INFLUENCE OF PAPER MULCH
ON
A CLAY SOIL

by

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INTRODUCTION

The first extensive use of paper as a soil covering was made in 1914 by C. F. Eckart, of the Olaa Sugar Company in Hawaii who not only observed that paper mulch helped to control weeds, but also that the crop plants grew more vigorously on the mulched than on the unmulched area. The Hawaiian Pineapple Company made trial plantings with mulch paper in 1919 and so effective did the paper prove in controlling weeds and stimulating crop growth, that by 1931 it was used on approximately 80 per cent of the pineapple plantings in Hawaii.

From Hawaii the use of mulch paper spread to many countries and is now being employed on a variety of crops under varying climatic conditions. With few exceptions, the results from numerous world sources indicate increased crop yields of higher quality and earlier maturity following the use of mulch paper.

Since 1926 paper mulch has been used in a limited way on the more important vegetable crops at the Dominion Experimental Station at Saanichton, British Columbia, (24), and while most crops, particularly the heat loving ones, have given increased yields of higher quality, the use of mulch paper is as a rule only justifiable with specialized crops such for instance as the cantaloupe.

Many research workers have concerned themselves with the effects of paper mulch and while not in entire agreement, their general conclusions appear to be that the paper conserves moisture, raises soil temperature and increases the retention or elaboration of available nitrogen.

In view of the importance of paper mulch in the production of cantaloupes at Saanichton, a study of the bacteriological, chemical and physical changes occurring in a mulched soil was undertaken in an effort to determine the specific factor or factors or combination of same responsible for the beneficial effects noted.

REVIEW OF LITERATURE

The effect of mulch paper on soil temperature has been investigated by many workers, the majority of whom report an increase following its use. Ferretti, (5), in Italy, found that a paper covering insured higher soil temperatures during the early part of the season, but exerted little or no effect during the summer months.

Hartung, (9), conducting extensive tests for the Hawaiian Pineapple Company, found that mulch paper increased the soil temperature from 3 to 4.5° F. over that of the non-papered soil. This increase in temperature was noted in the top 3 inches of soil and the differences were more apparent when the paper was black in colour. Macoun, (13), of Ottawa, concluded that paper mulch tended to raise soil temperatures, and this he offered as an explanation for the observed increase in size of vegetable plants when grown on mulched areas. Magistad, Farden and Baldwin (14) in Hawaii found that mulch paper stimulated growth by reducing soil temperature fluctuations. Magruder (15) in Ohio, after conducting mulch paper tests with vegetables, concluded that soil temperature might be the most important single factor in increasing the yield of early maturing crops. Smith (19) in California, found that the greater the proportion of the surface covered by paper, the more positive was the effect on soil moisture, soil temperature and crop yield. He also found that black papers raised the soil temperatures, whereas grey papers reduced them. In Hawaii, Stewart, Thomas and Horner (23) recorded temperature differences at a 4-inch depth as great as 12 to 15° F. in the afternoon and 5 degrees during the night in favour of the mulched areas. Musso (17), working in the vicinity of Leningrad, used different coloured papers to bring about what he termed desirable temperature changes for specific crops. Contrary to the findings of most workers, he found that for best growth, plants should be subjected to varying temperature changes and concluded that it would be advantageous to have a mulch paper that would retard the warming of the soil to midday, but which would encourage warmth from this time on. Musso contended that a paper mulch acts as a medium of isolation between soil and air temperatures, thus bringing about a marked temperature difference, which he concluded to be beneficial to plant growth.

After four seasons' work at Rosslyn, Virginia, with paper mulch, Flint (7) found that the paper served to conserve soil moisture, particularly to the 4-inch level. Flint suggested that one of the benefits of the paper lay in the more efficient distribution of moisture, thereby permitting a wider feeding range for the plants and enabling them particularly to utilize the top inch of soil which is rich in available plant foods. Smith (19) in California found that the non-perforated black paper was the most effective in conserving moisture. This effect, as already noted, was confined to the surface 4 inches of soil and Smith concluded that it was due to the condensation of water underneath the paper. Ferretti (5) observed that a paper covering conserved moisture by reducing evaporation, while Bronsart (2) found no significant difference in moisture content, between mulched and unmulched soils. Hartung (9) concluded that mulch paper served to maintain a soil moisture content, under dry conditions nearer to the optimum for plant growth, than had previously been achieved in general practice in Hawaii. Magistad, Farden and Baldwin (14) noted that mulch paper conserved moisture by reducing evaporation and Stewart, Thomas and Horner (23) found that the soil moisture was consistently higher under paper than that found in the unmulched soil area. Shilova (18), in Russia, tried out different types of mulches and found that a black paper mulch was the most efficient for maintaining an optimum moisture content in the soil.

Flint (7) was unable to detect a greater quantity of nitrates in soil which had been subjected to mulch paper treatment. After one season's work with vegetables, Magruder (15) concluded that the differences in nitrate nitrogen content of the soil during this period were hardly consistent or large enough to be responsible for the increase in yield from the paper mulch. Bronsart (2), working with soils that had received no nitrogen fertilizers in 5 years, took nitrification as an index of the activity of the microorganisms in the soil. His determinations were made at depths of 5, 15 and 35 cm. and the differences in nitrate nitrogen in mgs. per 100 gms. dry soil sample, in favour of the mulched soil, were respectively 1.70, .10 and .35 mgs. He concluded that the increase in nitrates was due to increased activity of the soil micro-organisms under the paper and not due to leaching in the unmulched area. Using samples of laboratory-cultured soil, Ferretti (5) reported definite gains in ammonification and nitrification due to paper, with little influence on nitrogen-fixation. Magistad, Farden and Baldwin (14) concluded that because of higher soil temperatures and greater soil moisture, biological processes in the soil were considerably accelerated, resulting in a more rapid liberation of plant food, especially nitrates. Stewart, Thomas and Horner (23) reported that a greater quantity of nitrates was consistently found under mulch paper, which, to these workers, seemed to indicate a more rapid elaboration of the principal plant nutrients. Hartung (9) found that mulch paper stimulated nitrification, thereby enhancing the available nitrogen content of the soil. Yakovleva (29) basing his conclusions on the greater amount of nitrogen fixed and carbon dioxide evolved from the covered soil, concluded that paper mulching increased the bio-chemical activities of the soil. Shilova (18) found that mulch paper increased the accumulation of nitrate nitrogen, as well as bringing about the more complete utilization of the nitrate nitrogen by the plant. He also observed that the accumulation of ammonia nitrogen was favoured by mulching, though the amount was insignificant compared with that of nitrate nitrogen.

EXPERIMENTAL

CHARACTER OF THE CANTALOUPE

The plant selected for the mulch paper study was the cantaloupe, Cucumis melo, the variety chosen being Hale's Best, a netted melon of medium size and excellent quality. Being native to Asia and Africa, the cantaloupe is more or less specific in its heat requirements and generally takes unkindly to the cool nights and the moderate summer day temperatures commonly experienced at Saanichton. It is definitely a heat loving plant and can not be said to be naturally adapted to conditions on Vancouver Island. Tests at Saanichton indicate that success with the crop is only attained when due care is given to date of planting, judicious choice of soil and exposure factors and the creation of suitable environmental conditions through the use of mulch paper, with or without hot caps.

A study of the root system of the cantaloupe (28) gives some indication of its food requirements and its habit of growth. It has a root system consisting of a very extensive shallow portion and a poorly developed deeper part. The lateral root system of a cantaloupe plant may have a spread of 10 to 12 feet, most of this being found in the top foot of soil. Being a rapidly growing crop under optimum conditions, it requires an abundance of nutrients and usually makes its maximum growth in a deep friable loam, rich in humus. Analyses of melon plants indicate a relatively high percentage of calcium, which may possibly explain why cantaloupes appear to do best in a soil with an hydrogen-ion concentration around the neutral point.

PROCEDURE

This study respecting the influence of paper mulch on production of cantaloupes at Saanichton was conducted under field conditions. The cantaloupes were grown in a 3-year rotation following broccoli and preceding tulips. The area devoted to each crop was approximately .20 acres.

Immediately upon setting out the young cantaloupe plants the soil was hand-raked and the mulch paper was then laid down. Raking was for the purpose of preventing lumps from subsequently breaking the paper if trod upon. The èdges of the paper were held down with the lumps of earth removed in raking.

The paper used was a good grade of building paper impregnated with asphalt. Each roll contained 400 square feet, was 30 inches wide and weighed 25 pounds.

The experiments reported at this time covered four years' work, 1935 to 1938 inclusive, with some additional observations being made in 1939.

Soil and Climatic Conditions.

Soil selected for the experiments was a clay loam as determined by the hydrometer method (1). Clam shell totaling about 15 tons per acre had been applied over a period of years immediately preceding 1935 and as a result the soil had a pH of 7.0. Barnyard and green manures are regularly applied for the other crops in the rotation, the practice usually followed being to apply the manure immediately prior to planting the broccoli. Upon harvesting this crop the land is seeded to a green manure crop which is turned under prior to the planting of the cantaloupes about the latter part of May.

Records over a 26-year period at Saanichton show that the mean daily air temperatures for June, July and August (the main growing months) are respectively 59, 63 and 62° F. The hours of sunshine for the 3 months are respectively 269, 324 and 293 hours, or approximately 900 hours of sunshine between the time of planting the cantaloupes, (May 24) and the time of harvesting at the end of August or early in September. As temperature records are not available covering a 24-hour period, the total effective temperature required to carry the cantaloupe plants through the vegetative and reproductive phases, under Saanichton conditions, cannot be computed at this time. The mean rainfall for the months of June, July and August over a 26-year period, has been computed respectively at 1.11, .66 and .73 inches per month; the mean yearly rainfall recorded over a similar period is 30.01 inches per annum.

Soil Sampling and Plating.

A standard system of soil sampling was adopted for both the mulched and the unmulched areas at the outset in 1935 and this was only slightly modified through out the following years. The procedure was as follows: Three representative stands were chosen on each area and three borings were made at each stand, at a distance of nine inches from a plant. In 1935, 1936 and in 1937, sterilized brass tubes were used for taking the samples, the core of soil in each instance being placed in a sterilized glass jar. In the 1938 tests, sterilized aluminum spoons were used to obtain soil samples at the exact depth required. In order to make conditions as comparable as possible on both the mulched and the unmulched soil areas, all samples were taken at moisture level. This eliminated the inch of air dry soil commonly found on the surface of the unmulched soil area during the growing season, which from the standpoint of biological life, is generally considered to be relatively barren.

The glass jars used for holding the soil samples were provided with approximately 500 gms. of soil, sealed with screw tops and taken to the laboratory, where the contents of each jar was carefully emptied on to a sheet of sterilized paper, quickly mixed and again placed in the original container. From this jar samples of soil were taken for bacteriological counts and moisture tests. These determinations were made without undue delay after bringing the samples in from the field. The soils used for the available nutrient and hydrogen-ion determinations were immediately air-dried.

Bacteriological work was pursued at all times with persistent attention to all the details whereby contamination might be eliminated from the time of sampling to the pouring of the plates. Control plates were always poured to guard against contamination which might interfere with the final results. Dilutions for plate counts were made by employing the standard technique, beginning with 10 gms. of soil, shaking this for 15 minutes in 1000 ml. of sterilized tap water and diluting to the desired degree.

The dilutions used for plating varied as follows: Actinomyces and bacteria, 1:100 Thousand or 1:1 Million; and for fungi, dilutions varied from 1:10 Thousand to 1:100 Thousand, depending on seasonal variation.

The media used throughout was that as outlined by Fred and Waksman (8) and was as follows:

Actinomyces -- Sodium Asparaginate Glycerol Agar (M35)
Bacteria -- Sodium Caseinate or Nutrose Agar (M4)
Fungi -- Peptone-Glucose Acid Medium (M18)

In 1935 plate counts were made for radiobacter in the

Table 1. Total actinomyces, bacteria and fungi per gram of soil reported in thousands from mulched and unmulched soils in 1936 and 1937.

	1936 0-6 Inch Depth			1937 1 Inch Depth			1937 4 Inch Depth		
	Act.	Bact.	Fungi	Act.	Bact.	Fungi	Act.	Bact.	Fungi
May 20									
Mulched				3,000	5,800	60			
Unmulched				7,000	8,500	50			
June 3-4									
Mulched	12,000	15,700	1,800	5,200	6,800	90	4,000	9,600	130
Unmulched	5,100	9,000	2,300	2,200	4,000	80			
June 26									
Mulched	13,100	7,900	800						
Unmulched	16,100	9,100	900						
July 8-9									
Mulched	10,900	16,000	900	14,500	10,200	50	5,200	6,300	80
Unmulched	8,700	12,300	400	16,600	14,200	100	2,600	5,700	60
July 30									
Mulched				12,700	9,400	50	3,500	4,800	30
Unmulched				12,700	10,100	30	2,900	4,400	40

	1936			1937					
	0-6 Inch Depth			1 Inch Depth			4 Inch Depth		
	Act.	Bact.	Fungi	Act.	Bact.	Fungi	Act.	Bact.	Fungi
August 9-11									
Mulched	13,700	12,700	1,000	3,000	4,600	40	17,600	16,900	80
Unmulched	16,200	14,700	1,400	3,200	4,800	30	6,000	6,000	80
August 26									
Mulched	6,500	7,200	500						
Unmulched	4,100	6,200	400						
August 31									
Mulched				3,200	5,600	60	4,800	8,900	70
Unmulched				3,600	5,700	50	14,300	16,200	150
September 15									
Mulched				8,200	8,400	80	2,700	2,200	60
Unmulched				16,900	21,500	60	6,100	3,500	80

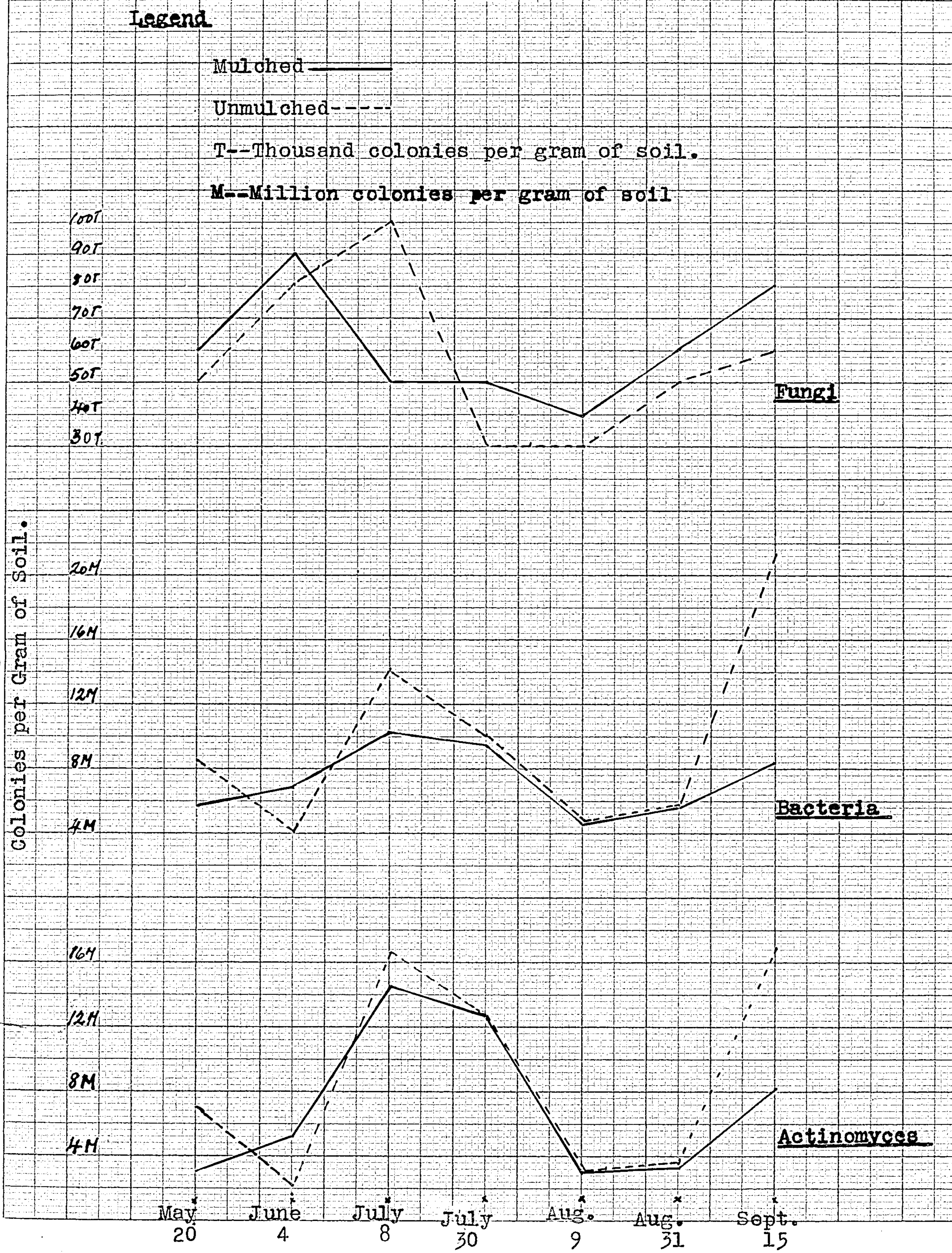

Figure 1. Showing the variation in total plate counts of actinomyces, bacteria and fungi on the mulched and the unmulched soil areas in 1937.

soil, the medium used in this instance being Glycerol-nitrate Agar (21). The two dilutions used were 1:100 Thousand and 1:1 Million.

In 1937 and in 1938 Azotobacter counts were made using the mannite agar medium as modified by Curie (3).

BIOLOGICAL STUDIES

Total Plate Counts.

Total numbers of actinomyces, bacteria, radiobacter and fungi were determined in mulched and unmulched soils at approximately two-week intervals throughout the summer months over a three-year period. Marked variation in plate counts, even greater than had been anticipated, was observed, hence even the six to twelve replications were not sufficient to smooth out the irregularities. In 1935 a slight increase in total numbers during June and July were apparent under the paper mulch, but these observations were not verified during the subsequent two years. Hence no significant differences between numbers of actinomyces, bacteria, radiobacter and fungi in mulched and unmulched soils were demonstrated.

Due to inconclusiveness of data only that for 1936 and 1937 is presented in table 1. Note irregularity in data.

Azotobacter Tests.

Azotobacter represent an important group of soil micro-organisms and their physiology is such that should there be a variation in numbers in mulched and unmulched soils, additional information as to the general conditions for growth would be forthcoming. Tests were therefore undertaken in 1937 to determine their numbers in the soil, with and without paper mulch. The procedure adopted was to sprinkle a 1-gram sample of soil on plates of Curie's mannite agar (3) and incubate at 28° C. After 4-7 days white gelatinous colonies (later turning yellow-brown) appeared around the soil particles and were identified as Azotobacter. The profusion of growth on the plates made accurate counting impossible, hence the soil inoculum was reduced from one gram to 0.5 gms. following the initial tests. These plates were prepared periodically throughout the summer of 1937 and an examination of the data reveals no significant differences in Azotobacter numbers under the paper mulch as compared with the unmulched soil.

Table. 2. Azotobacter counts (~~in thousands~~) per gram of dry soil 1938.

	Mulched Area		Unmulched Area	
	Cropped	Uncropped	Cropped	Uncropped
April 16 #	5		5	
May 23 #	38		44	
June 25	12	8	4	16
July 12	10	8	.2	9
August 5	2	2	2	5
August 15	10	3	.5	6
August 30	2	1	.20	9

: Composite samples taken from those areas later designated as mulched and unmulched.

A greater degree of success accompanied the isolation of Azotobacter in 1938, due possibly to the consistent use of only 0.5 gms. of soil sprinkled over the mannite medium. The colonies were sufficiently well differentiated to permit of closer observation and study.

The summary of all counts made from April to August (1938) is shown in Table 2 and reported in each instance as number of colonies per gram of dry soil, computed from a mean of 6 plates. Here again no significant difference in numbers of Azotobacter was apparent between the mulched and the unmulched soil areas. The highest mean Azotobacter count for the season was found on the unmulched, uncropped plots which were left uncultivated, except that given for weed control, with the mulched, cropped area being slightly higher than the unmulched, cropped plots.

Direct Influence of Mulch Paper on Bacterial Activity.

As coal tar products are sometimes used in the making of the building paper commonly used for mulching purposes, it was suggested that this paper might contain certain growth promoting substances. On giving consideration to the possibility of these being effective under field conditions,

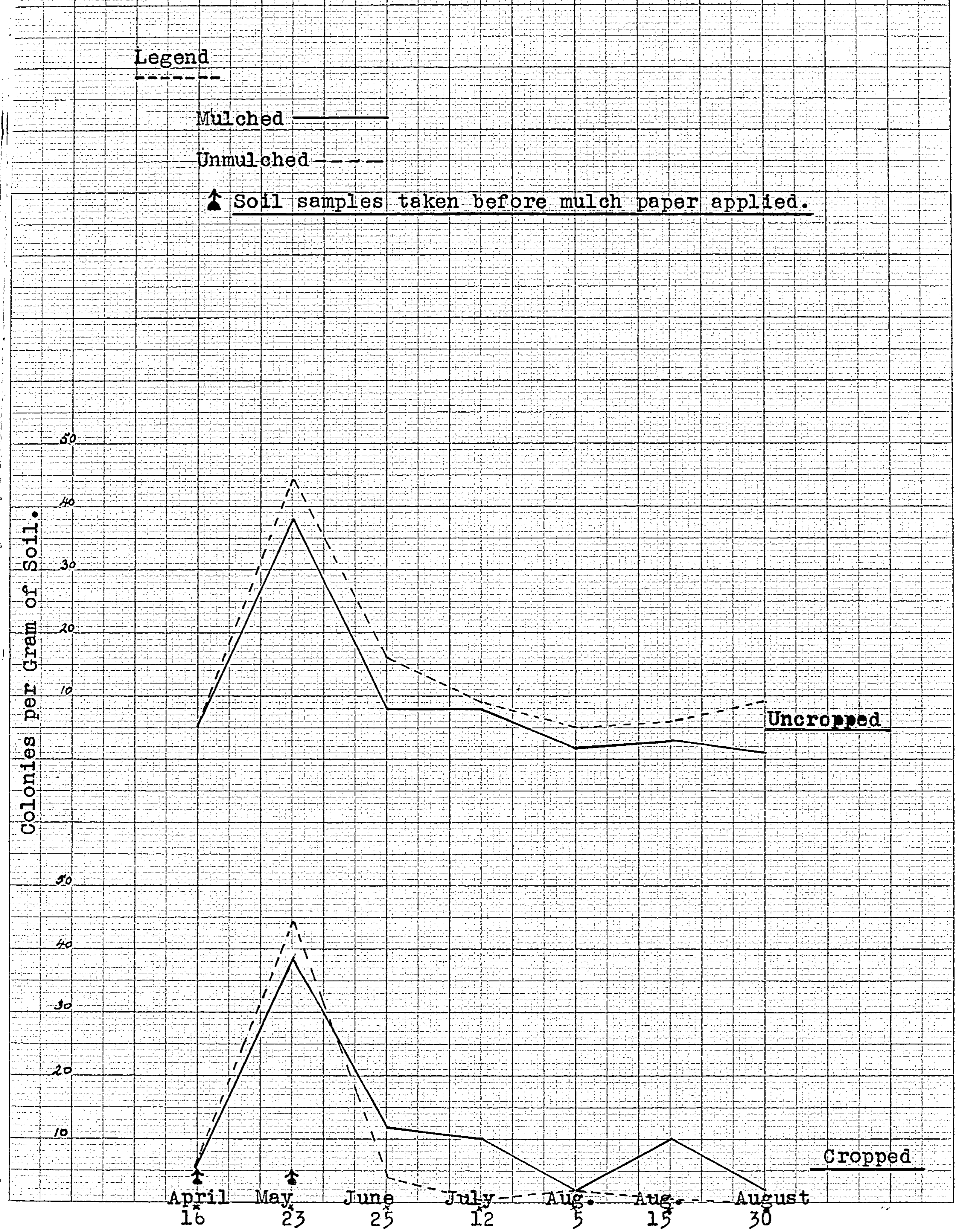

Figure 2. Showing the Azotobacter plate counts from the mulched and the unmulched soil areas in 1938.

it was assumed that they must be water soluble. Mulch paper was accordingly macerated with warm water and incorporated into sodium caseinate agar in varying concentrations. Plates prepared with this medium were seeded with giant colonies of two different protein splitting actinomyces. The influence of the paper mulch was determined by measuring the digested casein ring appearing as clear areas around each individual colony in the mulch paper plates as compared with controls. Measurements were made over a 6-day period at approximately the same time each morning.

Plates replicated 6 and 12 times for mulch paper and controls respectively were prepared and incubated at 28° C. The averages of these replications and results with the varying concentrations of paper used are presented in Table 3. A study of this table will indicate that the mulch paper, at the concentrations specified, had varying effects on the two organisms in question. In the case of the Ml-1 organism, concentration of 1.5 per cent slightly stimulated activity while beyond this point digestion of the casein decreased with increasing concentration. On the other hand, with Ul-C, stimulation is noted at all concentrations up to 6 per cent with the maximum occurring at 3 per cent. Slides were prepared from each of the mulch paper concentrations and from the checks. Microscopic examination did not indicate any variation in cell structure or staining properties from the various plates, in either the Ml-1 or Ul-C series.

The contact effect of mulch paper on soil organisms was also observed in the following manner: Washed sand was dried and sodium caseinate fluid medium added; eight-inch petri plates were then filled with this sand medium and sterilized in the autoclave. Each plate was then seeded with 30 cc of a water suspension of the 2 organisms, Ml-1 and Ul-C, which had been grown on sodium caseinate agar and brought to optimum moisture content through addition of water. Sterilized mulch paper discs, the same diameter as the plates, were then placed directly over the sand, covered with a petri plate and incubated at room temperature for 8 days. Unmulched sand plates were similarly made up and incubated.

At the end of the 8-day period, the unmulched plates showed a dense white growth, typical of the organisms concerned. On lifting up the mulch paper discs, a similar heavy growth was found to be growing directly on the paper, indicating the entire absence of toxic material in the paper, at least in respect to the two organisms studied.

Table 3. Direct influence of mulch paper on bacterial activity as measured by casein digestion.

Organisms Studied	Concentration of Medium	Days When Observations Made. Measurements in Millimeters. 1	2	3	4	5	6
Ml-1	check	8	10	13	15	20	24
"	.75 %	6	9	10	14	21	24
"	1.50 %	7	10	14	17	23	26
"	3 %	6	7	8	12	16	17
"	6 %	#	#	6	9	14	17
Ul-C	check	6	10	13	16	20	23
"	.75 %	7	16	18	21	22	23
"	1.50 %	6	10	12	15	18	24
"	3 %	6	22	26	29	32	33
"	6 %	7	13	17	21	24	26

: No indication of protein splitting evidenced; colony growth only.

Carbon Dioxide Production.

The evolution of carbon dioxide is often used as a measure of biological activity in a soil (20) and for comparative purposes at least, is generally considered to be of value.

For the purpose of measuring the production of carbon dioxide from mulched and unmulched soils, respiration chambers similar to those described by Smith, Brown and Millar (20), were made and set up. The chambers were made out of grain storage tins 6.5 inches high with an inside diameter of 4.5 inches. The inside was thoroughly lined with liquid paraffin, all joints being made air tight. Aeration was provided through a guard tube of soda lime. A metal rack, also covered with paraffin, served to suspend the beaker of earth inside the chamber.

The procedure adopted for the respiration chamber studies was as follows: 100 ml. portions of barium hydroxide were added to each chamber, 200 gms. of soil in a wide mouth beaker were placed on the metal rack and each chamber closed, sealed and left to incubate at room temperatures. Aliquots of barium hydroxide (.1N) were drawn off periodically by means of a stop cock placed in the bottom of the chamber and titrated with .1N hydrochloric acid. Duplicate chambers were used for comparing the production of carbon dioxide from the mulched and unmulched soils and controls. From the difference between the check and the soil titrations, the number of milligrams of carbon dioxide evolved per 200 gms. soil was accordingly calculated.

The soils used were obtained from the mulched and the unmulched soils at a depth of 1 inch and were incubated as soon as the moisture content was determined. When this had been done, sufficient sterile water was added to each sample to bring it up to an optimum of 25 per cent moisture. In selecting the 200-gram sample, due care was taken to eliminate any particles of living root tissue which might interfere with the readings. Soil samples were taken periodically throughout the summer of 1937 and determinations made but the data did not indicate any significant difference in bacterial activity between mulched and unmulched soils.

CHEMICAL STUDIES 1935-38

Mulched and unmulched soils were subjected periodically throughout the growing season to semi-quantitative tests for available nutrients (22). While it must be admitted that the procedure used lacks preciseness, it does, bearing in mind its limitations, permit of comparison between two soil

Table 4. Available nutrient tests and hydrogen-ion determinations. All nutrients reported in parts per million.

		Nitrate	P	K	Ca	Mg	pH
1935 0-6" Depth							
May 29	Mulched	25	.5	5	175	5	-
	Unmulched	25	.5	5	175	5	-
June 22	Mulched	25	.5	5	175	6	7.5
	Unmulched	8	.25	5	175	6	7.5
July 22	Mulched	25	.50	5	175	6	7.2
	Unmulched	25	.25	5	175	2	7.2
September 3	Mulched	25	.50	5	175	6	-
	Unmulched	5	.25	5	175	3	-
1937							
May 20	Mulched 1"	15	.50	8	125	-	7.2
	Unmulched 1"	15	.50	8	125	-	7.2
June 4	Mulched 1"	50	.50	8	150	-	7.1
	" 4"	25	.50	8	150	-	7.1
	Unmulched 1"	10	.50	8	150	-	7.0
July 8	Mulched 1"	25	.75	5	175	-	7.0
	" 4"	25	.75	5	175	-	7.4
	Unmulched 1"	5	.75	5	175	-	7.1
	" 4"	8	.75	5	175	-	7.2
July 30	Mulched 1"	25	.50	5	175	-	7.1
	" 4"	8	.50	5	175	-	7.2
	Unmulched 1"	8	.50	4	175	-	7.1
	" 4"	5	.25	4	175	-	7.1
August 9	Mulched 1"	25	.50	8	175	-	7.1
	" 4"	15	.50	8	175	-	7.1
	Unmulched 1"	20	.50	8	175	-	7.1
	" 4"	10	.75	8	175	-	7.1
August 31	Mulched 1"	40	.50	5	175	-	7.2
	" 4"	8	.50	5	175	-	6.8
	Unmulched 1"	5	.50	5	175	-	7.2
	" 4"	8	.50	5	175	-	6.8

		Nitrate	P	K	Ca	Mg	pH
September 15	Mulched 1"	50	.50	5	175	-	7.2
	" 4"	15	.50	5	175	-	7.1
	Unmulched 1"	10	.50	5	175	-	7.4
	" 4"	10	.50	5	175	-	7.4

1938

Mulched 2", Unmulched 3"

		Nitrate	P	K	Ca	Mg	pH
April 16	Mulched	2	.50	5	175	7	7.2
	Unmulched	2	.50	5	175	7	7.2
May 23	Mulched	5	.50	5	175	7	7.2
	Unmulched	2	.50	5	175	7	7.2
June 25	Mulched-cropped	25	.50	5	200	7	7.2
	" uncropped	25	.50	5	200	7	7.0
	Unmulched-cropped	20	.50	5	200	7	7.1
	" uncropped	20	.50	5	200	7	6.8
July 12	Mulched-cropped	25	.50	3	200	7	7.2
	" uncropped	25	.50	7	200	7	7.2
	Unmulched-cropped	25	.50	3	200	7	7.2
	" uncropped	25	.50	3	200	7	7.2
Aug. 5	Mulched-cropped	25	.50	5	200	7	7.2
	" uncropped	25	.50	5	200	7	7.2
	Unmulched-cropped	15	1.	7	200	7	7.2
	" uncropped	15	1.	7	200	7	7.1
Aug. 15	Mulched-cropped	35	.50	5	200	7	7.1
	" uncropped	50	.50	5	200	7	7.0
	Unmulched-cropped	50	1.	5	200	7	6.9
	" uncropped	50	1.	5	200	7	6.9
Aug. 30	Mulched-cropped	30	.50	5	200	7	7.0
	" uncropped	40	.50	5	200	7	6.9
	Unmulched-cropped	35	.50	5	200	7	6.9
	" uncropped	35	.50	5	200	7	7.0

conditions.

In all cases the soil used represented a composite sample. It was first air dried, then lightly pulverized in a mortar before measuring out the sample for analysis.

Nutrient tests over a 4-month period in 1935 indicated a slight increase in the concentration of available nitrates in the mulched soil. Tests on August 20 in 1936 on soil samples at depths of from 0 to 6 inches, indicated more nitrates at all depths, from the unmulched soil areas. In 1937 the nitrate content was definitely higher in the mulched soil, while in 1938 there was no appreciable difference between the two areas.

One possible explanation for this variation in nitrate content in the mulched and unmulched soils from year to year might be that the melon plants varied in their nitrate requirements according to the season. That of 1936, for instance, was not particularly favourable for melons on Vancouver Island. Comparatively cold, wet weather in the critical month of June particularly delayed growth in the unmulched plots, which did not have the benefit of the extra heat units supplied by the paper as did those on the mulched plots. Consequently, the melon plants on the unmulched plot made poor growth, utilizing little of the soil nitrates and hence the comparatively high nitrate test as compared with the mulched soil. Conversely, the season of 1937 was a better melon year, the plants on the unmulched plots were able to make good growth, thereby utilizing more of the soil nitrates.

Due to the better heat conditions afforded by the paper, it is also assumed that a more favourable environment is set up for the nitrifying bacteria, thus ultimately giving a higher nitrate content to the mulched soil.

As a study of Table 4 will show, there was little variation in the available nutrients, other than nitrates, in the mulched and the unmulched soils either from month to month or from year to year. The concentration of phosphorus and potassium both remained relatively constant, with the amounts of calcium being slightly lower in the early spring, as were also the nitrates. Under Saanichton conditions at least, the available nitrates were leached away by the winter rains, and generally it is not until the advent of higher temperatures in May and June, that more are elaborated by biological activity in the soil.

Hydrogen-ion determinations were determined by the colorimetric method. The accuracy of this procedure was

Available nutrient tests on mulched and unmulched melon plant tissues - 1937.

	Nitrates	Phosphorus	Potassium
August 3			
Mulched	High	High	High
Unmulched	Very high	Deficient to medium	Medium to high
August 13			
Mulched	High	High	Low
Unmulched	High	Low	High
September 4			
Mulched	Medium to high	Very high	Very high
Unmulched	Very high	High	Very high
September 20			
Mulched	Low	Very high	Very high
Unmulched	Very high	High	Very high

checked against a standard potentiometer apparatus and found to be satisfactory. Barium sulphate (10) was found very useful in clearing the soil solution and tests indicated that its use did not materially effect the accuracy of the readings. As Table 4 will indicate, no significant difference was noted in the pH values between the mulched and the unmulched soils, both fluctuating slightly from month to month.

Available nutrient tests were run on mulched and unmulched plant tissues in 1937, employing the Thornton procedure (25). Terminable growth material was used for this purpose, as it was considered to be the most suitable. The outstanding finding in these tests was the extra supply of nitrates in the unmulched plants and the higher phosphorus content in the case of mulched melon plants.

PHYSICAL STUDIES.

Soil Temperature.

Soil temperatures were recorded throughout the growing season of 1937 and 1938. Readings were taken three times daily on both mulched and unmulched soils. During 1937 these readings were taken at 1" and 4" depths, while at only a 2" depth in 1938.

Air temperatures at 9 inches above ground level were also taken at the same times as were the soil temperatures. All readings were taken from duplicate thermometers, the mean of the two readings being reported in each instance. In order to facilitate comparisons between the mulched and the unmulched conditions, the daily readings for 7-day periods were averaged.

The soil thermometers used were of the hot-bed type, while those used for recording the air temperatures were wall thermometers mounted on a stout stake. All instruments, before being set in position, were carefully checked against a thermometer of known accuracy.

An examination of the data as presented in Tables 5 and 6 reveals no significant difference in soil temperatures between the mulched and the unmulched soil areas either in 1937 or in 1938. The data does suggest, however, that slightly higher temperatures do prevail under the paper during the early part of the season, with a tendency toward lower temperatures during the latter part of the season. Mulched soil shows a narrower temperature range throughout the season than the unmulched. Consistently higher air temperatures were recorded over the mulch paper both in 1937

Table 5. Summary of thermometer readings on mulched and unmulched soil areas at Saanichton in 1937.

	Time	Mulched Area 1"	4"	Air	Unmulched Area 1"	4"	Air
May 17-23	8 A.M.	57.7		56.3	56.		56.4
	1 P.M.	68.1		65.4	68.1		65.
	5 P.M.	69.4		63.4	69.6		61.4
May 24-31	8 A.M.	60.4		61.	60		60.3
	1 P.M.	71.1		67.6	71.3		66.4
	5 P.M.	74.6		68.1	74.1		67.
June 1-10	8 A.M.	66.4		66.5	67.4		65.7
	1 P.M.	81.1		74.9	79.1		73.2
	5 P.M.	82.8		75.7	81.3		74.5
June 14-21	8 A.M.	62.6	62.4	57.4	62.	61.6	57.
	1 P.M.	68.	66.1	62.7	68.4	66.9	61.3
	5 P.M.	68.6	67.7	59.6	68.	68.3	58.8
June 22-30	8 A.M.	65.5	63.5	64.9	64.7	63.	63.4
	1 P.M.	77.5	72.2	71.7	78.1	74.6	70.6
	5 P.M.	77.5	74.4	71.7	77.2	76.1	70.6
July 2-9	8 A.M.	69.6	68.	66.6	68.1	67.7	65.
	1 P.M.	83.9	77.9	75.4	85.9	80.6	74.1
	5 P.M.	85.8	82.2	75.0	87.	85.2	75.7
July 10-17	8 A.M.	71.4	70.4	71.3	74.	71.4	70.3
	1 P.M.	84.	79.4	76.6	87.7	82.7	75.6
	5 P.M.	85.7	82.	77.2	86.8	85.2	77.2
July 19-24	8 A.M.	69.7	69.2	69.5	72.5	70.7	68.
	1 P.M.	82.8	80.3	79.7	90.2	84.8	78.8
	5 P.M.	85.	84.6	82.	87.8	88.2	80.6
July 26-31	8 A.M.	68.7	69.	66.8	71.5	70.8	65.
	1 P.M.	79.6	77.6	73.	85.0	82.0	72.
	5 P.M.	80.6	79.	73.8	83.4	82.6	72.
Aug. 2-9	8 A.M.	66.7	66.	66.7	68.4	68.2	63.1
	1 P.M.	78.	76.4	75.	82.1	80.	73.3
	5 P.M.	77.6	78.	75.6	81.3	82.3	73.4
Aug. 10-17	8 A.M.	64.2	63.4	64.3	65.8	66.	61.3
	1 P.M.	74.2	72.	72.8	78.7	77.7	70.7
	5 P.M.	74.	74.	73.2	78.	78.7	71.2

	Time	Mulched Area 1"	4"	Air	Unmulched Area 1"	4"	Air
Aug. 18-24	8 A.M.	64.	64.5	65.8	66.2	65.8	62.
	1 P.M.	73.	70.2	71.8	75.7	75.3	68.5
	5 P.M.	71.7	71.8	71.2	75.2	76.	68.8
Aug. 25-31	8 A.M.	60.3	61.	59.2	60.8	60.8	56.3
	1 P.M.	68.3	67.	68.2	71.3	70.5	65.8
	5 P.M.	68.3	69.5	67.	71.7	72.3	64.
Sept. 1-8	8 A.M.	61.2	62.	62.7	62.	62.	59.3
	1 P.M.	72.2	70.2	74.5	75.2	75.7	72.
	5 P.M.	71.	72.7	71.7	74.7	75.7	69.7
Sept.10-25	8 A.M.	63.	63.4	64.6	63.6	63.6	62.
	1 P.M.	73.2	71.8	78.	77.8	77.6	75.
	5 P.M.	72.6	74.8	76.4	78.4	79.2	74.

Table 6. Summary of thermometer readings on mulched and unmulched cropped areas at Saanichton in 1938.

	Time	Mulched Area Soil 2"	Air	Unmulched Area Soil 2"	Air
May 28 - June 3	7.30 A.M.	65.4	59.	64.	58.7
	1 P.M.	81.6	69.6	81.3	69.5
	5 P.M.	82.6	69.7	82.5	69.1
June 4 - 13	7.30 A.M.	69.1	63.1	67.1	62.1
	1 P.M.	84.	70.3	81.5	70.3
	5 P.M.	84.3	70.	82.5	70.4
June 14 - 20	7.30 A.M.	67.1	59,7	66.4	59.
	1 P.M.	78.3	68.4	78.4	68.
	5 P.M.	79.4	69.	79.5	67.7
June 21 - 27	7.30 A.M.	70.7	65	70.9	64
	1 P.M.	85.8	73.7	86.9	72.7
	5 P.M.	88.1	75.6	89.3	75.2
June 28 - July 4	7.30 A.M.	67.7	59.3	67.4	58.1
	1 P.M.	80.1	67.4	81.	66.
	5 P.M.	80.7	67.4	81.4	67.3
July 5 - 12	7.30 A.M.	66.3	63.3	67.	61.4
	1 P.M.	82.	70.5	84.3	70.
	5 P.M.	84.	70.1	84.1	69.3

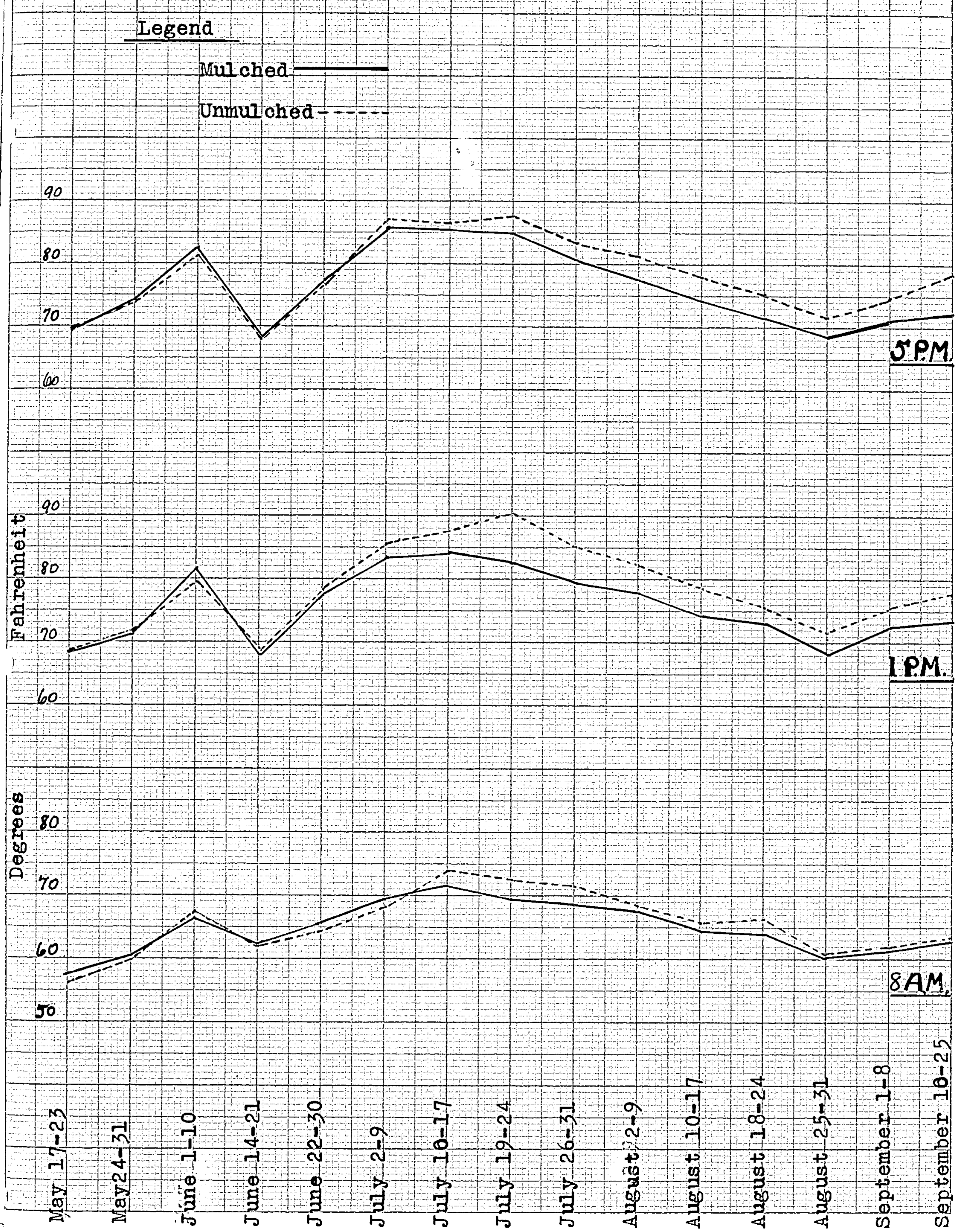

Figure 3. Showing the soil temperature changes on the mulched and the unmulched soil areas in 1937.

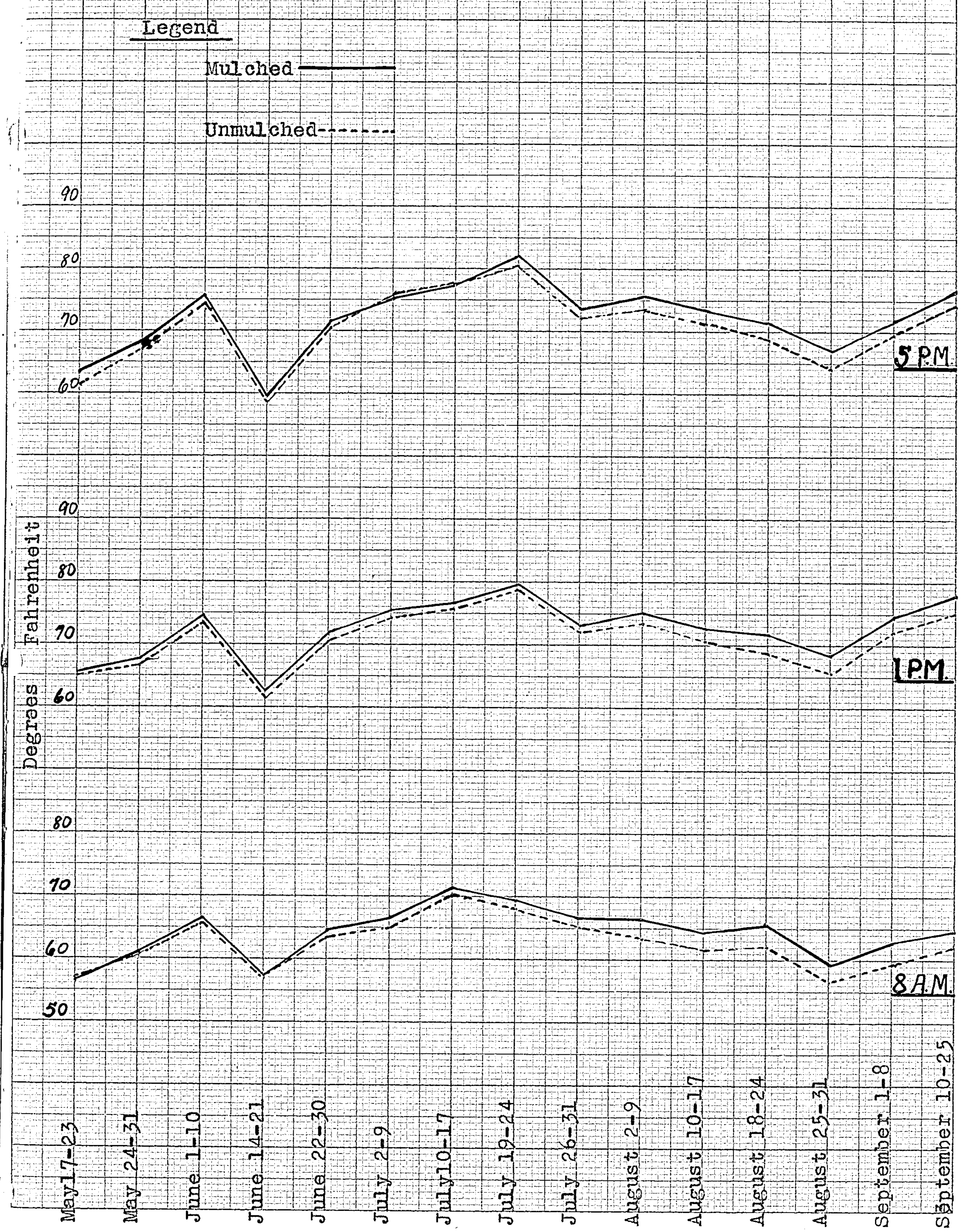

Figure 4. Showing the air temperature changes on the mulched and the unmulched areas in 1937.

	Time		Mulched Area Soil 2"	Air	Unmulched Area Soil 2"	Air
July 13 - 19	7.30	A.M.	71.	68.1	72.7	68.1
	1	P.M.	88.8	79.	89.6	78.3
	5	P.M.	91.1	82.7	91.9	79.1
July 20 - 27	7.30	A.M.	70.6	65.1	71.7	62.7
	1	P.M.	84.1	76.9	84.1	74.4
	5	P.M.	86.6	76.6	84.1	75.6
July 28 - August 4	7.30	A.M.	66.3	61.1	67.7	58.4
	1	P.M.	80.4	68.3	80.1	66.5
	5	P.M.	83.5	71.3	81.5	69.3
August 5 - 12	7.30	A.M.	65.1	58.9	65.6	56.4
	1	P.M.	77.1	66.4	77.3	64.9
	5	P.M.	77.5	68.5	76.8	65.8
August 13 - 20	7.30	A.M.	64.3	57.4	62.8	55.3
	1	P.M.	74.1	67.1	73.8	63.5
	5	P.M.	76.6	67.	73.8	64.4
August 22 - 29	7.30	A.M.	63.	56.9	62.4	56.4
	1	P.M.	74.4	68.1	74.3	67.7
	5	P.M.	76.9	69.5	75.3	67.9
Aug. 30 - Sept. 7	7.30	A.M.	61.3	53.9	61.3	51.3
	1	P.M.	68.9	64.	69.4	61.9
	5	P.M.	70.5	63.6	70.5	60.6
September 8 - 15	7.30	A.M.	60.7	55.4	60.1	54.3
	1	P.M.	71.1	67.3	71.5	65.5
	5	P.M.	72.3	66.5	71.3	64.6

Table 7. Summary of thermometer readings on mulched and unmulched, uncropped areas at Saanichton in 1938.

	Time	Mulched		Unmulched	
		Soil 2"	Air	Soil 2"	Air
May 28 - June 3	7.30 A.M.	65.	59.	64.9	58.
	1 P.M.	79.1	70.7	80.6	69.1
	5 P.M.	81.	70.7	81.	69.
June 4 - 13	7.30 A.M.	68.7	63.5	67.7	61.9
	1 P.M.	82.4	72.3	81.7	69.4
	5 P.M.	82.5	71.1	82.3	69.1
June 14 - 20	7.30 A.M.	66.9	60.4	67.4	59.4
	1 P.M.	77.9	69.3	78.3	68.
	5 P.M.	78.3	69.3	79.9	68.1
June 21 - 27	7.30 A.M.	71.1	65.6	71.7	65.1
	1 P.M.	85.	75.4	87.5	74.1
	5 P.M.	86.	77.3	89.6	76.3
June 28 - July 4	7.30 A.M.	68.3	60.7	68.5	58.9
	1 P.M.	79.4	68.9	81.4	67.7
	5 P.M.	78.9	68.9	81.9	68.3
July 5 - 12	7.30 A.M.	66.7	65.5	68.1	63.5
	1 P.M.	81.7	73.	85.7	72.
	5 P.M.	81.4	72.5	86.3	71.4
July 13 - 19	7.30 A.M.	72.1	71.	73.3	68.3
	1 P.M.	87.4	82.1	90.2	82.5
	5 P.M.	87.1	84.	93.1	84.3
July 20 - 27	7.30 A.M.	70.9	67.	73.	64.7
	1 P.M.	82.9	79.7	76.1	78.9
	5 P.M.	83.9	79.8	88.4	79.7
July 28 - August 4	7.30 A.M.	67.7	63.9	69.1	60.9
	1 P.M.	80.1	71.9	82.4	72.7
	5 P.M.	81.5	74.3	85.2	74.3
August 5 - 12	7.30 A.M.	66.	62.	67.7	58.7
	1 P.M.	77.3	68.7	80.3	68.6
	5 P.M.	78.	69.8	81.	69.5
August 13 - 20	7.30 A.M.	64.4	60.	64.4	57.
	1 P.M.	76.4	70.3	79.3	68.7
	5 P.M.	77.8	70.	81.	69.2
August 22 - 29	7.30 A.M.	62.9	60.1	64.1	57.6
	1 P.M.	76.4	67.9	80.3	70.7
	5 P.M.	77.4	72.4	83.9	72.9

	Time	Mulched Soil 2"	Mulched Air	Unmulched Soil 2"	Unmulched Air
Aug. 30 - Sept. 7	7.30 A.M.	61.1	57.9	62.3	53.6
	1 P.M.	71.1	68.5	72.9	66.
	5 P.M.	71.8	68.5	74.5	65.6
September 8 - 15	7.30 A.M.	61.4	61.8	62.	56.4
	1 P.M.	74.1	72.7	77.	70.7
	5 P.M.	72.1	69.8	78.1	68.1

Table 8. Summary of thermometer readings on blackened untreated, mulched and unmulched areas.

		Mulched Areas Blackened	Mulched Areas Normal	Unmulched Area
June 20 - 28	7.30 A.M.	66.2	64.6	62.6
	1 P.M.	80.	76.7	73.7
	5 P.M.	83.3	78.5	76.7
June 29 - July 7	7.30 A.M.	66.5	64.1	63.1
	1 P.M.	76.9	72.6	72.2
	5 P.M.	81.0	75.3	75.
July 11 - 19	7.30 A.M.	67.8	65.	64.
	1 P.M.	82.1	76.5	76.8
	5 P.M.	82.6	75.9	77.1
July 20 - 28	7.30 A.M.	72.3	69.5	69.3
	1 P.M.	91.1	84.1	84.2
	5 P.M.	95.2	86.2	88.4
July 31 - August 8	7.30 A.M.	70.7	68.5	70.2
	1 P.M.	84.5	83.	84.
	5 P.M.	87.7	85.2	87.3
Daily Mean: June 20 - August 8		79.2	75.	74.97

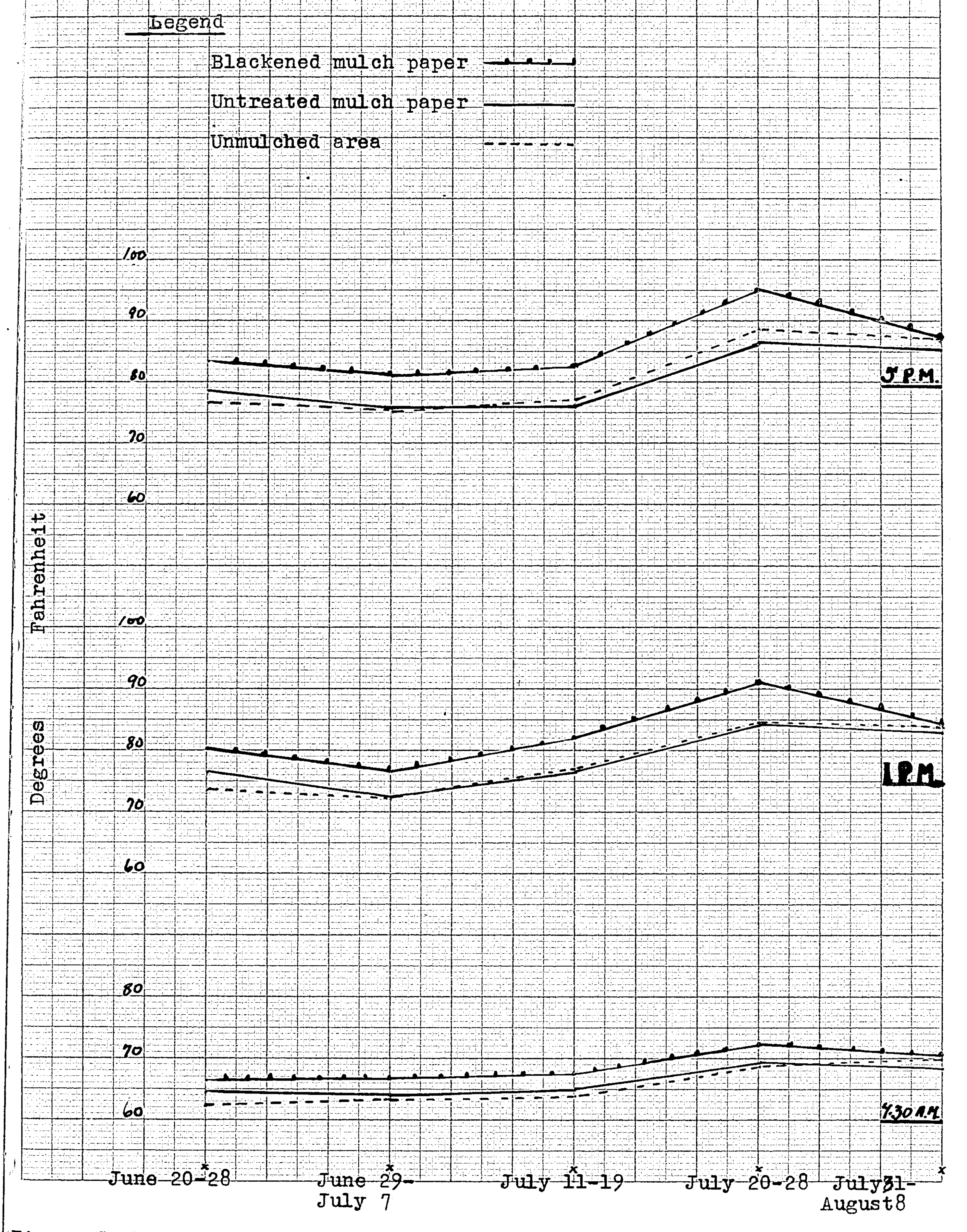

Figure 5. Showing the effect on soil temperatures of artificially blackening the mulch paper in 1939.

and in 1938.

In comparing the temperature readings on the mulched and the unmulched, uncropped areas shown for 1938 in Table 7, it is to be noted that the range of air temperatures in the uncropped areas are higher than on the corresponding cropped areas. This also holds to a more limited degree with the soil temperatures.

Temperature as Influenced by Colour of Mulch Paper.

Tables 5 and 6 indicate a slight increase in soil temperatures in early season due to the useof mulch paper, but this advantage is only noticeable for a relatively short time, the unmulched soil temperatures being higher than the mulched from mid-season on. The explanation of this was not clearly understood until 1939, when 2 areas 15 by 30 feet were blackened with lamp black and linseed oil and temperature readings taken, these being compared with the unpainted paper and with the unmulched areas. Readings were not taken until June 20, when the untreated paper had been bleached by exposure to the sun during May and June. It will be apparent from Table 8 that there is an appreciable increase in soil temperatures due to the blackening of the mulch paper. The difference in 1939 apparently was proportional to the temperature; the maximum difference occurring in July 27 at 5 P.M. when the normal mulch registered 89 degrees Fahrenheit and the blackened 99.5 degrees. The unmulched reading at the same time was 92.5 degrees Fahrenheit.

In the light of this data it is now possible to explain the lower soil temperatures recorded on the mulched areas after the latter part of June, as indicated in Tables 5 and 6. As the mulch paper bleaches, the heat is reflected rather than absorbed, with a consequent loss of heat units retained by the soil under the mulch paper.

Soil Moisture.

Prior to 1937, moisture determinations on the mulched and the unmulched soil areas were made only on those occasions when bacteriological tests were conducted and were made for total moisture only. This was done by drying a 10-gram sample of soil in an electric oven maintained at 105 degrees centigrade, until a constant weight was reached.

In 1937 and in 1938, periodic moisture tests were made from May to September for capillary moisture; in 1937 these tests included determinations at depths of 1 and 4 inches from the cropped areas only and in 1938 samples were taken at a 2-inch depth, from both cropped and uncropped areas as indicated in Table 10.

Clean cultivation was maintained throughout the season on the unmulched areas with no attempt being made to maintain a dust mulch.

Determinations at all times were made in duplicate and as far as possible were conducted the same day as the samples were taken, the soil being stored in air-tight glass jars from time of sampling until the determinations were made.

Capillary moisture was determined by air drying 10 gms. of soil at room temperatures in standard aluminum drying pans, these being placed in a glass covered cage to prevent dust contamination. The cage measured 2 by 2 by 1 feet, this being deemed large enough to provide uniform conditions of humidity; it was kept at all times in a shaded portion of the laboratory, away from any direct sunlight. The soil samples were kept under these conditions until a constant weight was attained.

An examination of the data, relative to the uncropped plots, as presented in Table 9 shows clearly the influence of paper mulch on the conservation of moisture. Here it is to be observed that the average moisture level under the mulch was 3.2% higher than in the unmulched soil. This difference is not observed in the soils of the cropped plots for the same year, in fact the unmulched cropped plots show an average of 0.5% higher moisture content. This is undoubtedly due to the higher moisture requirements of the larger plants and higher yield occurring under mulched conditions.

A study of the data on the cropped areas for 1937 reveals no difference in moisture content in soils of the mulched and unmulched plots for the reasons given above. Upon referring to the rainfall data in Table 10 one finds an explanation for the higher moisture content in the unmulched soil as observed in the data for August 30.

One is safe in concluding from the foregoing data that paper mulch does conserve appreciable amounts of moisture.

Table 9. Capillary moisture on mulched and unmulched areas expressed in per cent.

Time	Cropped						Uncropped	
	1937				1938		1938	
	Mulched 1"	Mulched 4"	Unmulched 1"	Unmulched 4"	Mulched 2"	Unmulched 2"	Mulched 2"	Unmulched 2"
June 4	9.99	-	7.55	-	-	-	-	-
" 25	-	-	-	-	5.50	7.07	8.91	4.42
July 10	9.63	11.97	8.84	10.31	8.67	7.65	9.09	7.44
" 30	5.26	7.17	5.41	4.30	-	-	-	-
Aug. 9	6.43	6.96	5.79	7.51	5.64	5.22	9.76	5.48
" 15	-	-	-	-	6.19	7.64	8.40	7.37
" 30	10.86	11.96	13.03	12.62	4.65	5.73	9.50	4.97
Sept. 15	3.70	5.49	5.35	6.65	-	-	-	-
Average:	7.64	8.71	7.66	8.28	6.13	6.66	9.13	5.93

Table 10. Rainfall data relative to moisture determinations for 1937-38 period.

		1937	1938
May	27	.02 inches	
	28	.04	
June	9	.41	
	13	.02	
	14	.06	
	15	.02	.02 inches
	16	.91	.01
	17	.28	
	18	.07	
	19	.45	
	20	.45	
	22	.05	
	23	.14	
	29	.01	
Total for June		2.87	.03
July	2		.17
	3	Trace	
	7		.05
	10		.10
	13	Trace	
	18	Trace	
Aug.	5	.34	
	9	.01	
	10	.04	
	11		.45
	12		.01
	13		.03
	16		.59
	17		.02
	21	.39	
	22	.04	
	24	.01	
	25	.02	
	29	.78	
	30	.33	
Total for August		1.96	1.10
Sept.	4	.02	
	15	.02	

INFLUENCE OF PAPER MULCH ON PLANT GROWTH

Every year with the advent of warm weather, one observes the almost phenomenal growth of the melon plants on the mulched paper plots. With the soil temperature holding above 70° F., the melon plants on the mulch paper spring to life as though the mulched soil contains a stimulant which is lacking in the unmulched. Not only do the mulched plants establish themselves more readily, but their extra vigour throughout the season is readily apparent to the most casual observer.

In 1937 preliminary observations were recorded concerning the effect of mulch paper on the root development of melon plants. Representative plants from the mulched and the unmulched areas, which in the green condition weighed 1360.8 and 283.5 gms. respectively, were selected for study. The roots were exposed by digging a trench 2 feet deep at a radius of 18 inches from each plant. Then by means of a small, slow stream of water, the roots were laid bare, gently separated from the soil and weighed, the mulched being 42 gms. and the unmulched 26.5 gms. Under the conditions prevailing at Saanichton in 1937 (and in other years when observations were made), the main feeding roots of the mulched plant were found to be within 1 inch of the surface of the soil, while those of the unmulched were 2 inches from the surface. Apart from position and size little difference in the character of the respective root systems was noted.

In order to determine the approximate growth rate of the melons on the mulched and the unmulched areas, 5 typical plants were selected in each area in 1937 and the laterals measured at definite periods. The mean daily growth rate, as determined over the 12-day period from July 12 to July 24, was 1.82 inches for the mulched plants, compared with .97 inches in the case of the melon plants on the unmulched area.

When the melon plants had attained their maximum growth which in 1937 was on September 3, representative leaves were taken from 5 typical plants on each area, weighed and measured. The mean weight of each leaf from the plants on the mulched area was 5.57 gms. compared with 4.08 gms. on the unmulched. The mean lengths of mid-rib per leaf for the mulched and the unmulched plants were 4.05 and 3.15 inches respectively, while the maximum diameters at right angles to the mid-rib were 5.32 and 4.30 inches.

In 1939 yields were taken from those melon plants growing on the mulched and the unmulched areas and from areas where the paper had been artificially blackened. These results are presented in table 11 and indicate that the blackened mulch gave an increase of approximately 33 per cent in total number and also in total weight of fruits over the untreated paper, with 259 per cent increase in number and 300 per cent increase in weight over the unmulched. In respect of green weight of tops, the blackened mulch gave an increase of 61 per cent over the untreated paper and a 400 per cent increase over the plants on the unmulched soil area.

Table 11. Summary of yields on mulched and unmulched areas, 1939.

	Mulched Area		Unmulched
	Blackened	Normal	
Number of Plants on Test	Yield Per Plant	Yield Per Plant	Yield Per Plant
	39	70	29
Marketable Fruits			
Number per plant	5.5	3.8	1.6
Weight (lbs.) average	8.1	5.6	2.0
Unmarketable Fruits			
Number per plant	4.2	3.5	1.1
Weight (lbs.) average	3.5	3.1	.8
Total			
Number per plant	9.7	7.3	2.7
Weight (lbs.) average	11.6	8.7	2.8
Green Weight of Tops (lbs.)	2.9	1.8	.58

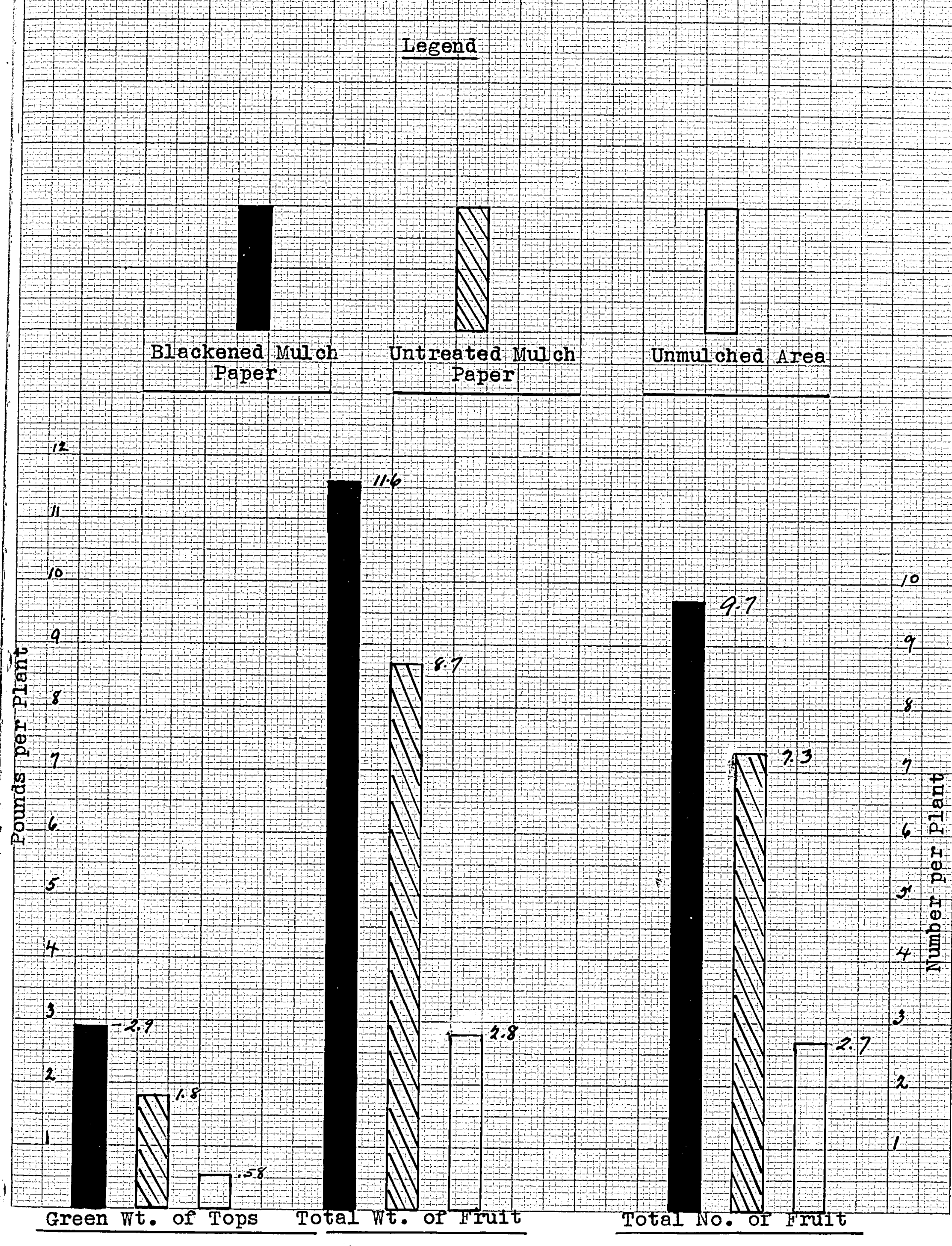

Figure 6. Showing the effect of artificially blackening the mulch paper on the green weight of tops and the number of cantaloupe fruits per plant.

DISCUSSION

After a 5-year study of mulch paper on a clay loam at Saanichton, results indicate that the paper does definitely stimulate growth, but the various factors contributing to this increased growth have not been specifically determined. The findings to date would indicate that temperature and moisture may be the major factors.

With respect to bacteriological studies it was felt that total counts would possibly give a more comprehensive picture relative to the activities of the soil organisms in the breaking down and the elaboration of plant food in the soil, than might be attained by the detailed study of the functions of any specific group. Total counts were therefore made for actinomyces, bacteria and fungi from mulched and unmulched soils, but no consistent differences were recorded throughout the 5-year period of study. Ferretti (5), one of the few workers who have attempted a quantitative study of the micro-organisms under mulch paper, reported an increase in bacteriological numbers due to paper. Unfortunately, however, his observations were based on only one month's findings and consequently do not show any seasonal trends. While plate counts are generally considered to present only a part of the biological picture existing in any soil at a given time, yet as pointed out by Thornton (26,27) they have some value in indicating bacterial activity.

Taking the evolution of carbon dioxide as an index of biological activity, respiration chambers studies were conducted in 1937, but here again no significant difference in activity was observed under laboratory conditions between the mulched and the unmulched soils.

Tests for Azotobacter, the aerobic nitrogen fixing organism, were conducted on mulched and unmulched soils in 1937 and 1938, using Curie's mannite agar (3) but significant differences were not observed. Physiological and microscopic examinations indicated that <u>Azotobacter chroococcum</u> was active under both soil conditions. Considering the increase in available nitrates found generally in mulch paper soils and the consistently more vigorous, verdant growth of the plants, it was rather to be expected that the nitrogen-fixing Azotobacter might be present in greater quantities under the paper, but actual colony counts failed to substantiate this theory.

To determine further the influence of mulch paper on bacterial activity, mulch paper was incorporated into sodium caseinate agar in varying concentrations and then seeded with two actinomyces cultures. The effect of the paper on the metabolism of the soil organisms was measured by their ability to break down the casein in the media. Measurements over a 6-day period indicated that the paper had little significant effect on the activity of the two organisms in question.

The suggestion having been made that the paper might contain certain growth promoting substances, barley seedlings in culture solutions were used to test the influence of a mulch paper extract on plant growth. Measurements of tops and roots were made, which indicated that the mulch paper extract had no significant effect on plant growth.

Periodic semi-quantitative determinations for available plant nutrients (22) were made over a four-year period. In 1935 and again in 1937 the tests indicated a definite increase in nitrates in the mulched soils. In 1936, however, the tests indicated more nitrates under the unmulched conditions, and in 1938 there was no marked difference between the mulched and unmulched soils. This variation in nitrate content from year to year is not quite clear, but may be due to the varying nitrate requirements of the melon plants and their ability to utilize the supply in the soil. The melon plants on the mulched plots made consistently good growth under Saanichton conditions, while the unmulched plants varied with season, and usually, the poorer the growth, the more nitrates were found in the soil. Possibly, as Magruder (15) found under Ohio conditions, the differences in plant growth were due to other factors than those of nitrates.

Equipment did not permit of more exacting quantitative tests being made on the nitrate content of mulched and unmulched soils. It is realized that these tests gave only approximate values, serving, in the writer's opinion, their greatest usefulness in demonstrating the presence of available nutrients at their extreme concentrations. From this standpoint they are considered to be of some value for comparing two soils with the same physical characteristics, as they existed under the conditions outlined for this experiment.

No significant differences were observed in the relative amounts of phosphorus, potassium and calcium under mulched and unmulched conditions.

Available nutrient tests were run on plant tissues (25), care being taken to secure comparable portions of the melon plants from both the mulched and the unmulched areas. The unmulched plants gave a higher available nitrate test than did the plants from the mulched area, where the soil had been found to contain more nitrates. The mulched plants definitely contained more phosphorus than did the unmulched, which fact might explain the earlier maturity that is found generally with the mulched plants from year to year.

Colorimetric determinations for hydrogen-ion concentrations were made periodically on mulched and unmulched soils, with little difference being noted from year to year on these two areas. Both soils held consistently around neutrality, ranging from 6.8 to 7.4, with a mean pH reading of approximately 7.1. The accuracy of these determinations, as well as the method employed for clearing cloudy soil solutions by the addition of barium sulphate (10), was assured by periodic checking with proven electrometric hydrogen-ion equipment.

Soil temperature studies at a 2-inch depth would indicate little significant difference between the mulched and the unmulched soils, except in May and June, at 8 A.M., 1 P.M. and 5 P.M., when the paper has been left untreated and consequently subject to bleaching. When the paper, however, was treated to preserve the black colour, preliminary tests indicated that the mulch paper soil temperatures were approximately 2, 4 and 6° F. higher than the unmulched soil throughout the day.

Air temperatures over the mulched paper (untreated) were consistently higher than over the unmulched, both in 1937 and in 1938. Readings were taken 9 inches above ground level and showed an increase of approximately 2°F. This obviously was due to the use of mulch paper.

Temperature and growth relations are difficult to separate from other factors, hence the heat requirement is difficult to evaluate (16). One method of evaluating the temperature factor is to establish a plant zero base (4), or that temperature below which development is comparatively quiescent. Effective temperatures are computed from this plant zero up, the assumption being that the effectiveness of temperature in promoting growth in plants, is directly proportional to the number of degrees of effective heat units above this plant zero base. Erwin, Shepherd and Morgan in Iowa (4) set the zero for muskmelons at 55° F. and used the summation method for evaluating the total effective temperatures, with due consideration being given to the sunshine factor. They found that the crops were matured under effective temperatures ranging approximately between 2100 and 2400° F. Their findings indicated that the temperatures in June had the greatest effect on time of maturity of any single month and that temperatures in July had the least. The temperature records at Saanichton do not cover a 24-hour period, hence the total effective temperatures for the mulched and the unmulched areas cannot be compared with conditions holding in Iowa. It is suggested at this time, however, that herein may lie one of the secrets of mulch paper stimulation.

In addition to its ability to absorb more heat on the mulched area (when the paper is black), the mulch paper also acts as a reservoir for heat units over a 24-hour period, thus tending to create more optimum growth conditions for the plant throughout the season. Particularly would this be effective in the critical month of June, when every degree of heat is needed to give the newly set plant an early stimulus. Preliminary tests at Saanichton would indicate that the colour of the paper plays an important part in the heat units absorbed by the paper. Further work now in progress may indicate that certain coloured papers may materially effect the amount of heat absorbed by the soil under the paper (17).

Moisture determinations at Saanichton would indicate that there is a significant difference in moisture content between the mulched and the unmulched soils. Moisture tests from cropped and uncropped soils showed that the paper did serve to conserve more moisture than did the uncovered soil. This surplus apparently was utilized by the greater plant growth commonly found under the mulched conditions which sometimes gave a lower percentage than did the unmulched.

It is suggested that mulch paper may have some effect on the soil moisture index, since Linford (12) has shown that more moisture is absorbed by a soil stored under darkened conditions than one kept in the light. Kalinovsky and Ivanova (11) found that if peat, manure or straw were used for mulching purposes, a change was brought about in the "climate" of the atmospheric layers adjacent to the soil, causing water to condense. At Saanichton, water of condensation collected on the under side of the blackened paper, with a lesser amount on the untreated paper.

Preliminary root measurements of mulched and unmulched melon plants indicated little difference in the respective root systems. Leaf measurements indicated that the mean diameter of the leaves from the mulched plants was 1.02 inches greater than from the unmulched. Fisher (6) working with apple trees, found that the size of the fruit was increased by a larger leaf area and found a positive correlation between size of fruit and leaf extent. This correlation has still to be proved for melons, but results at Saanichton would point in this direction, as the fruits from the mulched plants are invariably larger than those from the unmulched.

Measurements were made at the height of the growing season, when the mean daily growth rate for the mulched plants was found to be 1.82 inches, compared with .97 inches in the case of the melon plants on the unmulched area.

One-year tests indicated that blackening the mulch paper with lamp black and linseed oil materially increased the yield of cantaloupes. The yields of fruit per plant from the blackened mulch, untreated mulch and unmulched areas were respectively 11.6, 8.7 and 2.9 pounds, indicating that for the season of 1939, blackening the paper gave increased returns.

CONCLUSIONS

Results with a black building mulch paper on a clay loam soil at Saanichton were as follows:

(1) Total plate counts for actinomyces, bacteria and fungi indicate that there is little significant difference in the mulched and the unmulched areas at depths varying from 2 to 6 inches.

(2) Biological activity, as measured by the evolution of carbon dioxide in respiration chambers, showed no appreciable difference between the mulched and the unmulched soils.

(3) Nitrogen fixation, as indicated by plate counts on mannite agar for Azotobacter, the aerobic nitrogen-fixing organism, showed no significant difference between the two areas in question.

(4) Laboratory tests indicated that macerated mulch paper in concentrations of .75, 1.50, 3.0 and 6 per cent respectively, while slightly influencing certain microorganisms, had no apparent effect on barley seedlings when grown in media containing this material.

(5) A water soluble mulch paper extract in concentrations of 1, 3 and 5 per cent respectively, had no apparent effect on barley seedlings when grown in a nutrient solution to which the extract had been added.

(6) In some seasons mulch paper increased the quantity of available nitrates in the soil, but this finding did not hold for all seasons.

(7) Mulch paper increased the soil temperatures slightly in

the month of June, but presumably due to subsequent bleaching, this advantage was not maintained over the unmulched area unless the paper was artificially blackened.

(8) Air temperatures were approximately 2 degrees Fahrenheit higher over the mulched area throughout the greater part of the growing season.

(9) Blackening the paper in the 1939 tests increased soil temperatures to a maximum of 10 degrees Fahrenheit over the untreated paper and increased the yield per plant by 33 per cent.

(10) When the two uncropped areas were compared, it was found that the mulched plots conserved 3.2% more moisture than did the unmulched plots.

(11) It is concluded that the better growth and higher yields obtained with cantaloupes under mulch paper is due to the cumulative effect of the paper in conserving moisture and in storing heat with a resultant increase in effective heat units during the period of growth.

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Influence of Paper Mulch on a Clay Soil.

Photographic Section.

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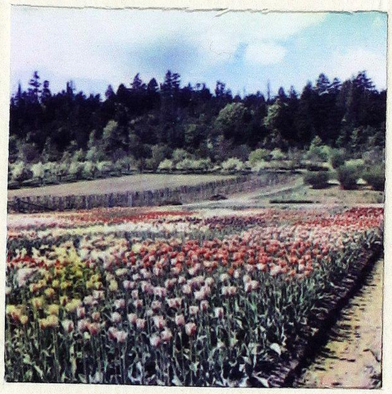

Figure 7. A natural colour photograph of tulips,this crop being grown at Saanichton in the melon rotation.

Figure 8.-A natural colour photograph showing colonies of actinomyces growing on sodium asparaginate medium.

Figure 9. Ploughing in a green manure crop prior to the planting of the melons. The 3 year rotation followed included tulips and broccoli.

Figure 10. Showing how the melon transplants were placed into small triangular openings in the mulch paper. Two additional strips of paper were laid before the next row of melons were planted, which resulted in planting distances of 6 by 3 feet.

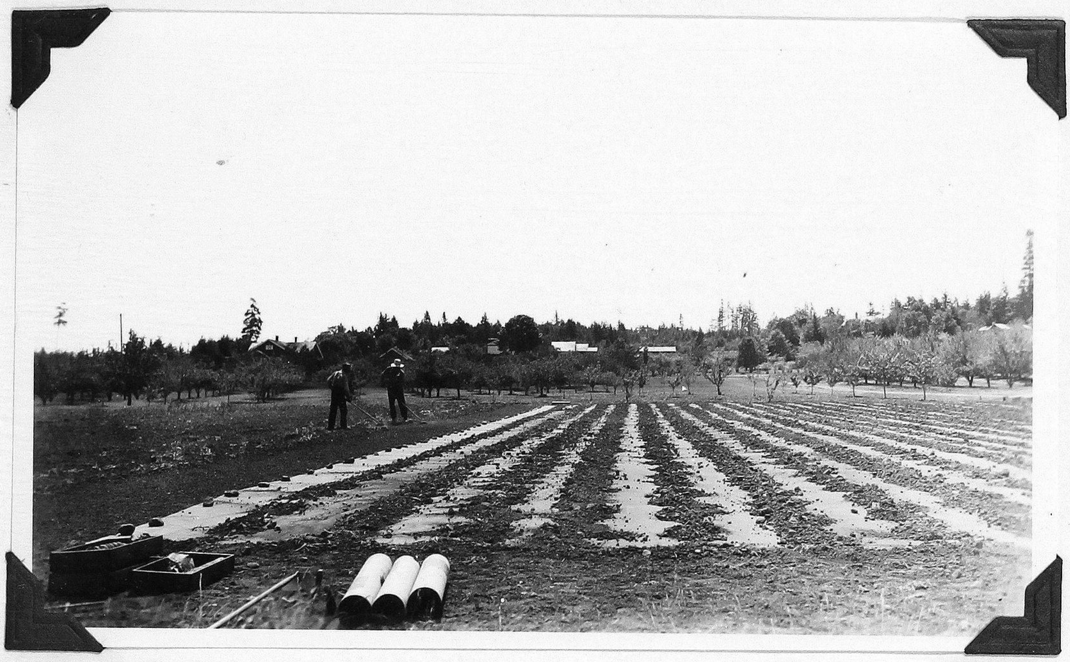

Figure 11. The ground was hand-raked before the paper was applied, the lumps of earth and stones thus removed were then used to anchor the paper.

Figure 12. Hot caps were used to advantage as a protection against unfavourable weather changes in 1937. Air and soil thermometers can also be seen in the foreground.

Figure 13. A typical melon plant growing on mulch paper. This covering apparently supplies the necessary heat stimulus needed by the young plants in the critical month of June.

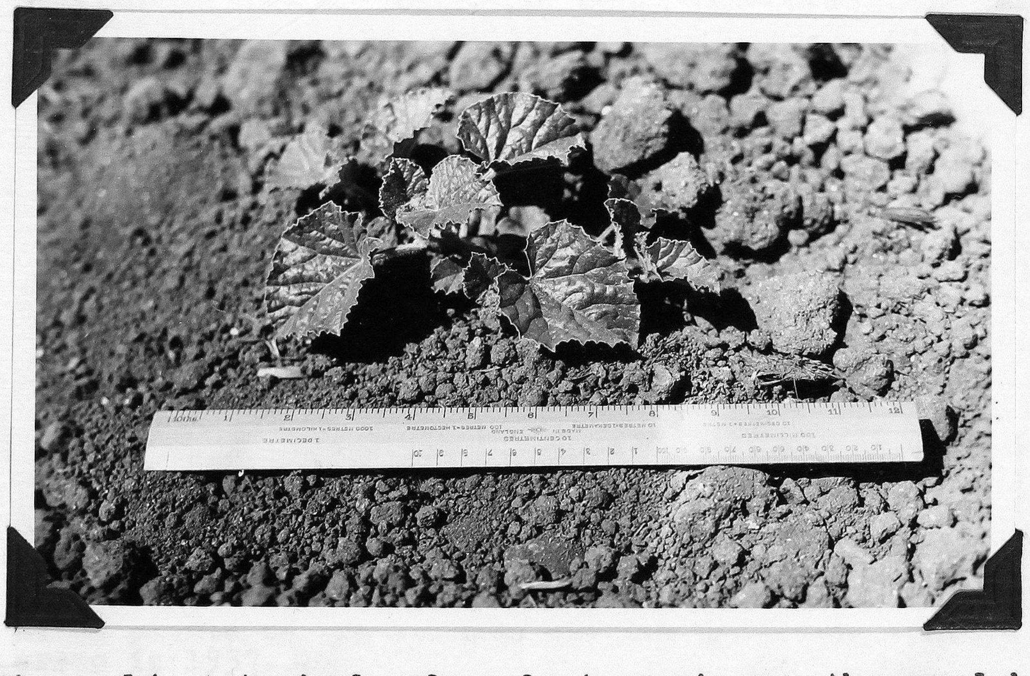

Figure 14. A typical melon plant growing on the unmulched soil area and planted at the same time as the mulched plant shown in Figure 13.

Figure 15. Illustrating the comparative growth of the melon plants growing on the mulched and the unmulched soil areas in 1935.

Figure 16. Illustrating the comparative vigour of the melon plants on the mulched and the unmulched soil areas in 1937.

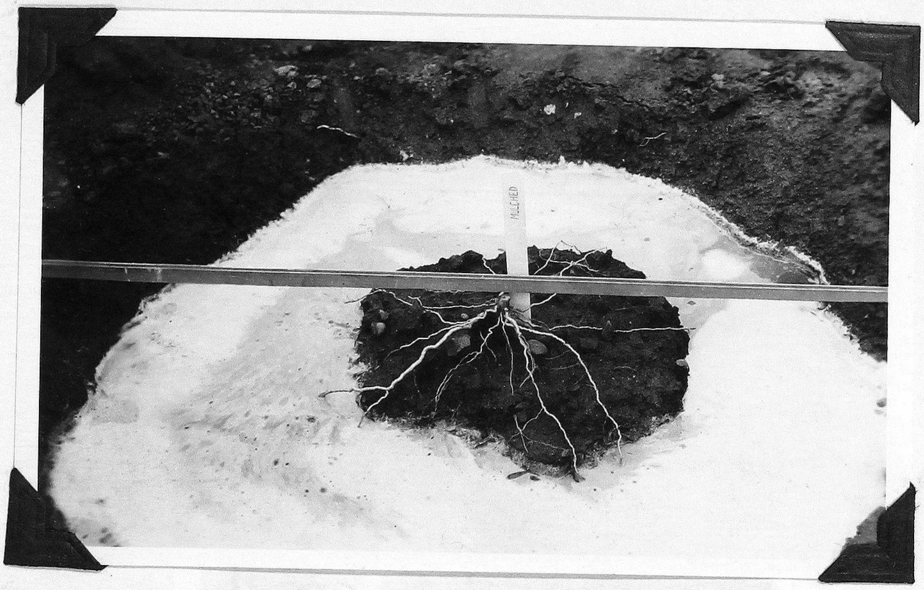

Figure 17. Partial root system of a melon plant grown on mulch paper.

Figure 18. Partial root system of a melon plant grown on the unmulched soil area. Apart from the fact that the paper tended to bring the roots closer to the surface, there was little significant difference between the root systems of the plants grown on the two areas.

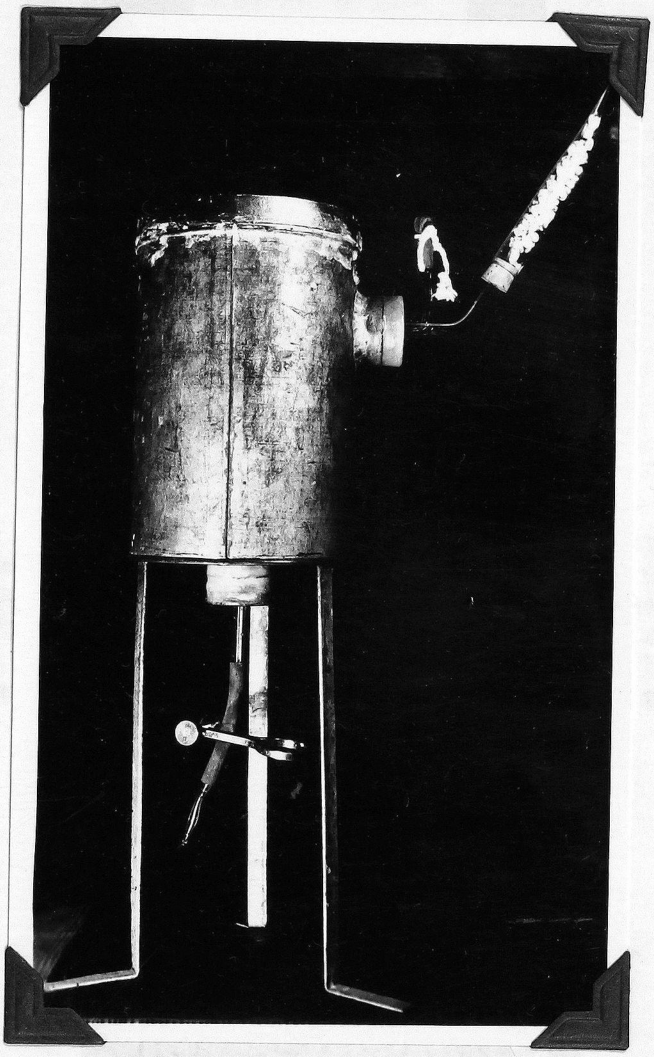

Figure 19. Type of respiration chamber used to measure the evolution of carbon dioxide from mulched and unmulched soils.Little significant difference was apparent between these two areas,at least as measured by the apparatus here illustrated.

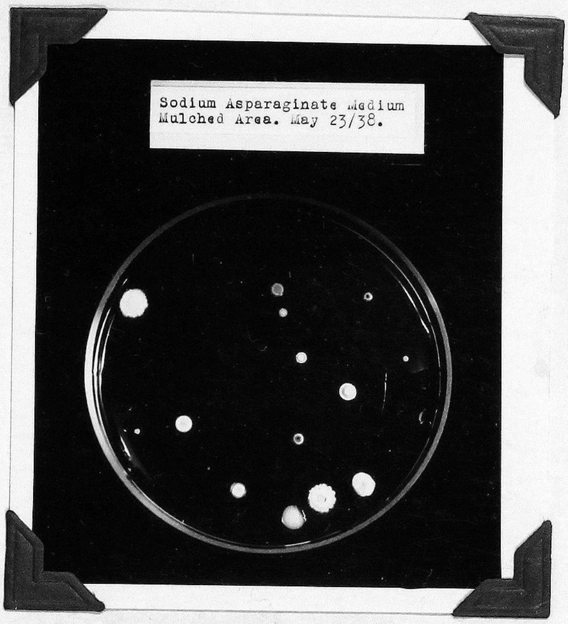

Figure 20. Colonies of actinomyces as they appeared on sodium asparaginate medium,plated from soil obtained from the mulch paper area.Plate counts extending over a 3 year period, would indicate little significant difference in total numbers of actinomyces, bacteria or fungi between the mulched and the unmulched soil areas.

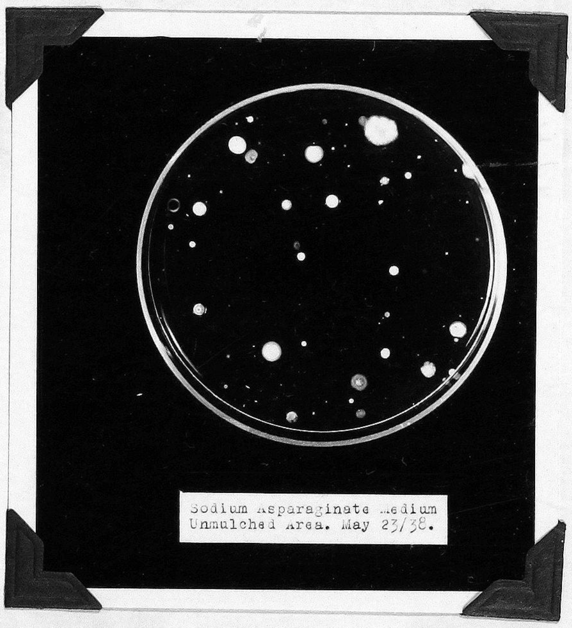

Figure 21.Colonies of actinomyces plated from unmulched soil.

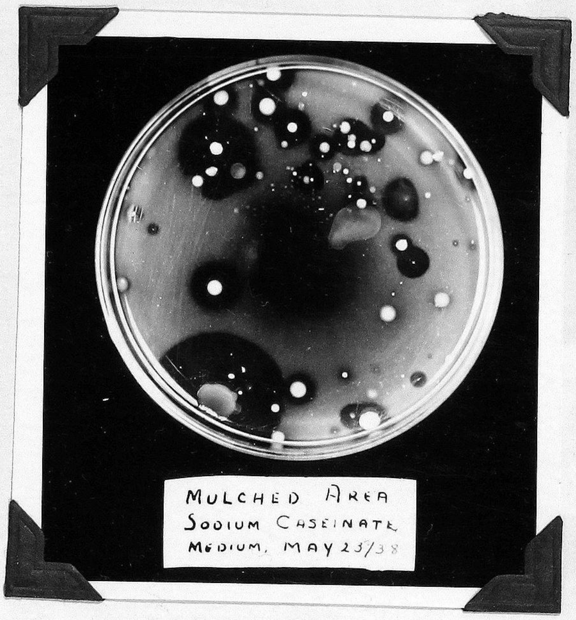

Figure 22. Colonies of bacteria(and actinomyces) plated from mulched soil. Note the clear areas around certain colonies,indicating the ability of the organism to break down the casein in the medium.This protein-splitting action was used to advantage to measure the direct effect of mulch paper on biological activity(see Table 3).

Figure 23. Colonies of bacteria plated from the unmulched soil area.

Figure 24. Azotobacter colonies from mulched soil appearing on Curie's mannite agar medium.

Figure 25. Azotobacter colonies from unmulched soil. Physiological tests indicated these to be similar to those isolated from the mulched soil, both apparently belonging to the species Azotobacter chroococcum.

Figure 26. Showing the contact effect of mulch paper on a soil organism, indicating that the paper had no inhibitory effect on the growth of the actinomyces in question.

Figure 27. The same organism growing without the influence of mulch paper.