminized film, which kept the soil cool. Although the yield of eggplant with black film was only about half that of other films, it was significantly greater than the bare soil and bare soil plus Dacthal plots. Yields on the bare soil and the bare soil treated with Dacthal did not differ significantly.

The yield of eggplant in September 1980 did not plateau as in September 1979 because in August 1980 conditions for fruit set were favorable. During August 1980 mean minimum temperature was higher than in August 1979 and within 1 C (2 F) of the optimum 20 C (68 F) required for fruit set. In August 1980 there were only 6 days with minimum temperature below the required 20 C (68 F) compared to 20 days in 1979. This supports our contention that poor yields in September 1979 were due to cool nights in August. Further, early yields in late July and early August were small because late June and early July nighttime temperatures had not reached the optimum temperature for fruit set.

Eggplant-1981 In 1981 we tested whether the mulches that warmed the soil or kept it cool affected the time to mature fruit. Observation of tagged fruit revealed that the number of days from flowering to harvest-size (350-550 gm) varied from 28 days in early July to 31 days in late July and 36 days throughout August. Fruit set in September never reached marketable size before frost in mid October.

Differences among treatments in days to maturity throughout the growing season were more dramatic (Table 3). Plants mulched with clear film produced fruit in 26 days, a significantly shorter time than with either black or aluminum film. Aluminized film, which kept the soil cool and released little stored heat at night, produced mature fruit in 46 days, a significantly longer time than all other treatments. Thus clear film, which warmed the soil by day and the air around the plants by night, caused plants to mature fruit more swiftly. Because harvesting promotes additional flowering and fruit set, plants mulched with clear film also had the highest total yields. In 1981 the yields in plots with clear film were significantly greater than black or aluminized film, and over two-fold greater than bare soil.

Table 3. The effect of various plastic films on the time to produce harvestable eggplants.

Treatment	Days from flowering to harvest
Clear film	26 a[1]
Bare soil	30 ab
Black film	34 b
Aluminized film	42 c

[1] Treatment means followed by the same letter do not differ at p = .05 with Duncan Multiple Range Test.

Zucchini Squash-1980 The growth of Zucchini squash is shown in Figure 7. Harvest in all plots began June 19th, 5 weeks after planting the seedlings. Treatments are similar to Eggplant-1980. Clearly, all treatments with plastic film yielded more than bare soil and bare soil plus herbicide Prefar. Among plastic film treatments yields did not differ significantly; nor did the two bare soil plots differ. As with eggplant, the clear film, which warmed the soil, and aluminized film, which kept the soil cool, had the greatest yields; plots with bare soil yielded least. After August 7th or the 12th week, yields on the plots with clear film declined as plants invaded by squash vine borers began to die. Yields on aluminized film and on bare soil declined on the 13th week and the yields on black film declined after 14 weeks. Harvesting was terminated August 28th, 15 weeks after planting, because the remaining plants became infected with powdery mildew.

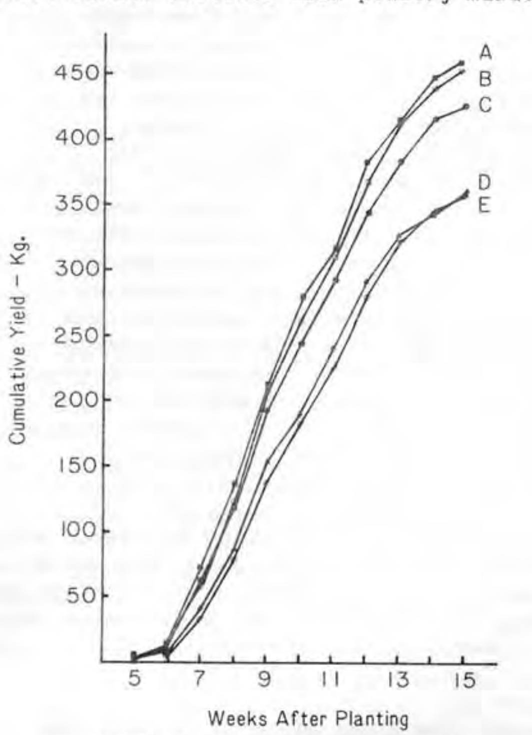


FIGURE 7 Cumulative yield of zucchini squash from each treatment throughout the 1980 growing season. Treatments are: A – clear film and Prefar, B – aluminized film, C – black film, D – bare soil control, E – bare soil control and Prefar.

Tomatoes-1980 The growth of tomatoes mulched with black paper, grass clippings, and raw leaves is shown in Figure 8. Regardless of treatment yields on all plots began 9 weeks after planting seedlings despite the significant differences in fruit set among treatments described earlier. Yields began to diverge in the 12th week and differed most in the 14th week (mid August), when the yields declined significantly in the bare soil. All mulched plots yielded more than the bare. The greatest yields in all plots occurred during the 12th to 14th weeks. Reduced yield during the 15th week was probably caused by blossom-end-rot during the 11th and 12th weeks on half-grown fruit that would have matured in 3 weeks. Clearly, grass clippings, which kept the soil cool, benefited tomato yields most throughout the season. The greatest benefit was increased soil moisture, but this did not occur until the 13th week (mid August). The yield on black paper mulch was higher than on leaves and bare soil. The advantage of black paper did not become apparent until the 16th week. Early yield on plots with black paper was diminished by large losses of fruit during the 11th to 13th weeks to blossom-end-rot. Fully 11% of the fruit on black paper was lost compared to 5% on grass clippings, 3% on the bare soil, and 0.1% on raw leaves. The black paper warmed the soil and produced larger plants until mid August. During late August droughts, the soil beneath the paper was drier than under other treatments. Plants could no longer extract sufficient water from the dry soil, and extraction of water from the developing fruit caused the tell-tale symptoms of blossom-end-rot.

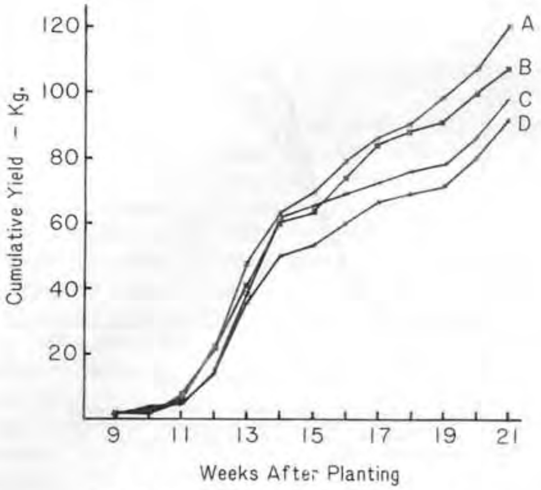


FIGURE 8 Cumulative yield of tomatoes from each treatment throughout the 1980 growing season. Treatments are: A – grass clippings, B – black paper mulch, C – raw leaves, D – bare soil control.

Tomatoes-1981 In 1981 mulches were chosen to create wider differences in soil temperature. The growth of tomatoes treated with black and clear film and grass clippings applied in mid May and late July is shown in Figure 9. Plants in all treatments began to yield fruit in the 8th week, 8 days earlier than 1980, due to warmer, above-average temperatures during June. Cumulative yields of all treatments were similar until the 14th week in late August. Early heavy yields in the 13th and 14th weeks resembled those in 1980. During this early harvest, the grass mulch (placed early and late) and bare soil yielded significantly more than both clear and black films. Yield declined markedly in the 16th week followed by another burst in the 18th week when the yields in grass mulch were significantly greater than from clear film, black film, and bare soil. After the 19th week yields leveled and did not differ significantly among treatments. Final harvest was on October 27th, the 23rd week after planting, some 2 weeks later than in 1980.

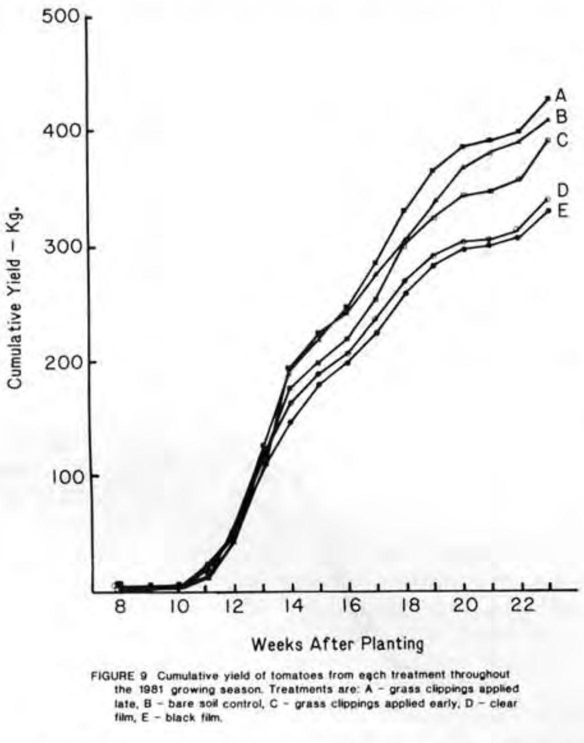


FIGURE 9 Cumulative yield of tomatoes from each treatment throughout the 1981 growing season. Treatments are: A – grass clippings applied late, B – bare soil control, C – grass clippings applied early, D – clear film, E – black film.

Late in July a severe episode of blossom-end-rot occurred. Soil beneath films was drier than beneath grass clippings or bare soil. Over 6% of the fruit was lost to blossom-end-rot from plants with black film, 3% from plants with clear film, but only about 1% from plots mulched with grass or from bare soil. This early episode partially accounts for reduced yields in the 16th week late in August.

A second objective of the 1981 experiment was to determine if pruning influenced the size of fruit. Pruning suckers to reduce the number of fruiting stems, is thought to increase the size of fruit on remaining stems. To test this notion, yield of plants pruned to 1, 2 or 3 stems, was compared with unpruned controls. Suckers from below the soil surface were pruned from all plants. Neither mulch nor level of pruning produced significant differences in fruit size. Unpruned plants produced the smallest fruit, 226 grams (8.0 oz), while the largest, 245 grams (8.6 oz), were on plants with 2 stems. There was a significant difference, however, in size throughout the season. The fruit harvested during the first four weeks mostly came from the first flower clusters, and averaged 209 grams (7.4 oz). The weight of fruit from the 2nd and 3rd flower clusters, harvested during the next 4 weeks, increased significantly to 294 grams (10.3 oz). During the next 4 weeks the size of the fruit decreased to 274 grams (9.6 oz) and then to 203 grams (7.1 oz) in the final weeks of harvest in mid September to mid October.

The earliest fruit was produced by plants that were inefficient in producing and storing food. The largest was produced in early August. The gradual decrease in fruit size during late August and September was probably caused by drought as the plants supported more roots, leaves and fruit.

Total Yield

Although a specific mulch may favor early production in some crops, that same mulch may not produce the largest crop. Let us now examine the total yields to determine which mulch produced the greatest yield for each crop.

Broccoli The total yield of broccoli mulched with leaves over black film, which kept the soil cool, was significantly greater than all other treatments (Table 4). This is not surprising since broccoli is considered a cool-weather crop. The insulation provided by the leaves underlain by black film kept the soil cooler throughout the warm summer months and prevented evaporation from the soil. Yields among the remaining mulches did not differ significantly.

Raw leaves alone yielded less than raw leaves underlain by black film, although both treatments kept the soil cool. In fact, raw leaves alone yielded less than bare soil. The reduced yields were attributed to phytotoxic phenolic compounds released during decomposition of the raw leaves and leached into the soil by rain or irrigation. This

Table 4. Total yield per plant of broccoli, peppers, and eggplant in soils mulched with raw leaves, black or clear film, or combinations.

	Broccoli[1]	Peppers[1]	Eggplant
Treatment	Yield/plant Kg (lb)	Yield/plant Kg (lb)	Yield/plant Kg (lb)
Leaf mulch	0.55 (1.21) a[2]	0.52 (1.14) a	1.63 (3.59) a
Leaves over black film	0.88 (1.94) b	1.28 (2.82) b	1.83 (4.03) ab
Clear film over black film over leaves	0.65 (1.43) a	1.84 (4.05) c	2.80 (6.16) b
Bare soil	0.66 (1.55) a	0.50 (1.10) a	1.42 (3.12) a
Black film	0.69 (1.52) a	1.37 (3.01) b	1.71 (3.76) a
Clear film over black film	0.71 (1.56) a	1.17 (2.57) b	2.46 (5.41) ab

[1] Data from Hankin, Hill and Stephens. 1982. "Effect of mulches on bacterial populations and enzyme activity in soil and vegetable yields". Plant and Soil 64:193-201.

[2] In each column, yields per plant followed by the same letter do not differ significantly at $p = .05$ with the Duncan Multiple Range Test.

phytotoxicity, which inhibited roots and stunted the plants, was not evident where the leaves were placed on top of black film. Black film under leaves separated the leaves from the soil, delayed their decomposition and partially prevented leaching. Raw leaves beneath clear and black film decomposed but leaching of phenolic compounds by rain was prevented.

In a greenhouse experiment watering broccoli plants with leachate from composting maple leaves suppressed height growth 10% and yield 12% (D. E. Hill, unpublished). Leachate from composting oak leaves suppressed height growth 10%, but yield did not differ significantly from that of control plants supplied with tap water. This different response of broccoli plants to leachate from oak and maple leaves may be due to the faster decomposition of maple leaves and release of more phenols.

Peppers The total yield of peppers, a warm weather crop, mulched with clear and black film over raw leaves, which kept the soil moderately cool, was significantly greater than all other treatments (Table 4). Again, the plants mulched with raw leaves alone yielded significantly less than all other treatments except the bare soil. Unlike broccoli, the phytotoxicity from decomposing raw leaves was not evident. The only tangible benefit of raw leaves was suppression of weeds and conservation of moisture. Black film, a warming treatment, increased yield 2.5-fold compared to bare soil.

Eggplant Eggplant, another warm weather crop, yielded most with clear and black film over leaves as did peppers (Table 4). This high yield, however, was only significantly greater than the yields with raw leaves, black film and bare soil. It was not significantly greater than yield with leaves over black film or clear film over black film. Again, raw leaves alone produced slight increase in yield compared to bare soil. As with peppers, there was no evidence of phytotoxicity of raw leaves.

In 1980 a wider range of soil temperatures was created using clear, black and aluminized film. Favorable weather and disease-free plants produced a bumper crop. The plants mulched with clear film yielded significantly more fruit than with black film but not significantly more than plants in soil kept cool with aluminized film (Table 5). Yields from all plastic mulches were significantly greater than from bare soil. In 1981 relative yields among treatments were similar to those in 1980 except that verticillium wilt, present in the entire crop, significantly reduced the total yields. Plants with clear film yielded significantly more than all other treatments. Black film, with second greatest yields, did not differ significantly from aluminized film. Again all plastic mulches yielded significantly more than bare soil. In the 1980 and 1981 experiments, the great warming by clear film produced the highest yields even in a poor year with a diseased crop. This is not difficult to understand in light of the data on the effects of mulch on maturity. Plants that flower abundantly and mature fruit quickly have an advantage over plants that flower less and require longer to produce the fruit. The increased yield may be due partly to warm soil temperature and partly to favorable moisture and higher air temperatures. In 1979, however, the greatest yield was on clear and black film over leaves, which did not warm the soil. The reason for the difference among years is not apparent. The yield data from 1979 are difficult to reconcile, however, because the clear film was used with raw leaves, a treatment that kept the soil cool.

Table 5. Total yield per plant of eggplant (2 yr) and Zucchini squash (1 yr) mulched with clear, black, or aluminized film.

Treatment	Eggplant 1980 Yield/plant Kg (lb)	Eggplant 1981 Yield/plant Kg (lb)	Zucchini Squash 1980 Yield/plant Kg (lb)
Clear film + Herbicide[1]	7.18 (15.80) c[2]	4.65 (10.23) d	11.17 (24.57) c
Black film	5.91 (13.00) b	3.44 (7.57) c	10.41 (22.90) abc
Aluminized film	6.86 (15.09) bc	2.87 (6.31) bc	11.01 (24.22) c
Bare soil + Herbicide	4.54 (9.99) a	2.22 (4.88) ab	8.68 (19.10) ab
Bare soil	4.73 (10.41) a	1.39 (3.06) a	8.67 (19.07) a

[1] Dacthal for eggplant, Prefar for squash.

[2] In each column yields per plant followed by the same letter do not differ significantly at $p = .05$ with the Duncan Multiple Range Test.

Zucchini Squash Zucchini squash on clear film yielded most but not significantly more than plants with the black or aluminized films (Table 5). Although all plastic films produced more than the bare soil, only the clear and aluminized films produced significantly more. All films increased yield of Zuchini squash by maintaining a more favorable moisture supply compared to bare soil.

Table 6. Total yield per plant of Big Boy tomatoes mulched with black paper, grass clippings, and raw leaves.

Treatment	Yield/plant Kg (lb)
Grass clippings	7.21 (15.86) b[1]
Black paper	6.29 (13.84) ab
Raw leaves	6.08 (13.38) ab
Bare soil	5.57 (12.25) a

[1] Yields per plant followed by the same letter do not differ significantly at $p = .05$ with the Duncan Multiple Range Test.

Tomatoes The yields of tomatoes mulched with black paper, grass clippings and raw leaves are shown in Table 6. Plants in soil kept cool with grass clippings yielded most and this was the only treatment that yielded significantly more than bare soil. Although black paper and raw leaves produced more than bare soil, the increases were not significant. During August and September the soil beneath the black film was as dry as bare soil and dry soil favored blossom-end-rot and reduced yield in both treatments. Although the plots with raw leaves yielded slightly more than the bare soil, this treatment yielded least of all the organic mulches, despite greatest moisture conservation. This observation is consistent with those from similar treatments on broccoli, peppers and eggplant.

The effects of mulches on yields of tomatoes differed with pruning (Table 7). Pruning plants to 1 stem negated benefits of mulch. Plants pruned to 2 stems yielded significantly more with grass clippings (early or late) and bare soil than with clear but not black film. Plants pruned to 3 stems, yielded significantly more with grass (late) than with grass (early) and with black film. Yields of unpruned plants mulched with grass clippings (early or late) and the bare soil control were significantly greater than the yields of plots mulched with black film. In general, late mulching with grass clippings benefited pruned but not unpruned plants. Plants in bare soil yielded similarly to grass-mulched plots at all pruning levels. The significantly reduced yields of plants with clear or black film is probably due to insufficient soil moisture. The soils beneath the plastic mulches were always drier than the soils beneath the grass mulch because the impermeable plastic film hampered resupply by rain or irrigation. Unpruned plants yielded most regardless of mulch. Compared to unpruned plants, pruning to 3, 2, and 1 stems reduced the yield 19%, 28%, and 53%, a significant reduction for each pruning.

Table 7. Total yield per plant of Better Boy VFN tomatoes mulched with clear film, black film and grass clippings applied after transplanting (early) and after setting of first fruit clusters (late). Tomato plants pruned to 1-stem, 2-stems, 3-stems, and unpruned.

Treatment	Pruning Level			
	1-stem	2-stems	3-stems	Unpruned
	Kg (lb)/plant	Kg (lb)/plant	Kg (lb)/plant	Kg (lb)/plant
Grass clippings (late)	8.08 (17.78) a[1]	12.38 (27.24) b	14.50 (31.90) c	15.75 (34.65) b
Grass clippings (early)	7.46 (16.41) a	10.88 (23.94) b	12.22 (26.88) ab	16.40 (36.09) b
Bare soil	7.10 (15.62) a	11.46 (25.21) b	12.93 (28.45) bc	16.19 (35.62) b
Clear film	6.50 (14.30) a	9.30 (20.46) a	12.90 (28.38) bc	13.80 (30.36) ab
Black film	6.69 (14.72) a	11.32 (24.90) ab	10.03 (22.07) a	13.15 (28.93) a
% of unpruned yield	46.6 a[2]	72.0 b	81.4 c	100.0 d

[1] In each column yields per plant followed by the same letter do not differ significantly at p = .05 with the Duncan Multiple Range Test.

[2] Yield per plant for each pruning level differed significantly at p = .05 with the Duncan Multiple Range Test.

CONCLUSIONS

From our experiments we conclude the following:

Mulches applied to the soil altered soil temperature to a depth of 10 cm (4 in). Compared to bare soil, clear film warmed soil as much as 7 C (12 F) at midday, while raw leaves kept the soil up to 11 C (20 F) cooler, a differential of 18 C (32 F).

Mulches also affected air temperature within the plant canopy. On sunny days aluminized film increased temperatures near and under leaves 15 cm (6 in) above the ground about 3 C (6 F). Clear film warmed the soil by day, lost heat at night and raised air temperatures near and under leaves 15 cm (6 in) above the ground about 1.5 C (3 F).

Effect of mulches on:

Broccoli -- Yield was greatest with mulches that kept the soil cool during hot summer months. Raw leaves, however, may be phytotoxic to the roots, stunt growth, and reduce yield.

Peppers -- Yield in soil warmed with black plastic began 2 weeks earlier than other treatments but clear and black films over leaves, which kept the soil cool, produced the greatest total yield, mostly late in the season.

Eggplant -- Plants in soil warmed with clear film yielded significantly more than all other treatments. Clear film also produced the greatest fruit set from the first flowers in early July and promoted rapid maturation of fruit (26 days) compared to mulches that kept the soil cool (43 days). Flowers with stalk diameters less than 2.5 mm seldom set fruit even in favorable weather; those with diameters greater than 4 mm always set fruit in favorable weather.

Zucchini Squash -- Yield was greater in soil warmed with clear plastic but the increase was not significantly greater than black or aluminized films. Plants with all films yielded significantly more than those in bare soil because of more favorable moisture.

Tomatoes -- Tomatoes mulched with grass clippings yielded significantly more than plants mulched with clear or black films. Drying of the soil beneath impermeable films caused greater loss of fruit from blossom-end-rot. Mulches had little effect on fruit set of the first flower clusters of tomatoes in seasons with favorable nighttime air temperatures (above 13 C/55 F). In seasons with low nighttime air temperatures (10 C/50 F or less), which cause the first flowers to abort, clear film and black paper mulches lost stored heat at night and improved the setting of fruit about 10%. Pruning to reduce the number of stems did not produce larger fruit than unpruned plants. The largest fruit were produced from the 2nd and 3rd flower clusters. Pruning the plants to 1 or 2 stems reduced yield by half and to a fourth compared to unpruned plants.

Evaluation of mulches used:

Clear film -- Strongly warmed the soil, reduced evaporation, and interfered with recharge of moisture by rain or irrigation. Back radiation of stored heat at night permitted greater fruit set of tomatoes in seasons with below average minimum temperature, produced highest yields of eggplant and Zucchini squash, and promoted early flowering and shortest maturation time for eggplant. Yield of tomatoes may be significantly lower than bare soil, unless frequently irrigated.

Black film -- Moderately warmed the soil, reduced evaporation, interfered with recharge of moisture by rain or irrigation, favored early yield of peppers, and produced yields significantly greater than bare soil for peppers, eggplant, and Zucchini squash. Yield of tomatoes may be significantly lowered compared to bare soil if the soil beneath the film dries excessively.

Black paper -- Moderately warmed the soil, reduced evaporation, and interfered with recharge of moisture by rain or irrigation. Loss of heat at night permitted greater fruit set of tomatoes in years with cold in June. Black paper produced significant increases in yield of tomatoes compared with bare soil; however, soil became excessively dry allowing greater losses of fruit by blossom-end-rot.

Aluminized film -- Kept the soil moderately cool, reduced evaporation and interfered with recharge of moisture by rain or irrigation. It produced significantly greater yields of eggplant and Zucchini squash compared to bare soil, but because it did not favor early flowering of eggplant, most benefits accrued in August and September. The cooler soil delayed maturation of fruit (42 days) compared to mulches that warmed the soil (26-34 days).

Grass clippings -- Kept the soil moderately cool, reduced evaporation, and permitted recharge of moisture by rain or irrigation. It reduced losses of tomato fruit by blossom-end-rot, produced significantly greater yield of tomatoes than plastic films, but inhibited early fruiting in abnormally cooler seasons. Late application of mulch after the first flower clusters set fruit increased yield if the plants were pruned. Grass clippings from lawns treated with herbicides may inhibit crop growth.

Raw leaves -- Greatly retarded warming of the soil, reduced evaporation, and permitted recharge of moisture by rain or irrigation. It reduced losses of tomato fruit by blossom-end-rot. Yields were not significantly increased for any vegetable compared to bare soil. Yield of broccoli may have been suppressed due to phytotoxicity of phenols that leached from decomposing leaves. Placing plastic film between the leaves and the soil inhibited decomposition of the leaves and reduced direct leaching.

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