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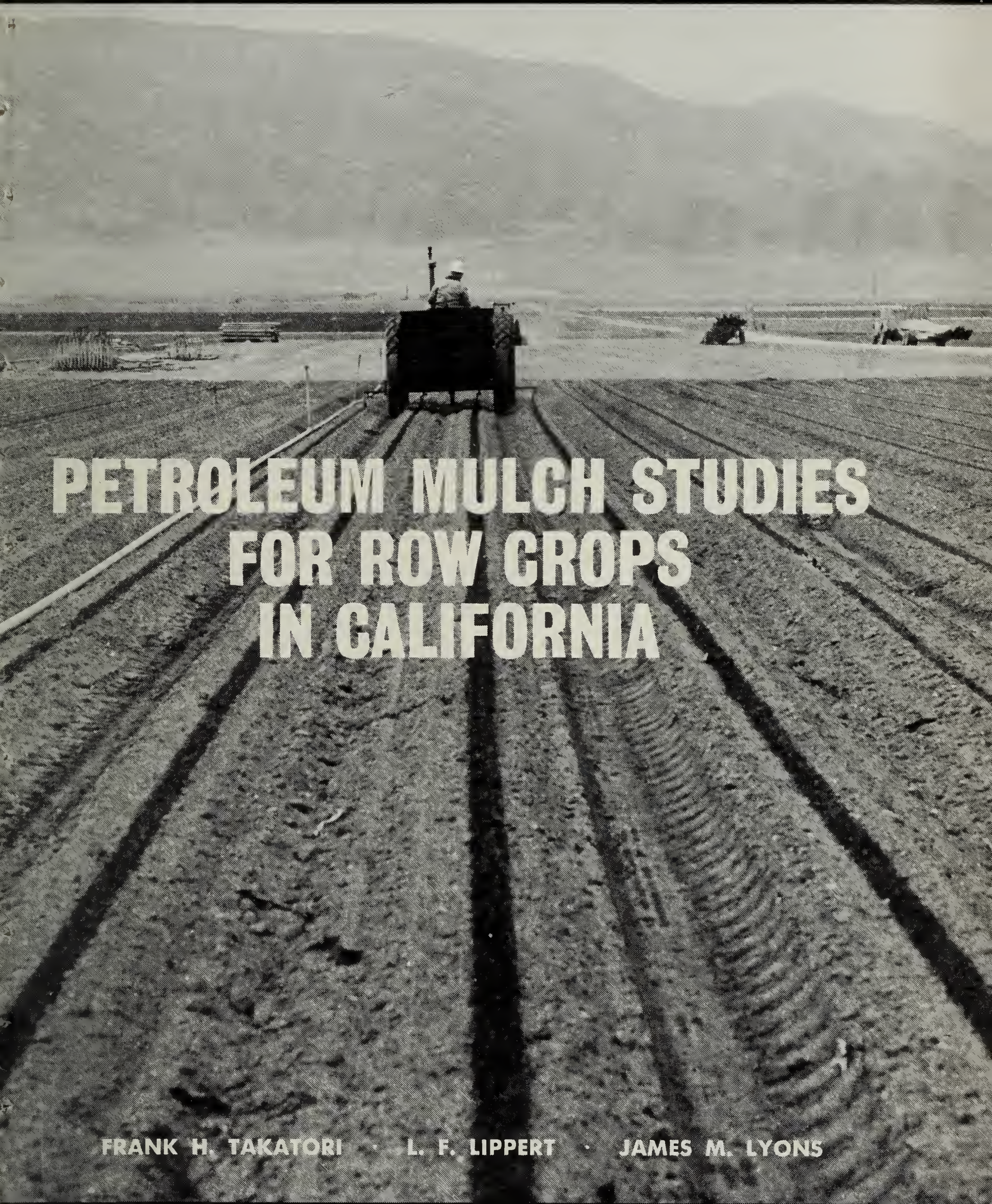

PETROLEUM MULCH STUDIES FOR ROW CROPS IN CALIFORNIA

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION

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This bulletin summarizes the results of studies with petroleum mulches. It reports the findings of field, laboratory and greenhouse trials on the influence of petroleum mulch on soil temperatures, soil moisture, crop responses, and weed control. Effective rates, methods and timing of applications, as well as width of mulch bands, are suggested. Additional studies covering the important considerations of soil preparation and degradation of asphalt residues are summarized.

This bulletin will aid vegetable growers and other agricultural personnel to assess the potential value of petroleum mulches in their cultural operations.

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PETROLEUM MULCH STUDIES FOR ROW CROPS IN CALIFORNIA[1]

PHYSICAL NATURE OF PETROLEUM MULCH

Petroleum mulch is a liquid emulsion of asphaltic resins of suitable consistency and viscosity for spray application. The liquid phase of the emulsion is generally water, and the asphalt content ranges between 50 and 60 per cent by weight. These mulch materials are applied without heating.

TABLE 1
PHYSICAL PROPERTIES, DOCAL 1055 AGRI-MULCH (TM)*

Viscosity, SSF at 77°F	70
Asphalt content, per cent by weight	58.5
Penetration of residue, dmm/100g/5 sec/77°F	180
pH	3.0
Sieve, maximum	0.10

* (TM) Registered trademark of Douglas Oil Co., Paramount, California.

The physical specification of a typical commercial product is given in table 1.

[1] Submitted for publication May 14, 1970.

Petroleum mulch is applied as a spray directly over the seed row. Upon drying, the material forms a black continuous coating, between 10 and 20 mm thick, over the soil surface. The film is in intimate contact with the surface soil particles but does not penetrate deeply into the soil (figure 1).

The thin film is little damaged by wind, rain, or irrigation, but is readily destroyed by cultural operations such as cultivation. The pliable texture of the material does not impede the emergence of most seedlings. Under normal conditions, the film remains intact throughout the germination period and is eventually destroyed by normal cultural practices.

Test materials have been stored for one season without noticeable change in characteristics; however, the recommendations of the manufacturer concerning storage conditions should be followed.

Fig. 1. Field plot established for comparative evaluations of petroleum mulch (background) and black and clear polyethylene films.

Land preparation and field cultural practices

The majority of the field tests were conducted at the Citrus Research Center, University of California, Riverside, on Ramona fine sandy loam soils. Field preparations included pre-irrigation, deep plowing, and rototilling of the soil before the beds were formed. After bed shaping, the soil was compressed with a 200-lb lawn roller to insure a firm, smooth mulching surface. In tests which were planted to vegetables the planters were attached to the bed shaper and the area seeded prior to the firming operation. The test area was irrigated immediately after the mulching operation until the beds were completely saturated. Subsequent irrigations were dictated by the nature of the trials or by the water requirements of the crops.

Spray equipment

The asphalt emulsion was applied with a portable sprayer utilizing a pressurized system capable of maintaining 35 psi nozzle pressure. The spray system (figure 2), including the compressor and storage tanks, was mounted on either an Allis Chalmers Model G tractor or Farmall "Cub" tractor.

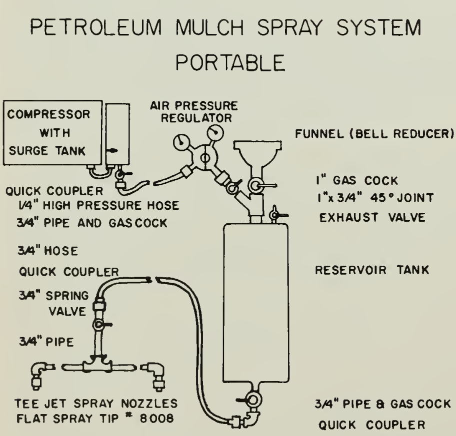

Fig. 2. Schematic diagram of tractor-mounted, pressurized spray system for petroleum mulches.

The sprayer was adapted with "Tee Jet" nozzles No. 8004–8010, generally 8008, under 35 psi delivery pressure. Two spray nozzles in line spaced 8–12 inches apart were directed to spray forward and rearward over each seed row to insure good coverage of the soil surface and to provide a continuous deposit (film) of asphalt.

Gear pumps have been used to spray asphalt mulches, but they must be modified for greater spacing between the gear teeth. Even with this alteration the working parts tend to clog. The high speeds and shearing action of the pump tends to break the emulsion, that is, separate the water from the solids, thereby resulting in the precipitation of asphalt solids which clog the gears and the spray system (Scudder and Darby, 1964). Clogging may be a major problem with any system but can be minimized by screening the petroleum mulch through window screen during filling of the tank. Also, additional screening units may be installed in the flow system.

Spray concentration

The effective concentration of petroleum mulch per acre has been established within rather wide ranges. Concentrations from 125 to 1,000 gallons "per full acre coverage" have been used. It was found that rates from 250 to 500 gallons generally gave adequate results. The benefits obtained from rates in excess of 500 gallons per acre are not sufficient to warrant the additonal expense of the mulch. The term "full acre coverage" is used as a means of convenience. If two factors are known, i.e., row spacing and band width of mulch, the actual gallonage of mulch applied per acre can be determined. For example, with a rate of 500 gallons per full acre coverage and a 6-inch band sprayed on single rows spaced 30 inches apart, the material

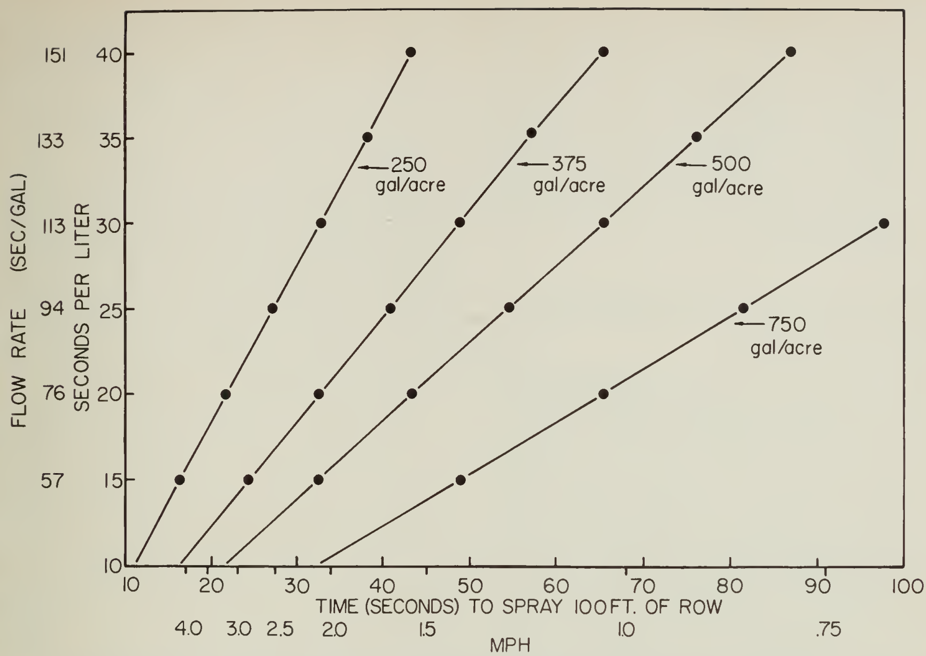

Fig. 3. Calibration graph for determining mulch concentration based on flow rate through the spray system (sec/liter or sec/gallon) and tractor speed (sec/100 feet or miles/hour).

will cover 20 per cent of the acre surface, and would require 20 per cent of the 500 gallons, or 100 gallons of actual mulch per acre. Comparable calculations will determine gallonage of mulch required per acre for any variation in band width or row spacing.

Calibration of spray equipment

1. Time of delivery of a given quantity of mulch through a single row nozzle system in either seconds per liter or seconds per gallon.

2. Using this delivery figure on the vertical axis of the graph (figure 3), move across horizontally to the proper concentration line in gallons per full acre coverage, then read vertically down to the horizontal axis. The value on the horizontal axis indicates the seconds required to cover 100 feet of row, or miles per hour speed.

3. Establish tachometer reading, mph rate, or throttle position on tractor by marking out 100 feet of row and timing how long (seconds) it requires to move this distance. Adjust movement to match the value of seconds per 100 feet obtained from the graph.

4. This will give the proper per acre rate of mulch based on this particular pressure system and nozzle selection.

Note 1: The time required to deliver a measured amount of mulch will vary considerably with nozzle orifice and pressure of the spray system. If the speed of movement down the row obtained from the graph is not satisfactory, the spray system must be modified. If speed is to be increased, increase either pressure or orifice size of nozzle. This reduces the time required to deliver a measured amount which enables an increase in tractor speed. Similarly, if you want to reduce the speed indicated from the graph, increase delivery time by reducing either pressure or orifice size, or restrict to a single nozzle per row.

Note 2: The ability of the petroleum mulch to flow is somewhat dependent upon the temperature of the mulch at time of application. It is suggested that the system be calibrated for each major change in temperature, such as cool-morning or warm-afternoon mulch applications.

Temperature and moisture measurements

Soil temperatures were measured with an automatic recorder (Honeywell Electronic 15, ultipoint recorder) equipped with copper constantin wire thermocouples, or taken manually with a Rubicon potentiometer at designated intervals. Temperature readings were recorded at soil depths of ¾, 1½, 3, 6 and 12 inches and just under the soil surface to determine influence of soil heating by mulch in relation to soil depth. During crop response evaluations under petroleum mulch, temperature was measured at the ½–1 inch depth, which coincides with the planting depth of most vegetables.

Soil moisture was determined either by weight measurement of soil samples from the 0–2 inch and 2–4 inch depth profiles by the oven dry weight method, or by electrical conductivity through porous gypsum moisture blocks positioned at the 1-inch soil depth (Cannell and Asbell, 1964).

Greenhouse studies were conducted at 70°F night and 80°F day air temperatures. Soil tanks were placed in constant temperature baths to maintain different soil temperatures. Light source was 250-watt heat lamps placed 18 inches above the test beds. All temperature readings for the greenhouse trials were taken during the evening hours to prevent the interference of natural sunlight.

RESPONSES FROM PETROLEUM MULCH

Soil temperatures

Black-colored surfaces absorb a higher proportion of incident solar radiation than light-colored surfaces. Black asphalt bands sprayed on the soil surface significantly increased the temperature of the soil under the band compared to the adjacent nonmulched soil. This solar radiation in the form of heat energy was conducted readily into the soil. Heat movement was rapid because the asphalt overlay was attached intimately to the surface soil particles eliminating air spaces, or films of air, which exist under other discrete coverings such as polyethylene films (Honma, *et al.*, 1959, and Waggoner, *et al.*, 1960).

The influence of petroleum mulch films on soil temperature was diurnal with little or limited retention of soil heat during the night. As illustrated in figure 4, soil temperatures increased rapidly during the morning hours, with the peak attained around 2:00 p.m., then gradually decreased during the late afternoon. After sunset, little difference in soil temperature was recorded between the mulched and nonmulched areas. Similar diurnal temperature responses were reported under growing conditions in other states (Williams, *et al.*, 1968).

The amount of soil temperature benefit derived from the use of asphalt films depends largely on the intensity and duration of solar radiation. Cloudy days produced smaller temperature changes than clear, sunny days (figure 5). Soil temperatures under petroleum mulch generally exceeded control soil temperatures by 5° to 10°F at the 1-inch soil depth under normal spring sunlight, but may show as high as an 18° to 20°F

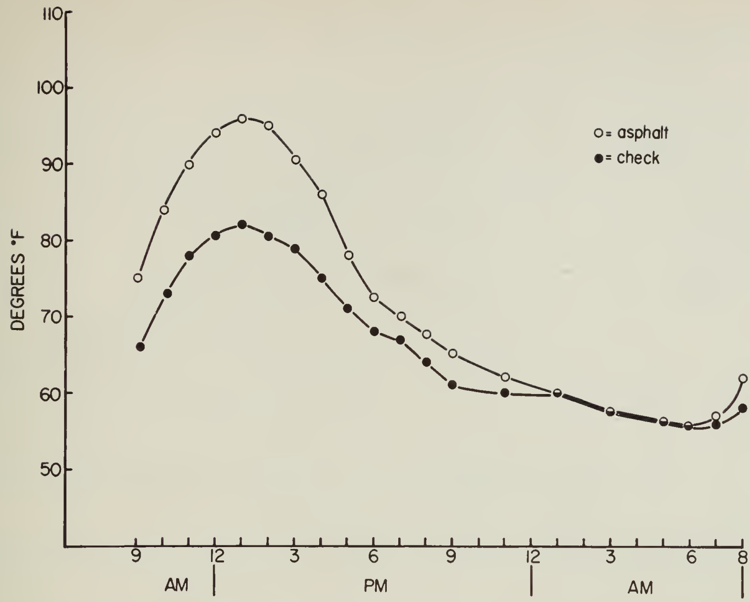

Fig. 4. Diurnal temperature patterns at the 1.5-inch soil depth under the control soil and a 6-inch band of petroleum mulch.

differential at the soil surface on a warm, bright day, or as low as 1° to 2°F under cloudy conditions or at greater soil depths. This suggests that growing areas subject to periods of rain, clouds, or fog cover would realize only limited benefit from asphalt overlays.

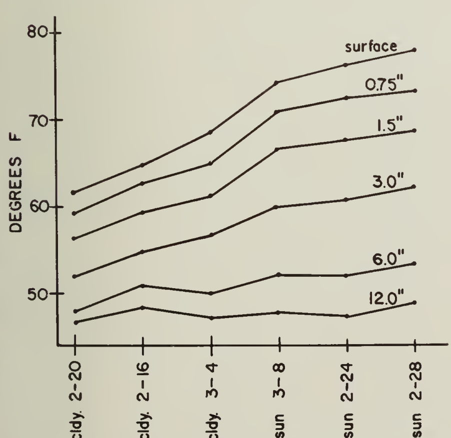

Fig. 5. Soil temperature at various depths under 6-inch bands of petroleum mulch as influenced by available solar radiation.

Influence of different band widths. The relationship among different widths of asphalt bands and soil temperature are shown in figure 6. In general, as the width of the band increased, soil temperatures increased; however, the progression was not a linear effect. Band widths of 3 inches produced little or no change in soil temperature. The 6-, 12- and 24-inch bands increased soil temperatures significantly over the nonmulched control. Band widths of 12 and 24 inches did not consistently increase soil temperatures above those for the 6-inch band and statistically showed no significant difference. These data were developed from a mulch concentration of 500 gallons per full acre coverage, but results of band width studies using other concentrations show the same general trends.

Band width and soil temperature interacted positively at various soil depths. Higher temperatures were recorded on the surface of the soil with increasing band width than were obtained at the greater soil depths. Regardless of band widths used, no significant increases in

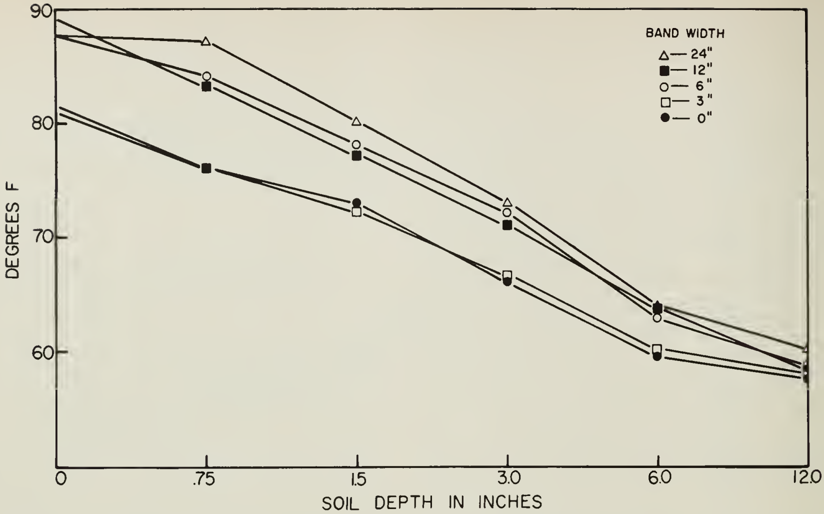

Fig. 6 Interrelationship of band width and soil depth on soil temperature under petroleum mulch.

soil temperature were obtained with petroleum mulch below the 6-inch soil depth.

Considering the location of the seed zone for most crops and the amount of mulch material required to form a band larger than 6 inches, the data suggest that a 6-inch band is the most feasible width to consider for row crop use in agriculture. Williams, *et al.* (1968), working with band widths of 2-, 6- and 12-inches, also reported that the greatest advantage at an acceptable cost per acre was obtained with the 6-inch band applied directly over the seed row.

Effect of soil surface condition and initial soil temperatures on the performance of asphalt films. Effective application of petroleum mulch requires a smooth soil surface in order to develop a thin continuous film at a minimum application rate. Where trials were conducted on carefully prepared seed beds, mulch performance was generally good (Cannon, 1965; Takatori, *et al.*, 1964). Under field conditions where soil types and environmental conditions vary, it is important that these two variables be more precisely defined.

Four aggregate classes of fine sandy loam soil, and fine sand (silt) and peat soils were tested with a 6-inch band of asphalt mulch under five soil temperatures ranging from 4.4° to 26.7°C (40° to 80°F). The loam soil was screened to provide aggregate classes of less than ⅛ inch, ⅛ to ¼ inch, ¼ to ½ inch, and ½ to 1-inch sizes. All tests were conducted in the greenhouse in watertight fiberglass containers designed to fit into controlled temperature water baths (Lippert, *et al.*, 1968).

Two infrared lamps (General Electric Infrared Heat, 250W) provided heat simulating the sun's energy. The energy discharge of each lamp was standardized by height and orientation to a heat output of 5.6×10^6 ergs/cm^2/sec. This heat level approximates 10 times normal sunlight on a clear summer day.

Asphalt mulch overlays at concentrations of 500 and 1,000 gal/full acre coverage increased soil temperatures for each soil type and aggregate class (figure 7). However, the greatest temperature differential tended to occur in the smooth soil surfaces represented by less than ⅛ inch aggregate and the sandy soils. The aggregate sizes above ⅛-inch

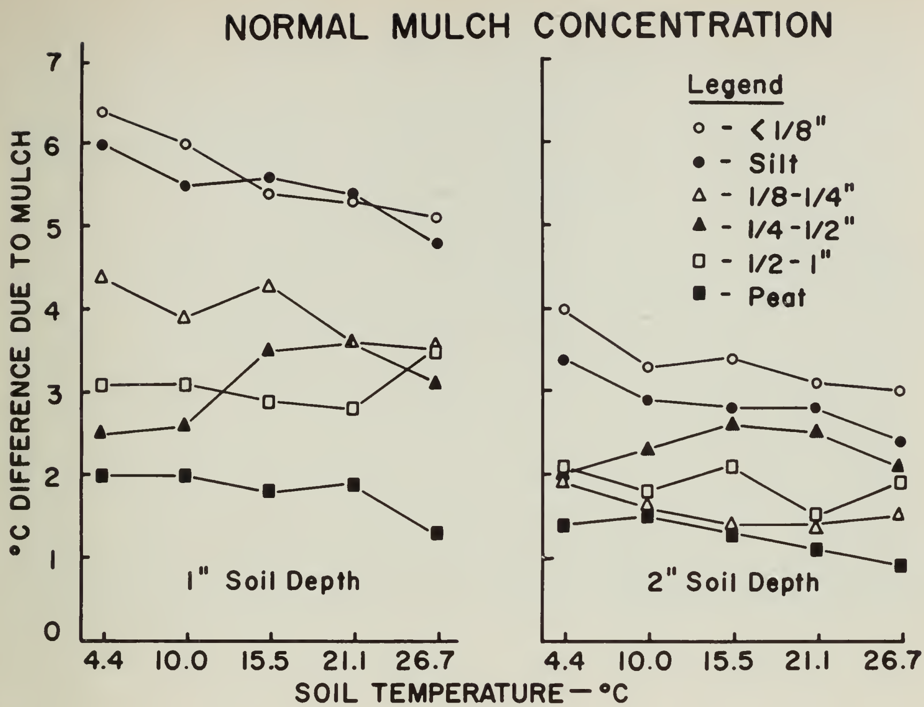

Fig. 7. Increase in soil temperature due to petroleum mulch at 500 gal/full acre concentration at 1- and 2-inch soil depth under various soil types and aggregate conditions.

diameter gave erratic and unpredictable temperature response. The general increase in temperature due to mulch was lower from these large aggregates. These differences in temperature responses were associated with the continuity of the asphalt film. As the aggregate size was increased, it became more difficult to develop a continuous film over the soil surface. Increasing the volume of spray material may help develop a continuous film over the medium-sized soil particles, but has limited effectiveness on particle size over ½ inch.

Soils starting with lower initial temperatures responded most to the mulch treatments. At the 1-inch soil depth, the mulched area with initial temperature of 4.4°C (40°F) increased 22° to 27°C (40° to 48°F) above the initial temperatures. By contrast, where the initial soil temperature was 26.7°C (80°F) the increase was smaller, ranging from 15 to 19.6°C (27° to 36°F) for the various aggregate classes and soil types. The relationship between initial soil temperatures and aggregate size is also illustrated in figure 7.

The above mentioned tests were conducted in the greenhouse where the air temperature was maintained at 24°C (75°F). When the air temperatures surrounding the soil were maintained at 5°C (41°F), increases in soil temperatures under petroleum mulch were lower, ranging between 7° to 9°C (12° to 16°F). The temperature differential between the two comparisons was caused by the difference in heat exchange between the soil and its environment.

These controlled studies indicate the importance of a smooth, homogeneous

Table 2

AVERAGE SOIL TEMPERATURE AT THE 1-INCH DEPTH UNDER THREE PETROLEUM MULCH FORMULATIONS RECORDED BETWEEN 11 A.M. AND 3 P.M.

Date	E.A.P. 2000				E.A.P. 2514				E.A.P. 2512				Control
	gal/full acre coverage				gal/full acre coverage				gal/full acre coverage				
	500	375	250	125	500	375	250	125	500	375	250	125	
	degree F												
5/3/65	87.2	85.7	85.4	81.4	84.8	86.5	84.0	77.4	85.1	86.8	85.8	83.2	78.8
5/6/65	90.6	91.1	91.2	88.4	91.6	90.6	87.8	86.4	91.5	91.5	91.4	90.2	86.5
5/7/65	93.6	94.3	94.0	90.6	93.5	93.4	90.5	89.1	96.2	94.2	94.9	92.6	88.6
5/9/65	100.2	101.6	100.1	97.1	100.4	100.2	97.5	96.2	101.4	101.4	101.0	99.7	95.3
Ave.	92.9 b*	93.2 b	92.8 b	89.4 ab	92.6 b	92.8 b	90.0 ab	87.3 a	93.7 b	93.5 b	93.3 b	91.4 ab	87.3 a

* Any two means not having letters in common are significantly different at the 5 per cent level by the Duncan test.

soil surface with a minimum of clods to obtain maximum performance from petroleum mulches under field application. Equipment for seedbed preparation for petroleum mulching has been developed and described by Frost (1966).

Influence of the thickness of the film on soil temperature. The thickness of the asphalt film in difficult to measure because the soil particles on the surface of the soil are fused with the film and presents a nonuniform surface with larger quantities of mulch in the air spaces between the soil particles than on the particles themselves. Thus, film thickness was evaluated on the basis of the volume of material applied per acre. It was assumed that when the band width was held constant, a rate of 500 gal/full acre coverage would produce a film between 10 and 20 mm thick. Reducing the application rate by half (250 gal/full acre coverage) would create a film approximately half as thick, and doubling the rate to 1,000 gal/full acre coverage would produce a film twice as thick.

Three different materials were tested in the field at rates of 125, 250, 375 and 500 gal/full acreage coverage applied as a 6-inch band. Prior to mulch application the soil was rototilled twice and pressed with a 200-lb lawn roller to form as smooth a surface as possible. The soil temperatures obtained for the three materials at the four mulch concentrations are given in table 2.

The 125 gal rate for all three materials failed to increase soil temperature. The soil particles were visible in many areas of the band, indicating that the film was not continuous at this low concentration. Petroleum mulch concentrations of 250, 375 and 500 gal/full acre coverage increased soil temperatures significantly over both the 125-gal rate and the nonmulched control. The differences in temperatures among the three higher rates, in most instances, was only 1° or 2°F.

Fig. 8. Evidence of moisture conservation in the soil area protected by the asphalt deposit from a petroleum mulch band.

These data further suggest that the effectiveness of petroleum mulch is dependent on the development of a continuous black film. Beyond the volume of material required to produce a continuous film, additional material does not strongly influence soil temperatures. On a carefully prepared seed bed, lower rates (approximately 250–300 gal/full acre coverage) will provide this continuous film, whereas, in the presence of clods, holes, or debris, even very large quantities (in excess of 500 gal/full acre) may fail to effectively cover the soil surface.

Soil moisture

The bulk of the soil moisture lost from an open surface is by evaporation. Although somewhat porous, the mulching film restricts the evaporation rate which reduces the loss of soil moisture (figure 8).

Effect of width of mulch band on moisture retention. The same 6-inch-wide band which provided the most economical temperature response also was adequate for a significant conservation of moisture during the early seedling stage (Lippert, *et al.*, 1964). Moisture content of the soil was determined from a noncropped test area in which petroleum mulch bands of 0, 3, 6, 12 and 24-inch widths were replicated four times on 40-inch raised beds. Mulch application was at the rate of 500 gallons per full acre coverage and band widths were controlled by use of wooden templates over the bed area. The total plot was furrow irrigated to saturation after mulch application and recorded a 19.8 per cent moisture content two hours after completion of irrigation. Soil samples from the 0–2 and 2–4 inch depths were obtained from each plot at four-day intervals for three weeks. Moisture percentage was calculated on the basis of dry weight of soil after drying in a forced-air oven for 24 hours at 105°C (40.5°F).

Table 3

MEAN SOIL MOISTURE PERCENTAGES UNDER BAND WIDTHS OF PETROLEUM MULCH

Band Width	Mean soil moisture percentage			
	Days after mulch application			Mean of readings over 20-day period
	12	16	20	
inches	*per cent*			
0	7.55 a*	7.36 a	7.60 a	11.10 a
3	8.18 a	7.88 ab	8.34 b	11.43 ab
6	9.48 b	8.48 bc	8.05 ab	11.92 bc
12	9.95 b	9.02 c	9.94 c	12.39 cd
24	10.50 b	9.73 d	10.44 d	12.75 d

* Any two means in vertical order not having letters in common are significantly different at the 5 per cent level by the Duncan test.

The mean moisture values for band widths of petroleum mulch are presented in table 3. These data show a nearly linear trend for higher soil moisture retention as band width increases during a winter (February) test. Duncan's mulitple range test indicates significant differences only between third-position means. Therefore, with the narrow band widths, significant moisture retention was obtained with a band of approximately 6 inches, whereas in the wider bands, larger increments of width were necessary for significance (approximately 18 inches between 6- and 24-inch bands).

Figure 9 shows that the moisture content was significantly higher at the 2- to 4-inch depth than at the 0- to 2-inch depth. Also, there was a continuing and significant loss of moisture from the soil at progressive sampling dates. These trends in soil moisture are expected in a field study of this type.

Similar tests on band widths initiated during summer (July) and fall (October) conditions at Riverside showed seasonal differences compared to winter and spring conditions. The drying rate of the soil was so rapid under these warm environments that no significant moisture retention was recorded from any band width of petroleum mulch.

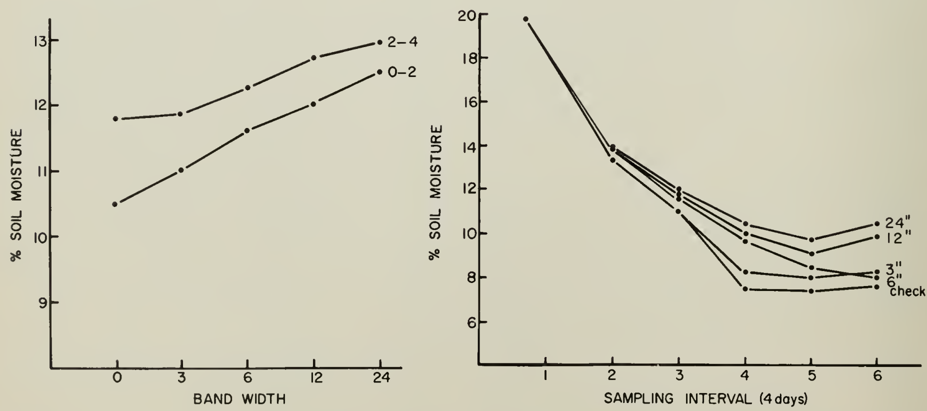

Fig. 9. Influence on soil moisture by mulch band widths at two soil depths and at various sampling intervals.

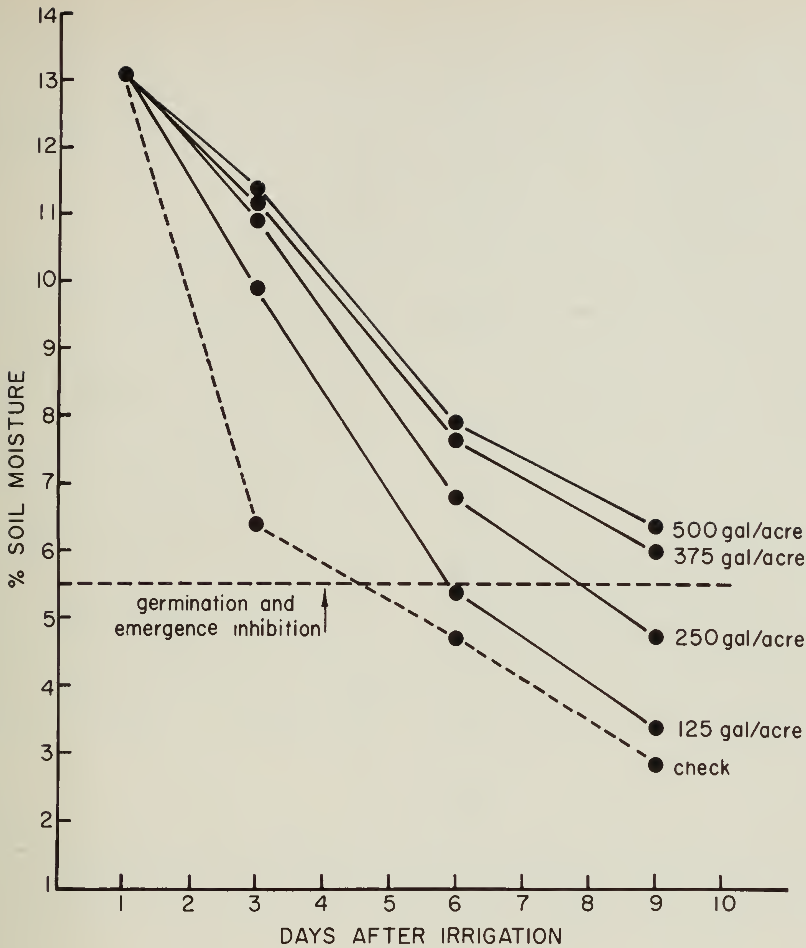

Fig. 10 Pattern of soil moisture depletion or conservation under 6-inch bands of petroleum mulch as influenced by mulch concentration. Results represent a February-March trial at Riverside.

Effect of formulation and density of the film on moisture retention. Three formulations of petroleum mulch at rates of 500, 375, 250, and 125 gal/acre (full acre coverage basis) were evaluated for effects on soil moisture using 6-inch wide bands. Changes in both formulation and concentrations influenced the retention of soil moisture. Progressively higher moisture readings were obtained up to the 375 gal/acre rate in each sampling date for a nine-day period (figure 10). The difference in moisture retention between films for the 375 gal and 500 gal/acre rate was not significant. Changes in formulation created differences in the functional properties of petroleum mulch which appear associated with the formation of a continuous film.

The greatest proportion of soil moisture lost from an open surface is through evaporation. The band of petroleum mulch present on a soil surface is porous, containing numerous pin-sized or larger holes. Yet, in general, these mulch bands are in better moisture condition than nonmulched soils (figure 8). Considering that the soil is warmer, the better soil moisture under the mulch band apparently is caused by the asphalt deposit acting as a barrier against loss of water vapor. This would result directly in a better moisture condition and might also assist in maintaining a continuous moisture column which permits capillary movement of moisture throughout the lower soil levels toward the surface.

This moisture effect is evident for only a few days following planting and mulching, but may be important in the emergence of crop seedlings. As an example, soils drop from the field capacity level of soil moisture to a stage where moisture is at a sufficiently low level as to be a critical factor in seed germination and seedling emergence. In the Riverside soils, this period from field capacity to critical moisture was reached in five to six days without mulch during spring trials. Under mulch, the critical level was delayed for three to four days; that is, moisture was available to the germinating seeds for up to eight to ten days after irrigation (figure 10). This effect is not large enough to greatly reduce total water requirement to an irrigated crop, but it does offer benefits during the early germination and seedling stages.

Crop responses

The influence of asphalt mulch on the production of vegetables was evaluated in southern California between 1961 and 1968 (Takatori, *et al.*, 1964). Most of the field tests were initiated during February and March. Weather conditions during this period are cool and soil temperatures approach the critical minimum range for good germination and emergence of warm-season vegetable crops.

The width of the petroleum mulch band was standardized at 6 inches and the mulch was applied at the rate of 500 gallons per full acre coverage.

The responses of various vegetables

TABLE 4

THE INFLUENCE OF PETROLEUM MULCH OVERLAYS ON VEGETABLE GERMINATION, SEEDLING DEVELOPMENT, AND PRODUCTION*

Vegetable		Germination		Seedling	Production	
Species	Variety	Early	Total	Vigor (wt)	Early (no.)	Total (no.)
Beans	Tendergreen	+	+			
Beets	Detroit Dark red	+	+	NS	P	NS
	Holly H.H. 5	+	+	+	–	+
Cantaloupe	P.M.R. 45	+	+	+	NS	+
Carrots	Imperator	+	+			
Celery	Utah 52–70	NS	NS			
Cucumber	Marketeer	+	+	+	+	+
Lettuce	Great Lakes	+	+			
Onions	S Spanish	+	+	+	P	NS
	Early Grano	+	+			
Peppers	Yolo wonder	+	+			
	Floral Gem	NS	NS			
	green chili	+	+			
Squash	zucchini	+	+	+	+	+
Sweet corn	Golden Bantam	+	NS	NS	+	NS
Sweet potato	Velvet (for shoots production)					+
Tomato	Pearson Imp.	+	+	+	P	NS
Watermelon	W.R. Klondike 88	+	+	+	P	+

* + = significance at 5 per cent level
NS = not significant
P = possible. No data because of single harvest

Table 5

INFLUENCE OF PETROLEUM MULCH OVERLAYS ON THE PRODUCTION OF VEGETABLES. EXPRESSED ON THE BASIS OF 10 FEET OF ROW

Variety	Germination				Seedling vigor		Yield			
	Initial		Total				Early		Total	
	Mulch	No Mulch	Mulch	No Mulch	Mulch	No Mulch	Mulch	No Mulch	Mulch	No Mulch
	days				*g/seedling*		*pounds*			
Zucchini	22.7*	6.2	39.0*	30.0	5.6*	3.8	19.5	13.2	62.0	53.0
Golden Bantam......	10.5*	1.7	15.0	18.0	7.0	8.0	10.7	9.0	23.0	28.0
Detroit D red..	129.2*	51.2	177.0*	110.0	2.8	2.2			48.0	42.0
Holly HH 5....	125.5*	34.5	157.8*	128.0	2.4	1.1			71.9*	63.6
PMR 45........	31.7*	0.0	52.0*	20.0	0.6*	0.3	4.2	1.2	16.8*	4.0

* Significantly different at the 5 per cent level by the Duncan Test.

to petroleum mulch are summarized in table 4. Except for pepper variety Floral Gem, celery variety Utah 52-70, and Golden Bantam sweet corn, the rate and total germination for every crop were increased with the use of mulch. Where petroleum mulch overlays were not used (control plots) the germination and emergence period extended over a longer period resulting in either a reduced final stand or a stand with young plants of different sizes. This delay in germination was particularly noticeable for cantaloupes, cucumbers and watermelons. In one test, cucumbers failed to germinate without the aid of petroleum mulch because of the existing cold soil temperatures.

Plant size, measured either by weight or height of the seedlings approximately one month after emergence, was used as an index of seedling vigor. This stage of plant growth corresponds closely to the time when most vegetables are thinned to final stand in a commercial operation. By virtue of an early germination and continued favorable soil temperature under the petroleum mulch soil cover, these plants were larger and more vigorous than plants from the non-mulched control areas during the seedling stage of plant growth.

For some vegetables the stimulus of early germination and final seedling vigor was manifest throughout the growing season and resulted in increased yields. Zucchini squash and cantaloupes are examples of this type of response (table 5). For other vegetables the initial advantages of earlier germination and increased seedling vigor did not persist throughout the growing season when measured as differences in yield. In many crops the failure to show yield differences may be caused by the cultural practices used in producing the crop. For example, the seeding rate for both table beets and sugar beets is normally increased over the amount required for a final stand and the plant population is regulated by thinning to a given stand. When the comparative stand between the treated and nontreated areas was similar, as was the case for table beets (table 5), the advantages of increased percentage of germination was negated and no differences in yield were obtained. When a differential in the final stand occurred (sugar beets) the initial treatment effects were reflected in increased total production.

The greatest effect on yield by use of petroleum mulches appears to relate back to better emergence and particularly better thinned stands associated with early crop responses. Yield differences are more directly related to increased plant populations than to yield differences among individual plants. Therefore, if the plant population has been increased by mulching, resultant yields should be increased. As the industry shifts more toward precision planting, or the positioning of seeds on a plant-to-stand basis, petroleum mulch through its benefits of increased rate and percentage of germination could be a critical fatcor in achieving the desired high plant population.

The rate of maturity or earliness of production for many crops may be as important to the grower as total yield. For table beets and onions, the harvest was delayed and the yield determined on a single harvest which minimize the difference in the rate of maturity. In sweet corn, cucumber and squash, where differential harvests were made, a significant increase in earliness of production was obtained.

In summary, crop responses from petroleum mulches were as follows:

1. Petroleum mulch overlays are effective and beneficial for most crops for establishment of a good stand during seasons of the year when weather conditions and soil temperatures are in the minimal range for optimum performance.

2. Plants aided by petroleum mulch will generally be larger and exhibit more vigor during the seedling stage than nonmulched plants.

3. For some vegetables, early germination and increased vigor will produce earliness of maturity and increased yields. For other crops, the advantage of higher percentage germination, seedling vigor, etc., will be minimized because of cultural practices such as thinning-to-stand.

4. Total yield increases for most vegetable crops relate to increased plant populations due to mulching, rather than to yield differences among individual plants.

THE INFLUENCE OF ASPHALT RESIDUES ON VEGETABLES

One of the most frequently asked questions regarding petroleum mulches is: "What is the effect of the asphalt residue from petroleum mulches on soil characteristics and subsequent crop growth?" To obtain answers to these important considerations, asphalt mulch from three petroleum companies was incorporated into the soil at rates of 500, 1,500, 3,000, 4,500 and 6,000 gallons per acre (Takatori, *et al.*, 1968). These quantities simulate the amount of asphalt that would be added to the soil if a field was mulched for 5, 15, 30, 45 and 60 years, based on an annual application of 100 gallons of actual mulch per acre. The mulch was applied over a 6-month period at a maximum rate of 1,000 gallons per acre per

TABLE 6

THE EFFECT OF DIFFERENT AMOUNTS OF PETROLEUM MULCH INCORPORATED INTO THE SOIL ON THE GERMINATION OF 4 VEGETABLE SPECIES*†

Crop	Material	Gallons/acre					
		0	500	1,500	3,000	4,500	6,000
		Germination count					
Tomato..........	1	33.8	40.0	48.0	38.0	43.0	37.5
	2	38.0	35.0	41.2	42.5	36.2	37.0
	3	40.0	42.0	39.2	37.0	... ‡	...
	Ave.	37.2 a	39.0 a	42.9 a	39.1 a	39.6 a	37.2 a
Sweet corn..........	1	10.5	15.0	14.5	16.2	10.0	11.2
	2	12.5	13.0	13.7	10.5	12.5	10.0
	3	14.5	11.2	12.5	13.0	.....	....
	Ave.	12.5 a	13.0 a	13.5 a	13.2 a	11.2 a	11.1 a
Sugar beets	1	37.5	17.5	25.0	17.5	27.5	20.0
	2	12.5	20.5	8.0	17.5	18.7	18.8
	3	20.0	14.5	12.5	20.5	.....	.....
	Ave.	23.3 a	17.5 a	15.1 a	18.5 a	23.1 a	19.4 a
Turnips..........	1	305	192	228	250	225	228
	2	262	245	210	210	235	222
	3	230	168	228	240	.....	.....
	Ave.	265 a	201 b	222 b	233 b	230 b	225 b

* Within each row any two means not having letters in common are significantly different at the 5 per cent level by the Duncan test.
† Number of plants/10 ft row.
‡ Material 3 was not tested at rates above 3,000 gal/acre.

month. The material was exposed on the soil surface for 30 days before incorporation into the soil.

Sweet corn, tomatoes and sugar beets were planted the first season (April 1967). The second season the entire test area was planted to turnips and followed with a crop of cantaloupes. All five plant species grew vigorously and appeared normal, with no visual symptoms observed throughout the growing season that would indicate asphalt toxicity. The germination count for four of the crops is presented in table 6. Except for turnips, no differences in germination rates among treatments were obtained. The germination count for the asphalt-treated plots was less than for the non-treated control for the turnip crop; however, this was caused by planting difficulties which necessitated replanting rather than by asphalt levels in the soil.

No differences in yield were obtained among treatments for the five plant species tested in this study.

Soil samples were collected periodically throughout the test. The asphalt content of the soil was determined by spectrophotometric analysis of solvent extracts of the soil by Douglas Oil Company, Paramount, California. The relative asphalt content of the soil at various time intervals during the test is given in table 7.

Just prior to the initial planting, the asphalt content of the soil was .053, .081, .139, .156 and .316 g/100 g of soil for treatment rates of 500, 1,500, 3,000,

Table 7

THE DEGRADATION OF ASPHALT CONTENT IN THE SOIL

Sample Date	Amount of material applied gal/acre†					
	Control	500	1,500	3,000	4,500	6,000
	grams/100 grams of soil					
Nov. 1966	.009	.082	....	....	...	...
Dec. 1966	.039	.091	.178	....	....	....
Jan. 1967	.008	.042	.098	.155	....	....
Apr. 1967	.014 a*	.053 ab	.081 bc	.139 cd	.156 d	.316 e
Jan. 1968	.018 a	.035 a	.046 a	.053 a	.114 b	.123 b
Sept. 1968	.017 a	.039 b	.086 bc	.099 cd	.112 cd	.120 d

* Any two means not having letters in common for a given sampling date are significantly different at the 5 per cent level by the Duncan test.

† Petroleum mulch applied over a 6-month period at a maximum rate of 1,000 gal/acre/month.

4,500 and 6,000 gallons per acre, respectively. The nonmulched control soil indicated a background level of .014 g/100 g soil. As shown in table 7, the asphalt content progressively increased with increasing amounts of petroleum mulch applied. The differences in asphalt content in soils from the control and the 500 gallon treatments were not significant, suggesting that the asphalt was degraded during the 6-month period between application and the first planting date.

Soil samples collected nine months later (January, 1968) showed that the asphalt content of the soil for all treatments up to the 3,000 gallon per acre rate had decreased to the comparable background reading of the controls. At the higher concentrations (4,500 and 6,000 gallons per acre), the asphalt content was reduced to approximately one-half the original preplant level.

Twenty months after the first application of petroleum mulch, the field was reworked and sampled on the flat ground surface. All of the treated plots showed traces of asphalt residues; however, the

Table 8

THE INFLUENCE OF VARIOUS AMOUNTS OF ASPHALT RESIDUE ON THE INFILTRATION RATE OF THE SOIL*

Material	Sampling time interval	Amount of petroleum mulch applied gal/acre					
		0	500	1,500	3,000	4,500	6,000
	minutes	*inches of water/hour*					
1	30	.126	.304	.223	.281	.170	.177
	60	.171	.453	.298	.414	.255	.229
	120	.252	.614	.607	.718	.395	.315
2	30	.272	.205	.388	.465	.701	.727
	60	.412	.317	.668	.735	1.152	1.147
	120	.680	.400	1.080	1.120	1.650	1.640
Ave.	30	.199	.254	.305	.373	.435	.452
	60	.291	.385	.483	.574	.703	.688
	120	.466	.507	.843	.916	1.022	.977

* Tests made 9 months after petroleum mulch was incorporated and after the removal of one crop.

quantities were small. The data suggest that under normal agricultural use, little or no asphalt accumulation should occur by repeated seasonal applications. The four vegetables and sugar beets were not susceptible to asphalt toxicity for the amounts utilized in this test, which would suggest that most crops are not highly susceptible to asphalt mulches.

Soil additives frequently alter some physical characteristics of the soil. The infiltration rate of water into the soil was determined nine months after the mulch was incorporated and after the first crop was removed from the test area. Under field conditions these data were difficult to determine because of the extreme variability among samples within treatments as well as among replications. In general, there was a trend for increased infiltration rate of water into the soil with the addition of petroleum mulch.

The average rate of percolation for the various treatments and materials is given in table 8. Each figure represents an average of 24 determinations. With the exception of the 500 gal/acre rate for Material 2, the average water infiltration rate for the mulched plots was increased over the nonmulched plots.

THE INFLUENCE OF PETROLEUM MULCH OVERLAYS ON HERBICIDE PERFORMANCE

Petroleum mulch stimulates the germination of weed seeds as well as seeds of crop species. Trials were initiated to evaluate the effectiveness of herbicides in combination with petroleum mulch under furrow irrigation. The following three factors were considered: (1) whether the combination with petroleum mulch modified crop response to the herbicide; (2) whether the combination enhances weed control; and (3) whether petroleum mulch could serve as a method of herbicide incorporation, i.e., whether a surface application of herbicide covered by petroleum mulch would be equivalent to the standard (under semiarid conditions with furrow irrigation) mechanically incorporated nonmulch method of herbicide application.

Herbicides

Herbicides used in trials 1 and 2

EPTC
CIPC
CDEC
Diphenamid

Herbicides used in trials 3 and 4

Alanap
CDEC
CIPC
EPTC
Bensulide
Diphenamid
Dacthal
Benefin
Trifluralin

The effect of petroleum mulch alone on the emergence of the weed population is shown in table 9. Trials 1 and 2 (February and April, 1964) were duplicate tests initiated on different dates, as were trials 3 and 4 (April, 1965). When temperatures were cool (Trial 1) petroleum mulch stimulated weed seed germination as expected. Trials 2, 3, and 4 were installed when temperatures of the nonmulched soil were sufficient for weed seed germination, and little or no difference was obtained between mulch and nonmulched treatments. Because of this variability in temperature, results of each trial must be interpreted separately,

Table 9

THE EMERGENCE OF WEEDS FROM CONTROL PLOTS OF 4 HERBICIDE TESTS

Trial	Date application	Rainfall during trial	Time after application	Grass weeds		Broadleaf weeds	
				Mulch	No mulch	Mulch	No mulch
		inches	*weeks*	*Number*		*Number*	
1	2/27/64	2.7	3	79.9	42.1	47.1	4.4
			4	68.8	54.4	29.6	5.3
2	4/14/64	0.4	2	32.0	32.5	47.4	17.2
			3	46.0	40.0	38.8	22.8
3	4/1/65	4.7	5	195.0	92.0	85.0	94.0
4	4/27/65	0.0	2	236.0	241.0	209.0	296.0
			4	207.0	181.0	171.0	198.0

Table 10

THE EFFECT OF HERBICIDES, MULCH OVERLAYS, AND MECHANICAL INCORPORATION ON WEED CONTROL AND GERMINATION OF VARIOUS VEGETABLES

Crop	Trial No.	EPTC				CIPC				CDEC				Diphenamid			
		Mulch		No Mulch		Mulch		No Mulch		Mulch		No Mulch		Mulch		No Mulch	
		S	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I
Grass	1	a	a	d	a+	b	a	a	a	c	b	d	a+	a	a	a	a
	2	a	a	d	b+	d	a+	d	a+	a	a	d	a+	d	a+	d	a+
Broadleaf	1	a	a	d	d	d+	d	b	a	a	d+	d	c	a	a	a	a
	2	a	a	d	b	d	d	d	b	a	c	d	a+	c	a	d	a+
Corn	1	a	a	a	a	a+	d	d+	d	a	a	a	a	a	a	a+	c
	2	a	a	a	a	a+	d	d+	d	a	b	a	a	a	b	a	a
Cucumber	1	d	d	d	d	c+	d	d	d	b+	d	a+	d	b	b	a+	d
	2	d	d	c	d	d	c	d	d	d	d	a+	d	d	d	c	d
Onion	1	d	d	b	a	b+	d	d+	d	a+	d	b+	d	b	b	a	b
	2	d	d	a+	d	d	d	a+	d	a	a	a+	d	a+	d	a+	d
Tomato	1	a	a	d	d	d	d	d	d	b	a	d	d	a	a	d	d
	2	d	d	a+	d	d	d	d	d	d	a	d	d	a	a	d	a+

Symbols:
- a = 90–100 per cent control of weeds or percentage of stand of vegetable species
- b = 80–90 per cent control of weeds or percentage of stand of vegetable species
- c = 70–80 per cent control of weeds or percentage of stand of vegetable species
- d = 60 per cent or less control of weeds or percentage of stand
- + = significant differences at 5 per cent level of probability
- S = surface applied herbicide
- I = incorporated herbicide

and it is difficult to compare data between trials.

The relationship of herbicides, mulch overlays, and mechanical incorporation on weed control and emergence of various vegetables is shown in table 10. In general, weed control was enhanced by mechanical incorporation both with and without petroleum mulch. The most apparent instance of benefit from a mulch overlay is shown with EPTC. Because of the volatility of EPTC, the mulch overlay was apparently effective in preventing volatilization, and hence its performance was equal whether surface-applied under mulch or incorporated. In contrast to these results, without mulch EPTC was rather ineffective when applied to the surface as compared to mechanical incorporation (grass weed control, trials 1 and 2). In the one instance where mulch-surface herbicide application was significantly better for weed control than herbicide incorporation (Trial 1, CIPC), the percentage of stand for both treatments was below 60. The importance of rainfall as a factor in influencing herbicide performance is clearly shown in comparing some of the results between trials 1 and 2. In trial 1 (2.7 inch rainfall), Diphenamid performed equally well whether mechanically incorporated

Table 11

THE EFFECT OF SURFACE APPLIED HERBICIDES WITH MULCH OVERLAYS, AND NONMULCH MECHANICAL INCORPORATED HERBICIDES, ON WEED CONTROL AND GERMINATION OF VARIOUS VEGETABLES

Crops	Trial No.	EPTC		CIPC		CDEC		Diphenamid	
		Mulch Surface	No mulch Incorp.	Mulch Surface	No mulch Incorp.	Mulch Surface	No mulch Incorp.	Mulch Surface	No mulch Incorp.
Grass	1	a	a	b	a	c ——	—— a+	a	a
	2	a	b	d ——	—— a+	a	a	d ——	—— a+
	3	a	b	b	a	b	d	b	c
	4	c	a	c ——	—— a+	d	b	a+——	—— d
Broadleaf	1	a+——	—— d	d ——	—— a+	a	c	a	a
	2	a	b	d ——	—— b+	a	a	c ——	—— a+
	3	d	b	d	c	b	b	d	d
	4	c	b	d	c	a	a	d	d
Corn	1	a	a	a+——	—— d	a	a	a+——	—— c
	2	a	a	a+——	—— d	a	a	a	a
Cucumber	1	d	d	c+——	—— d	b+——	—— d	b+——	—— d
	2	d	d	d	d	d	d	d	d
Onions	1	d ——	—— a+	b+——	—— d	a+——	—— d	b	b
	2	d	d	d+——	—— d	a+——	—— d	a+——	—— d
Tomatoes	1	a+——	—— d	d	d	b+——	—— d	a+——	—— d
	2	d	d	d	d	d	d	a	a
Lettuce	3	b+——	—— d	b	a	a+——	—— d	a	a
Cantaloupe	4	d	d	b+——	—— d	c+——	—— d	b+——	—— d

Symbols:
a = 90–100 per cent control of weeds or percentage of stand
b = 80–90 per cent control of weeds or percentage of stand
c = 70–80 per cent control of weeds or percentage of stand
d = 60 per cent or less control of weeds or percentage of stand
+———— significant difference at 5 per cent level

or not, with and without a mulch overlay, whereas in trial 2 (0.4 inch rainfall) the surface application (both with and without mulch) was ineffective. In the first trial, there was enough rainfall to effectively incorporate Diphenamid and in the later trial there was not.

No added crop injury was incurred as a result of using a herbicide-mulch combination over that with herbicide alone. In most instances, surface application was less toxic (also gave less weed control) than the incorporation treatment. This condition occurred in both mulch combinations and in nonmulch treatments.

The comparison of surface applied herbicides with mulch overlays, and nonmulched mechanical incorporated herbicides on weeds and vegetables is shown in table 11. Although differences were dependent on the herbicide, in general, the nonmulch incorporated herbicide gave the best weed control. This was particularly noticeable for CIPC. As stated above, with the more volatile herbicides such as EPTC, the data indicates that a surface application covered with mulch can be as effective as mechanical incorporation without mulch. Similar results were reported by Mills, *et al.* (1968).

As in table 10, the crops showed equal or greater tolerance to herbicides applied on the surface with a mulch overlay, than mechanically incorporated without mulch, except for one instance with onions treated with EPTC.

From the data available, the general recommendation for weed control in petroleum mulch operations would be to select the most effective herbicide for the crop, apply it in the method for best weed control results, and overlay the soil surface with a band of petroleum mulch for temperature and moisture response for the crop.

GENERAL CONSIDERATIONS FOR A SUCCESSFUL MULCHING OPERATION

Successful results from petroleum mulch depend upon considerations of the following:

Production areas. Localities which have clear, sunny days during the early planting season will produce best results from petroleum mulching.

Types of crops to be mulched. Best results are obtained with warm season crops seeded during cool seasons.

Soil preparation. A smooth, fine-textured soil surface, free of clods, debris and uneven areas will provide the required continuous asphalt film for maximum temperature and moisture responses.

Mulch concentration and band width. Spray mulch at a concentration of approximately 400–500 gallons per full acre coverage (see concentration chart, figure 3) as a 6-inch band directly centered over the seed row. Dual spray nozzles per row, one spraying forward and one rearward provides best soil coverage.

Weed control. Petroleum mulches stimulate germination and growth of weed species, so that herbicides recommended for the crop should be used in conjunction with the mulching operation.

Handling of the mulch product. Follow the recommendations of the mulch supplier for proper spray equipment and procedures, and for handling and storage of the petroleum product.

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LITERATURE CITED

CANNELL, G. H., and C. W. ASBELL
1964. Prefabrication of mold and construction of cylindrical electrode-type resistant units. Soil Sci. **97**: 108–12.

CANNON, M. D.
1965. Thermal environments under synthetic strip mulches. Amer. Soc. Agr. Eng. Trans. **8**(3): 374–76.

FROST, K. R.
1966. Shallow strip tillage in seedbed preparation. Amer. Soc. Agr. Eng. Trans. **9**(4): 456–57.

FROST, K. R.
1968. Application of asphalt-emulsion for early seed germination. Div. Petroleum Chem., Amer. Chem. Soc., Symposium on New Uses of Asphalt. Preprints **13**(4): C53–C58.

HONMA, S., F. MCARDLE, J. CAREW, and D. H. DEWEY
1959. Soil and air temperature as affected by polyethylene film mulches. Quart. Bul. Michigan Agr. Exp. Sta. **40**(4): 834–42.

LIPPERT, L. F., F. H. TAKATORI and F. L. WHITING
1964. Soil moisture under bands of petroleum and polyethylene mulches. Proc. Amer. Soc. Hort. Sci. **85**: 541–46.

LIPPERT, L. F., F. H. TAKATORI and M. O. HALL
1968. Performance of asphalt mulch in relation to surface condition and temperature of the soil. Div. Petroleum Chem., Amer. Chem. Soc., Symposium on New Uses of Asphalt. Preprints **13**(4): C59–C63.

MILLS, C. L., A. R. HAMSON and C. F. WILLIAMS
1968. Effects of combinations of asphalt mulch overlay with selected herbicides on vegetable crops. Div. Petroleum Chem., Amer. Chem. Soc., Symposium on New Uses of Asphalt. Preprints **13**(4): C68–C75.

SCUDDER, W. T., and J. F. DARBY
1964. Equipment for the application of plastic and petroleum resin mulches. Proc. Florida State Hort. Soc. **76**: 208–13.

TAKATORI, F. H., L. F. LIPPERT, and F. L. WHITING
1964. The effect of petroleum mulch and polyethylene films on soil temperature and plant growth. Proc. Amer. Soc. Hort. Sci. **85**: 532–40.

TAKATORI, F. H., L. F. LIPPERT, and R. L. DUNNING
1968. The influence of asphalt mulch residue accumulation on the soil on vegetable production. Div. Petroleum Chem., Amer. Chem. Soc., Symposium on New Uses of Asphalt. Preprints **13**(4): C64–C67.

Waggoner, R. E., P. M. Miller, and H. C. Deroo
1960. Plastic mulching, principles and benefits. Connecticut Agr. Exp. Sta. Bul. **634**: 44p.

Williams, C. F., A. R. Hamson, and T. A. Reeve
1968. The effects of petroleum mulches on the emergence of vegetable seedlings. Div. Petroleum Chem., Amer. Chem. Soc., Symposium on New Uses of Asphalt. Preprints **13** (4) : C76–C83.

ABSTRACT

The results of many laboratory and field studies with petroleum mulch on soil temperature, soil moisture, crop response, and weed control are summarized. Soil temperature effects were diurnal with large increases during the day and little or no retention of heat during the night. The evaporation rate of the soil was reduced with mulching films. The germination rate and stand for most crops were favorably influenced when grown during periods of adverse weather conditions. The degradation rate of asphalt at concentrations recommended for agricultural use was rapid. A description of petroleum mulch, spray equipment soil preparation, and general considerations for a successful mulching operation have been included.

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