Reprinted from Soil Science
Vol. 91, No. 4 April, 1961

INFLUENCE OF SOIL SURFACE CONDITIONS ON NET RADIATION, SOIL TEMPERATURE, AND EVAPORATION

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Received for publication June 15, 1960

The practice of soil surface treatment, usually by some type of mulch, is probably as old as agriculture itself. The usual purposes of surface treatment were to prevent water loss by evaporation, to influence soil temperature, or to minimize weed growth. Jacks, Brind, and Smith (4) recently published an extensive review of literature on this subject. Evaporation was reduced by a mulch where the soil moisture content at the surface was maintained at a high level, by a water table close to the surface, or by frequent rains. In less humid regions where the surface soil moisture content was not maintained at a high level, the influence of mulch on evaporation was almost negligible.

The usual effect of a mulch is to lower soil temperature during the summer and increase soil temperature during the winter. Since the thermal conductivity of a mulch is usually much lower than the soil, the heat gain or loss is less under a mulch. Many investigators have listed this effect on soil temperature as one of the reasons why evaporation is less. Hanks (2) showed that, if all other conditions, such as moisture content or thickness of mulch, are equal, evaporation was directly proportional to the temperature of the soil. Under field conditions there may be no direct relationship between evaporation and soil temperature, because other factors become limiting. Gardner (1) showed that evaporation from soil columns with a uniform initial moisture content could be predicted by an isothermal flow equation with vapor movement neglected. The experiments were conducted under what might be called sub-humid conditions, i.e., the evaporated moisture was not replenished by a shallow water table or frequent rains. Different evaporative environments gave practically identical evaporation rates. Gardner (1) concluded that evaporation under conditions similar to those investigated was limited by the flow of liquid water within the soil.

The general purpose of the present investigation was to clarify the relationship of net radiation, soil temperature, and soil surface conditions on evaporation. The specific investigation was designed to determine the influence on those three factors of widely varying soil surface conditions.

EXPERIMENTAL METHODS

The general plan of the investigation called for intensive measurements of soil temperature, net radiation, and evaporation for a few days every month throughout the growing season. Measurements were confined to periods of relatively clear weather during 1958 and 1959. In some cases in 1959 trouble with the temperature recorder and portable a.c. power unit prevented the procuring of reliable measurements of all desired factors.

The five soil surface conditions studied were: (*a*) check (bare soil); (*b*) 4 tons wheat straw per acre; (*c*) 1 inch gravel (¾ to 1½ inches diameter) painted with flat black paint; (*d*) 1 inch gravel painted aluminum; and (*e*) plastic-covered ridges about 6 inches high (about one-half the area was covered with plastic). The plots were 15 feet square and the treatments were replicated twice. Soil dikes were formed around each plot to eliminate runoff; in a few instances, however, these dikes failed, and in 1958 some runoff occurred from the check treatment. Runoff was prevented in 1959 by reinforcing the dikes with boards. The plastic used in 1958 was clear polyethylene, which disintegrated about midsummer and had to be replaced. In 1959, black polyethylene was used and it was more nearly satisfactory.

Net radiation was measured with the "Economical Net Radiometer" (Agmet Products Co., Middleton, Wis.) as described by Suomi and Kuhn (7). Preliminary tests of the economical

[1] Joint contribution from the Western Soil and Water Management Research Branch, Agricultural Research Service, U. S. Dep. Agr. and Kansas Agricultural Experiment Station. Contribution No. 694, Department of Agronomy, and Contribution No. 77, Department of Physics.

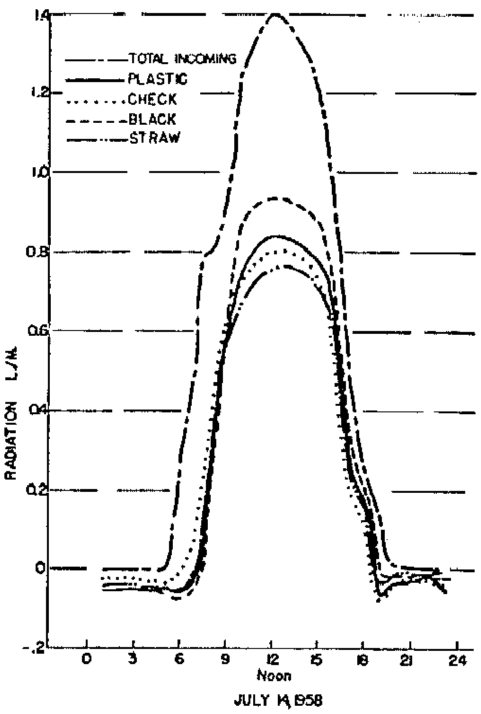

FIG. 1. Influence of soil surface conditions on net radiation (1958).

net radiometers were made in which they were compared with a more precise, ventilated net radiometer (6). Very close agreement was shown between the two. In addition to the low cost of the "Economical Net Radiometers," their use was advantageous because the measurement made was temperature, which permitted measurements of net radiation and soil temperatures on the same recorder.

Soil temperature was measured at depths of 1, 4, 16, 64, and 152 cm. with copper-constantan thermocouples. For depths of 1, 4, and 16 cm., three thermocouples of equal length were attached in parallel to give a better average of the temperature. The thermocouple junctions were coated with an insulating paint ("Insuldip"). Measurements were made in regard to the soil surface on all treatments and not the surface of the mulch. In 1959 temperature measurements were made in the air immediately above the surface with a thermocouple shielded both above and below by two aluminum plates.

Two methods were used to measure evaporation. Frequent measurements of soil moisture content were made with the "Neutron" soil moisture meter (d/m-gauge of Nuclear Chicago Corporation). Continuous measurements of evaporation were also made on the check and straw treatment using floating lysimeters similar to those described by King, Tanner, and Suomi (5).

The experiment was conducted on the Kansas State University Agronomy Farm near Manhattan, Kansas. The soil was a Geary silt loam. The rainfall in 1958 was 43.55 inches, and in 1959 30.47 inches; the long-term mean is 31.73 inches.

RESULTS AND DISCUSSION

Figure 1 shows hourly recorded net and total radiation for a representative day from May through August, 1958. The average daily totals for each period are shown in table 1. Net radiation was greatest over black-painted gravel. Net radiation was next largest on the clear plastic plot in 1958 and the black plastic and check plot in 1959, followed by the straw and aluminum-painted gravel plot. During the early part of the season net radiation was lowest on the straw plot, but at the end of the season it was higher on the straw plot than on either the aluminum-painted gravel or the check plot. This was due to the darkening of the straw with time.

Figure 2 shows average temperatures at a 1-cm. depth for the same day as in figure 1; the clear plastic-covered treatment had the highest temperature during the day and the check treatment the next highest, followed by black-painted gravel, aluminum-painted gravel, and straw. Figure 3, with soil temperatures at 16 cm., shows the same general trends, of course, but with less difference between treatments. Table 2 shows the average temperatures computed for the hourly measurements for all of the depths measured; average temperature was lowest at all depths on the straw-mulch treatment. The difference in average temperature in 1958 between plastic and straw was about 19°F. at 1 cm., 15°F. at 4 cm., 11°F. at 16 cm., 6°F. at 64 cm., and 2.5°F. at 152 cm. The relative differences in 1959 were similar to 1958, except that the temperatures under the black-plastic treatment were much lower in 1959 than under the clear plastic used in 1958. Air temperature above the plots was highest by about 4°F. over the black-painted gravel but was about the same above the rest of the surfaces.

The higher soil temperature under the black-painted gravel, in comparison with the aluminum-

TABLE 1

Influence of soil surface condition on net radiation

Time	Radiation (*in Langleys/day*)					
	Total	Net				
		Check	Black	Aluminum	Straw	Plastic
1958:						
May 28–30	683	321	393	294	281	331†
June 17–19	600	288	299	237	237	292†
July 12–14	530	300	—	302	310	304†
Aug. 25–30	563	269	323	261	277	—
Ave., 1958	594	295 (50)*	341 (57)*	274 (46)*	276 (46)*	309 (52)*
1959:						
June 6–8	647	370	408	333	310	—
Sept. 5–7	527	—	394	248	268	298‡
Ave., 1959	587	370 (57)*	401 (57)*	290 (49)*	289 (49)*	298 (57)*

* Per cent of total radiation. † Clear. ‡ Black.

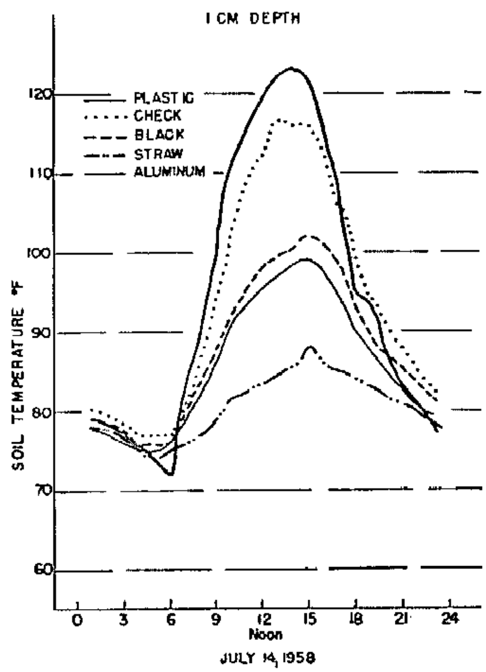

FIG. 2. Influence of soil surface conditions on soil temperature at 1 cm. (1958).

painted gravel, was undoubtedly a result of the increased net radiation on the black-painted treatment. The higher temperature under the clear plastic compared with the check was probably due to the "greenhouse effect" produced under the plastic, the decreased ventilation of the soil surface, and the increased net radiation over the plastic plot. The higher soil temperature of the check plot in comparison with the black-painted gravel plot was probably due to the effectiveness of the gravel mulch on the black plots as an insulator. This influence was sufficient to counteract the increased net radiation of the black plot.

The measurement of evaporation was not sufficiently precise to distinguish any difference among treatments, with the exception of the check treatment. Figure 4 shows the soil moisture content of the treatments with time in 1958.

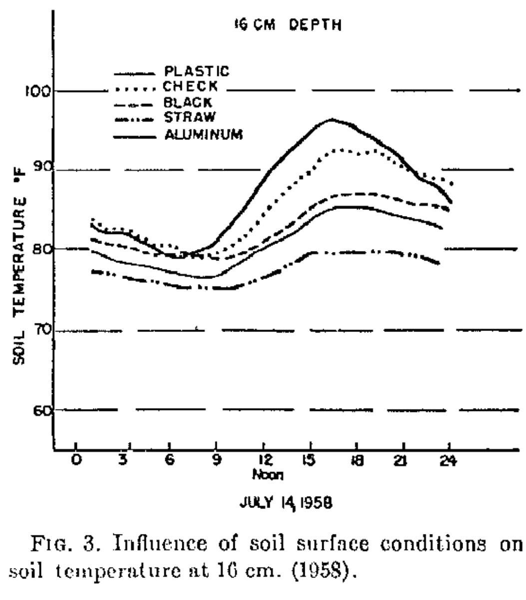

FIG. 3. Influence of soil surface conditions on soil temperature at 16 cm. (1958).

The lower moisture content of the check is due to runoff in some instances as well as increased evaporation. In 1959, when runoff was eliminated, the same general differences were evident, but the total difference in moisture content was about ¾ inch of water between the check and other treatments. Lysimeter measurements of soil moisture loss due to evaporation are illustrated in figure 5. The data show that the cumulative evaporation loss from the bare check plot was about 0.06 inch more in 6 days than from the straw-covered plot. The precision of the lysimeter measurements is illustrated by the data of figure 5, where a 0.14-inch rain occurred on August 25.

Some evidence regarding the mechanism of moisture flow within the soil can be deduced from

TABLE 2

Influence of soil surface conditions on soil temperature in 1958 and 1959

Date	Check	Black	Aluminum	Straw	Plastic	Check	Black	Aluminum	Straw	Plastic
	°F					°F				
	1 cm. depth					*64 cm. depth*				
1958:										
May 28–30	83.7	80.1	75.1	70.5	98.7	69.0	68.3	65.6	62.6	72.5
June 17–19	82.4	81.6	78.6	76.6	94.5	75.4	74.7	71.3	73.3	77.6
July 12–14	90.1	83.8	80.9	78.4	89.8	78.8	76.7	74.9	73.1	80.2
Aug. 25–30	81.3	79.5	76.2	74.0	92.6	76.6	76.3	74.6	73.2	—
Ave. 1958	84.4	81.3	77.7	74.9	93.9	75.0	74.0	71.6	70.6	76.8
1959:										
June 6–8	91.4	87.0	81.5	72.0	—	70.7	71.2	68.3	63.8	—
Sept. 5–7	88.5	84.6	82.7	74.5	—	77.5	81.5	77.8	72.0	77.4
Ave. 1959	90.0	85.8	82.1	73.2	—	74.1	76.3	73.0	67.9	—
	4 cm. depth					*152 cm. depth*				
1958:										
May 28–30	81.5	79.6	75.1	69.7	93.2	59.0	58.4	55.1	57.7	61.1
June 17–19	81.4	81.2	78.3	76.3	91.5	68.1	69.5	68.9	66.6	68.1
July 12–14	86.2	83.2	80.7	77.9	87.7	70.4	69.6	68.5	67.9	72.8
Aug. 25–30	81.0	79.3	77.2	74.0	84.8	73.4	72.3	71.6	71.2	70.8
Ave. 1958	82.5	80.8	77.8	74.5	89.3	67.7	67.4	66.0	65.9	68.2
1959:										
June 6–8	86.3	85.2	80.0	71.0	—	60.6	61.3	59.5	58.9	—
Sept. 5–7	85.8	84.6	82.4	74.2	81.7	72.4	—	73.9	69.7	72.2
Ave. 1959	86.0	84.9	81.2	72.6	—	66.5	—	66.7	64.3	—
	16 cm. depth					*Air temperature above surface*				
1958:										
May 28–30	77.8	76.4	70.3	67.3	85.3					
June 17–19	80.4	79.6	77.1	76.1	86.2					
July 12–14	83.3	81.0	78.7	76.3	85.1					
Aug. 25–30	79.6	78.4	76.2	73.6	80.8					
Ave. 1958	80.3	78.9	75.6	73.3	84.3					
1959:										
June 6–8	81.4	81.2	75.9	69.0	—	79.5	83.6	77.7	78.5	—
Sept. 5–7	82.4	82.0	80.2	73.6	80.4	85.2	88.9	84.5	84.5	81.8
Ave. 1959	81.9	81.6	78.0	71.3	—	82.3	86.2	81.1	81.5	—

Values are averages of hourly readings.

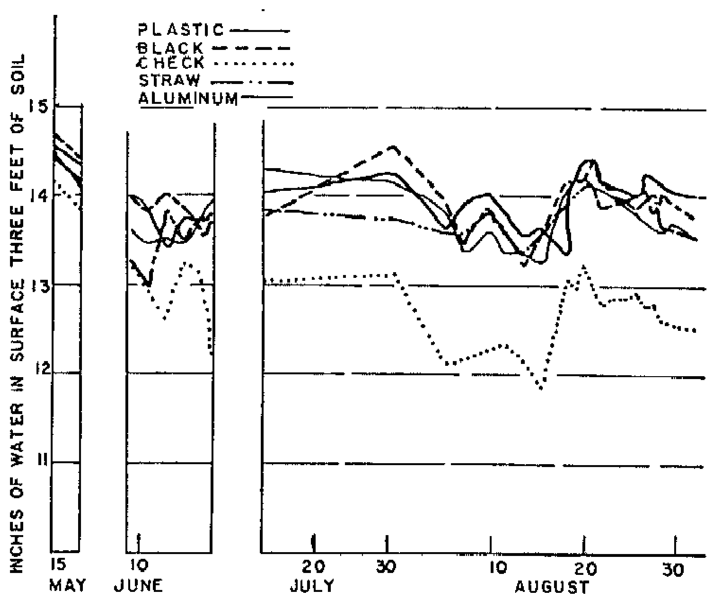

FIG. 4. Influence of soil surface conditions on moisture content (1958)

the data in table 2. The direction of water vapor movement within the soil can be deduced from vapor pressure gradients. If the soil moisture content is greater than 15 atmosphere percentage, the relative humidity at equilibrium is greater than 98 per cent, and the soil vapor pressure is approximately equal to the saturated vapor pressure. Since saturated vapor pressure increases with temperature (air pressure constant), water vapor would move from a high temperature to a low temperature.

The data (table 2) show that the average temperature decreased with depth for all treatments throughout the summer. This indicates that net water vapor movement was downward throughout the summer season. The assumption of 100 per cent relative humidity was probably not valid for the surface 1-cm. measurement because of surface drying, but soil moisture measurements made throughout the seasons indicated that the assumption was reasonable below a depth of 4 cm. Consequently it appeared that water movement to the soil surface, in response to evaporation, was in the liquid phase and not as vapor. Vapor movement was probably of importance only within the soil surface. Thus it appears that evaporation, where moisture is not readily available at the soil surface, would have little relation to soil temperature but would be limited by liquid water movement to the surface.

This confirms the laboratory studies on soil drying of Gardner (1), who showed that evaporation could be predicted quite accurately from the soil by considering only isothermal liquid flow within the soil. It should be emphasized that this conclusion is valid only under sub-humid conditions, where moisture is not readily available at the soil surface. In humid areas where moisture is readily available, evaporation would depend on the energy available, i.e., the net radiation (8).

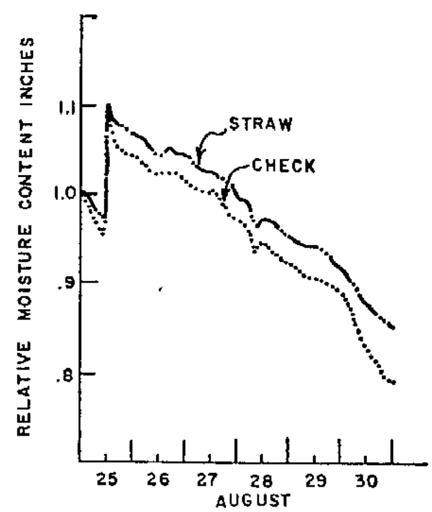

FIG. 5. Relative moisture content *vs.* time on straw mulch and check plots as measured by floating lysimeters.

It is apparent from the data that, even in 1958 when the soil was comparatively wet, moisture was not readily available for any appreciable period of the year. Visual observation of the check plot following a rain indicated that the surface soil dried within a few hours after the rain. Once the soil dried a "soil mulch" was formed. Hanks and Woodruff (3) showed that a "soil mulch" may be much more effective in decreasing water vapor flow than either a straw or gravel mulch.

SUMMARY

Investigations were made to determine the influence of straw, black-painted gravel, aluminum-painted gravel, and plastic mulches on net radiation, soil temperature, and evaporation. Net radiation was highest on the black treatment followed by the plastic-covered, check, straw-covered, and aluminum-painted gravel treatments. Soil temperature was highest under the clear plastic treatment, followed by the check, black-painted, aluminum-painted, and straw-covered treatments, respectively. Evaporation was greatest on the check plot but was about equal on all of the other treatments. The total difference in evaporation over the year between the check and other treatments was no more than 1 inch of water.

There was no direct relationship under the conditions of this experiment between net radiation or soil temperature and evaporation. This is probably due to the great limiting influence of soil moisture within the soil after the soil surface dries.

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