EVAPORATION AND TRANSPIRATION
FROM WINTER WHEAT PLOTS

by

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INTRODUCTION

Production of an agricultural crop is dependent upon an available supply of water during the growing season. Little of this water is actually combined into plant material with evapotranspiration being responsible for the bulk of the water used. Evapotranspiration consists of evaporation from the plant surface, called transpiration, and evaporation from the soil surface. At the present time there seems to be relatively little that can be done to limit the moisture movement through the plant. The other alternative for reducing water loss is to reduce evaporation from the soil surface. To see how practical this is, we must know what portion of the total evapotranspiration is due to evaporation and what is due to transpiration.

The total amount of water needed by a growing crop in the field can be measured fairly easily, particularly if the amount of water received by the crop can be controlled or evaluated. In the past it has been difficult to separate the amount of soil water transpired by the plant from the amount lost by evaporation from the soil. Recently developed plastic films allow air movement through the film but restrict the movement of water molecules. Studies utilizing this type of plastic film have shown that evaporation may account for as much as one-half of the total evapotranspiration. Therefore, reducing the amount of evaporation would appear to be a highly significant means of conserving soil moisture.

The purpose of this study was to experimentally estimate the amount of water lost by evaporation from a winter wheat crop under Oklahoma conditions and to study some of the factors affecting evaporation from the soil surface.

REVIEW OF LITERATURE

Measuring Evaporation

Evaporation of water from soils has been the subject of much controversy for a long time (1) 1/. This is especially true from the point of view of the practical significance of water losses by evaporation and methods for controlling or minimizing such losses.

Loss of moisture from the soil surface has generally been considered small in comparison with that transpiring from plants (21, 23, 28). Most losses by evaporation are included in evapotranspiration or consumptive use measurements. Many methods of estimating evapotranspiration have been developed, such as those of Penman (28) and Blaney and Criddle (2). However, these procedures do not give an estimate of the amount of water lost by evaporation.

Evaporation from bare soil has been approached through a study of evaporation from open water, seeking an absolute relation between weather conditions and water evaporation, and comparative relations between losses from the soil and losses from open water exposed to the same weather. Relationships of this kind have been established where the soil is adequately supplied with moisture. Penman (28) calculated that water loss from moist bare soil

1/ Figures in parenthesis refer to Literature Cited, page 37.

was 90% of that from a free-water surface. Evaporation under some conditions may even be more rapid than from open water, because the soil with its minute irregularities presents a larger evaporating surface (36). As long as the soil can supply water to the surface fast enough to keep it moist, this rate of loss persists (31). As soon as the surface dries, the rate drops sharply (20, 36, 27, 31, 38) to as low as one-tenth of the previous rate according to Russell (31). The loss of moisture from unsaturated soil is more dependent upon soil factors than meteorological conditions (1). Therefore, evaporation from a soil surface under most soil conditions cannot be correlated conveniently with free-water evaporation.

The amount of moisture retained by fallow plots has been widely used to estimate evaporation. Mathews and Cole (26) state that in the Great Plains it is possible to store only 20 to 25% of the precipitation. At Goodwell, Oklahoma, Finnell (11) estimated that 65.8% of the rainfall was lost by evaporation. In a study at College Station, Texas, Fisher and Burnett (12) found that on small bordered plots of clay loam, over 60% of the rainfall failed to become stored moisture. Experiments at Spur, Texas, on plots similar to those at College Station, Texas showed that the first year of fallow retained 50.6% of the moisture received, while the second year of fallow on the same plots lost an amount equal to 104% of the moisture received that year (9). Fortier (13) found that evaporation from soil tanks with a water table at 16 inches was only 2.6 inches less than from a free-water surface. At Rothamsted, England (31), fallow drain gauges during the summer averaged losing 1/2-inch of water in the first 5 days following a rain. The rate then dropped to about one-twelfth to one-twentieth inch per week. Burr (6) reported that only 10 to 33% of the season's rainfall could be stored by summer fallowing in western Nebraska and that a rainfall of 1/2-inch or less is entirely dissipated by evaporation unless the surface soil is still moist from a previous rain.

Evaporation from a soil surface is believed to be reduced when vegetation is growing on the soil (23). As noted before, most workers have felt that loss of moisture by evaporation is small in comparison with transpiration. However, relative water losses by evaporation and transpiration in field corn have been determined by several workers (18, 29, 32) by the use of a plastic ground cover, and it was found that as much as 50% of the evapotranspiration during the period measured could be accounted for by evaporation from the soil surface.

Shaw (32) has criticized the method of subtracting transpiration (measured in the plastic covered plots) from evapotranspiration (measured in the natural plots) to obtain estimates of evaporation. He maintains that the differences in microclimate between the two treatments are too great to justify the results obtained. However, Peters and Russell (29) and Harrold et al. (18) believe that the differences can be accounted for and that this is a good method for estimating the magnitude of evaporation in a growing crop.

Factors Affecting Evaporation

Evaporation of water from soil is controlled by meteorological and soil factors. The rate of evaporation is proportional to the difference in vapor pressure between the air immediately at the evaporating surface and in the air above (37). Any meteorological or soil effect that tends to increase the vertical vapor pressure gradient at the soil surface will increase evaporation (1). Lemon (25) has named radiant energy, wind speed, relative humidity, and temperature as the most important meteorological factors.

Soil factors assume the dominant role in evaporation after the soil surface dries. Baver (1) has stated that the degree of saturation with moisture is the most important soil factor. Other factors are soil particle size, state of aggregation, soil color, soil temperature and temperature gradients, soil depth, and soil stratification (1, 21).

Energy from the sun is the major factor in the evaporation process (1). Heat is used up to satisfy the requirement for specific heat by water as the temperature is raised and to provide the latent heat of vaporization. Richards (30) points out that for every gram of water evaporating from the soil surface, a quantity of heat energy equivalent to approximately 580 calories is lost by the soil. The amount of radiation absorbed by the soil is influenced by soil color, soil moisture, direction of exposure, time of year, and condition of the soil surface (1, 3, 20, 30).

In Arizona, soil temperatures at the 6-inch depth averaged 50°F. and 95°F. in winter and summer, respectively (5). Hide (19) found that the maximum air and soil surface temperatures were almost the same during October, November and December, and only slightly different in January and February. He also observed that soil surface temperatures were lower than air temperatures on mornings when evaporation occurred, but on mornings when the relative humidity was 100% the soil and air temperatures were similar. In 1913, Bouyoucos (3) measured differences of as much as 11°F. at a depth of 2 inches between soils covered with white and black sand. Everson and Weaver (10) found that 4000 pounds per acre of carbon black in the top 2 inches of the soil increased the soil temperature by 3.4°F. at a 2-inch depth.

Gurr (15) has shown that the effect of a temperature gradient on the movement and distribution of water in soil is a net transfer of water from hot to cold soil. Brawand and Kohnke (4) state that water vapor transfer from the subsoil toward the top layer normally remains confined to night hours during the period from March to October and that a two-directional moisture loss from the ground surface layer takes place in the daytime. Apparently part of the moisture can be driven to greater soil depths while perhaps a larger part is subject to evaporation. They also reasoned that water vapor transfer from the subsoil to the surface may be a continuous process in winter. Maximum vapor movement in soils increases with moisture tension up to slightly below the wilting point (22). Water vapor transfer in dry soil can be accounted for by simple diffusion according to Hanks (16).

The movement of water molecules from water to air is termed evaporation and the reverse movement is condensation. The rate at which molecules leave a water surface depends on the temperature of the surface. The rate at which water molecules re-enter the liquid depends solely on the concentration and temperature of the water vapor in the air (20). The concentration of water vapor in the air is determined by the amount of turbulent mixing and by the supply of moisture available (37). Turbulent mixing may be considered almost wholly reponsible for any loss of moisture from an evaporating surface freely exposed to the air. Hanks and Woodruff (17) measured an increase in evaporation of 10 to 15 times when the wind speed was increased from 0 to 25 miles per hour even though the soil surface was covered with a straw or gravel mulch. Evaporation was increased only 2 to 6 times with a 0 to 25 mile per hour increase in wind speed when the soil surface was covered with a mulch of compacted dry soil.

The creation of a dry surface layer by radiation or high air temperatures during the summer will reduce evaporation by at least 90% (31). Penman (27) believes that this "self mulching" effect is the reason that organic mulches do not conserve moisture in the summer time. He suggests that mulching will be effective only during the isothermal part of the year when soil surface and air temperatures are approximately equal. Lemon (25) also found that plots mulched with as much as 16 tons of sorghum stalks failed to show any conservation of moisture over a period of several months. Organic mulches apparently reduce the rate of evaporation, but increase the length of time that evaporation takes place as compared to a bare soil. Other types of mulches have been used with varying degrees of success (17, 24, 33). Plastic mulches appear to be one of the best means so far developed for reducing the amount of evaporation (8).

METHODS AND MATERIALS

A field experiment was established in the fall of 1959. The site selected was in a summer fallowed field that would have wheat planted on all the area immediately surrounding the plots.

Location and Description of Soil Used

The experiment was located on the Perkins Agronomy Research Station near the east end of series 1200 on a Norge loam soil. Norge loam is moderately fertile, productive, and responsive to good management practices. The soil is uniform with a 7-12 inch A horizon and a surface gradient of about 2%. A complete description of this soil is available in an Oklahoma State University publication (14).

Experimental Procedure

The experiment was designed as a randomized block with 9 treatments and 3 replications. The replications were placed end to end running from east to west. The individual plots were 6 feet square with a 2 foot border between plots. A list of the different treatments used is reported in Table I.

TABLE I

SOIL SURFACE COVERS

Treatment No.	Type of Treatment	Abbreviation
I	Wheat - black plastic surface	Wh. in Bl.Pl.
II	Wheat - natural soil surface	Wh.
III	Black plastic surface	Bl.Pl.
IV	White plastic surface	Wh.Pl.
V	Black cloth surface	Bl.Cl.
VI	White cloth surface	Wh.Cl.
VII	Black coal surface	Coal
VIII	White sand surface	Sand
IX	Natural soil surface	Fallow

The black and white plastic used was 4 mil vinyl plastic. A double layer of cheese cloth was used for the cloth cover, the normal cloth being designated as the white cloth, and white cheesecloth dyed black was designated as the black cloth. Cheesecloth was replaced by nylon chiffon that had been factory dyed when it was found that the black cheesecloth would not retain its color for more than 3 or 4 weeks. Coal ground to pass through a 20 mesh screen was used to simulate a dark soil surface, and commercial white quartz sand was used for the light soil surface. The coal and sand were applied in a very thin layer, with applications being repeated when necessary to maintain the desired contrast in surface color. It is believed that the layer was thin enough so that it did not materially interfere with the evaporation or infiltration processess.

The plots were not bordered to prevent runoff in order to more nearly simulate moisture accretion under field conditions.

The wheat plots were planted in rows 12 inches apart. The plots that were to be covered with black plastic were slightly ridged to facilitate drainage away from the wheat plants which were planted in the top of the ridge. The plastic was then placed on the plot and small holes were cut down the top of each ridge to allow the germinating wheat to grow through the plastic.

The soil profile was considered filled to field capacity by October 10 at which time Triumph wheat was planted and the covers were placed on all plots except those that were to retain their natural soil surface. Soil moisture samples were taken with a Veihmeyer tube as soon as possible after planting. Subsequent moisture determinations were made with a neutron moisture meter (34) with readings being taken on all three replications.

Moisture readings with the neutron moisture meter were obtained at the following depths: six inches, twelve inches, twenty-four inches, thirty-six inches and forty-eight inches. The first 2 readings were taken to represent 6-inch increments and the latter three, 12 inch increments. This was done on the assumption that the soil was reasonably uniform at these depths. The moisture content in the top 3 inches is not estimated with the neutron moisture meter. This layer does however, have some effect on the 6-inch measurement, increasing this reading when the layer is wet and reducing the reading when it is dry. Over a period of time this difference would have a tendency to cancel out. However, it is felt that this layer had considerable influence on the total moisture picture in this study and may explain some of the apparent irregularities in moisture measurements from one date to the next.

Soil temperature measurements were taken by reading Weston bi-metallic dial type thermometers located in one replication. Readings were taken at a 1-inch depth in most cases. Radiation measurements were obtained on one replication by the use of "Economical Net Radiometers" (35).

The Perkins Agronomy Research Station rainfall records were used to determine the amount of rain received by the plots. Air temperatures used were those recorded by radio station KSPI located in Stillwater. Open pan evaporation data were obtained from the records of a weather station located at the Stillwater Municipal Airport.

It is believed that the large volume of air flowing across the small plots, located crosswise to the prevailing wind, tended to eliminate any temperature or humidity differences that might have been caused by differences in the microclimate of the various treatments. Thus, the air blowing across the plots did not represent "equilibrium air" for each particular treatment. However, it was not intended that such an effect should exist.

RESULTS AND DISCUSSION

Soil Moisture Measurements

Moisture determinations on all three replications were not possible until the first part of April. Owing to a colder than normal spring the wheat had just started to grow by this time. Moisture conditions had been favorable up to this time and moisture readings showed very little difference in the first four feet of all plots, with the exception of the first 6 inches of the plastic covered plots where no wheat was growing. This layer contained more moisture than in the other plots. The lower side of the plastic was covered with drops of water and this concentration of water without any attendant evaporation would tend to keep this layer moist. Since the different treatments had not been appreciably affected by evaporation, this would appear to have been a satisfactory time to begin comparative moisture determinations.

Moisture measurements with the neutron moisture meter were limited to a depth of 4 feet because of the length of pipe available. However, gravimetric moisture determinations obtained in November and again on June 23 show that there was very little moisture used from the 5th and 6th feet of soil (Table II).

TABLE II

SOIL MOISTURE PERCENTAGES

Depth	November 15, 1959		June 23, 1960	
	Wheat Only	Wheat in Black Plastic	Wheat Only	Wheat in Black Plastic
0-6"	10.6	10.9	9.6	6.0
6-12"	15.0	15.3	11.0	8.0
12-24"	15.8	16.4	11.0	11.0
24-36"	13.4	13.6	10.2	11.0
36-48"	11.0	11.1	9.6	9.5
48-60"	10.2	10.1	9.9	9.1
60-72"	9.7	11.0	9.5	10.2

A graph of the soil moisture content of the wheat in the plastic covered plots for the period measured is presented in Fig. 1. The black plastic was not a perfect seal as far as preventing the entrance of water during a rain. It seems reasonable to assume that if rainwater could leak in, some water could also evaporate out, so this amount may not have been too significant. From the data reported in Table III it can be seen that there was no moisture lost after June 4. Although the wheat was not completely mature at this time, it apparently did not need or use any more water. By subtracting the amount of water in the soil on June 4 from the amount present on April 9, a net loss of 2.79 inches of water was recorded. This is considered to be an estimate of moisture used in the transpiration process.

In order to obtain an estimate of the amount of water lost by evaporation, the data from the wheat plots with a natural soil surface were used (Table III). The wheat on these plots matured later than wheat on the plastic plots and apparently moisture use continued until June 13. The plants on these plots appeared to be nitrogen deficient, since they were shorter and had smaller heads than plants on the plastic plots. It is not known whether these factors appreciably affected the rate of transpiration.

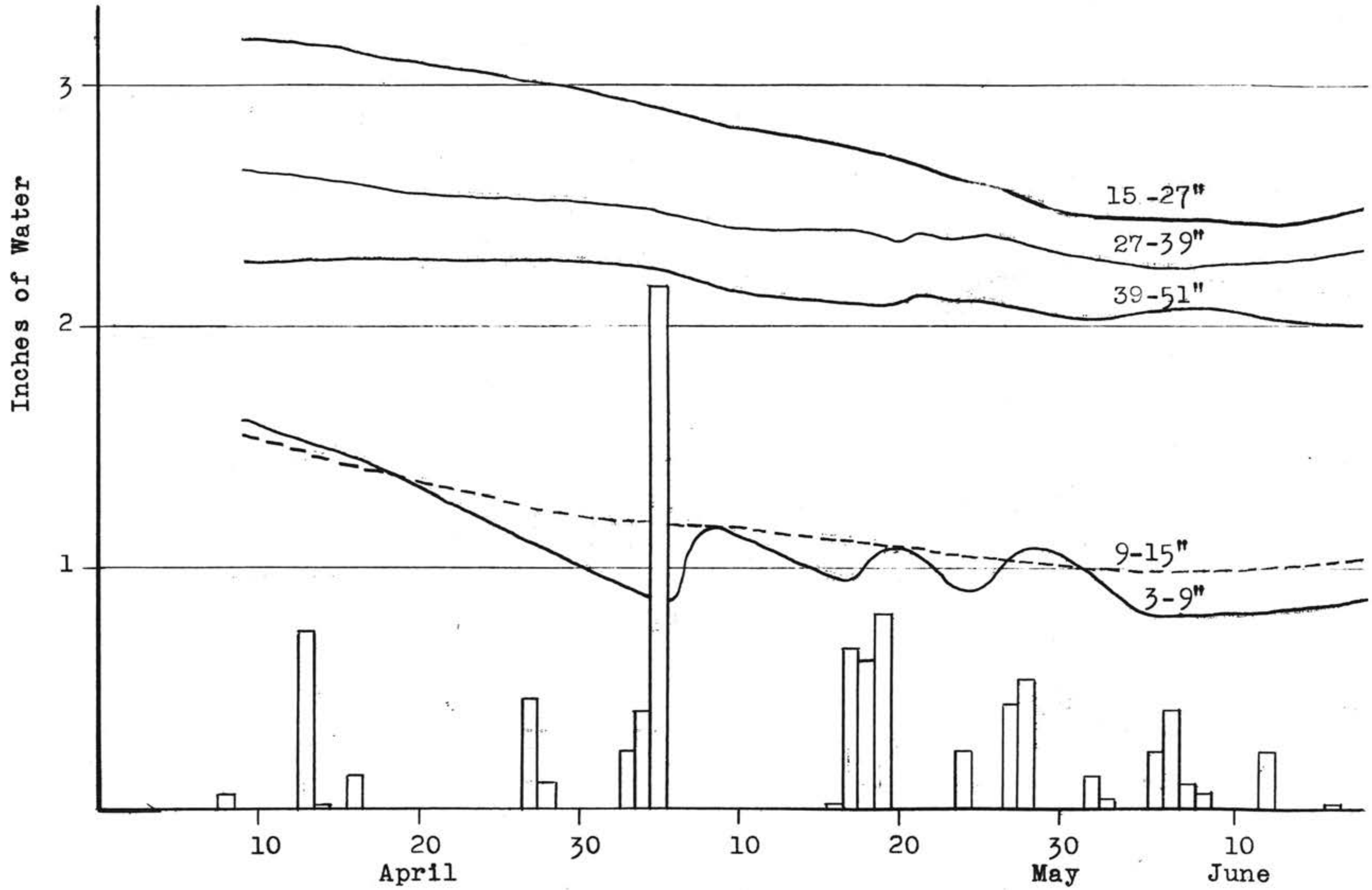

Figure 1. Soil moisture content at 5 depths on the wheat in black plastic treatment for the period April 9 to June 18, 1960, and rainfall received for the same period.

TABLE III

SOIL MOISTURE CONTENT OF THE WHEAT IN BLACK PLASTIC AND THE WHEAT ON THE NATURAL SOIL SURFACE TREATMENTS IN INCHES OF WATER FOR THE PERIOD APRIL 9 THROUGH JUNE 18, 1960.

	Wheat in Black Plastic													
	Date													
Depth	4/9	4/22	5/2	5/9	5/17	5/20	5/21	5/23	5/25	5/30	6/4	6/8	6/13	6/18
3-9"	1.62	1.25	0.96	1.15	0.94	1.04	1.04	0.90	0.91	1.04	0.80	0.80	0.83	0.89
9-15"	1.54	1.34	1.20	1.17	1.09	1.07	1.07	1.05	1.03	1.01	0.98	0.99	1.00	1.03
15-27"	3.19	3.06	2.94	2.82	2.73	2.66	2.66	2.61	2.59	2.44	2.44	2.45	2.42	2.48
27-39"	2.64	2.53	2.51	2.39	2.40	2.34	2.40	2.35	2.37	2.29	2.23	2.24	2.26	2.32
39-51"	2.27	2.26	2.25	2.13	2.24	2.08	2.13	2.09	2.11	2.02	2.07	2.08	2.00	2.00
Total	11.26	10.64	9.86	9.66	9.40	9.19	9.30	9.00	9.01	8.80	8.47	8.56	8.51	8.72
	Wheat on Natural Soil Surface													
3-9"	1.59	1.53	1.44	1.74	1.39	1.91	1.83	1.60	1.58	1.63	1.35	1.55	1.29	1.33
9-15"	1.46	1.34	1.31	1.30	1.26	1.23	1.25	1.20	1.22	1.14	1.14	1.17	1.13	1.13
15-27"	3.15	3.01	2.94	2.87	2.78	2.58	2.72	2.58	2.70	2.55	2.55	2.56	2.52	2.53
27-39"	2.65	2.58	2.51	2.44	2.46	2.34	2.45	2.35	2.43	2.34	2.26	2.34	2.34	2.37
39-51"	2.41	2.37	2.30	2.29	2.29	2.19	2.29	2.20	2.27	2.13	2.18	2.19	2.11	2.21
Total	11.26	10.83	10.50	10.64	10.18	10.25	10.54	9.93	10.20	9.79	9.48	9.81	9.39	9.57

Moisture use (evaporation and transpiration) on the natural soil surface plots was obtained by subtracting the amount present on June 23 from the amount present on April 9 for a total of 1.87 inches. The rainfall for this period (8.64 inches) as reported in Table IV was added to this amount and the amount of runoff (3.21 inches) as calculated in Table V was subtracted. This left an estimated 7.30 inches of water for use in evapotranspiration as compared to an estimated 2.79 inches used in transpiration. Moisture lost by evaporation would therefore amount to 4.51 inches or approximately 62% of the total evapotranspiration.

The amount of water lost by runoff is considered to be a liberal estimate and any reduction in this amount would increase the percentage lost by evaporation. It is felt that the plots were small enough to eliminate any effective microclimatic differences. The variation in soil temperatures and net radiation on the two treatments was small and it was assumed that these factors did not significantly influence the rate of transpiration. Therefore, it is believed that the 62% loss by evaporation is a reasonable estimate under the conditions of this experiment. The 62% figure compares to the 50 to 70% figure obtained by Peters and Russell (29) on corn in Illinois and the 65% figure obtained by Harrold, et al. (18) in Ohio.

The moisture content of the fallow plots is shown in Table VI. These plots actually lost 0.13 inches of water

TABLE IV

RAINFALL AND EVAPORATION DATA
FOR APRIL THROUGH JUNE, 1960

Date	April		May		June	
	Rain-fall	Evapo-ration	Rain-fall	Evapo-ration	Rain-fall	Evapo-ration
1		-		-	.13	-
2		-		.49	.04	-
3		-	.23	.33		.32
4		.19	.40	.01		.30
5		.22	2.17	*	.22	.29
6		.34		*	.40	.43
7		.40		.48	.09	.31
8	.07	.10		.25	.05	.16
9		.17		.38		.67
10		.30		.31		.27
11		.23		.31		.37
12		.35		.23	.22	.17
13	.73	*		.29		.39
14	.01	*		.13		.25
15		.60		*		-
16	.13	.36	.01	.37	.01	.38
17		.50	.64	.26		.36
18		.28	.61	.17		.43
19		.38	.79	*		.35
20		.26		.51	.45	.40
21		.52		.29		.57
22		.37		.25		-
23		*		.31		-
24		.53	.26	.32	.48	-
25		.31		.39		-
26		.29		.37		-
27	.44	*	.42	.32		-
28	.11	.22	.53	.32		-
29		.24		.18		-
30		.36		.30		-
31				.30		
Total	1.49		6.06		2.09	

* Evaporation on these dates is included in the amount reported for the following day.

TABLE V

RAINFALL LOST BY RUNOFF FOR SELECTED PERIODS FROM APRIL 9 TO MAY 30, 1960

Period	Gain or Loss of Soil Moisture	Rainfall	Moisture to be Accounted for	Calculated Evaporation 1/	Calculated Transpiration 2/	Runoff 3/
4/9 to 4/22	-.43	0.87	1.30	0.38	0.62	0.30
5/2 to 5/9	+.14	2.70	2.56	0.72	0.42	1.42
5/17 to 5/20	+.07	2.04	1.97	0.68	0.18	1.11
5/25 to 5/30	-.41	0.95	1.36	0.68	0.30	0.38
Total	-.63	6.56	7.19	2.46	1.52	3.21

1/ Evaporation from a moist soil surface was considered equal to open pan evaporation. The period of time used to calculate the amount of evaporation was from the day after it started to rain until the soil surface became dry. Evaporation from the soil was considered equal to any rain received that was less than open pan evaporation for that day if the rain was preceded by a day when no rain fell.

2/ Transpiration was calculated from the wheat in plastic plots for the 4/9 to 4/22 period since moisture content of both soils was approximately equal. Transpiration for other periods was figured at 0.06 inches per day. This was considered the average loss on the plastic plots after 4/22 on dates when it appeared reasonable estimates could be made.

3/ The periods selected were the ones that included rains of over one-half inch. It is recognized that some runoff may occur from rains of less than one-half inch, but from first-hand observations at the plots it was felt that this loss was not great during this particular period of time.

TABLE VI

SOIL MOISTURE CONTENT OF THE FALLOW, COAL, AND SAND TREATMENTS IN INCHES OF WATER PER INDICATED DEPTH OF SOIL FROM APRIL 9 TO JUNE 18, 1960

Fallow

Depth	Date 4/9	4/22	5/2	5/9	5/21	5/23	5/25	6/8	6/14	6/1[illegible]
3-9"	1.57	1.57	1.64	1.70	1.95	1.68	1.74	1.79	1.62	1.5[illegible]
9-15"	1.54	1.53	1.50	1.59	1.60	1.54	1.56	1.57	1.54	1.5[illegible]
15-27"	3.27	3.22	3.20	3.18	3.19	3.13	3.17	3.19	3.25	3.2[illegible]
27-39"	2.65	2.58	2.57	2.55	2.56	2.51	2.59	2.56	2.55	2.5[illegible]
39-51"	2.29	2.20	2.24	2.18	2.24	2.20	2.27	2.24	2.23	2.2[illegible]
Total	11.32	11.10	11.15	11.20	11.54	11.06	11.33	11.35	11.19	11.1[illegible]

Coal

Depth	Date 4/9	4/22	5/2	5/9	5/21	5/24	5/25	6/8	6/13	6/18
3-9"	1.71	1.68	1.68	1.82	1.99	1.81	1.81	1.79	1.70	1.6[illegible]
9-15"	1.58	1.56	1.55	1.64	1.64	1.56	1.59	1.57	1.57	1.51
15-27"	3.16	3.11	3.10	3.08	3.09	3.13	3.01	3.09	3.14	3.08
27-39"	2.52	2.47	2.46	2.50	2.40	2.43	2.44	2.40	2.44	2.40
39-51"	2.25	2.20	2.20	2.18	2.14	2.22	2.17	2.13	2.17	2.18
Total	11.22	11.02	10.99	11.22	11.26	11.15	11.02	10.98	11.02	10.80

Sand

Depth	Date 4/9	4/22	5/2	5/9	5/21	5/24	5/25	6/8	6/13	6/18
3-9"	1.68	1.72	1.72	1.90	2.02	1.73	1.86	1.91	1.78	1.67
9-15"	1.58	1.56	1.55	1.59	1.62	1.62	1.59	1.60	1.57	1.54
15-27"	3.16	3.11	3.10	3.08	3.04	3.13	3.01	3.03	3.09	3.03
27-39"	2.57	2.53	2.52	2.50	2.45	2.48	2.44	2.50	2.49	2.45
39-51"	2.41	2.42	2.36	2.39	2.35	2.38	2.33	2.35	2.39	2.29
Total	11.40	11.34	11.25	11.46	11.48	11.34	11.23	11.39	11.32	10.98

from April 9 to June 14. All rainfall during this period was evidently either lost by runoff, evaporation, or deep percolation. This would seem to substantiate previous evidence showing the futility of trying to store any extra water during the second year of fallow, at least in this section of the country (9).

Although there was a consistent difference in temperature and net radiation between the coal and sand treatments, there was no measurable difference in moisture losses. It is felt that there was more moisture lost from the coal than the sand plots, but because it is not possible to obtain moisture readings with the neutron moisture meter in the top 3 inches of soil where the loss by evaporation is greatest (20), it was not possible to show that there were differences. Also, frequent showers during this period would probably have offset most differences that may have developed.

There was also practically no difference between the white and black cloth treatments, as can be seen from Table VII. These plots were similar in moisture content to the fallow plots. It had been believed that the cloth covers would tend to decrease runoff and retard evaporation as compared to the fallow plots.

Moisture content of the plastic covered plots did not seem to be affected by the color of the plastic. The only apparent difference was in the 3-9 inch depth (Table VII) and this was

TABLE VII

SOIL MOISTURE CONTENT OF THE BLACK AND WHITE CLOTH AND THE BLACK AND WHITE PLASTIC TREATMENTS IN INCHES OF WATER PER INDICATED DEPTH OF SOIL FROM APRIL 9 TO JUNE 22, 1960

Black Cloth

Depth	4/9	4/22	5/2	5/9	5/21	6/8	6/22
3-9"	1.65	1.68	1.68	1.86	2.02	1.87	1.67
9-15"	1.59	1.58	1.58	1.64	1.70	1.52	1.54
15-27"	3.13	3.17	3.15	3.19	3.19	3.19	3.08
27-39"	2.59	2.58	2.57	2.55	2.56	2.61	2.56
39-51"	2.38	2.42	2.41	2.34	2.40	2.40	2.34
Total	11.34	11.43	11.39	11.58	11.87	11.69	11.19

White Cloth

Depth	4/9	4/22	5/2	5/9	5/21	6/8	6/22
3-9"	1.65	1.68	1.64	1.78	1.95	1.87	1.63
9-15"	1.56	1.58	1.55	1.64	1.68	1.62	1.54
15-27"	3.02	3.22	3.20	3.19	3.25	3.19	3.13
27-39"	2.59	2.58	2.62	2.55	2.56	2.56	2.50
39-51"	2.22	2.26	2.20	2.18	2.24	2.24	2.18
Total	11.04	11.32	11.21	11.34	11.68	11.48	10.98

Black Plastic

Depth	4/9	4/22	5/2	5/9	5/21	6/8	6/22
3-9"	1.97	1.96	1.95	1.70	2.06	1.99	1.91
9-15"	1.62	1.60	1.63	1.59	1.65	1.62	1.57
15-27"	3.18	3.17	3.17	3.19	3.19	3.14	3.14
27-39"	2.48	2.53	2.52	2.55	2.50	2.50	2.45
39-51"	2.22	2.26	2.25	2.24	2.19	2.19	2.18
Total	11.47	11.52	11.52	11.27	11.59	11.44	11.25

White Plastic

Depth	4/9	4/22	5/2	5/9	5/21	6/8	6/22
3-9"	1.97	1.92	1.99	1.94	1.99	1.95	1.87
9-15"	1.59	1.60	1.63	1.59	1.65	1.60	1.57
15-27"	3.18	3.17	3.26	3.18	3.19	3.25	3.19
27-39"	2.64	2.69	2.67	2.66	2.66	2.66	2.61
39-51"	2.38	2.37	2.36	2.34	2.34	2.34	2.29
Total	11.76	11.75	11.91	11.71	11.83	11.80	11.53

evidently the result of moisture entering the plastic from holes torn by hailstones during a rainstorm on May 19. Both of the treatments appeared to lose a small amount of moisture over a period of time. It is not known whether this is significant or not.

Soil Temperature Measurements

Soil temperature records were obtained by reading dial-type stem thermometers. These were placed at a 1-inch depth in all treatments on one replication and also at 3-inch and 6-inch depths on the coal and sand treatments. The trends in soil temperatures were similar from April through June, with differences among treatments becoming more apparent as the season progressed. Readings from a typical day were selected and are shown in Figures 2 and 3.

Soil temperatures on all treatments were considerably higher than the air temperature during the daylight hours, with the sand being 12°F. higher and the black and white plastic being 27°F. higher on the day illustrated by the graph. As a general rule, soil temperatures dropped rapidly after 3 or 4 p.m. with soil and air temperatures approaching and equilibrium by about 4 or 5 a.m. except for the plastic plots.

The black and white plastic plots were generally near the same temperature during the morning hours, with the white plastic generally being warmer in the afternoon and at night.

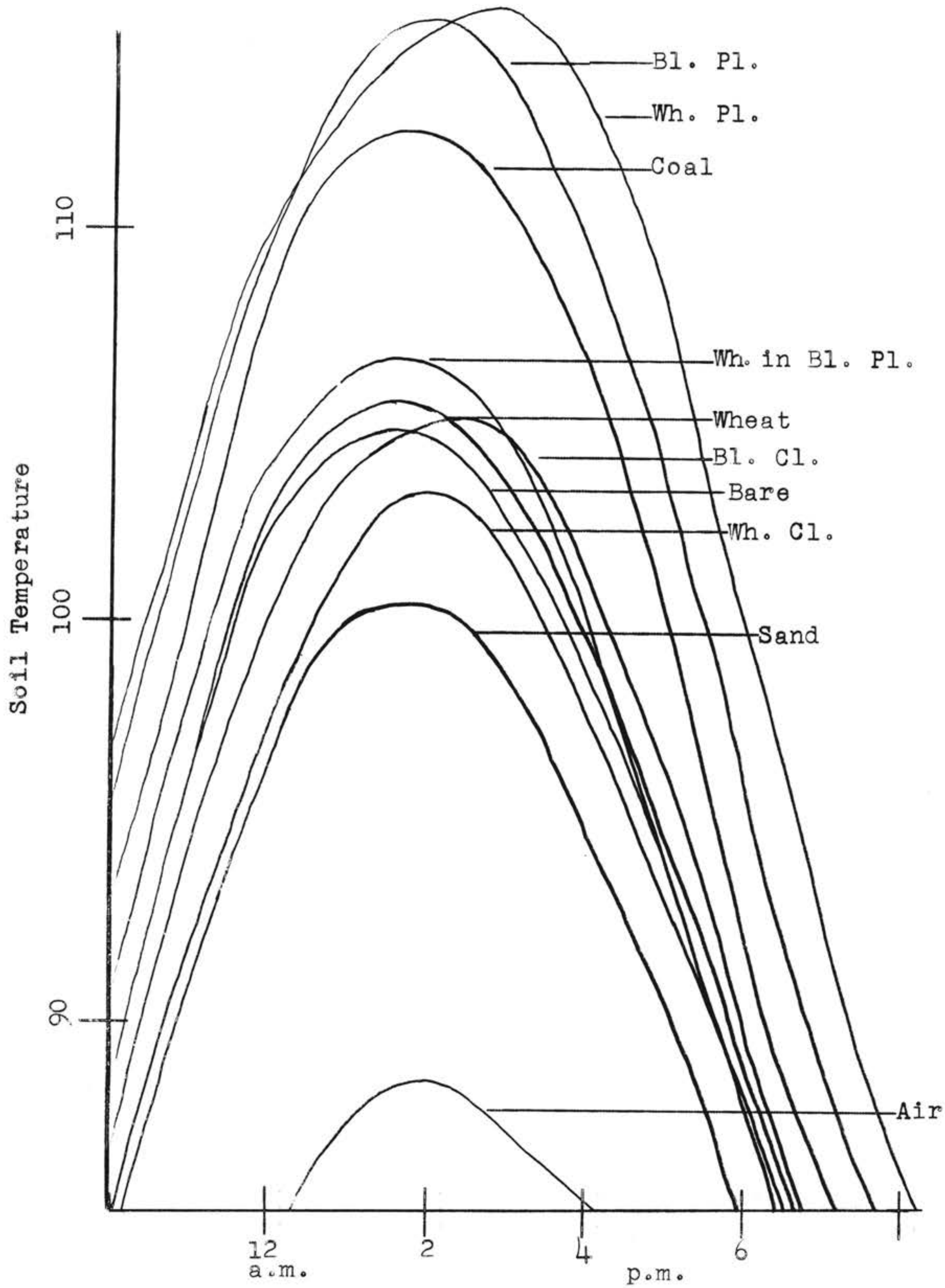

Figure 2. Daytime soil temperatures on May 27, 1960.

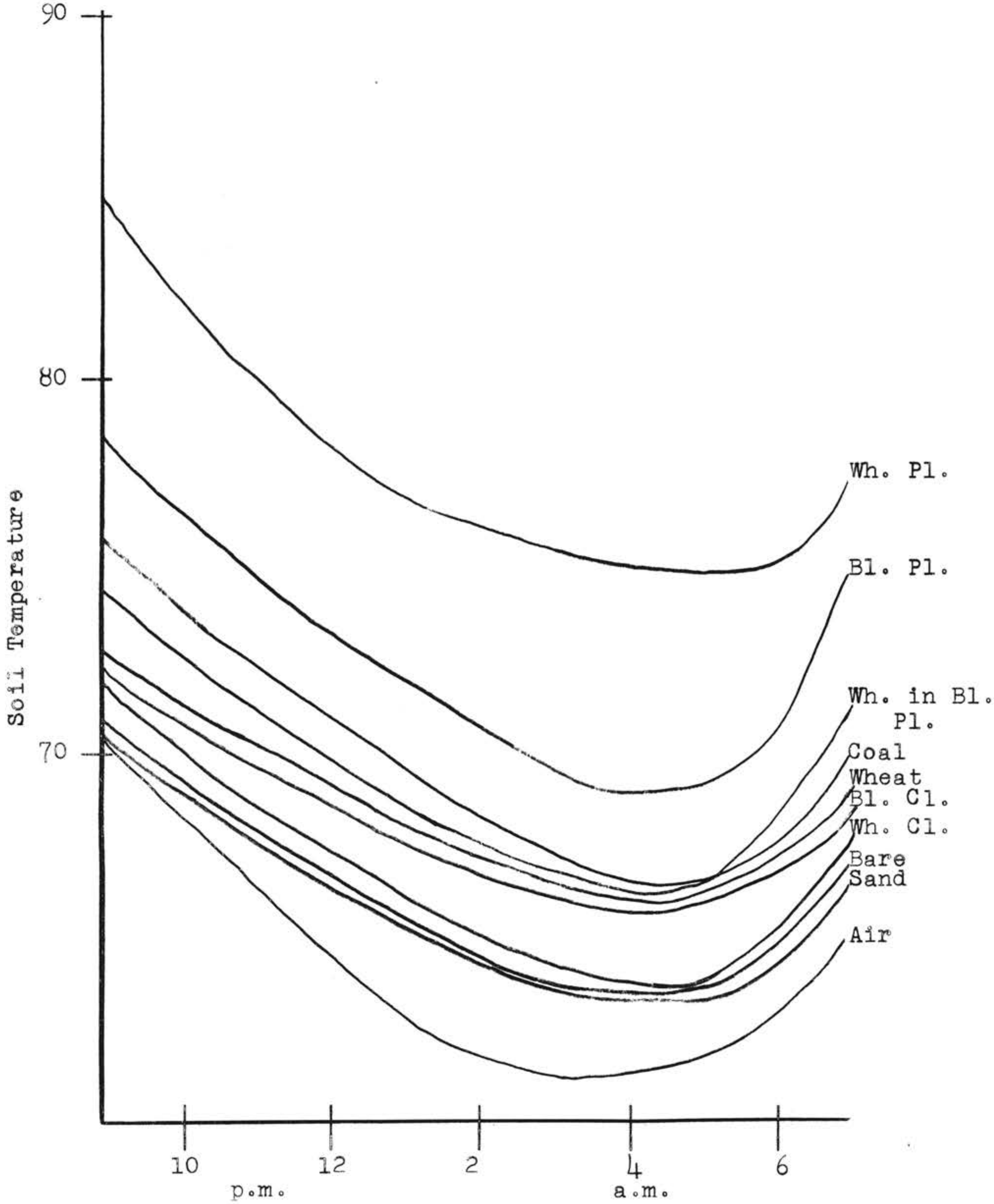

Figure 3. Nighttime soil temperature on May 26 and 27, 1960.

The highest maximum temperatures of any treatment occurred under the white plastic. This was due to the greater amount of light penetrating the plastic to warm the soil. There was considerable weed growth under the white plastic and none under the black plastic. The weeds lifted the white plastic off the ground, creating a blanket of air next to the soil surface. It was felt that this layer was the reason the white plastic did not cool off as much at night as did the black plastic. Both the black and the white plastic remained considerably warmer at night than did any of the other treatments.

The soil temperatures on the wheat in the plastic plots were never as warm as the plastic plots without wheat. This was probably due to the shading action of the wheat. The wheat in plastic was only slightly warmer than on the wheat plots with a natural soil surface.

Temperatures under the black cloth were generally slightly higher than under the white cloth although occasionally this trend was reversed during the afternoons of clear, sunshiny days.

The coal plots averaged considerably higher than the sand plots with the fallow plots being intermediate between the two. Some difficulty was encountered in maintaining the desired surface color. The coal and sand were washed off by rain and blown off on windy days. The surface layer had to be renewed after nearly every rain received and this

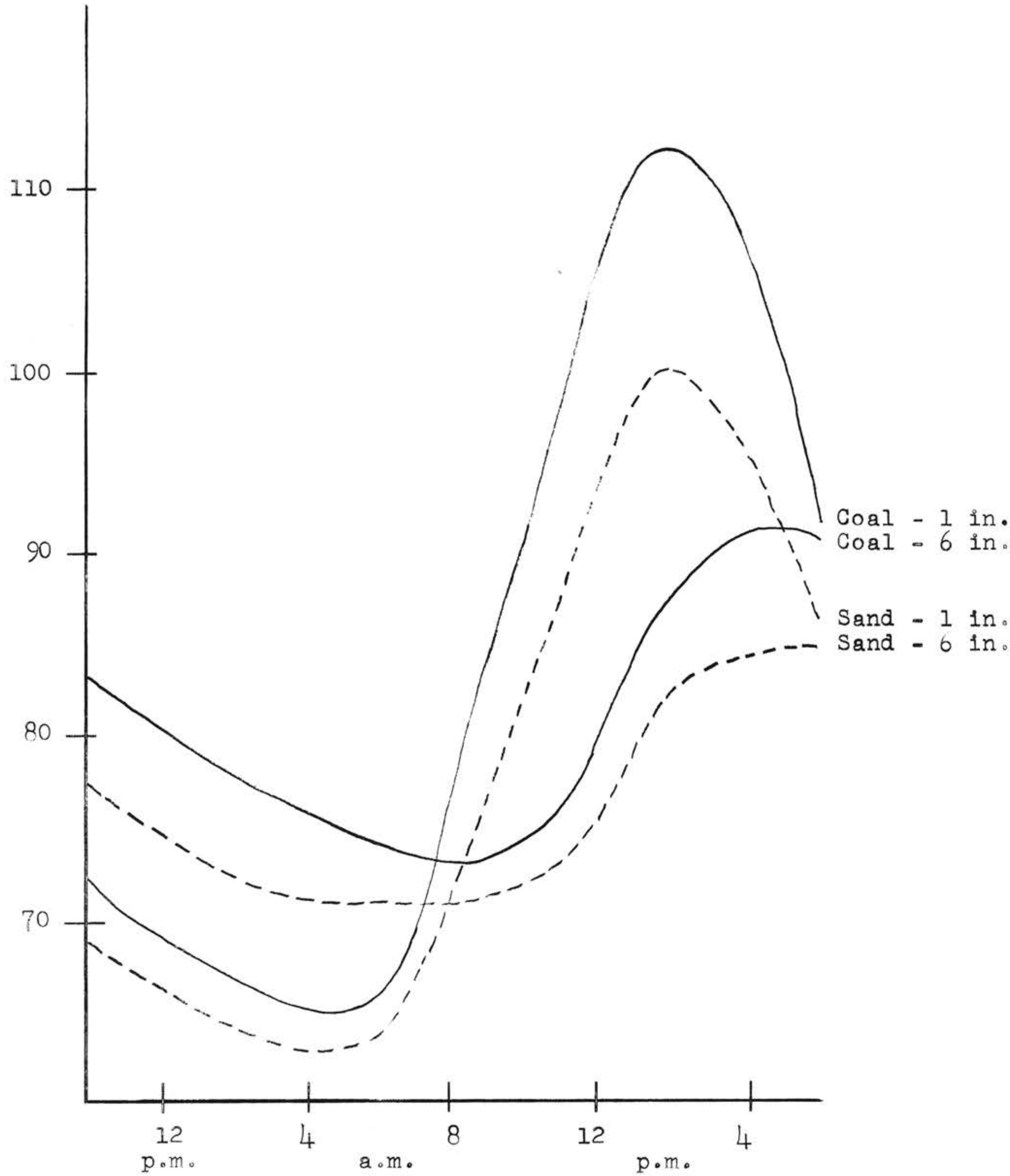

Figure 4. Soil temperatures at 1-inch and 6-inch depths on the sand and coal treatment on May 26 and 27, 1960.

may have tended to reduce the rate of evaporation as compared to the natural soil surface.

Measurements at 6 inches below the surface on the coal and sand plots show that temperature differences were definitely present at this depth. This is graphically illustrated in Figure 4.

Net Radiation Measurements

Readings for net radiation measurements are reported in Table VIII. The 12 noon reading was generally the highest with the readings rising rapidly to a peak near this time and dropping just as rapidly afterwards. Readings were taken only on clear days.

Net radiation did not appear to increase from April 9 through May 2, except on the wheat plots. All readings had increased by May 21 but were apparently reduced by June 28.

The greatest variation in trends seemed to occur on May 21 and 25. On these two dates the soil surface was moist and it is believed that evaporation of the surface moisture was responsible for the higher net radiation readings. Since there was no increase in net radiation at this time on the wheat in black plastic plots, which were assumed to have no surface evaporation, this would tend to confirm the above statement.

It is felt that soil washing onto the black and white plastic influenced the radiation absorbed by these plots. Although the plot surfaces were swept with a broom before

TABLE VIII

NET RADIATION IN LANGLEYS PER MINUTE
READINGS TAKEN AT 12 NOON

Date	Top Reading in °C.	Fallow	Wheat	Wheat in Bl.Pl.	Black Plastic	White Plastic	Coal	Sand	Black Cloth	White Cloth
4/9	88	.750	.734	.767	.798	.669	.763	.734	.768	.702
4/21	92	.724	.724	.757	.774	.656	.740	.706	.757	.601
5/2	93	.746	.812	.877	.796	.711	.762	.711	.779	.659
5/9	99	.850	.951	.984	.850	.763	.918	.815	.934	.850
5/21	98	.961	1.023	.975	.961	.827	1.086	.961	.961	.894
5/25	101	.965	1.047	.998	.931	.827	1.062	.915	.965	.880
6/28	103	.822			.858	.729	.822	.786	.840	.804
	Average	.831	.882	.893	.853	.755	.879	.804	.858	.770
	Rank	4	8	9	5	1	7	3	6	2

readings were taken, a considerable amount of soil remained on the surface. The coal and sand covers had to be renewed periodically and it can be assumed that the surfaces were not identical from one reading to the next. The black and white cloth treatments were also renewed periodically with the white cloth becoming progressively more discolored and the black cloth gradually losing its color between changes.

The amount of net radiation absorbed by the different surfaces was least on the white plastic and steadily increased through the white cloth, sand, bare, and black plastic treatments (Figure 5). The average net radiation on the black

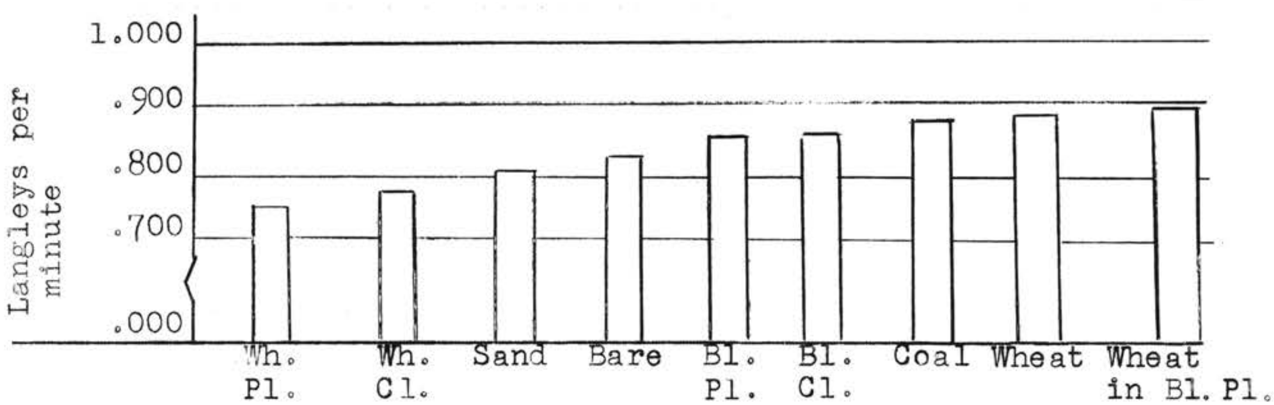

Figure 5. The average net radiation absorbed by each treatment as measured at 12 noon on selected days from April 9 to June 28, 1960.

plastic and the black cloth were approximately equal, but less than the coal, wheat, and wheat in black plastic. The latter plots absorbed the largest amount of radiation, but were not greatly different from each other.

It is recognized that net radiation measurements on these small plots would not be representative of measurements on similar treatments covering a wide area. The large heat sink provided by the air flowing across the plots would considerably reduce the amount of energy reaching the lower surface of the radiometers. However, it is felt that these measurements do provide information on trends among the different treatments.

Yield and Nitrogen Percentages

The plots were purposely made only large enough to obtain accurate moisture readings and it was not intended that the plots with wheat growing on them should be harvested for yield estimates. However, wheat growing in the black plastic was more vigorous, grew taller, produced larger heads, and in general appeared to have a better supply of nitrogen than the wheat on the natural soil surface plots. Hence, it is believed that there were yield differences between the two treatments. These observations are in agreement with results obtained on other crops (7, 8). Clarkson (7) reported that a plastic mulch on corn in North Carolina was about as effective as the addition of 50 pounds of nitrogen on unmulched corn.

The wheat grown in black plastic produced an average of 426 grams of grain per plot with a nitrogen percentage of 3.26%. The wheat grown on the natural soil surface produced an average of 333 grams of grain per plot with a nitrogen percentage of 2.907. The difference in nitrogen percentage was significant at the 1% level.

SUMMARY AND CONCLUSIONS

A field experiment was conducted to determine the relative amounts of water lost by evaporation as compared to transpiration on a winter wheat crop and to study the effect of different types and colors of soil surfaces on the loss of water from the soil.

The following conclusions are based on data obtained from this study:

1. Moisture lost by evaporation from a winter wheat crop was estimated to account for 62% of the amount lost by evapotranspiration during the period from April 9 to June 13, 1960.

2. When evaporation from the soil was prevented, wheat plants needed only 2.79 inches of water from the time growth started in the spring until the plants were mature.

3. The moisture content of fallow plots showed a net loss of 0.13 inches from April 9 to June 13, 1960.

4. The color of the soil surface in the form of either a layer of finely ground coal, white quartz sand, black and white cloth, or black and white plastic did not have a measurable effect on the loss of soil moisture from uncropped plots.

5. The only apparent effect of the type of soil surface cover was a slightly higher, more uniform moisture content in the 3-9" depth of the plastic plots.

6. Soil temperatures at a depth of 1-inch were higher under the coal than under the sand surface, lower under the black plastic than under the white plastic, and were not appreciably different under the black and white cloth treatments.

7. Soil temperatures were only slightly higher under the wheat in black plastic as compared to the wheat without a plastic covering.

8. Soil temperatures were consistently higher at a depth of 6 inches under the coal surface than under the sand surface.

9. Net radiation was similar on the wheat, coal, and wheat in black plastic treatments and was higher on these than any of the other treatments. The white plastic absorbed the least amount of radiation.

10. Nitrogen percent of the grain from the wheat in black plastic plots was significantly higher than from the wheat grown on the natural soil surface plots.

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