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Paper Mulch for the Vegetable Garden

Its Effect on Plant Growth and on Soil Moisture, Nitrates, and Temperature

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PAPER MULCH FOR THE VEGETABLE GARDEN

Its Effect on Plant Growth and on Soil Moisture, Nitrates, and Temperature

ROY MAGRUDER

SUMMARY

This bulletin covers the experimental work and observations on six kinds of mulching paper tested during the growing season of 1928 in the gardens of the Ohio Agricultural Experiment Station at Wooster. Thirty-one crops of the following vegetables were grown to maturity: spinach, head lettuce, cabbage, cauliflower, beets, carrots, turnips, rutabagas, peas, green pod beans, wax pod beans, bush lima beans, celery, onions, potatoes, sweet corn, cucumbers, eggplant, sweet peppers, and tomatoes.

Three of the papers used in this test were special soil mulching papers; the other three were papers used in the building trades, page 12.

All six papers were effective in preventing weed growth in the covered area, page 17.

One of the building papers (No. 2) proved to have a depressing effect upon the early growth rate of some of the vegetables. This effect was probably produced by some harmful water-soluble material contained in the paper, page 16.

Two of the papers, building paper No. 1 and a special soil mulching paper No. 4, proved unsatisfactory because of excessive shrinking and partial disintegration.

The use of the black mulching papers along each side of the row increased the speed and percentage of germination of seedlings. It also increased the growth rate during the early portion of the plant's growing period, page 18. This increased early growth rate resulted in earlier maturity and larger early yields on most of the crops. Pruned and staked tomatoes, late wax-pod beans, and early cauliflower were the exceptions.

Twenty-eight of the thirty-one crops produced as large or larger total yield from the black paper mulched area as from the cultivated area. Dry onions from seed, head lettuce from seed, and late turnips produced slightly less on the mulched area, pages 20 to 44.

Paper mulched vegetables were usually of better quality, due to larger size, larger percentage of No. 1 grade, or cleanness.

Paper mulched soil in which wax beans and sweet corn were growing contained more moisture most of the time than the cultivated soil, page 45.

In the cultivated section, the soil samples taken between the rows contained more moisture most of the time than samples taken in the row between the plants of beans or of corn. In the paper mulched area, the results were not consistently in favor of either location.

The soil on which beans were growing contained more moisture most of the time than that on which sweet corn was growing.

There was no consistent difference in the nitrate nitrogen content of the soil between the cultivated and paper mulched areas, page 49.

Soil samples from between the rows of early beans and sweet corn in both the cultivated and paper mulched sections had a higher nitrate nitrogen content than samples taken in the row between the plants.

The soil in which beans were growing was higher in nitrates most of the time than that in which sweet corn was growing.

Under similar conditions during May, June, and July, the paper mulched soil had the higher daily mean temperature 95 percent of the days. On 5 percent of the days there was no difference.

The daily mean temperature under the paper was as much as 6.5° F. higher than the cultivated soil and the maximum difference at any time was 8.5°.

The greatest difference in soil temperature due to the mulching with paper was on bright sunshiny days, cloudy weather and rain decreasing the difference between the paper mulched and cultivated areas. The differences in temperature were greater in May than in July.

The use of paper mulch seemed to be of most benefit on early, quickly-maturing crops, for the warm season crops, and in periods of moisture shortage.

The greatest obstacles to the extensive use of mulch paper at the present time are its cost and the need of tools for laying and anchoring the paper and planting seed and plants thru it.

The papers used in these experiments were practically of no value for use another year, after being carefully removed at the end of one growing season.

RECOMMENDATIONS

The value of paper mulch in weed control and plant stimulation as shown in the experimental work conducted at Wooster leads the writer to recommend it for trial in a limited way in the production of vegetable crops. It has already been demonstrated that weather conditions, the kind of crop grown, fertility of the soil, kind of paper used, and other variable factors greatly influence the results obtained from paper mulch. It is to be expected, therefore, that it may not always prove of value. Familiarity thru trial is the only way for a grower to determine the extent of its usefulness under his conditions.

At present, its greatest usefulness seems to be for the home gardener who is not so much concerned about its cost and the increased earliness or yield from its use as he is in its controlling weeds.

The most suitable way to use paper in the home garden is to place it between the rows of vegetables that are sown thickly in rows, and to cover the entire area to be devoted to crops planted in hills, later planting the seed or setting the plants thru holes cut in the paper at the proper distances. In covering the entire area the paper should be lapped with the upper edge toward the top of any slope, the paper extending crosswise of the slope, that rain may enter the soil along the lapped edge. This system reduces hand weeding to the minimum.

Any method of securely anchoring the paper may be used.

Covering the entire edge of the paper with two or three inches of soil has been the most satisfactory method of anchoring. The aisles between the strips of paper should only be wide enough to provide sufficient soil for covering the edges of the adjacent strips. Cultivation or scraping of the aisles will be necessary to prevent weed growth in them.

This system may be more practical than the first mentioned, especially where the garden is large and where it would be difficult or costly to secure sufficient anchoring materials for the complete coverage system.

The cost of materials and labor involved in anchoring the paper where soil is not used preclude its economical use on a commercial scale for crops such as radishes, spinach, and carrots, the rows of which are usually close together and where it would be impractical to anchor with soil along the edges.

The present high acre cost of the material and hand labor required in its use limit its profitable use on a commercial scale to those crops of high acre value on which it produces the greatest stimulating effect on either earliness or total yield, or both.

The use of soil along the edge of the strips would seem to be the logical method of anchoring the paper in the commercial garden where facilities are already present for repeatedly covering the edge with soil and for preventing weed growth between the strips.

Where hastened germination and early growth are desired on crops requiring considerable space, such as the vine crops, the 18-inch paper may be the most economical. Where midsummer drouths are common wider strips may be more practical. The maximum advantage from the paper will be secured by growing only one plant in a hill, the hills being as close together as practical.

The most economical method for other plants or seeds that may be grown in hills, would seem to be to plant two rows about 20 inches apart on a 3-foot strip. The hills in adjacent rows should be staggered. The distance between hills and between strips of paper will depend somewhat upon the crop grown, and on the fertility of the soil, but should be sufficient for normal development and to allow space for cultivation of the aisle, harvesting, and other necessary operations.

Any black, waterproof paper sufficiently durable to withstand one season's weathering without disintegrating or shrinking, tough enough to walk on without puncturing after the ground beneath has settled, and containing no water soluble materials harmful to germination or plant growth may be used for soil mulching.

INTRODUCTION

Preliminary investigations indicate that special soil mulching papers are to have an increasingly important place in our modern agriculture.

A history of the development of paper mulch and a review of the literature prior to 1928 are given in Flint's recent bulletin on the subject.[1] A brief report of the preliminary experimental work with paper mulch by the writer is published in the July-August, 1928, Bimonthly Bulletin of the Ohio Agricultural Experiment Station.

Altho Eckart is credited with developing the use of an impervious paper for soil mulching, paper for this purpose seems to have

[1]Flint, L. H. 1928. Crop Plant Stimulation with Paper Mulch U. S. Department of Agriculture Tech. Bul. No. 75.

been used previous to his experiments. Mrs. Berger,[2] writing in 1915, describes a method of using "superfluous paper that accumulates about a house" as a mulching material for rose bushes. Several layers of paper were spread over the entire surface of the bed and kept in place by covering with grass, weeds, Spanish moss, or other material.

Practically all of the preliminary tests with soil mulching paper prior to 1928 were conducted with the original patented paper developed for use in the pineapple fields of Hawaii. Several new brands of paper have recently been introduced and recommended for soil mulching.

This bulletin reports the results of experiments conducted during 1928 in the garden of the Ohio Agricultural Experiment Station at Wooster on six different kinds of paper. The primary purpose of these tests was to determine whether any of the papers are actually injurious to plant growth and whether they would prevent weed growth in the covered area during an entire growing season. The effect upon yield, earliness, and quality of the crops grown, and upon the temperature and moisture and nitrate nitrogen content of the soil was also studied to a limited extent.

EXPERIMENTAL METHODS

Cutting the paper.—The 18- and 36-inch widths of paper, as manufactured, seemed unnecessarily wide for the home garden, so the 3-foot width was cut into 1- and 2-foot widths. This was first attempted by sawing the roll, but this proved impractical as the teeth of the saw were soon clogged with the impregnating asphalt. Finally the strip was slit with a sharp knife as it was unrolled, the two parts being rerolled at the same time.

Laying the paper.—In order to cover small areas with one kind of paper, strips 10 feet 2 inches or 15 feet 2 inches long were cut. These strips when lapped 2 inches at the ends and laid side by side formed 10- or 15-foot sections of the same kind of paper extending crosswise of the rows as shown in Figures 1 and 3. Papers Nos. 1 to 4 were laid in 10-foot blocks and Nos. 5 and 6 in 15-foot blocks. The use of these small strips necessitated the following procedure.

The first row of strips was laid and a row of seeds planted as closely as possible to the edge. Another row of seeds was then planted at the proper distance. To allow for any deviation from a straight line in planting, the rows were placed 14 or 26 inches apart. The space between the two rows was then leveled with a

[2]Berger, Mrs. E. W. Our Roses. Florida State Hort. Soc. Proceedings, 1915. p. 193.

rake before the paper was unrolled (Fig. 1). When plants were used they were set close to the edge of the paper, the soil leveled and another strip laid before the next row was set. This process was repeated until the entire space was covered. By retreating across the garden in this way it was possible to plant the entire area without walking on the paper.

Fig. 1.—Showing steps followed in planting paper mulched garden, 1928

Seed drilled along a string to insure straight rows.
Surface between rows leveled off with rake.
Paper unrolled between rows and held in place with wire staples.
Lettuce plants were set along edge of one strip before next strip was unrolled.
Note size and placement of wire staples.

Anchoring paper.—Pieces of old No. 9 wire from a dismantled grape arbor were bent by hand into U-shaped staples, the legs of which were 6 to 8 inches long and about 12 inches apart. The corners were as nearly square as possible to prevent the wire from cutting thru the paper when forced into the ground. The cross bar was bent down slightly to press against the paper between the legs, thus holding the edge of the paper close to the ground. These staples were placed 1 to 1½ inches from the edges of the paper strips and with 15- to 18-inch intervals between them (Fig. 1).

No experiment was made to determine whether it was necessary to place the staples this close together. The staples kept the paper in position thruout the growing season, altho it was necessary to replace them where the paper pulled away by shrinking.

Garden location and fertilizer treatment.—This garden was located on a plot of fairly fertile Wooster silt loam soil previously used for garden purposes. Altho tile drained, the soil is retentive of moisture and crusts badly following heavy rains. The garden slopes slightly to the south end, which has been observed to be more moist than the north end.

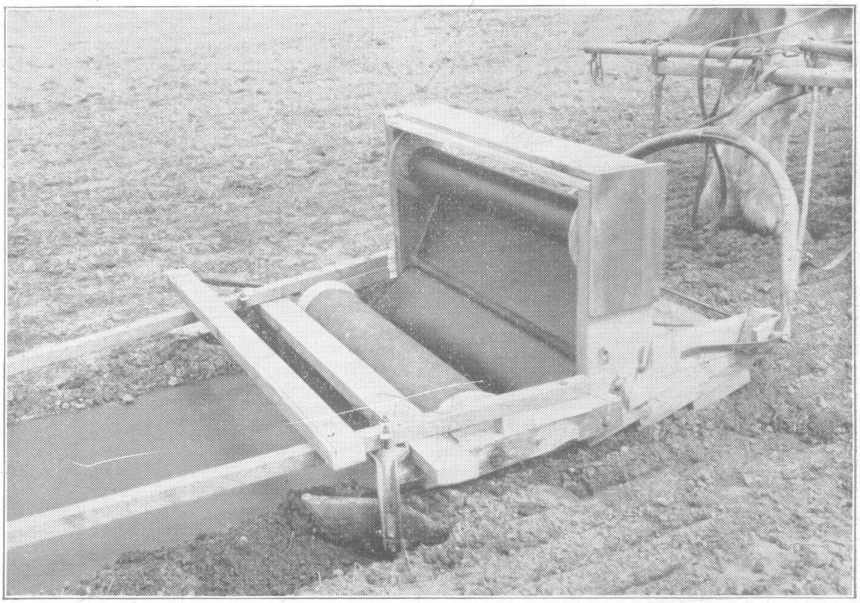

Fig. 2.—A machine made and used by the Experiment Station for smoothing the soil, laying the paper, and covering the edges with soil in one operation

About 25 tons of manure per acre was plowed under, after which 200 pounds of nitrate of soda and 500 pounds of 16 percent superphosphate per acre were broadcast previous to fitting the land for planting.

Planting plan.—The planting plan is presented in Table 1. The early, frost-hardy vegetables were planted May 1 and 2, and the tender ones May 19. Planting began at the east side of the garden and progressed to the west, as described in the section on laying the paper.

The first lot of succession crops was planted July 18-21, and the second on August 16. In preparing for the second crop the heavy roots of spinach, head lettuce, cabbage, cauliflower, and beans were twisted out, disturbing the soil and tearing the paper as

little as possible. The paper was folded back while the potatoes were being dug, then the soil was leveled, and the paper relaid before planting the next crop. The uncovered strip of soil was then loosened up with a Hazeltine ¾-inch blade hand weeder. As soon as the loosened soil had dried off a little the seeds were either drilled in with the garden drill or planted in hills by hand. Plants were set by hand and watered to insure a good stand.

TABLE 1.—Planting Plan of Paper Mulch Garden, 1928

Row No.[1]	Date planted	Vegetable	Variety	Distance between	
				Rows	Plants
1	May 1	Radish	Scarlet Globe	14	Drilled
2	May 1	Spinach	Long Season Bloomsdale	14	Drilled
3	May 1	Lettuce (plants)	New York	14	12
4	May 1	Lettuce (seed)	New York	14	12
5	May 1	Onion (plants)	Sweet Spanish	14	4
6	May 1	Onion (seed)	Mountain Danvers	14	Drilled
7	May 1	Beet	Detroit Dark Red	14	Drilled
8	May 1	Carrot	Chantenay	14	Drilled
9	May 2	Peas	Laxtonian	26	Drilled
10	May 2	Celery	White Plume	26	6
11	May 2	Cabbage	Copenhagen Market	26	24
12	May 2	Cauliflower	Early Snowball	26	24
13	May 2	Potatoes	Irish Cobbler	26	12
14	May 19	Beans	Stringless Green Pod	26	12†
15	May 19	Beans	Pencil Pod Black Wax	26	12†
16	May 19	Beans	Fordhook Bush Lima	26	12†
17	May 19	Peppers	Early Giant	26	24
18	May 19	Eggplant	Mammoth Purple	26	36
19	May 19	Sweet Corn	Golden Bantam	26	12†
20	May 19	Sweet Corn	Country Gentleman	26	12†
21	May 19	Tomatoes (staked)	Bonny Best	49	24
22	May 19	Tomatoes (on ground)	Marglobe	49	48
23	June 28	Cucumbers	Early Fortune	49	24†
1	July 18	Turnip	Purple Top White Globe	14	Drilled
2	July 18	Rutabaga	American Purple Top	14	Drilled
3	July 18	Carrot	Chantenay	14	Drilled
4	July 18	Beet	Detroit Dark Red	14	Drilled
5					
6	Aug. 29	Spinach	Long Season Bloomsdale	14	Drilled
7	July 18	Head Lettuce	New York	14	12
8	July 21	Celery	Columbia	14	6
9	July 20	Cauliflower	Dry Weather	26	24
10	July 19	Cabbage	Danish Ballhead	26	24
11	July 18	Beans	Giant Stringless	26	12†
12	July 18	Beans	Pencil Pod Black Wax	26	12†
13	Aug. 16	Peas	Laxtonian	26	Drilled
14	Aug. 16	Chinese Cabbage	Chihli	26	12
15	Aug. 16	Chinese Cabbage	Narrow Head	26	12

*Rows numbered from east to west side.
†Thinned to 2 plants per hill

The distance between rows in Table 1 is the distance of each row from the next one to the east. These planting distances were entirely satisfactory under the conditions of this experiment and gave all the space necessary for home gardens. The varieties used are dependable ones of the highest quality.

It will be noticed that the crops requiring little space were planted on one side of the garden and those requiring the greatest space on the opposite side.

An abundance of seed was planted and later the plants were thinned to insure a perfect stand. Number of plants per hill and per foot of row are noted in Table 1 and in the discussion of yield.

Fig. 3.—View of the paper mulched garden looking toward the south, taken June 11. Note the light color of paper No. 1 and method of laying in blocks extending crosswise of the garden. Cultivated sections on both ends

Cultivation.—A 30-foot strip at each end of the garden was cultivated weekly as long as practical, with a two-wheel hand cultivator equipped with hoes or narrow teeth. Each cultivation was as shallow as possible. The crop from the cultivated areas was used as a basis in estimating the effect of paper mulch.

Weather conditions.—At planting time, the first of May, the soil was rather dry, and continued dry thruout the month, the total rainfall, 1.69 inches, being 2.23 inches below the 40-year average for May. On only three days was the rainfall more than .2 inch.

The mean temperature for May was below the average, partly because of cool nights. Killing frosts occurred on the 8th and 12th, and light frosts on the 11th and 24th. The unusually late frost of the 24th killed the edges of tomato leaves in flats that had been watered heavily, but did no damage in the field to plants which had been subjected to several days wind and sun.

June, like May, was unusually cool. Only three Junes in the last 40 years at Wooster had a lower mean temperature. Unlike May, June was unusually wet; the total rainfall of 5.17 inches was 1.19 inches above the 40-year average, and was well distributed thruout the month.

The mean temperature of July was slightly above the average. The rainfall of 4.45 inches was also slightly above normal and well distributed, so there was plenty of moisture at all times during the month.

August likewise had a higher rainfall (.5 inch) and higher mean temperature (3.1° F.) than the average. With the exception of 1 inch on the 18th, there was no rain of value after the 5th. The light showers which occurred were soon evaporated. High air temperatures increased the rate of this loss. As a consequence plants suffered from lack of moisture during the middle and latter part of the month.

September was a month of drouth, there being only 3 days on which .01 inch or more of rain fell. The total for the month was only .65 inch. Vegetation suffered considerably from lack of moisture, many plants wilting during the middle of the day. The average temperature was also lower than usual for September. A light frost occurred September 24, followed by heavier ones on the 26th, 27th, and 28th. These killed bean vines, but not peppers nor staked tomatoes.

The drouth, which began in August, continued until the middle of October. There was only one rain, .3 inch, during this time. The temperature was higher than normal during this period. Following a series of rains, there was a heavy frost on October 21.

A frost on the 27th was followed by a series of heavy freezes, the temperature going down to 19° F. on the morning of October 30.

May and June were favorable for the development of the early cool season crops. July and August provided ideal conditions for the growth of the warm season vegetables. September and October were extremely unfavorable for all plant growth due to the extended drouth.

EXPERIMENTAL RESULTS

NOTES ON PAPERS USED

Six kinds of papers were secured from four different sources. Three of these were manufactured for soil mulching purposes, and three were building papers recommended for trial. For convenience in keeping records the papers were numbered from one to six in the order laid, No. 1 at the north and No. 6 at the south end of the garden. These numbers are used instead of the names, as given below.

Paper No. 1, the trade name of which is Fibreen, was made for use in the building trades, but was recommended for soil mulching purposes. It is made of two sheets of No. 1 Kraft paper with a cementing layer of asphalt in which are imbedded sisal fibers extending in both directions. Rolls 36 inches wide and containing 900 square feet weighed 45 pounds.

It did not stick together in the roll, was very easily laid and was tough enough to walk on without breaking thru. Toward the end of the season the two layers of kraft paper were becoming separated and partially decomposed in spots. Before disintegration became apparent this paper was impervious to water (Fig. 4). None of this paper had any re-use value after the end of the growing season.

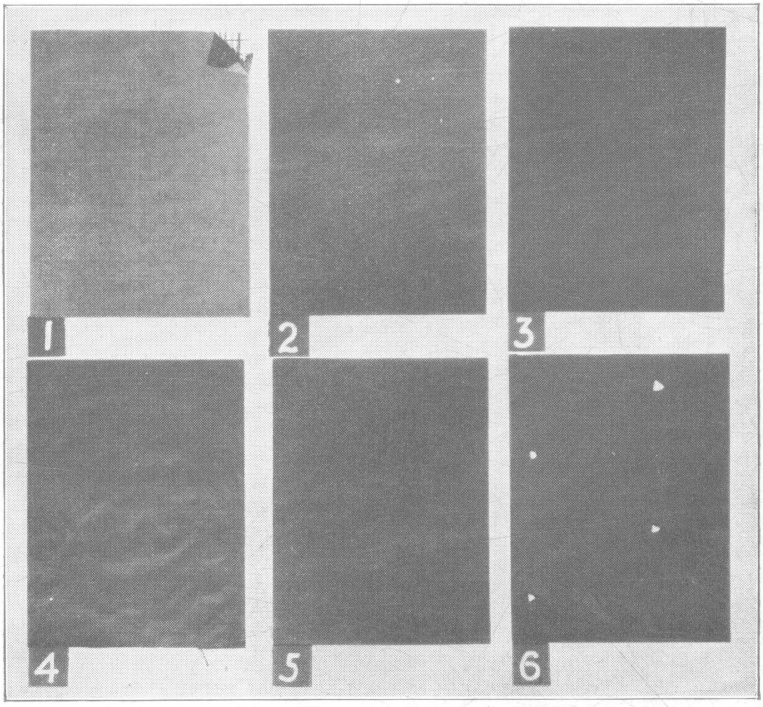

Fig. 4.—Showing six kinds of paper used on 1928 paper mulched garden. Note sisal fibers extending both directions in No. 1 and the rough burlap-like appearance of No. 2. The shiny surface of No. 3 does not show in the photograph. Note also the string imbedded in No. 4 and the size and placement of perforations in No. 6.

The light brown kraft paper upon exposure to the sun gradually became light yellow instead of darkening as claimed by the manufacturer. This light yellow color according to theory would not absorb as much heat from the sun as black and, therefore, this paper would not be as effective as black paper in raising the soil temperature. No records were taken of the soil temperatures under the two types, so no data are offered to prove or disprove

this point. Under California conditions it was found that the soil under white or light gray papers was cooler than that under black paper or the uncovered cultivated soil.

Within a short time the paper was shrinking and pulling away from the staples. This was especially noticeable where two 2-foot strips lapped to form the 4-foot space between the tomato rows. The shrinkage here was great enough to pull both edges from under the staples (Fig. 4). On October 13 several strips were smoothed out on a board while damp and measured to determine the amount of shrinkage. The 12-inch strips shrank about an inch and the 24-inch strips from 2 to 2¾ inches.

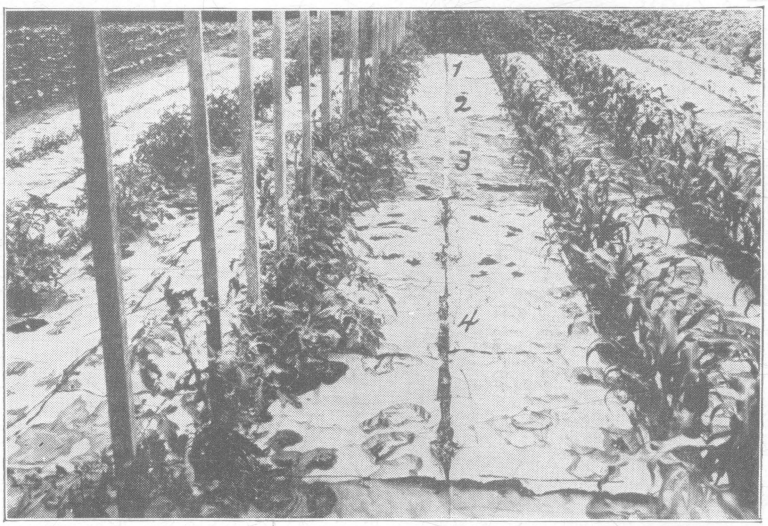

Fig. 5.—This view of the experiments, taken July 25, shows the curling up of the edges and shrinking of paper No. 4 and the shrinking of paper No. 1. No. 3 has been relaid to show the amount of lap and position of wire staples on the lap. Staples have been reset on No. 4. Note weeds growing in uncovered space along melon row at extreme left, also pools of water in depressions. Numbers in figure refer to paper number.

Paper No. 2 was described as an "asphalted slater's fibre". It was dark brown in color, rather open in texture, with a rough finish somewhat resembling the surface of burlap. Rolls 36 inches wide and containing 500 sq. ft. weighed about 25 pounds. Altho light weight, it was fairly thick, did not stick in the roll, was easily laid, and tough enough to walk on without danger of breaking thru. It changed to light brown in color upon exposure. Toward the latter part of the season it began to disintegrate along the edges and in

spots where the surface of the soil was uneven. It was impervious to moisture during the greater part of the growing season and there was no apparent shrinking.

Paper No. 3, also a building paper, known as Richardson's Black Waterproof Paper, was asphalt saturated and coated. It had a smooth, shiny black surface and, when exposed to the hot sun, had a tendency to stick in the roll. When unrolled in the hot sun it became limp and pliable and difficult to handle without tearing. After several weeks exposure the surface became dull; the paper stiffened and could be walked on without puncturing. The 3-foot width rolls, containing 500 sq. ft., weighed 50 pounds. Altho it did not disintegrate along the edges, by the end of the season it had become brittle and had more holes in it than Nos. 4 and 5. It did not shrink and was impervious to moisture thruout the season.

Paper No. 4, Safepack Mulching Paper, made especially for soil mulching purposes, was rather thin with a smooth dull black finish. It had a cord imbedded between the layers, 1¼ inches from each edge, was tough, did not stick in the roll, and was easily laid. The 36-inch width, containing 750 square feet, weighed about 40 pounds per roll.

After a short time the edges began to curl up and the paper shrank so much that it pulled away from the staples (Fig. 4). In the fall the curled edges were disintegrating and there were holes in the paper between the rows where the greatest wear occurred.

Paper No. 5, Bird's Paper Mulch, unperforated, was manufactured under the original Eckart patents as devised for Hawaiian conditions. The 36-inch width rolls, containing 900 square feet, weighed 45 pounds. It had a fairly smooth, dull black finish; was thicker than No. 4; tough enough to walk on without breaking; and was easily laid, as it did not stick in the roll. It withstood wear better than any of the other papers except No. 6, did not disintegrate along the edges, nor shrink, and was impervious to moisture thruout the season.

Paper No. 6, known as Bird's Paper Mulch, Improved Perforated, was identical in its physical characteristics with No. 5, except that it was perforated. These perforations, or V-shaped cuts, were placed in several rows across the paper to allow the water which falls on the paper to drain thru into the soil. The flaps did not curl up but lay flat and prevented the growth of weeds in the covered area. No attempt was made to determine the amount of soil moisture lost thru these openings.

If the soil is leveled to eliminate depressions in which the water can gather on top of the paper, it is doubtful whether the perforations are desirable in strips up to 36 inches in width.

Probably the amount of wear involved in an experimental study of this nature was greater than would occur in a commercial or home garden. If so, the paper would be in poorer condition for re-use than it would under ordinary conditions. At the end of the growing season it was found to be almost impossible to remove all the paper without considerable damage. When dry it was so brittle that it cracked readily and when wet it tore easily.

By taking two of the used strips for each middle and shifting them so as to cover the holes and torn places it might be possible but hardly practical to re-use all of the papers, except No. 1. Ranking them on re-use value resulted in the following order: No. 5, No. 6, No. 3, No. 4, and No. 2.

DETRIMENTAL EFFECTS OF PAPER NO. 2

It was pointed out in the early work that papers containing soluble tar products proved detrimental to plant growth. Paper No. 2 exhibited a temporary detrimental effect upon some of the plants in this experiment suggesting the presence of such materials.

Within three weeks after the paper was applied the growth of radishes, spinach, onion seedlings, beets, cabbage, peppers, and eggplant under No. 2 paper was much slower than under the other papers. No difference could be detected on cauliflower or onion plants. The tissues along the edges of the first leaves of all except cabbage were killed and the leaves somewhat distorted. The effect on size of spinach and beets is shown in Figure 6. The yield of spinach showed a reduction of almost one-half in weight over the two adjacent papers.

The sweet peppers were in bud and flower when transplanted, but not a fruit set until after the middle of July on the plants in No. 2 plot, whereas green mature fruit was picked from the other plots at this time. All except the bud leaves were wilted for two or three weeks following the first heavy rain after planting. Wilting occurred on the eggplant also, but did not continue as long.

The depressing effect of No. 2 paper seemed to persist for only a short time and the longer season crops, like cabbage and dry onions from plants, eventually overcame the early stunting effect and produced as large crops as the other paper areas. This might indicate that the detrimental material was water-soluble and present in small quantities, which were soon sufficiently diluted in the soil solution to render them harmless.

Altho no markedly depressing effect on the early growth-rate of some of the other crops was noted, the total yield from this paper plot was lower than from the black paper. This was the case with early spinach, early beets, early wax beans, late green beans, late carrots, dry onions from seed, yellow and white sweet corn, peppers, and both staked and unstaked tomatoes.

Fig. 6.—Detrimental effect of No. 2 paper on spinach (above) and beets (below) on June 11. Paper No. 3 on the left and No. 2 on right. The lines on background are 1 foot apart

Germination was not noticeably affected, probably because there were no heavy rains to wash the objectionable material into the soil solution until after germination had taken place.

EFFECT OF PAPER ON WEED GROWTH

No weeds grew in the paper covered areas, except in the spaces along the row or thru holes in the paper. It was necessary to hand weed the rows only twice. In the drilled rows the first weeding was deferred until the plants were large enough to thin so both operations were performed at the same time. The paper had the same stimulating effect upon weeds that it had on cultivated crops and it was necessary to do the hand weeding early to prevent the weeds from robbing the cultivated crops of moisture and plant food. Note the amount of weed growth on Figure 4.

Where the entire space between rows was covered with the paper, a hand weeding hook was the only implement needed in cultivation. A small L-shaped weed hook with a double edged

blade about ¾ inch wide was very convenient in weeding along the rows and between plants as well as for loosening the soil preparatory to planting a succession crop.

EFFECT ON GERMINATION AND EARLY GROWTH

Potatoes, beans, cucumbers, and sweet corn were the only early planted crops on which paper showed any stimulating effect on germination. There were several probable reasons why no difference was noted in the rate of germination of the early cool-season crops. There was very little, if any, difference in the moisture content of the soil in the paper mulched and unmulched plots during the time of germination. Seedlings under both conditions had an equal opportunity in emerging unhampered from the soil, as there was no hard crust formed before they came up.

The plantings of May 19 and the succession plantings were handicapped by the hard crust which forms on this soil following heavy rainfall. In the cultivated area the crust became so hard that seedlings were materially delayed or prevented from emerging from the soil. Many bean plants were broken off. Table 2 gives the percentage of hills of the different kinds of beans in which one or more plants per hill had succeeded in emerging by June 1 in the paper mulched and cultivated areas.

TABLE 2.—Percentage Germination of Bean Plants on June 1, 1928 Paper Mulched and Cultivated Areas

Variety	Paper mulch	Cultivated
Pencil Pod Black Wax	95	76
Giant Stringless	85	47
Fordhook Bush Lima	57	16

The soil between the strips of paper was visibly more moist than the cultivated soil for two or three days following rain. If tender seedlings germinated when the cultivated soil was dry and hard and the mulched soil still moist, the percentage of germination was much higher in the mulched soil. The stand of the late sown succession crops was much better in the mulched sections. No germination counts were made.

The potato plants appeared three days earlier on the papered plots than on the cultivated ends. Leaves of sweet corn plants on the mulched plots were unrolled by the time the first shoots were visible on the cultivated area. Cucumber seedlings also made their appearance several days earlier on the mulched section. Since

moisture was not a limiting factor during the germination period of these crops, this hastening of germination may be attributed in part to the higher soil temperature under the paper mulch.

Fig. 7.—Looking south over the paper mulch garden August 27. Note the smaller size of late planted carrots, head lettuce, celery, cauliflower, and cabbage and the poor stand of head lettuce and celery on the cultivated area in foreground. Left to right: turnips, rutabagas, carrots, beets, onions, vacant row, head lettuce, celery, cauliflower, cabbage, and beans.

Altho none of the crops, except potatoes, planted on May 1 and 2 showed any stimulating effect of the paper on germination, within a month almost all were larger on the mulched section. This greater rate of early growth was also very noticeable on the late-sown crops (Fig. 7). The most striking example was Country Gentleman sweet corn (Fig. 11). A record was made of the date on which each stalk first showed silk, from which the average date of silking for each treatment was calculated, Table 3.

TABLE 3.—Average Date of Silking of Country Gentleman Sweet Corn, 1928

Plot	Average date of silking
North and south cultivated	August 5.30
Paper No. 1	4.58
Paper No. 2	4.44
Papers Nos. 3-6	3.44

From this table it is seen that the average date of silking of corn on the black paper mulched soil was almost 2 days earlier than of that on the cultivated sections. Papers Nos. 1 and 2 delayed the average date of silking when compared with the black papers.

Altho the average date of silking was not determined on the Golden Bantam variety, some interesting results were obtained by calculating the percentage of plants in tassel and in silk July 19 on the different plots. These results are given in Table 4.

TABLE 4.—Percentage of Plants of Golden Bantam Sweet Corn in Tassel and Silk, July 19, 1928

Plot	In tassel	In silk
	Pct.	*Pct.*
Cultivated	64	0
Paper No. 1	93	6
Paper No. 2	100	10
Paper No. 3	100	40
Paper No. 4	92	35
Papers Nos. 5 and 6	81	14

These figures show that the paper mulched plots on this date had a much higher percentage of the plants in tassel and in silk and indicate a marked stimulation of early growth with subsequent earlier maturity.

The lower figures from papers No. 5 and 6 may be explained by the fact that, due to unfavorable weather conditions, these papers were not laid until 4 days after the corn was planted. This delay in laying the paper seems to have delayed the maturity of the corn in Plots 5 and 6 as compared with 3 and 4

EFFECT ON EARLINESS, YIELD, AND QUALITY OF VEGETABLES

Because of the detrimental effect of Paper No. 2 on the early growth of some crops and the light color of paper No. 1, the results for these two papers are given separately in the yield tables and the other four papers are grouped together. The average yield of the north and south cultivated sections, unless otherwise noted, is used as a basis for calculating increases from the paper.

It is realized that the areas under consideration, without numerous repetitions, are hardly large enough to give reliable yield results and the figures are included only to give an idea of the relative response of the different crops under the described conditions.

Radishes.—Scarlet Globe radishes planted May 1 were large enough to harvest June 1. The largest radishes were about an

inch in diameter. A heavy infestation of root maggots, however, completely ruined this crop. Plants attacked early were either killed by June 1 or so badly stunted that yield records were of no value. More of the plants survived on the paper mulched area than on the cultivated plots and they were also larger.

Early spinach.—The early crop of Long Season Bloomsdale spinach sown May 1 was in first-class condition for harvesting on June 12. The plants were cut at the surface of the ground and the bottom two leaves, which had started to turn yellow, were removed. The number of plants and the weight before washing were recorded separately for each treatment.

TABLE 5.—Early Spinach

Plot	Plants per foot of row	Weight per foot of row	Increase in weight over cultivated
	No.	*Lb.*	*Pct.*
Cultivated	7.1	0.25	.....
Paper No. 1	7.0	.30	20
Paper No. 2	9.9	.18	−28
Papers Nos. 3-6	8.5	.37	48

The number of plants per foot of row might indicate a better germination due to the paper covering between rows. It is felt that the difference in stand was not sufficiently great to influence the yield, as it was observed that the plants grew larger where more space was given than where they were closer together.

These figures also show that paper No. 2 materially reduced the final yield of spinach. The plants under No. 1 were not as large as those under the black papers.

Since the entire plant was harvested these figures might also be used as an index of earliness. If each plant were cut at the time it reached a height of 5 inches it is probable that the black paper mulched sections could have been cut four or five days earlier than the cultivated sections. All of this spinach was of the finest quality, but the paper mulched product was relatively free from soil on the lower leaves and therefore would be preferred by the discriminating housewife.

Late spinach.—The late-sown crop of spinach, due to the protracted drouth, never reached marketable size. It was evident, however, that the stand and size of plants were much reduced on the cultivated, particularly on the north section.

Early head lettuce from plants.—Seed of the New York variety of head lettuce was sown in the greenhouse March 22. Seedings

were shifted into flats and spaced 2¾ inches apart each way. They were set in the field May 1, when the leaves were from 3 to 4 inches long.

They grew rapidly and were ready for harvest June 25, when they were cut and trimmed as for retail trade. The heads were allowed to remain as long as possible in order to secure the maximum yield and to allow them to become solid. Hot weather just previous to harvest, however, caused some tipburn, which was followed by soft rot by the time the heads were cut. The extremely rapid growth, which was partly responsible for the susceptibility to tipburn, also produced a large number of double and triple heads, heads that grew so fast that the cover leaves were unable to hide the several small heads within.

TABLE 6.—Early Head Lettuce From Plants

Plot	Weight per head	Increase over cultivated	Double and triple heads
	Lb.	*Pct.*	*Pct.*
Cultivated	0.831	.....	50
Paper No. 1	1.240	49	60
Paper No. 2	1.156	39	44
Papers Nos. 3-6	1.069	28	66

Table 6 shows that the percentage of double and triple heads was slightly larger under the black paper. There is an indication that papers No. 1 and 2 were more favorable for this crop than the black papers. All paper plots, however, gave larger yields than the cultivated sections.

All of the heads were entirely too loose to be graded as No. 1 lettuce. The heads from the cultivated sections, altho not as heavy, were smaller and more solid and therefore of better quality than those from the mulched areas. No difference between the treatments could be noted in the amount of tipburn or soft rot.

Early head lettuce from seed.—Seed from the same lot as that of the plants was drilled the same day the plants were set. The plants were thinned when about 6 inches high to 12 inches apart in the row. They should have been thinned earlier but other work prevented and as a result 4 bushels of very fine quality leaf lettuce was cut as thinnings from the 130 feet of row. These plants did not mature as uniformly as those from greenhouse-grown plants and it was necessary to make two harvests, the first on July 10 and the second on July 16.

The yields of early head lettuce from seed indicate that the use of paper mulch for this later crop was slightly detrimental. The differences, however, are small and may not be greater than the experimental error.

TABLE 7.—Early Head Lettuce From Seed

Plot	Weight per head	Increase over cultivated	Heads cut at first harvest
	Lb.	*Pct.*	*Pct.*
Cultivated	0.773		68
Paper No. 1	.650	−15	50
Paper No. 2	.836	8	54
Papers No. 3-6	.741	− 4	84

The heads from the cultivated plot were again of better quality, as they were more solid. This crop was cut relatively earlier than the first; consequently there was very little tipburn, altho the loss from bottom rot was greater. The percentage of plants that headed was also lower than in the first crop.

Papers 1 and 2 had a slightly retarding effect and papers 3 and 6 had an accelerating effect on the rate of maturity.

Late head lettuce.—Seed for the late crop of New York head lettuce was sown in hills 1 foot apart July 18. Considerable difficulty was experienced in getting a stand on the north cultivated section and it was necessary to transplant seedlings to get a full stand. These plants were much smaller than those in the papered plots (Fig. 7). During the September drouth all plants "shot to seed", those in the paper mulched plots starting first.

TABLE 8.—Early Cabbage

Plot	Weight per head	Increase over cultivated	Heads cut at first harvest	Heads cut at last harvest
	Lb.	*Pct.*	*Pct.*	*Pct.*
Cultivated	2.56		25	43
Paper No. 1	3.08	20	60	20
Paper No. 2	3.85	50	0	100
Papers No. 3-6	3.70	44	48	20

Early cabbage.—Seed for the early crop of Copenhagen Market cabbage was sown in the greenhouse March 22, shifted into flats and spaced 2¾ inches apart each way April 5, and set in the field May 2. The first cutting was made June 29 and followed by others on July 5 and 10.

Table 8 shows that all of the paper mulches were effective in increasing the weight per head. Altho paper No. 2 had a marked depressing effect on the early growth of the early cabbage plants, it

did not reduce the total yield, but delayed materially the maturity of the heads. The other papers approximately doubled the percentage of heads cut at the first harvest and reduced the percentage of late heads.

The heads on the paper mulched plots were heavier and larger, those from the cultivated area more solid. This is an indication of too fast growth, probably induced by excessive moisture.

Late cabbage.—The plants of Danish Ballhead cabbage for the late crop were rather large when set on July 19. Water was applied to each plant when set, but in spite of this the plants wilted badly for several days. A few died and were replaced by others. The plants on the north end cultivated strip were much smaller than those in either the mulched sections or south cultivated section (Fig. 7). This difference in early growth was maintained thruout the season and resulted in the differences in final yield shown in Table 9. All marketable heads were cut October 29.

TABLE 9.—Late Cabbage

Plot	Weight per head	Increase over north cultivated
	Lb.	*Pct.*
North cultivated	1.63	
Paper No. 1	2.24	37.3
Paper No. 2	2.18	33.7
Paper No. 3	1.86	14.1
Paper No. 4	2.08	27.5
Paper No. 5	1.97	20.9
Paper No. 6	2.20	34.9
South cultivated	2.53	

The most noticeable feature in this table is the very low yield of the north cultivated section and the high yield of the south cultivated section. A probable explanation lies in the fact that, since there was a slight slope to the south, water from heavy rains ran from the higher north cultivated section onto the mulched areas where it was trapped, and from the southern sections of paper it ran into a slight depression in the south cultivated area. Any natural movement of soil water would also be toward the south cultivated section and tend to increase the soil moisture content on this plot. It was noticed when taking soil samples for soil moisture and nitrate nitrogen analyses that the soil from the south cultivated section was more moist than from the north cultivated section; but, as a composite sample was taken for the analyses, no data on the relative moisture content of the two soils are available.

In view of these facts it seems more reasonable to compare the paper mulch areas with the north cultivated section than with the average of the two cultivated sections.

The variation in yield of the paper mulched plots was probably due to the small size of the sample on which the average was based and not to a difference in paper used. The average weight per head on paper No. 5 was greatly reduced by two heads which only averaged .55 pound.

In the writer's opinion the average of the increases listed in Table 9 indicates the approximate benefit from the paper for this particular crop.

Early cauliflower.—The Early Snowball cauliflower seed was sown March 22 and the plants shifted April 5 and set in the field May 2. The first heads were cut June 29 and succeeding harvests made July 5, 7, and 9 as the heads matured. Blanching was accomplished by tying the leaves over the head with soft twine. All heads were trimmed as for retail sale.

There was no marked difference between the papered plots in time of maturity and no difference in quality, except as size may influence quality. From Table 10 it is evident that paper No. 2 exerted no deterimental effect on total yield of cauliflower. Paper mulch increased the yield of early cauliflower.

TABLE 10.—Early Cauliflower

Plot	Weight per head	Increase over cultivated
	Lb.	*Pct.*
Cultivated	1.27	
Paper No. 1	1.70	33
Paper No. 2	2.20	73
Papers Nos. 3-6	1.80	41

Late cauliflower.—The late cauliflower plants of the Dry Weather variety were rather small when set and as they were in an adjacent row encountered the same weather conditions described for late cabbage. They were allowed to remain in the field, however, until November 20, when all heads 3 inches in diameter or larger were cut. They were trimmed as for retail market and the individual heads weighed.

The data in Table 11 indicate that the shortage of moisture in the north end of the garden was more important in reducing the yield of late cauliflower than of late cabbage, altho the cauliflower had almost a month longer growing period. The fact that the yield of the paper mulched areas increased toward the south end of the garden might indicate that the soil moisture increased in the same direction.

Assuming that such was the case it obviously would be unfair to the mulched plots at both ends to compare them with the average of the cultivated plots. Therefore, the Thorne[3] method of grading between check plots was used in calculating the increases.

TABLE 11.—Late Cauliflower

Plot	Weight per head	Plants not cut	Increase over cultivated (Thorne method)	Heads cut, less than one pound
	Lb.	*Pct.*	*Pct.*	*Pct.*
North cultivated	0.30	.....	30	100
Paper No. 1	.40	— 9.0	20	100
Paper No. 2	1.00	72.4	0	40
Paper No. 3	1.24	72.2	0	20
Paper No. 4	1.60	88.2	0	0
Paper No. 5	1.70	71.7	14	16
Paper No. 6	1.52	34.4	0	0
South cultivated	1.27	.....	14	38

The use of mulching paper increased materially the average weight per head, the percentage of marketable heads, and the percentage of heads one pound or more in weight.

None of the heads had "riced" or broken curd, altho the majority of them were too small to be placed in first grade.

Early beet.—Seed of the Detroit Dark Red variety of table beets was sown in drills May 1. As soon as the plants were 6 inches high they were thinned to from 4 to 6 per foot of row. The first harvest was made on June 30, another July 10, and a cleanup on July 16. Since early beets are usually sold in bunches with the tops on, the tops were left on and the beets graded as in Table 12. Only the first two sizes were pulled at the first two harvests.

TABLE 12.—Early Beets

Plot	Total beets per foot, grades					Increase of No. 1 roots over cultivated	No. 1 beets per ft.	
	1*	2	3	4	Total		6/30	7/10
	No.	*No.*	*No.*	*No.*	*No.*	*Pct*	*No.*	*No.*
Cultivated	1.21	2.25	0.47	0.23	4.16	.....	0	1.17
Paper No. 1	1.00	3.40	.90	.50	5.80	—17	0	.90
Paper No. 2	.70	3.50	.60	.10	4.90	—42	0	.70
Papers No. 3-6	1.64	2.06	.20	0	3.90	35	.38	1.26

*No. 1 size 2-2½ inches in diameter; No. 2, 1½-2 inches; No. 3, 1-1½ inches; and No. 4, less than 1 inch.

The larger number of No. 1 beets under papers 3-6 indicates that these beets grew larger in a given time than those in the cultivated sections. The last two columns show the average number of the larger size roots for the first two harvests. These figures indicate also that the paper mulched beets grew faster than the cultivated beets. It would seem that both papers No. 1 and 2

[3]Ohio Agr. Exp. Sta. Bul. 381, 1924.

slowed up the growth rate of beets. The results from paper No. 2 indicate that the depressing effect upon early growth, as shown in Figure 5, was not entirely overcome at harvest time. The thicker stand on paper plots No. 1 and 2 may be partly responsible for fewer No. 1 roots per foot of row.

Late beets.—Detroit Dark Red seed for the late crop of beets was sown in drills July 18. When the plants were about 4 inches high they were thinned to five or six per foot of row. The entire crop was pulled October 30 and graded into two sizes. All but about one-half inch of the tops was cut off.

TABLE 13.—Late Beets

Plot	Beets per foot of row		Increase in weight over cultivated	Portion of No. 1* beets by	
				Number	Weight
	No.	*Lb.*	*Pct.*	*Pct.*	*Pct.*
North cultivated	5.1	0.52	.....	12.6	30.6
Paper No. 1	5.9	.43	—33	5.1	13.9
Paper No. 2	5.6	.58	—10	17.9	43.1
Papers Nos. 3-6	5.7	.77	20	21.1	43.7
South cultivated	4.8	.77	.....	30.4	57.4
Average cultivated	4.9	.64	.....	21.5	44.0

*No. 1 size, 2 inches or more in diameter, No. 2 size, less than 2 inches in diameter.

This late crop of beets showed the same increase in yield toward the south end of the garden as in late cabbage and cauliflower. In this case, however, paper No. 1 gave a lower yield than the adjacent cultivated plot. When the plots at the other end of the garden were compared there was no difference in total yield, but the percentage of No. 1 roots was higher on the south cultivated plot than on Papers 3-6. With fewer plants per foot of row and more moisture they might have been expected to grow more quickly and larger.

Early peas.—Laxtonian pea seed for the early crop was drilled thickly May 2. A good germination and growth of vines were secured. The first picking was made July 10 and others on July 16 and 20. The weights given in Table 14 are for the marketable green pods.

TABLE 14.—Early Peas

Plot	Total weight per foot	Increase over cultivated	First harvest	
			Weight per foot	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
Cultivated	0.35	.....	0.15	42
Paper No. 1	.38	8	.10	26
Paper No. 2	.47	34	.19	40
Papers Nos. 3-6	.49	41	.25	51

All of the papers except No. 1 increased the total yield. Not only was the total yield on paper No. 1 lower than on the other papers, but the early yield was lower and the crop as a whole much slower in maturing. The black papers increased the yield and earliness of the peas over those of cultivation.

Fig. 8.—Showing large size of plants on south cultivated area, in foreground, which extends to thermograph shelter. At right of thermograph pea vines are being removed preparatory to planting late crops. July 20, 1928.

The peas from the paper covered area were slightly longer, better filled, and more free from dirt than those from the cultivated sections. All however, were first grade, but because of their better appearance the paper-mulched peas would have sold first.

TABLE 15.—Late Peas

Plot	Weight per foot of row	Increase over cultivation
	Lb.	*Pct.*
Cultivated	0.034	.....
Paper No. 1	.045	32
Paper No. 2	.050	47
Papers Nos. 3-6	.050	47

Late peas.—The seed for this crop of Laxtonian peas was sown deep and thick on August 16. Germination was good but the weather conditions during September were exceedingly unfavorable for this crop. The few short and poorly filled pods were harvested on October 19 to indicate the difference which was so evident to the eye.

All the papers gave better yields than cultivation. The quality, altho poor, was also much better on the mulched plots.

Early green pod beans.—Seed of the Giant Stringless variety was planted in hills one foot apart on May 19. As soon as the plants had a good start they were thinned to two in each hill. They made a splendid growth, (Fig. 8) completely covering the space between rows by harvest time. The first harvest was made July 17, at which time all marketable pods were picked. Other pickings were made on July 23 and 30.

All plots had some well-filled pods in which the beans were full size but not hard, but the paper-mulched plots had the greater percentage. Had the pods been picked as soon as the first were marketable, the paper mulched plots could possibly have been picked 4 or 5 days earlier than the cultivated. Except for the larger diameter at the first picking there was no apparent difference in size of pods from the different plots. All produced a large crop of fine quality and remarkably free from disease. Dirt on the cultivated beans reduced their attractiveness somewhat.

TABLE 16.—Early Green Pod Beans

Plot	Weight per hill	Increase over cultivated	First harvest	
			Weight per hill	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
Cultivated	0.87		0.23	26
Paper No. 1	.74	—15	.24	32
Paper No. 2	.96	9	.37	39
Papers No. 3-6	.92	5	.35	37

Altho the percentage increases on the total yield were rather small, there was an increase of about one-half in the weight of beans per hill on the first picking from papers Nos. 2-6. All of the papers seemed to hasten slightly the maturity of the crop as shown by the portion of the total harvested at the first picking. Paper No. 1 seemed to delay maturity and decrease the crop in comparison with the other papers.

Late green pod beans.—The seed for the late crop of Giant Stringless beans was sown in hills 1 foot apart July 18. The plants were thinned to two in each hill. The unfavorable weather conditions reduced slightly the size of plants on the north cultivated section. This reduction was reflected in the smaller total yield of pods.

The first harvest was made September 7, others on the 14th and 24th. A light frost on the 24th killed the top leaves of the plants, so the pods were stripped off at this time. A frost on the 26th killed the entire plant.

Since there was no consistent increase in yield of the paper mulched plots toward the south end of the garden, the average of the cultivated plots was thought to give as accurate a basis for comparison as any, altho the yield of the south cultivated end was more than twice that of the north end. If the yield of papers No. 1 and 2 were compared with the adjacent north cultivated plot the percentage increases would be much greater than those given in the table.

TABLE 17.—Late Green Pod Beans

Plot	Weight per hill	Increase over cultivated	First harvest	
			Weight per hill	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
North cultivated	0.344	.....	0.098	28
Paper No. 1	.606	22	.194	32
Paper No. 2	.510	3	.044	8
Papers No. 3-6	.692	39	.154	22
South cultivated	.694	.....	.132	19
Average cultivated	.496	.....	.115	23

With the exception of No. 2, all the papers produced larger total yields and larger early yields than cultivation. The black papers did not increase the earliness of the late crop as they did the early crop, altho the yield at first picking was substantially larger than that from cultivation.

Early wax pod beans.—The Pencil Pod Black Wax variety was planted and harvested in the same way and on the same dates as the Giant Stringless beans.

TABLE 18.—Early Wax Pod Beans

Plot	Weight per hill	Increase over cultivated	First harvest	
			Weight per hill	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
Cultivated	0.770	.....	0.200	25
Paper No. 1	.852	10.6	.262	30
Paper No. 2	.612	—20.5	.200	32
Papers No. 3-6	.808	4.9	.286	35

Table 18 shows a very small increase in total weight due to paper mulch but a substantial increase, except No. 2, in the yield of beans per hill at the first picking. The beans mulched with black paper matured more quickly than those cultivated or mulched with paper No. 1 or 2.

Late wax pod beans.—The late crop of Pencil Pod Black Wax beans was planted and harvested in the same way and on the same dates as the late crop of Giant Stringless.

TABLE 19.—Late Wax Pod Beans

Plot	Weight per hill	Increase over cultivation	First harvest	
			Weight per hill	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
North cultivated	0.324	.....	0.072	22
Paper No. 1	.610	41	.082	13
Paper No. 2	.656	51	.104	16
Papers Nos. 3–6	.640	48	.096	15
South cultivated	.564	.....	.134	24
Average cultivated	.432	.....	.103	23

The total yield per plant of late wax beans was materially increased by each of the papers. The yield per plant at first picking, however, was not greater and the maturity of the crop was somewhat delayed by the paper mulch.

Because of the color of wax beans the relative absence of soil on the pods from the mulched plots was more important from a market standpoint than on green pod beans. The pods on the north cultivated section were noticeably smaller than on the other sections.

Bush lima beans.—Seed of the Fordhook Bush variety was sown in hills 1 foot apart May 19. The plants were thinned to two in each hill. They were picked the first time on August 25 and again on September 6 and October 1. The weights given in Table 20 are for green pods not shelled beans.

TABLE 20.—Bush Lima Beans

Plot	Weight per hill	Increase over cultivated	First harvest	
			Weight per hill	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
North cultivated	0.638	.....	0.576	90
Paper No. 1	.870	1	.656	75
Paper No. 2	.986	14	.670	68
Papers Nos. 3–6	.948	10	.676	71
South cultivated	1.014	.....	.580	56
Average cultivated	.862	.....	.578	67

The increase in total yield of the mulched plots was relatively small when compared with the average of the cultivated sections. Compared with the north section alone there was more than 30 percent increase from the paper, but compared with the south end

there was a slight difference in favor of the cultivated section. The yield at the first picking, however, was about the same as from the north cultivated section, so the increased yield must have come later in the season. This late production accounts for the lower percentage of the total yield at the first harvest on the south cultivated plot. The paper mulched beans produced more per hill at the first picking than the cultivated plants, altho the percentage figures would seem to indicate that there was little difference in rate of maturity when the entire season was considered.

The beans at the first picking from the paper-mulched area were of better quality; as they were cleaner, more uniform in size, better filled, and slightly larger.

Early celery.—Seed of White Plume celery was sown in the greenhouse March 22, the plants shifted into flats April 11, and set in the garden 6 inches apart in the row May 2. The plants, altho small, had good root systems and produced good celery at harvest. The plots were blanched by placing a 1-foot wide piece of the black mulching paper on edge on each side of the row and holding it in place by wire wickets which straddled the row and paper. The celery was well blanched in 12 days and was harvested July 19. The weights given in Table 21 are for the celery trimmed and graded as for retail market (Fig. 9).

TABLE 21.—Early Celery

Plot	Weight per hill	Increase over cultivated	First harvest	
			Weight per hill	Portion of total harvest
	Lb.	*Pct.*	*Lb.*	*Pct.*
Cultivated	0.48	.....	0.55	68
Paper No. 1	.61	27	.67	85
Paper No. 2	.82	71	.69	95
Papers Nos. 3-6	.66	37	.68	91

At the time the paper was put up for blanching the plants on the paper mulch plots were 4 or 5 inches taller than those on the cultivated sections.

The paper mulched plots produced larger yields in average weight of all the stalks than the cultivated plots. The average weight of the No. 1 grade stalks was about one-fourth more than the same grade from the cultivated areas (Fig. 9). The paper mulch, moreover, produced a larger percentage of first grade stalks.

Late celery.—Plants of the Columbia variety were set in the field July 21, but because of the extremely dry weather during September this crop was a failure. Altho the plants were watered

when set it was necessary to reset several. The plants in the north cultivated section were much smaller on August 17 than those under the paper (Fig. 7).

Fig. 9.—A dozen representative stalks of early celery as trimmed for market from the cultivated and mulched sections of the garden. The two outside stalks are representative of the larger plants grown with paper mulch.

Early carrots.—Chantenay seed was sown with a drill May 1 for the early crop of carrots. The plants were thinned when about 6 inches high and had made a good growth by July 19, when all were harvested. The tops were not removed and the roots were washed and graded before the entire plant was weighed. Straight, smooth roots 1¼ inches or more in diameter at the crown and 3 inches or more in length, were placed in grade No. 1, and the smaller or crooked roots in grade No. 2. The largest roots were 2¼ inches in diameter and 5 inches long. No difference could be seen in the size of the tops, which were from 12 to 15 inches high and constituted about one-half the weight of plant.

TABLE 22.—Early Carrots

Plot	Total roots per foot of row		Increase in weight over cultivated	No. 1 roots
	No.	*Lb.*	*Pct.*	*Pct.*
Cultivated	5.19	1.23	.....	57
Paper No. 1	6.50	1.54	25	66
Paper No. 2	4.20	1.27	3	64
Papers Nos. 3–6	4.04	1.23	0	73

The wide variation in number of roots made it difficult to evaluate the data in Table 22. Within certain limits, when roots are farther apart in the row they grow faster and are larger at any given time than those closer together. Following this line of reasoning, we would expect such a series as is found when we consider the percentages of No. 1 roots from papers No. 3-6, paper No. 2, and cultivated. The results from paper No. 1, however, were an exception and might be offered as evidence to show that the plants grew faster under the paper mulch.

Since no evidence is available on the effect of stand on total yield, we can only conjecture as to what the yields might have been had all plots had the same stand. The data at hand suggest that there was little if any effect on the total weight from the paper mulch.

Late carrots.—The Chantenay variety was used for the late crop also, the seed being sown July 18. When four inches high the plants were thinned. At that time the stand was much poorer on the cultivated than on the mulched sections. Later in the season the height was noticeably greater on the paper mulched plots (Fig. 7). Because of the dry weather, growth was slow and when the roots were dug October 27 very few were larger than 1½ inches in diameter. Every root larger than ½ inch in diameter was harvested, the top removed and the root washed before being graded and weighed. All roots 1 inch or more in diameter were classed as No. 1, and all smaller than this as No. 2.

TABLE 23.—Late Carrots

Plot	Total roots per foot	Weight of roots per foot of row	Increase in weight over cultivated	No. 1 roots
	No.	*Lb.*	*Pct.*	*Pct.*
Cultivated	3.3	0.31	.....	72
Paper No. 1	6.0	.39	25	66
Paper No. 2	6.3	.32	3	34
Papers No. 3–6	7.0	.53	71	55

The stand on the cultivated sections was only about half that on the paper mulched sections. Obviously this was responsible for the greater part of the difference in yield between these treatments. In view of the poor stand one would expect to find a greater percentage of larger sized roots in the cultivated section. The black mulching papers materially increased the yield of roots per foot of row.

Dry onions from seed.—Yellow Danvers seed was sown with a drill May 1 and the plants later thinned to about five per foot of row. Conditions were favorable for their growth and ripening and the quality was good, altho the onions were not large. Very few were over 2½ inches in diameter. No difference in growth between the paper mulched and cultivated plots was noticed until about a month before harvest when the onions on the cultivated ends were darker green in color. The same difference, which persisted until harvest, was noted in the row of onions from plants and was probably the visible effect of some unfavorable growth condition in the soil, as the yield of dry onions was found to be lower under the paper mulch.

As soon as the majority of the tops had fallen over, August 14, the plants were pulled and allowed to lie on the ground until the tops were dry. The tops were then removed, the onions graded and weights recorded. All onions over 1½ inches in diameter and well cured were placed in grade No. 1, and all smaller ones were placed in grade No. 2.

TABLE 24.—Dry Onions From Seed

Plot	Bulbs per foot of row		Increase in weight over cultivated	Portion of No. 1, by weight
	No.	*Lb.*	*Pct.*	*Pct.*
Cultivated	4.0	0.62	.....	98
Paper No. 1	4.5	.41	—34	80
Paper No. 2	4.1	.37	—41	81
Papers No. 3-6	4.7	.55	—11	92

None of the paper mulches gave as large total yield or as large yield of No. 1 grade as cultivation. The black papers gave better results than No. 1 or No. 2.

Dry onions from plants.—Seed of the Sweet Spanish variety was sown in the greenhouse March 22. The plants were root pruned several times by cutting along each side of the row with a butcher knife. At planting time, May 1, they had well developed root systems and were slightly less than ⅛ inch in diameter, which is too small to plant conveniently. The tops were cut back to about 3 inches in length and the plants set 4 inches apart in the row.

Conditions were ideal for rapid growth and for proper ripening. As a result an excellent crop of well ripened bulbs was produced. They were pulled September 14 and cured in the barn loft after which the tops were removed and bulbs graded into four

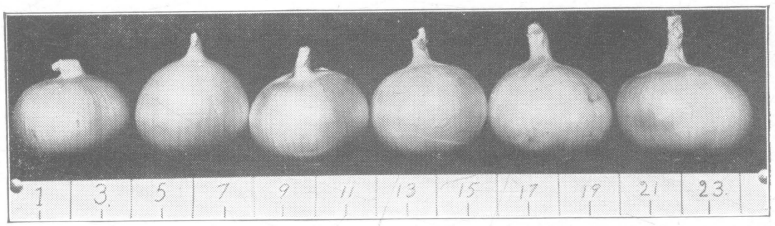

Fig. 10.—Six of the largest Sweet Spanish onions grown in the paper mulch garden in 1928 together weighed 6 pounds and measured 24 inches in diameter. Seed sown in greenhouse March 22; plants set in field May 1, 4 by 14 inches; and onions pulled September 17. Average weight .63 lb.

grades. Three grades were based on sizes as given in footnote of Table 25, and the fourth grade was called "doubles" from appearance of bulbs.

TABLE 25.—Dry Onions From Plants

Plot	Weight per bulb	Increase over cultivated	Portion by number in grade*			
			No. 1	No. 2	No. 3	Doubles
	Lb.		*Pct.*	*Pct.*	*Pct.*	*Pct.*
Cultivated	0.630	.....	29	52	1	18
Paper No. 1	.620	—1.6	13	54	10	23
Paper No. 2	.676	7	36	40	12	12
Papers No. 3–6	.636	1	34	45	5	16

*No. 1, 3½ inches or more in diameter; No. 2, 2½-3½ inches in diameter; No. 3, less than 2½ inches in diameter; doubles, from appearance.

There was little if any difference in yield or grade between the paper mulched and cultivated plots.

TABLE 26.—Early Potatoes

Plot	Total weight per hill	Increase over cultivated	Portion by weight of No. 1 grade
	Lb.	*Pct.*	*Pct.*
Cultivated	1.418	.....	69
Paper No. 1	1.500	5	71
Paper No. 2	1.810	27	79
Papers Nos. 3–6	1.720	21	79

Early potatoes.—Certified seed of the Irish Cobbler variety, cut into 2-oz. pieces was planted May 1 in hills 1 foot apart. The stand was almost perfect and the plots produced a fairly high yield of the finest quality tubers. When calculated on an acre basis with perfect stand the yield from the cultivated plots was 407 bushels per acre. At digging time all tubers less than 2 inches in diameter were placed in the second grade.

The entire plants were dead and dry on the north cultivated section when dug August 8, while those on the south cultivated section still retained a large percentage of their leaves. The leaves on the paper mulched plants had yellowed or dropped but the stems were still succulent.

The paper mulch increased the yield and the percentage of No. 1 grade tubers.

Yellow sweet corn.—Golden Bantam sweet corn was planted in hills 1 foot apart May 19. When the plants were about 4 inches high they were thinned to two plants in each hill.

Because of a misunderstanding, the corn was not harvested until the latest ears were ready for use, hence all the ears were pulled on August 14. Some ears were too mature for table use. The figures on percentage of plants tasselling and silking as given in the discussion on effect on early growth indicate the effect of the paper mulch on earliness of the crop.

TABLE 27.—Yellow Sweet Corn

Plot	Weight ears per hill	Increase in weight over cultivated	Average weight per ear
	Lb.	*Pct.*	*Lb.*
Cultivated	0.686		0.339
Paper No. 1	.906	32	.385
Paper No. 2	.778	13	.370
Papers No. 3–6	.876	27	.382

Table 27 shows a substantial increase in yield and average size of ear from the paper mulched sections. The average number of ears per plant was also slightly higher from these sections.

White sweet corn.—Country Gentleman sweet corn was planted in hills 1 foot apart May 19 and the plants later thinned to two in each hill. Harvests were made on August 20, 22, 24, and 30 and the ears graded into two sizes. Those under 5 inches in length or poorly filled were placed in grade No. 2; ears 5 inches or more in length and well filled were placed in grade No. 1.

TABLE 28.—White Sweet Corn

Plot	Weight per ear	Total weight per hill	Increase in weight over cultivated	Portion of total weight pulled on first two harvests	Portion by number of second grade
	Lb.	*Lb.*	*Pct.*	*Pct.*	*Pct.*
North cultivated	0.567	0.859		30	56
Paper No. 1	.629	.755	—17	0	73
Paper No. 2	.612	.980	7	18	81
Papers Nos. 3–6	.652	1.157	26	17	76
South cultivated	.662	.993		21	50
Av. cultivated	.605	.913		26	54

The average weight per ear was slightly larger on the paper mulched plots and the total weight per hill was also larger except on Paper No. 1. The percentage of second grade ears was lower and the crop as a whole was more rapidly matured than on the cultivated plots.

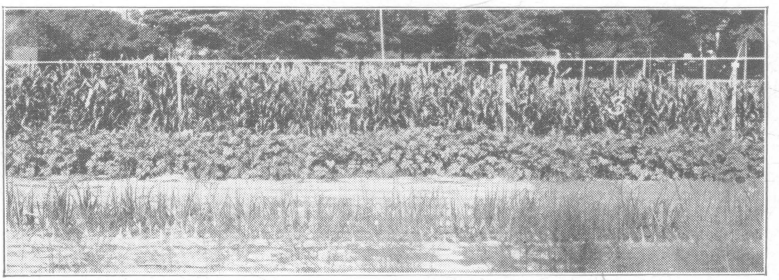

Fig. 11.—Shows the difference in height of sweet corn on paper mulched and cultivated plots, on July 20. Left to right between stakes, (1) black paper mulch No. 3, (2) light yellow and brown papers Nos. 1 and 2, (3) cultivated section at north end of garden. The white line above is 5½ feet from the ground.

Cucumbers.—Early Fortune cucumber seed was sown thickly in hills 2 feet apart June 28 and as soon as the first true leaves appeared the plants were thinned to two in each hill. The plants made rapid growth and were practically free from disease or insect injury. They were prematurely killed, however, by the dry weather of September.

TABLE 29.—Cucumbers

Plot	Average per hill		Increase over cultivated		No. 1 harvested first two pickings	
			No.	Wt.		
	No.	*Lb.*	*Pct.*	*Pct.*	*No.*	*Lb.*
Cultivated	8.0	6.24	.....	.....	3.03	2.93
Paper No. 1	11.6	9.94	45	59	4.10	4.01
Papers Nos. 3–6	10.6	9.06	32	44	4.81	5.10

The fruits were allowed to attain maximum size for slicing and were harvested on August 20, 24, 27, 31, September 6, and 14. They were graded into two grades; No. 1 contained all fruits 6 inches or more in length that were fairly straight and symmetrical and No. 2 those fruits less than 6 inches in length or badly crooked or misshapen. Some of the No. 1 grade were slightly over 10 inches in length and all were of excellent shape and quality.

No. 2 paper was not available so two lengths of No. 1 paper were used.

The paper produced a greater number and weight of cucumbers than cultivation.

Eggplant.—Seed of the Mammoth Purple variety was sown in the greenhouse March 22, shifted into flats and spaced 2¾ inches each way, and set in the garden May 19, three feet apart in the row. The cool wet weather of June prevented normal growth of this crop and as a result the set and total production was small. Harvests of all fruit as small as 4½ inches in diameter by 5 inches in length were made August 20, 31, and September 14. These three harvests form the early period referred to in Table 30. At the last harvest, October 3, all fruits larger than 2½ inches in diameter by 3 inches in length were removed.

TABLE 30.—Eggplant

Plot	Early yield per plant		Weight per early fruit	Total yield per plant		Increase over cultivated	
						No.	Wt.
	No.	*Lb.*	*Lb.*	*No.*	*Lb.*	*Pct.*	*Pct.*
Cultivated	1.15	2.37	2.06	2.05	3.08	.....	.....
Paper No. 1	1.25	3.01	2.40	2.00	3.68	— 2	19
Paper No. 2	1.38	3.03	2.27	3.00	4.25	46	37
Papers Nos. 3-6	1.80	4.47	2.48	3.13	5.42	52	75

The paper mulch produced more and larger early fruits and larger total yields.

Sweet peppers.—Early Giant sweet pepper seed was sown in the greenhouse March 22, the plants were shifted into flats 2¾ inches apart each way, and transplanted May 19 into the garden, 2 feet apart in the row. The cool wet weather in June retarded growth but a fair set of early fruit was secured. As soon as this early-set fruit was removed the plants made a new vegetative growth on which a good set of fruit was secured.

TABLE 31.—Sweet Peppers

Plot	Early yield per plant*			Total yield per plant			Increase in total yield over cultivated by	
	No.	Wt.	Av. wt.	No.	Wt.	Av. wt.	Number	Weight
	No.	*Lb.*	*Lb.*	*No.*	*Lb.*	*Lb.*	*Pct.*	*Pct.*
Cultivated	1.03	0.193	0.18	7.59	1.43	0.18	.....	.....
Paper No. 1	1.20	.160	.13	8.60	1.88	.21	13	31
Paper No. 2	0	0	0	7.40	2.05	.27	—2	42
Papers No. 3-6	1.58	.368	.23	10.40	2.34	.22	37	63

*Includes harvests of July 16, 24, and 31.

Three pickings, July 16, 24, and 31, removed about all the early-set fruit and the second cycle did not reach marketable size until August 20. Other harvests were made on August 31, September 12 and 24, and October 3 and 26. The fruits were allowed to remain until they were full size but still green in color. The average size was about 2½ inches in diameter by 3 inches in length.

The plants on paper No. 2 were a month later in maturing their first fruit than those of the other plots. The peppers which set late, however, reached a larger size.

The early fruit from paper No. 1 averaged much smaller than from the other papers or cultivation. The black mulching papers produced a much larger number and weight of early peppers per plant.

The paper mulches materially increased the number and total weight of fruit per plant and also the average size of fruit. The black papers were more effective in increasing the number and total weight of fruit than either paper No. 1 or 2.

Pruned and staked tomatoes.—Bonny Best was selected for the early crop, which was pruned to a single stem and tied to stakes. The seed was sown March 22, the seedlings shifted into flats 2¾ inches apart each way April 5, and set in the garden 2 feet apart in the row May 19. They were large plants just beginning to bloom when set and made a good vine growth in spite of the cool June. The set on the two lower clusters was rather light but that on the next three was heavy and matured before frost.

The first ripe fruit was picked July 19. Two or three pickings each week were made thereafter until September 24, when frost threatened and the vines were stripped of both green and ripe fruit. Fruits were removed as soon as the blossom end turned pink and sorted into two grades. All smooth, sound fruits 2¼ inches or more in diameter were placed in No. 1 grade and all smaller than this or misshapen were placed in No. 2 grade.

The plants under paper grew more rapidly than the cultivated ones, but when picking commenced it was evident that the larger vine growth was not producing the largest early yields. For the first month, the cultivated plots produced a larger number of ripe fruit and a slightly larger weight than the paper mulched plots. The average size of early fruit on the cultivated plots, however, was smaller.

The lower percentage of fruit picked during the first month indicates that larger size of plants on the black paper mulched plots was accompanied by later maturity.

TABLE 32.—Pruned and Staked Tomatoes

Plot	First month ripe fruit per plant		Weight per fruit	Portion of total weight		Ripe fruit per plant		Average weight per fruit	Increase over cultivated by		Green fruit per plant
				Picked first month	No. 1 grade				No.	Wt.	
	No.	*Lb.*	*Lb.*	*Pct.*	*Pct.*	*No.*	*Lb.*	*Lb.*	*Pct.*	*Pct.*	*Lb.*
Cultivated	9.70	3.05	0.314	48	91	17.62	6.27	0.355	.....	.....	0.91
Paper No. 1	8.40	2.99	.356	43	90	18.40	6.92	.376	4	10	1.35
Paper No. 2	8.20	2.74	.334	49	95	16.20	5.59	.340	−8	11	.65
Papers No. 3–6	8.46	2.89	.341	37	91	19.21	7.74	.405	9	23	13.0

There was practically no difference in percentage of No. 1 grade from the different plots and the only difference in quality was that of larger size in favor of the paper mulch, as shown in Table 32.

When the entire season's production is considered the black paper mulched plots produced a greater number and weight of fruits per plant and the average weight per fruit was also larger than from either of the other papers or from cultivation. Plots No. 1 and No. 3-6 had more green fruit on the vines at the end of the growing season than the cultivated section.

Paper No. 2 reduced both the number and total weight of fruits per plant below those of the other papers or cultivation.

Unpruned tomatoes.—The Marglobe was chosen for the mid-season crop of tomatoes. The plants were grown in the same manner and set out the same day as the Bonny Best but were spaced 4 feet apart in the row and were not pruned nor tied to stakes.

The first harvest of this variety was not made until July 30, but from this date on the fruits were picked on the same date and graded in the same way as the Bonny Best.

The paper mulched areas produced a larger number and greater weight of fruits during the first month of the picking season, as shown in Table 33. The average weight per fruit during this period, however, was slightly greater from the cultivated sections. There was very little difference in the percentages of the total weights harvested during this period.

The larger number of fruits per plant on the black paper mulched areas was reflected in a smaller average size fruit for the first month's harvest and also for the entire season. The percentage of total weight in No. 1 grade also indicates that there were more small fruits from the black paper plots.

The difference between plots in terms of total yield of ripe fruit was very small. At first glance it may seem strange that the increase was so small in comparison with other reported paper mulch experiments with this crop, but when we consider that the yield of the cultivated plants averaged more than 20 tons of ripe tomatoes per acre, it seems unreasonable to expect a large increase.

The reduction in number of fruits set under paper No. 2 resulted in a slight decrease in yield below that of the cultivated sections.

The smaller amount of green fruit per vine at the end of the season on the paper mulched plots indicates that these plants had practically completed their growing period while the cultivated plants were still setting fruit.

TABLE 33.—Unpruned Tomatoes

Plot	First month ripe fruit per plant		Weight per fruit	Portion of total weight		Ripe fruit per plant		Weight per fruit	Increase over cultivated by		Green fruit per plant
				Picked first month	No. 1 grade				No.	Wt.	
	No.	*Lb.*	*Lb.*	*Pct.*	*Pct.*	*No.*	*Lb.*	*Lb.*	*Pct.*	*Pct.*	*Lb.*
Cultivated	22.6	7.1	0.31	45	75	51	15.67	0.307	.....	.....	1.18
Paper No. 1	28.0	8.4	.30	51	74	67	16.47	.246	31.4	5.1	.45
Paper No. 2	28.3	8.0	.28	52	75	59	15.12	.256	15.6	—3.5	.50
Papers 3–6	27.6	7.9	.28	46	61	67	16.90	.252	31.4	7.8	.60

Late turnips.—Purple Top White Globe turnip seeds were sown July 18. The plants were later thinned to three or four per foot of row. Germination was fairly uniform but the plants at the south end of the garden grew more rapidly than those at the north end and consequently were larger at harvest. All roots 2¼ inches or larger in diameter were harvested October 9 and November 20. The tops and tap roots were trimmed off and the turnips weighed before washing.

TABLE 34.—Late Turnips

Plot	Roots per foot of row		Weight per root	Total roots per foot of row		Weight per root total	Increase over cultivated in wt. per foot of row
	No.	*Lb.*	*Lb.*	*No.*	*Lb.*	*Lb.*	*Pct.*
North cultivated	1.38	0.56	0.40	3.0	1.01	0.33	.....
Paper No. 1.....	1.00	.42	.42	2.7	.81	.30	—36
Paper No. 2..	1.00	.56	.56	2.3	.93	.40	—26
Papers 3-6	1.80	.89	.49	2.7	1.14	.42	—11
South cultivated.	2.01	1.26	.62	2.8	1.49	.53	.....
Average cultivated....	1.69	.91	.53	2.9	1.27	.43	.....

The paper mulch reduced the yield of the early harvested roots and also the total crop. It is evident that the yield increased from the north to the south cultivated, and for this reason the paper plots might be compared with the cultivated areas by the Thorne[4] method. This would give different percentages of decrease from those obtained from the average of the cultivated ends, but would still show higher yields for the cultivated plots.

Rutabaga.—American Purple Top rutabaga seed was sown in a row adjacent to the turnips on July 18. The plants were thinned as the turnips matured later. Few of the roots reached a diameter larger than 2½ inches, altho allowed to remain in the ground until November 20.

TABLE 35.—Rutabaga

Plot	Roots per foot of row		Increase in weight over cultivated
	No.	*Lb.*	*Pct.*
North cultivated	0.16	0.09	.....
Paper No. 1.....	.70	.46	119
Paper No. 2.....	.50	.34	62
Papers No. 3-6.....	.52	.30	43
South cultivated.....	.36	.32	.....
Average cultivated..	.26	.21	.. . .

The yield was poor and the increases based on the average of the cultivated ends were large. The lighter colored papers were more effective in increasing the yield of this crop than the black

[4]See footnote page 26.

papers. The high yield of the south cultivated section, however, can be partly explained by the fact that this end was more moist than the north end.

EFFECT OF PAPER MULCH ON SOIL MOISTURE[5]

Soil moisture was studied to determine first, whether there was any difference between the moisture content of the cultivated and paper mulched soils, and second, the effect that the impervious layer of paper might have on the distribution of moisture. In other words, would the soil under the paper midway between the 26-inch rows be as moist as that directly in the uncovered soil between the strips of paper? Samples were taken from plots growing snap pod beans and sweet corn for a comparison of the soil moisture and nitrate nitrogen content.

A composite sample of eight borings to a depth of 7 inches was taken at weekly intervals from the following locations in plots of wax beans and sweet corn:

In the cultivated row, midway between the hills
Between the cultivated rows, opposite samples in the row
In the mulched row, midway between the hills
Between the mulched rows, opposite samples in the row

The paper was loosened and laid back before the borings were made for the early samples between the rows on the paper mulched plots. Later in the season when the bean plants had reached mature size it was impossible to follow this system without injury to the plants, so the borings were made thru holes punched in the paper. The holes of succeeding samples were at least one foot from former holes.

The composite sample from the cultivated area consisted of four borings from each of the cultivated sections. The mulched samples were taken at equal intervals along and between the rows.

Samples in the row were taken from the row of wax beans; and samples between the rows, from the middle between the wax bean row and the adjacent row of green pod beans. The early crop of beans was removed August 2, after which the samples were taken in the late crop of beans. The first samples were taken August 8, when the plants were about 10 inches high; the last, September 29, after all the plants had been killed by frost on the 24th.

[5]Soil moisture and nitrate nitrogen determinations were made in the laboratories of the Department of Agronomy. The writer wishes to express his gratitude for this service as well as for helpful suggestions given by members of that department.

Samples were taken in the row of Golden Bantam sweet corn until August 9. Beginning with that date they were taken in the adjacent row of Country Gentleman corn. Between-the-row samples were taken in the middle between these two varieties. The last harvest of Golden Bantam was made on August 14, and of Country Gentleman on August 30. Samples were discontinued in the corn after September 24.

The period between the last rainfall and the time of sampling, the amount of rainfall at the last precipitation, and the amount of rain after last sampling influence the amount of moisture under the different treatments and in the various locations.

This information is given in Table 36 as an aid in interpreting the data in the following soil moisture and nitrate nitrogen tables. The weather record day closes at 5:00 p. m. Any rainfall between that hour and midnight is credited to the next day.

As mentioned in the discussion of the effect of the paper mulch on germination, it was apparent to the naked eye that the uncovered soil between the strips of paper was more moist than that in the cultivated rows. This difference was visible for 3 or 4 days following a rain. All the soil samples were taken to a uniform depth of 7 inches, so no data are available to show the regions in the soil profile where the greatest difference in soil moisture content occurred.

Flint,[6] in his work at Arlington, Va., found that the water conserving properties of paper mulch did not extend beyond the depth of 4 inches. Shaw[7] working at Berkeley, Calif., concluded that the paper mulch decreased the water losses from the upper 18 inches of soil, a large part undoubtedly coming from the upper 6 inches. Smith,[8] working at Davis, Calif., also concluded that "soil moisture differences were found to be confined to a depth of 4 inches and this difference was most marked during the early growth of the plants." Hartung[9] presented data which show that under Hawaiian conditions more water was conserved by the paper mulch in the upper 7½ inches of soil than in the section from 7½ to 20 inches deep.

From this brief summary one might conclude that a sample taken to a depth of 7 inches would cover the area of greatest soil moisture difference. Under the conditions of this experiment the majority of the plant roots would also be found in the top 7-inch soil section.

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[6]See footnote page 6.

[7]Shaw. C. F. 1926. The Effect of Paper Mulch on Soil Temperature. Hilgardia Vol. 1 No. 15 Calif. Exp. Sta.

[8]Smith, Alfred. Report of Calif. Agr. Exp. Sta. 1927. p. 91.

[9]Hartung, W. J. 1926. The Functions of Paper Mulch in Pineapple Culture. Hawaiian Pineapple Co., Ltd. Honolulu.

TABLE 36.—Rainfall and Soil Moisture in Cultivated and Paper Mulched Plots of Wax Beans and Sweet Corn

Sampling	Last rain before sampling		Rain since last sampling	Soil moisture						Favor between rows	
				In rows			Between rows				
				Cultivated	Mulched	Favor mulch	Cultivated	Mulched	Favor mulch	Cultivated	Mulched
Date	Date	In.	In.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Wax beans											
June 13	9	0.17	1.52	20.6	24.1	3.5	21.7	22.6	0.9	1.1	— 1.4
June 21	19	.13	.83	23.0	23.1	.1	21.9	23.0	1.1	—1.1	.0
June 28	27	.01	.16	18.8	19.0	.2	19.2	20.2	1.0	.4	1.2
July 7	5	1.33	2.15	20.4	22.6	2.2	20.2	21.6	1.4	— .2	— 1.0
July 12	11	.04	.16	16.4	19.0	2.6	16.8	19.0	2.2	.4	.0
July 19	19	.22	1.44	15.0	14.8	— .2	19.4	13.8	— 5.6	4.4	— 1.0
July 26	23	.08	1.07	14.4	17.6	3.2	17.2	18.0	.8	2.8	.4
Aug. 2	1	.46	.91	17.0	20.8	3.8	17.8	20.4	2.6	.8	— .4
Aug. 9	6	.04	1.85	18.6	20.6	2.0	17.8	18.0	.2	— .8	2.6
Aug. 31	30	.32	.48*	17.3	19.0	1.7	17.3	16.6	— .7	.0	2.3
Sept. 7	6	.27	.27	12.5	17.0	4.5	15.0	15.8	.8	2.5	1.1
Sept. 14	8	.01	.01	7.5	14.6	7.1	15.1	1.2†	—13.6†	7.6	—13.5
Sept. 22	20	.37	.38	6.6	7.6	1.0	12.6	8.4	— 4.2	6.0	.8
Sept. 29	25	.05	.09	10.6	20.4	9.8	13.2	19.6	6.4	2.6	— .8
Sweet corn											
June 13	9	0.17	1.52	21.3	22.5	1.2	20.8	22.4	1.6	— .5	— .1
June 21	19	.13	.83	21.9	22.9	1.0	22.2	22.2	.0	.3	— .7
June 28	27	.01	.16	19.0	18.0	—1.0	21.2	21.4	.2	2.2	3.4
July 7	5	1.33	2.15	19.2	20.0	.8	19.4	20.0	.6	.2	.0
July 12	11	.04	.16	14.2	16.2	2.0	15.8	17.2	1.4	1.6	1.0
July 19	19	.22	1.44	12.5	18.4	5.9	14.2	15.2	1.0	1.7	— 3.2
July 26	23	.08	1.07	17.6‡	10.2‡	—7.4	9.0	10.4	1.4	8.6	.2
Aug. 2	1	.46	.91	10.8	11.2	.4	12.4	14.4	2.0	1.6	3.2
Aug. 9	6	.04	1.85	15.4	16.6	1.2	13.6	13.4	— .2	—1.8	— 3.2
Aug. 31	30	.32	.48*	15.2	16.6	1.4	15.3	15.7	.4	.1	— .9
Sept. 7	6	.27	.27	5.8	3.2	—2.6	11.9	4.5	— 7.4	6.1	1.3
Sept. 14	8	.01	.01	5.2	9.0	3.8	4.1	2.2	— 1.9	—1.1	— 6.8

*In seven days previous.
†Obviously an error in sampling, as the corresponding samples in the row contained 14 6 percent moisture.
‡Also probably an error in sampling.

The results shown in Table 36 indicate that in the wax bean section the paper mulched soil contained more soil moisture both in the row and between the rows than the cultivated soil. Since the water that fell on the paper drained off into the small space in the row, we would expect this space to have more moisture for a period following rain than the cultivated area, in which the moisture would be absorbed where it fell, except perhaps as the plant foliage might direct a part of the rain into the space between the rows.

The higher moisture content of the cultivated areas between the rows on July 19, August 31, and September 22 may be explained by the fact that there had been a good rain within 48 hours of the time these samples were taken. The cultivated soil absorbed the rain as it fell while the paper mulched soil had to absorb it from the uncovered area in the row. The lateral diffusion thru the soil to a depth of 7 inches under the paper was apparently not as rapid as the diffusion downward in the cultivated soil.

The paper mulched soil both in the row and between the rows of sweet corn also had the greater soil moisture most of the time.

The samples from between the cultivated rows contained more moisture 10 out of 14 times for beans and 8 out of 12 for sweet corn than the samples from between the plants in the row.

The lower moisture content of the soil in the row might be expected as the result of several factors—namely: the faster loss of moisture from the slight ridge of the row than from the level cultivated space between these ridges, less absorption during periods of rainfall due to run-off and by leaves diverting rain into the space between rows and the use of more soil moisture by the greater mass of roots within the area between plants.

TABLE 37.—Soil Moisture in Wax Bean and Sweet Corn Plots Compared—In and Between Rows of Cultivated and Mulched Areas

Date	Percentage of moisture in rows						Percentage of moisture between rows					
	Cultivated			Mulched			Cultivated			Mulched		
	Corn	Beans	Favor beans	Corn	Beans	Favor beans	Corn	Beans	Favor beans	Corn	Beans	Favor beans
June 13	21.2	20.6	−0.6	22.5	24.1	1.6	20.8	21.7	0.9	22.4	22.6	0.2
June 21	21.8	23.0	1.2	22.9	23.1	.2	22.2	21.9	— .3	22.2	23.0	.8
June 28	19.0	18.8	— .2	18.0	19.0	1.0	21.2	19.2	−2.0	21.4	20.2	−1.2
July 7	19.2	20.4	1.2	20.0	22.6	2.6	19.4	20.2	.8	20.0	21.6	1.6
July 12	14.2	16.4	2.2	16.2	19.0	2.8	15.8	16.8	1.0	17.2	19.0	1.8
July 19	12.4	15.0	2.6	18.4	14.8	−3.6	14.2	19.4	5.2	15.2	13.8	−1.4
July 26	17.6	14.4	−3.2	10.2	17.6	7.4	9.0	17.2	8.2	10.4	18.0	7.6
Aug. 2	10.8	17.0	6.2	11.2	20.8	9.6	12.4	17.8	5.4	14.4	20.4	6.0
Aug. 9	15.4	18.6	3.2	16.6	20.6	4.0	13.6	17.8	4.2	13.4	18.0	4.6
Aug. 31	15.2	17.3	2.1	16.6	19.0	2.4	15.2	17.3	2.1	15.6	16.6	1.0
Sept. 7	5.8	12.5	6.7	3.2	17.0	13.8	11.8	15.0	3.2	4.4	15.8	11.4
Sept. 14	5.2	7.5	2.3	9.0	14.6	5.6	4.1	15.1	11.0	2.2	1.2	−1.0

In the paper mulched area of wax beans, however, the space between the rows had less moisture in 9 out of 14 samples than the space between plants in the row. Since all the water entered the soil in the mulched area thru the uncovered space in the row, we might expect this location to have a greater moisture content than the covered soil 13 inches away, particularly when the sampling was done shortly after a rain.

In the paper mulched area of sweet corn the results were not consistently in favor of either location. Of the 12 samples, 6 dates had a higher percentage of soil moisture in the row, 5 between the rows, and 1 the same.

The soil on which wax beans were growing contained more moisture most of the time than that on which sweet corn was growing. The bush beans evidently used less moisture from the upper 7 inches of soil than the sweet corn.

EFFECT OF PAPER MULCH ON SOIL NITRATES

A portion of each of the samples from which moisture determinations were made was used for the nitrate nitrogen analyses. After sifting a 200 gram portion thru a ¼-inch mesh sieve it was shaken with 1000 cc. of distilled water from 1½ to 4 hours. Nitrate determinations in duplicate were made on the filtrate, using the modified Devarda reduction method. The results of the nitrate determinations are recorded in parts per million of dry soil.

Figures on the nitrate nitrogen content of soil which is supporting plant growth are of limited value and of interest only because they supply an index of the amount of accumulation under different conditions or different crops. In view of the large number of plants and their uniform distribution on the cropped area it is not surprising then that the amount of nitrate nitrogen found in this soil is relatively low thruout the season and that the differences in most comparisons are small or inconsistent.

Flint[10] was unable to detect a greater quantity of nitrates in mulched than in unmulched soil supporting crop growth. He considered nitrate analyses of "limited significance as an index of soil fertility." He tested large, well-grown stalks of corn from the mulched plot and found an excess of nitrates in the plant tissues, whereas the smaller stalks from the cultivated area contained no excess or only a very slight trace. No significant difference was found in the soil nitrate nitrogen content of the two plots. From this he assumes that the "lack of nitrates on the unmulched soil was

[10]See footnote page 6.

a contributing cause of crop failure, while a substantial supply on the mulched soil was readily used up by the vigorous plants which it supported."

Hartung[11] and Stewart[12] each presented data to show that under Hawaiian conditions there was a greater nitrate nitrogen accumulation in paper mulched soil that was supporting a crop of pineapples than in cultivated soil. Hartung also found that nitrification was stimulated by paper mulch under certain conditions, the test being made on uncropped soil.

Considering the entire 14 samples taken in the row and between the rows of wax beans, Table 38, there seems to be no consistent or significant difference between the nitrate nitrogen content of the paper mulched and cultivated sections.

TABLE 38.—Nitrate Nitrogen in and Between Rows in Cultivated and Paper Mulched Soil, Parts per Million

Date	In rows			Between rows			In favor of between rows	
	Cultivated	Mulch	Favor mulch	Cultivated	Mulch	Favor mulch	Cultivated	Mulch
				Wax beans				
June 13	18.5	7.5	—11.0	9.0	14.2	5.2	—9.5	6.5
June 21	14.6	9.8	—4.8	33.5	19.3	—14.2	18.9	9.5
June 28	14.6	8.7	—5.9	20.9	21.6	.7	6.3	12.9
July 7	7.9	7.5	—.4	18.5	15.7	—2.8	10.6	8.2
July 12	6.7	7.5	.8	13.0	14.6	1.6	6.3	7.1
July 19	3.9	9.4	5.5	17.7	15.7	—2.0	13.8	6.3
July 26	2.0	17.7	15.7	13.0	5.9	—7.1	11.0	—11.8
Aug. 2	9.0	.4	—8.6	9.8	19.7	9.9	8.0	19.3
Aug. 9	23.2	9.8	—13.4	15.1	13.0	—2.1	—8.1	3.2
Aug. 31	5.9	9.8	3.9	13.8	9.8	—4.0	7.9	0
Sept. 7	17.7	13.8	—3.9	17.5	16.9	—.6	—.2	3.1
Sept. 14	13.4	29.1	15.7	19.3	15.7	—3.6	5.9	13.4
Sept. 22	13.8	15.3	1.5	11.8	13.8	2.0	—2.0	—1.5
Sept. 29	14.6	18.9	4.3	23.2	13.8	—9.4	8.6	—5.1
				Sweet corn				
June 13	12.6	9.0	—3.6	16.9	13.0	—3.9	4.3	4.0
June 21	11.8	5.9	—5.9	6.7	12.2	5.5	5.1	6.3
June 28	13.4	14.6	1.2	19.7	18.5	—1.2	6.3	3.9
July 7	7.1	7.5	.4	13.8	15.7	1.9	6.7	8.2
July 12	4.3	3.8	—.5	11.8	6.7	—5.1	7.5	2.9
July 19	3.9	6.7	2.8	5.9	3.9	—2.0	2.0	—2.8
July 26	2.4	5.5	3.1	3.9	6.7	2.8	1.5	1.2
Aug. 2	5.9	9.0	3.1	5.9	8.3	2.4	0	—.7
Aug. 9	7.9	5.9	—2.0	5.9	9.8	3.9	—2.0	2.9
Aug. 31	4.3	8.3	4.0	9.0	7.1	—1.9	4.7	—1.2
Sept. 7	9.8	24.0	14.2	11.8	13.8	2.0	2.0	—10.2
Sept. 14	7.9	10.6	2.7	6.7	13.8	7.1	—1.2	3.2

There is an indication that in-the-row samples of the cultivated section had more nitrate nitrogen for the first month than the mulched section. The nitrate nitrogen of the soil in the row on the

[11]See footnote page 46.

[12]Stewart, G. R., E. C. Thomas, and John Horner. 1926. Effects of Mulching Paper on Hawaiian Soils. Soil Science, Vol. XXII No. 1. pp. 37-59.

cultivated section decreased as the early crop of beans matured, first 8 samples, while the mulched section content remained fairly consistent.. Altho the differences were small, they were fairly consistent. The between-the-row cultivated samples had a higher nitrate nitrogen content than the mulched area samples for the late crop of beans, last 6 samples.

TABLE 39.—Nitrate Nitrogen in Soil of Sweet Corn and Wax Bean Plots Compared—In and Between Rows on Cultivated and Mulched Areas

Date	Parts per million in rows						Parts per million between rows					
	Cultivated			Mulched			Cultivated			Mulched		
	Corn	Beans	Favor beans	Corn	Beans	Favor beans	Corn	Beans	Favor beans	Corn	Beans	Favor beans
June 13	12.6	18.5	5.9	9.0	7.5	— 1.5	16.9	9.0	—7.9	13.0	14.2	1.2
June 21	11.8	14.6	2.8	5.9	9.8	3.9	6.7	33.5	26.8	12.2	19.3	7.1
June 28	13.4	14.6	1.2	14.6	8.7	— 5.9	19.7	20.9	1.2	18.5	21.6	3.1
July 7	7.1	7.9	.8	7.5	7.5	.0	13.8	18.5	4.7	15.7	15.7	.0
July 12	4.3	6.7	2.4	3.5	7.5	4.0	11.8	13.0	1.2	6.7	14.6	7.9
July 19	3.9	3.9	.0	6.7	9.4	2.7	5.9	17.7	11.8	3.9	15.7	11.8
July 26	2.4	2.0	— .4	5.5	17.7	12.2	3.9	13.0	9.1	6.7	5.9	— .8
Aug. 2	5.9	9.0	3.1	9.0	.4	— 8.6	5.9	9.8	3.9	8.3	19.7	11.4
Aug. 9	7.9	23.2	15.3	5.9	9.8	3.9	5.9	15.1	9.2	9.8	13.0	3.2
Aug. 31	4.3	5.9	1.6	8.3	9.8	1.5	9.0	13.8	4.8	7.0	9.8	2.8
Sept. 7	9.8	17.7	7.9	24.0	13.8	—10.2	11.8	17.5	5.7	13.8	16.9	3.1
Sept. 14	7.9	13.4	5.5	10.6	29.1	18.5	6.7	19.3	12.6	13.8	15.7	1.9

The mulched section had a higher nitrate nitrogen content "in the row" in 8 of the 12 samples, and in 7 of the 12 samples between the rows.

In the early crop of beans, first 8 samples, the samples taken between the rows had a higher nitrate nitrogen content than those taken in the rows, both in the cultivated and paper mulched sections, in 7 of the 8 samples. There was no consistent difference in the late crop results.

The differences were also in favor of the samples between the row on Golden Bantam sweet corn in 6 of the first 8 samples. The differences were not consistently in favor of either location on the last 4 samples.

This indicates that conditions were more favorable during the growth of the early crop for the accumulation of nitrate nitrogen in the space between the rows than in the spaces between plants in the row.

The nitrate nitrogen content in the row, shows that the cultivated area in beans had a higher content than that in corn in 10 out of 12 times. In the mulched area the difference was not so marked in favor of the beans, being only 7 out of 12 times.

Of the samples taken between the rows on only 1 date of the 12, in either the cultivated or mulched area, was the content of nitrate nitrogen higher in the corn than in the bean plot, thus emphasizing the fact that the soil in which beans were growing was higher in nitrates, most of the time, than was that in which sweet corn was growing.

EFFECT OF PAPER MULCH ON SOIL TEMPERATURE

A Friez double lead thermograph was used to record the soil temperature under the black paper mulch and in the cultivated soil. The thermograph cylinders were placed crosswise of the row 16 feet apart and between two cauliflower plants as shown in Figure 12. The top of the cylinder was buried 2 inches below the surface of the soil.

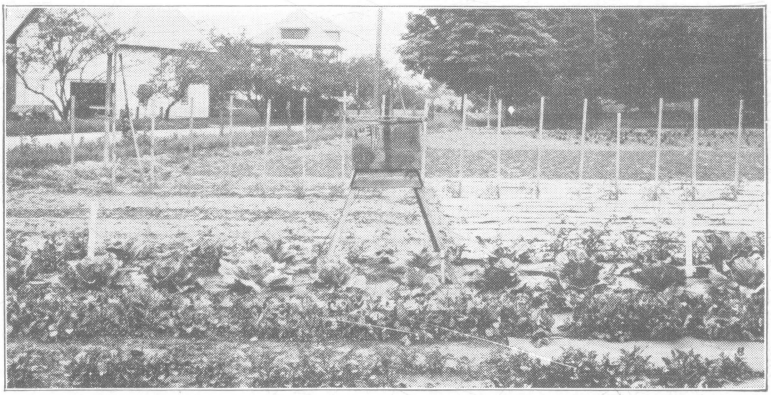

Fig. 12.—Showing location of thermograph shelter and leads in south end of paper mulch garden. The short white stakes indicate the position of the thermometers between cauliflower plants.

Records were taken from May 11 to July 26, when it was necessary to remove the thermograph for repairs. The daily mean soil temperature given in Table 40 is the mean of 12 readings at 2-hour intervals from the thermograph records, starting at midnight for each calendar day.

The daily mean air temperature was also calculated from 12 readings at 2-hour intervals from charts of an air thermograph stationed 400 feet from the garden in a standard U. S. Weather Bureau shelter. There was considerable lag in this record, behind the open air temperature above the thermograph leads. The exact amount was not determined.

The percentage of possible sunshine was calculated from the records of a Friez sunshine recorder located at the Administration Building, which is about a mile from the garden. These figures represent the fractional portion of the possible period of sunshine each day to which this instrument is sensitive. It gives no indication of the intensity or available solar energy of the light and is therefore only a rough measure of this important factor in the study of soil temperatures under paper mulch.

TABLE 40.—Air Temperature, Mean Soil Temperature in Cultivated and in Paper Mulched Areas, Sunshine, and Rainfall—Daily for May, June, and July

Date	Air temperature			Soil temperature—mean			Sunshine	Rainfall
	Max.	Min.	Mean	Mulched	Cultivated	Difference		
May							*Pct.*	*In.*
12	54	35	43.6	54.6	49.4	5.2	Part clear	
13	59	31.5	46.6	55.7	49.2	6.5	Clear	
14				55.8	49.8	6.0	Clear	
15				57.6	52.5	5.1	Clear	
16				58.0	55.2	2.8	Cloudy	0.07
17	75	60	66.4	59.8	58.3	1.5	Part clear	.01
18	77	60	67.5	63.3	61.8	1.5	Cloudy	.14
19	81	60.5	66.2	64.6	63.9	0.7	Part clear	.12
20	71	55	62.6	64.8	62.9	1.9	Clear	.52
21	77	49	63.0	66.8	62.3	4.5	Clear	
22	75	49	62.2	67.5	62.0	5.5	Clear	
23	60.5	39.5	52.1	62.5	56.7	5.8	Clear	
24	59.5	35	47.1	56.1	51.6	4.5	Part cloudy	
25	63	45	51.3	56.2	53.5	2.7	75	.24
26	68	45	53.6	57.7	53.9	3.8	88	
27	66	47.5	55.1	58.7	55.5	3.2	100	T†
28	66	43	51.1	57.9	54.8	3.1	61	.01
29	67	40	52.6	54.7	52.4	2.3	54	T
30	66	45	54.9	56.9	55.1	1.8	88	T
31	71	40.5	55.6	59.8	57.1	2.7	100	.15
June								
1	73	47	60.7	59.5	57.4	2.1	75	T
2	65	43	56.2	59.9	57.0	2.9	100	.08
3	63	37	52.2	56.3	53.6	2.7	100	
4				51.6	51.2	.4	0	1.13
5				55.7	55.7	.0	0	.32
6				56.2	56.2	.0	0	.82
7	66	50	56.7	57.5	56.7	.8	70	.21
8	64	50	55.8	55.0	54.0	1.0	30	.20
9	68	49.5	61.9	58.3	58.1	.2	54	.23
10	62	45	53.8	59.0	56.6	2.4	100	
11	70	42.5	53.2	61.9	58.2	3.7	100	
12	78	49	64.7	64 8	62.5	2.3	100	
13	84	64	73.3	70.6	68.2	2.4	100	
14	73	60	65.6	68.0	65.8	2.2	61	.03
15	65	46	56.9	65.6	62.0	3.6	100	
16				62.8	59.6	3.2	100	
17				67.4	64.6	2.8	100	
18	72	65	68.1	65.0	64.0	1.0	0	.63
19	72	62.5	67.3	65.9	65.3	.6	46	.06
20	81	61.5	70.5	68.0	67.8	.2	70	
21	79	62	71.3	69.5	69.0	.5	80	
22	82	59	70.0	69.1	68.2	.9	92	
23	76	61	70.0	68.2	67.5	.7	88	.38
24	76	56	66.4	66.2	65.6	.6	88	.02
25	73	55.5	58.3	65.0	64.2	.8	70	T
26	63	55	58.8	60.3	59.2	1.1	38	.05
27	77	53	64.0	63.7	63.2	.5	100	
28	74	52	64.2	62.9	61.5	1.4	75	T
29	77	61.5	65.8	63.7	63.7	.0	30	1.00
30	77	60	67.4	64.3	65.3	−1.0	75	.01

TABLE 40.—Air Temperature, Mean Soil Temperature in Cultivated and in Paper Mulched Areas, Sunshine, and Rainfall—Daily for May, June, and July—Continued

Date	Air temperature			Soil temperature—mean			Sunshine	Rainfall
	Max.	Min.	Mean	Mulched	Cultivated	Difference		
July							*Pct.*	*In.*
1	84.5	57	70.2	65.6	66.5	−0.9	100	.....
2	84	61	74.0	67.9	68.9	−1.0	100	T
3	87	66	75.6	70.0	70.4	− .4	100	....
4	88.5	70	77.6	72.0	72.7	− .7	100	....
5	79	62	71.1	69.5	70.4	− .9	75	1.33
6	81	57	69.4	67.4	68.9	−1.5	100	.....
7	90	59	74.4	72.1	72.7	− .6	100	.....
8	91	66	77.9	75.1	75.0	.1	100	.....
9	85	70	74.2	74.3	73.2	1.1	88	.08
10	85	67	75.0	72.9	72.2	.7	100	.....
11	88	64	75.1	72.1	71.5	.6	92	.02
12	80	62	70.2	70.3	70.0	.3	100	.....
13	67	58	62.8	62.0	61.6	.4	0	1.04
14	71	57	61.9	62.6	62.1	.5	38	.03
15	80	55	67.5	66.1	65.1	1.0	100	T
16	86	60	72.1	70.5	69.3	1.2	100	.....
17	89	58	73.1	73.7	71.3	2.4	100	.....
18	89	62	76.2	76.1	73.2	2.9	100	.....
19	90	70	78.0	79.4	76.4	3.0	69	.17
20	92	69	75.9	79.6	76.1	3.5	61	.05
21	91	69	76.9	77.3	76.9	1.4	61	.60
22	85	68	75.3	77.1	75.1	2.0	75	.05
23	82.5	65	72.5	77.2	74.7	2.5	100	.03
24	85	61	70.9	76.4	73.4	3.0	100	.....
25	87	60	72.2	77.1	73.5	3.6	100	.....
26	88	64	74.5	78.4	74.3	4.1	75	.....
27	85	66	73.0	77.1	73.4	3.7	....	.....

*Incomplete or no record.
†Trace of rain.

The rainfall records cover the period from 5:00 p. m. of the preceding calendar day to 5:00 p. m. of the current calendar day. The depressing effect of rain on soil temperature between 5 o'clock and midnight would be reflected in the day preceding that on which the rainfall is recorded. The exact time of starting and stopping of each rain for the 24 hours is not given on the weather records and it is therefore impossible to correlate accurately rainfall with the rise or fall of soil temperature. The rainfall figures given, however, are of some value in interpreting the soil temperature results.

Results.—The entire record at 2-hour intervals is too voluminous to be given in this report and has been condensed into daily means in Table 40. Figures 13 and 14 show graphically the soil temperature fluctuations during selected weekly and daily periods.

Of the 78 days on which complete records were obtained, 67 showed a higher daily mean soil temperature under the paper mulch, 8 had the higher daily mean temperature under the cultivated soil, and on 3 days there was no difference. The 8 days in which the cultivated soil was the warmer were between June 29 and July 8.

The harvesting record of the cauliflower shows that the two heads adjacent to the thermometer cylinder in the cultivated section were cut on the morning of June 29, whereas the head on the south side of the thermometer cylinder in the paper mulched area was not cut until the morning of July 9. When the heads were cut the remaining leaves were stripped from the stalks. The shading effect of the mature cauliflower plant on the paper mulched area was sufficient to cause the lower temperature during the middle of the day and the lower daily mean.

During bright days in May when the air and soil temperatures were low the mulched plot was as much as 8.5° warmer. The maximum temperature and maximum differences usually occurred between 2:00 and 4:00 p. m.

With higher air and soil temperatures the differences were not as great on bright days in July as in May. A part of this smaller difference may be attributed to the accumulation of soil on the paper which lightened the color and reduced the efficiency of the paper in absorbing the solar energy.

The duration and intensity of the sunlight appear to be the determining factors in the amount of difference in soil temperature due to the black mulching paper. There was a close correlation between the percentage of possible sunlight and the daily mean difference in favor of the mulched area in spite of the fact that no data were secured on the intensity or radiant energy content of the light.

A period of two or three days in succession without sunshine, such as June 4, 5, and 6, resulted in no difference in daily mean temperature.

The effect of a cloudy portion of the day in reducing soil and air temperatures is graphically shown in Figure 14. A cloudy period from 9:30 to 10:30 a. m. caused a marked decrease in temperatures. A longer cloudy period from 11:00 a. m. to 2:00 p. m. on May 24 resulted in a greater decrease in temperatures.

A series of partly cloudy days decreased the daily mean difference in soil temperature due to the mulching paper, as can be seen by referring to the periods of May 16-19, May 24-30, and June 18-30.

Heavy rains or continued cold showers also decreased any difference in soil temperature that might have accumulated. See data for June 4, 18, 20, and July 21, and Figure 13. The periods of May 20-23 and July 15-18 on the other hand, clearly indicate that a

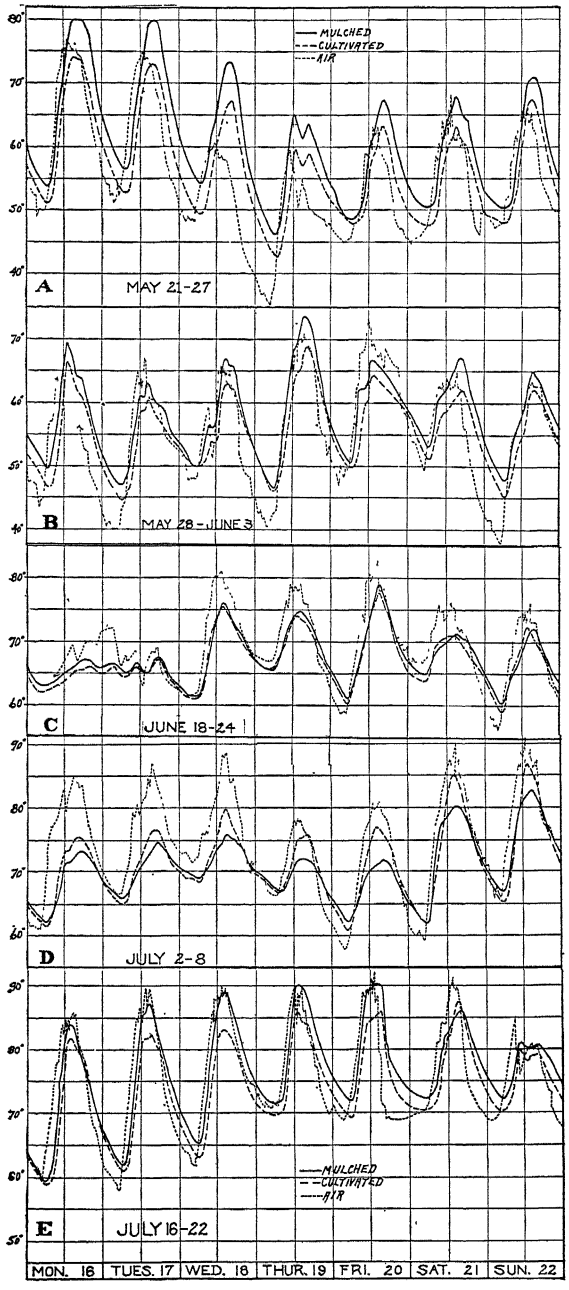
MULCHED
CULTIVATED
AIR
A
MAY 21-27
B
MAY 28-JUNE 3
C
JUNE 18-24
D
JULY 2-8
E
JULY 16-22
MULCHED
CULTIVATED
AIR
MON. 16
TUES. 17
WED. 18
THUR. 19
FRI. 20
SAT. 21
SUN. 22

Fig. 13.—Temperature records reproduced from thermograph sheets showing the difference between soil temperature of cultivated soil and paper mulched soil

A. The record for a week characterized by a period of rather high air temperature followed by a day of very low air temperature, which in turn was succeeded by a period of rising temperature. First three days and Sunday were clear with bright sun, middle three were partly cloudy. A light frost occurred on the 24th. Note the sharp drop in soil and air temperature caused by a cloudy period extending from about 11:00 a. m. until 2:00 p. m. on the 24th. The decrease in difference in soil temperatures on the morning of the 25th was caused by a rain of 0.24 inch which started sometime after midnight.

B. Shows the effect of a period of low temperatures and partly cloudy days on air and soil temperatures. Monday afternoon alternately clear and cloudy with light showers. Bright sun 3:40 to 5:35. Tuesday morning at 11:00 a light shower occurred and after 1:50 the afternoon was more or less cloudy. On Wednesday, note the effect of a shower of rain about 2:00 a. m. and a dark cloudy threatening rain period between 9:30 and 10:30 a. m. A light rain finally materialized sometime during the night bringing the soil temperatures down together. Thursday was clear and bright. Friday was characterized by periods of overcast sky interspersed by periods of bright sunshine. A rain of 0.08 inch accompanied by a high cold northwest wind Saturday night greatly lowered the temperatures. Saturday and Sunday were clear and bright altho the intensity of the light varied greatly on Saturday.

C. Two cloudy and rainy days reduced the difference between the soil temperatures and a series of partly cloudy days failed to establish any marked difference in the soil temperatures following such a period when the minimum air temperatures were rather high. Monday was cloudy all day and was preceded by a warm rain during Sunday night. Tuesday was likewise cloudy but for short periods the sun shone. A hard shower during the middle of the day brought the mulched and cultivated soil down to the same temperature. The remainder of the week was characterized by partly cloudy days.

D. This record shows the effect of shading on soil temperatures during a period of bright sunshiny weather. The cauliflower on both sides of the cultivated thermograph cylinder were harvested and plants removed on June 29 while the one on the south side of the paper mulched thermograph cylinder was not cut until July 9.

E. This record shows the difference in temperature between paper mulched and cultivated soil on which no plants were growing during a period of high air temperatures. The first three days were clear and bright while the last four were bright during the middle of the day but cloudy during early morning and late afternoon. The humidity was kept high by thunder showers during the night.

series of bright sunshiny days following a period of cloudy or partly cloudy days greatly increased the difference in soil temperature due to the paper covering.

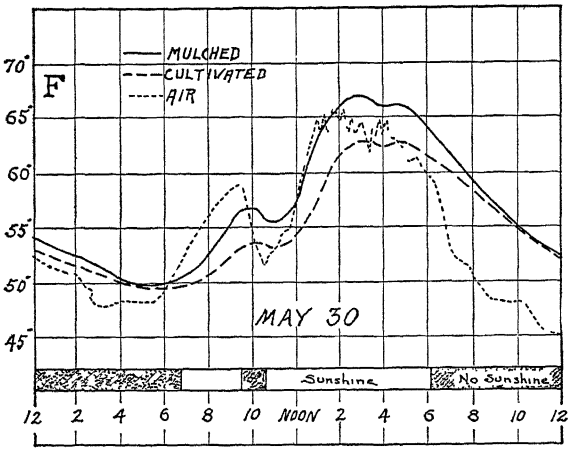

Fig. 14.—F. Temperature record reproduced from thermograph sheet for May 30, showing the effect of a shower about 3:00 a. m. in reducing difference in temperature between cultivated and paper mulched soil and, the effect of a cloudy period between 8:30 and 10:30 a. m. in lowering air and soil temperatures.

Stewart and co-workers[13] reported the same effect of sunshine and rain on the difference in temperature between cultivated and mulched soils under Hawaiian conditions.

DISCUSSION OF RESULTS

The test of different kinds of paper demonstrates that all papers sold or recommended for soil mulching purposes are not equally valuable, altho all in this trial controlled the weeds in the area covered by them. These results should also be taken as a warning to purchasers to buy only those brands guaranteed by the manufacturer, or proved by previous use, to contain no volatile or water soluble materials harmful to plants. They also emphasize the need for unbiased testing of the new kinds of mulching papers as they appear on the market.

None of the lighter weight papers now on the market were used in this test, hence no data are available on their use. Judging

[13]Stewart, G. R., E. C. Thomas, and John Horner. Some Effects of Mulching Paper on Hawaiian Soils. Soil Science, Vol. XXII, No. 1 July 1926. pp. 35-59.

from the experience with the heavier, or Type B, paper, however, it is doubtful whether they will prove practical for use where it is necessary to walk upon them.

The best of the heavier papers used in these experiments would probably have withstood another season's wear if allowed to remain in place over winter but their value for re-use was materially reduced in removing them. The paper had become so brittle when dry that it was impossible to roll it without breaking. The task of removing the paper while wet in the late fall with a view to using it again was very disagreeable.

The results on yield, earliness, and quality show that most of the 31 crops of the 19 vegetables grown responded favorably to use of the black mulching papers, altho the results in terms of percentage increases are not as large as most of those reported in the literature of the paper companies.

The few crops in this experiment which did not respond favorably to the use of the black mulching paper raise the question of why some plants respond favorably and others do not. A study of the changes brought about in the environment of the plant by the use of mulching paper throws some light on this question, but not until we know the optimum environmental conditions and the effect on vegetable plants of changes in each of the factors making up the plant's environment can we completely answer the question.

The early yellowing of the onion foliage on the paper mulched area is suggestive of a nitrogen shortage, which may in turn have been caused by soil temperatures detrimental to nitrification at a rate to take care of the normal demands of this crop.

The detrimental effect of high temperatures on the successful growth of head lettuce is well known. It is reasonable, therefore, to suppose that the increase in temperature of the mulched soil was at least partially responsible for the reduction in the yield of head lettuce grown from seed. The same reasoning might attribute the reduction in yield of paper mulched late turnips to the same cause, since moisture, a limiting factor on the late crops, was higher under paper than in the cultivated soil.

In view of the abundant moisture supply during the first 2½ months of the growing period, the greater amount of moisture under the mulch apparently was not responsible for the larger yields of the mulched vegetables that matured during this period. The differences in nitrate nitrogen content of the soil during the period were hardly consistent or large enough to warrant placing

much importance on them as a factor responsible for the increase in yield from the paper mulch. It would seem then that under these conditions the difference in soil temperature might be the most important single factor in increasing the yield of these early maturing crops. The fact that the rate of growth is increased by rise in temperature, within limits, lends credence to this conclusion.

Those crops most sensitive to difference in temperature, presumably those we class as warm season or frost tender, would likewise be expected to give the greatest response from the use of paper mulch, other factors being equal. The time of planting and harvesting being different, the data in this report are not comparable; but the results of this and other work under similar conditions seem to indicate greater benefit from the warm season crops.

The greatest differences in temperature between cultivated and paper mulched soil were found under conditions of relatively low soil and night air temperatures with bright sunshiny days. Fortunately these conditions are normal in Ohio in the early spring when the difference in temperature is most effective in increasing the earliness of the spring crop, thus enabling it to reach market early; and again in the fall, aiding the late crop to reach maturity before frost.

The soil moisture conserved by the paper mulch is especially valuable during periods of moisture shortage. This year's results indicate that under extreme conditions it may mean the difference between practically no crop and fair crop. On the other hand this moisture conserving ability of paper mulch proved detrimental in the 1924 experiments. In that year an excessive amount of rain fell during the early part of the growing period and the soil under the paper was practically saturated for several weeks.

In conclusion, then, paper mulch seems to have merit under Ohio conditions in the culture of early, quickly-maturing crops, for the warm season crops, and in periods of moisture shortage.

The disadvantages of paper mulch are its cost and the fact that no machinery is available to make its use practical on a large scale. Lowered costs of material and the production of inexpensive tools with which to lay the paper and for planting seed and plants thru it may result in marked changes in the production of some crops.

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