THE EFFECTS OF ROCK AND GREEN WASTE MULCHES ON SOIL MOISTURE AND SOIL TEMPERATURE

Donald F. Post, Jamie P. Dubay, and Allan D. Matthias

Abstract

A study was conducted at Tucson, Arizona to evaluate how rock and green waste mulches placed on the soil surface affect soil moisture and temperature. The study used ten 5-m^2 plots. Half received natural rainfall and half were irrigated with 15 cm of water applied every 14–18 days. Data were collected bi-weekly at 10, 25, and 50 cm depths between March 1998 and January 1999. The site was kept free of vegetation. The control (no mulch) plots had a mean of 4.9 and 7.6 cm of water in the soil to a depth of 35 cm for the natural rainfall and irrigated conditions, respectively. The mean water contents in the mulch-covered plots were 6.7 and 8.2 cm, 7.0 and 8.4 cm, 6.7 and 8.5 cm, and 7.4 and 9.0 cm for the buff granite, white marble, green waste (3.8 cm thick) and green waste (6.4 cm thick), respectively, for the natural rainfall and irrigated conditions. This is a mean of 37% (buff granite) to 51% (green mulch, 6.4 cm) more water than the control at the 0–35 cm soil depth with natural rainfall. For the irrigated plots there was 8–18% more water under the mulched plots. The mean soil temperatures to a depth of 50 cm were 22.9 and 20.9°C for the natural rainfall and irrigated control plots. The natural rainfall and irrigated mulched plots were 1.3 and 1.8°C warmer for the buff granite. With natural rainfall the white marble and green waste mulched plots were all 2.2°C cooler, whereas on the irrigated plots the white marble, 3.8 cm green waste, and 6.4 cm green waste were 1.1°C, 1.4°C, and 0.7°C cooler than the irrigated control plots, respectively. All of the mulches conserved soil moisture, but soil temperatures were both warmer and cooler. The albedos and heat capacity–heat conductivity of the mulches are different, which likely explains our results.

Introduction and Literature Review

Mulch is any material placed on the soil surface in and around plants to moderate the soil environment and enhance landscape esthetics. Mulches conserve soil moisture, moderate soil temperature extremes, reduce the number of weeds, and prevent soil erosion. Mulches can be inorganic or organic material, such as gravel, rocks, polyethylene plastic sheeting, wood chips, bark, compost, or yard waste.

The practice of mulching fields has been around for a long time. Evidence shows that ancient Hebrews used gravel mulches in the Sinai Desert (Corey and Kemper 1968). In addition, prehistoric dryland fields along the lower Verde River, northeast of Phoenix, contained rock-mulch features to enhance water and nutrient retention (Homburg and Sander 1997). Recently, there has been renewed interest in the practice of using mulches in arid regions and elsewhere.

Mulch prevents soil water loss due to evaporation by wind and hot sun; moisture moves by capillary action to the soil surface and evaporates, if not covered with a mulch. There is much evidence that surface mulches reduce water loss from soils by evaporation (Corey and Kemper 1968; Unger 1971; Lal 1978; Chung and Horton 1987; Groenevelt et al. 1989; Tolk et al. 1999). It has been shown that thin surface layers of gravel and coarse sands also reduce evaporation of recently wetted soils (Schleusener 1958; Corey and Kemper 1968; Modaihsh et al. 1985; Fairbourn and Cluff 1974).

Soil temperature is a major factor influencing the rate of evaporation of water and heat movement in soil. In arid and semi-arid regions, soils lose considerable amounts of water from evaporation. Soil temperature also affects seed germination, plant growth, crop harvest, chemical reactions in soil, and other biological activities. Mulches insulate the soil and keep it cooler in the summer and warmer in the winter.

Department of Soil, Water and Environmental Science, University of Arizona

The amount of solar radiation absorbed by the soil surface is a major factor influencing the fluctuation of soil surface temperatures (Van Wijk and DeVries 1963). In addition to its direct effect on soil, solar radiation also increases the ambient air temperature, resulting in additional energy transfer from air to soil by conduction and convection. Many factors influence the absorption of radiant energy by the soil surface, including latitude, vegetative cover, clouds, soil characteristics, and surface slope and aspect (Baver and Gardner 1972). The fraction of radiation reflected from the soil surface, called the albedo, is largely determined by soil color and moisture. Water content has profound influences on soil temperature. Water can transfer energy into soil by convection or remove latent energy by evaporation from the soil surface. In addition, precipitation can cool soils and increase their heat capacity.

The objective of this research was to measure the effects of mulches of various colors and composition on the moisture content and temperature of soil under both natural rainfall and irrigated soil conditions.

Materials and Methods

This experiment was completed at the University of Arizona Campus Agricultural Center (32.6°16' N latitude, 110°56' W longitude; 713 m above mean sea level). The soil series is the Gila, which is classified as a coarse-loamy, mixed, superactive, calcareous, thermic Typic Torrifluvent. Table 1 presents the particle size distribution data for a composite sample collected at 10, 25, 50, and 100 cm depths from each of the 10 plots.

Ten 190 x 277 cm plots (5.3 m^2) were prepared. Five plots received only natural rainfall, and five plots were irrigated with 15 cm of water every 14 to 18 days. The two types of rock mulch were buff-colored decomposed granite and white marble, applied to the soil surface at a depth of 3.8 cm. The rock particles ranged from 2 to 3.8 cm in size. The organic mulch consisted of green waste, mostly from shredded date palm leaves, applied to the soil surface at depths of both 3.8 cm and 6.4 cm. A bare soil plot served as a control.

Soil moisture content was determined by using a probe to collect samples at depths of 10 and 25 cm. We assumed that the 10 cm samples were representative of the 0–15 cm soil depth, and the 25 cm samples were representative of the 15–35 cm soil depth. The soil water contents, θ_{mass} and θ_{volume}, were calculated as follows:

$$\theta_m = \frac{\text{grams of moist soil} - \text{grams of oven-dry soil}}{\text{grams of oven-dry soil}} \times 100 = \%$$

$$\theta_v = \frac{\text{grams of water}}{\text{grams of oven-dry soil}} \times \frac{\text{bulk density of soil (g/cm}^3\text{)}}{\text{density of water (g/cm}^3\text{)}} \times 100 = \%$$

θ_v x thickness of soil horizon = cm of water for that soil depth (0–15 and 15–35 cm)

Soil moisture measurements at field capacity were 20.0 and 30.0% for θ_m and θ_v, respectively, for the 0 to 35 cm soil depth. The horizons from 35 to 100 cm were 18.0% and 27.0% for θ_m and θ_v, respectively, at field capacity. The lower horizons were sandier and had less organic matter, which explains the slight difference in field capacity. The bulk density of this soil averaged 1.5 g/cm^3 at all depths, which was used to convert θ_m to θ_v. The wilting point was not measured; however, Copeland (1989) and Post (1981) reported a fine sandy loam θ_m and θ_v of 7.0% and 10.5%, respectively.

Soil temperature was measured at 10, 25, and 50 cm in degrees Celsius with the use of copper-constantan thermocouples constructed in the lab. Two thermocouples were installed approximately 45 cm away from one another near the center of each plot, and temperature readings were taken five times a day every 14–18 days from March 24, 1998 to January 29, 1999. Temperatures were taken at sunrise, sunset, at the time near noon when the sun elevation was at its maximum, and midway between these times at intermediate sun angles. Means for the five sun angles and the three depths, and the two replications per depth, were computed for each of the 21 days for which data were collected.

The albedo for all treatments was measured when the surfaces were dry for both the irrigated and natural plots (Table 2). Albedo is the ratio of reflected to incoming short-wave radiation (0.3 to 2.8 μm). It was measured using an inverted Eppley (Newport RI) black-and-white pyranometer and an upright Licor (Lincoln, NE) LI 200S pyranometer as explained in Matthias et al. (1999).

Differences in soil moisture and soil temperature among the plots were statistically evaluated using a four-way analysis of variance and the least-square means comparisons as defined in SAS (1996). Significance was determined at probability values less than 0.05.

Table 1. Mechanical analysis data for the soil profile.

	Percent Sand	Percent Silt	Percent Clay	Percent Sand Fractions VC	C	Med	F	VF	Textural Class
10 cm	55	31	14	3	4	3	24	21	Fine sandy loam
25 cm	57	27	16	3	4	3	23	24	Fine sandy loam
50 cm	62	26	12	2	5	7	27	21	Fine sandy loam
100 cm	62	26	12	1	3	5	31	22	Fine sandy loam

Table 2. Albedo measurements when the soil-mulch surfaces were dry under the natural rainfall and irrigated soil conditions.

	May 22, 1998		April 21, 1999	
Treatments	Irrigated	Natural	Irrigated	Natural
Control	0.330	0.318	0.344	0.349
Marble Rock	0.338	0.462	0.384	0.463
Buff Granite Rock	0.186	0.162	0.182	0.162
Green Waste (3.8 cm)	0.262	0.292	0.250	0.281
Green Waste (6.4 cm)	0.259	0.272	0.259	0.271

Results and Discussion

Table 3 presents the water content expressed as centimeters of water in the 0–35 cm soil depth for the plots for the 21 sampling dates. The centimeters of rain and the reference crop evapotranspiration (ETo) for the 14–18 day time periods prior to the sampling dates are also noted. The meteorological data is from the Arizona Meteorological Network (AZMET) monthly summary. The AZMET station is located about 2 km east of the plots.

The mean moisture content for the natural rainfall and irrigated control plots was 4.9 and 7.6 cm for the 0–35 cm soil depth. All mulched plots had more moisture present in the soil than the control plots, which was expected. For the natural rainfall plots the mean water content and percentage increase in water content was 6.7 cm (37%), 7.0 cm (42%), 6.7 cm (37%), and 7.4 cm (51%) for the buff granite, white marble, 3.8 cm of green waste, and 6.4 cm of green waste, respectively. The two rock mulches and the 3.8 cm of green waste were essentially the same; however, the 6.4 cm of green waste plots were higher in soil moisture. Statistical analysis showed that the water content in the control natural rainfall plot was significantly different from the buff granite and 3.8 cm green waste plots, and very significantly different from the white marble and 6.4 cm green waste plots. There was also a significant difference between the buff granite and the 6.4 cm green waste; all other treatments were not significantly different.

A comparison with the control irrigated plot conditions showed that the buff granite, white marble, 3.8 cm, and 6.4 cm of green waste plots had 8, 11, 12, and 18 percent more water, respectively (Table 3). These were not significantly different ($P < .05$); however the 6.4 cm green waste treatment had 1.4 cm more water (18%) than the control, showing that the thicker organic mulch is most effective in conserving water.

Table 4 lists the mean monthly soil temperatures for the 10, 25, and 50 cm soil depths. The mean air temperature for the sampling time periods preceding the sampling dates is also noted. (Refer to Table 3 for sample dates.) The mean temperature of the natural control plot was 2.0°C warmer than the irrigated control plot, and the natural and irrigated control plots were 3.5°C and 1.5°C warmer than the mean air temperature. The natural rainfall buff granite plot was 1.3°C (6%) warmer, and the white marble, green waste 3.8 cm, and green waste 6.4 cm were all 2.2°C (10%) cooler than the control plot. Statistical analysis showed that the temperature of the natural rainfall control plot was very significantly different from

Table 3. Water content expressed in centimeters per 35 cm depth, centimeters of rainfall, and the ETo (reference crop evapotranspiration) in centimeters for the time periods preceding the dates.

Data Collection	Control		Buff Granite		White Marble		3.8 cm Green Wastes		6.4 cm Green Wastes		Meteorological Data	
Dates	Nat	Irrig	Nat	Irrig	Nat	Irrig	Nat	Irrig	Nat	Irrig	cm of rain	Sum of ETo
3/24/98	5.7	7.2	7.3	6.8	MD	7.8	7.7	8.9	7.9	8.2	0.6	4.8
4/9	6.3	7.5	8.3	8.5	8.9	7.9	9.5	MD	9.0	10.4	4.3	7.1
4/23	6.3	7.5	8.2	8.3	7.9	8.8	8.3	8.7	8.2	9.2	0.0	9.2
5/7	3.6	7.5	MD	7.8	7.0	MD	7.5	8.3	7.1	8.0	0.0	9.7
5/23	5.0	6.4	6.3	6.8	6.2	7.5	6.2	8.6	7.3	8.0	0.0	12.0
6/9	4.1	6.1	5.8	6.8	4.7	7.0	5.1	7.6	6.5	8.0	0.0	14.4
6/27	4.5	5.9	5.3	7.2	4.9	6.5	4.7	7.1	5.4	7.6	0.0	17.0
7/11	6.1	8.0	9.3	10.0	8.3	9.1	9.3	9.9	9.0	9.7	5.6	10.5
7/25	5.5	7.5	7.7	8.9	7.8	8.8	8.0	9.1	8.1	8.8	1.9	10.2
8/10	4.7	7.4	7.8	8.4	7.7	8.4	8.1	9.5	9.5	9.9	2.2	11.3
8/24	4.1	6.5	7.3	8.6	5.9	7.5	4.9	7.4	7.5	8.6	1.5	9.3
9/7	MD	8.0	6.6	8.4	7.9	9.2	5.5	8.3	7.2	8.8	2.4	9.1
9/23	4.6	7.2	6.1	7.8	7.1	8.1	6.4	7.8	7.4	9.3	0.3	10.2
10/9	4.0	6.9	5.5	8.0	6.1	7.4	5.1	6.9	6.6	8.9	0.0	10.1
10/25	4.3	7.6	5.1	8.5	5.8	8.5	4.7	8.8	6.5	9.1	0.3	8.2
11/8	4.6	8.2	5.3	8.3	MD	8.7	5.7	8.1	5.5	9.1	0.0	5.5
11/22	4.3	8.4	5.5	8.6	6.4	9.0	5.4	8.7	7.5	9.3	0.9	3.8
12/10	5.7	9.9	8.4	9.2	8.6	9.7	8.3	9.2	8.1	10.3	3.0	3.7
12/23	MD	9.3	7.2	9.1	7.8	9.6	7.4	9.4	7.7	9.7	0.0	4.0
1/10/99	MD	8.3	6.0	8.7	MD	9.1	6.9	8.7	7.3	8.5	0.0	5.0
1/29	4.7	7.4	5.7	7.0	6.2	8.7	MD	MD	6.7	MD	0.0	6.4
$\bar{x}$	4.9	7.6	6.7 (37%)*	8.2 (8%)*	7.0 (42%)*	8.4 (11%)*	6.7 (37%)*	8.5 (12%)*	7.4 (51%)*	9.0 (18%)*		

Field capacity = 10.5 cm/35 cm soil depth and wilting point = 3.7 cm/35 cm soil depth.
MD = missing data.
*Mean percentage increase in moisture compared to control plot for the two conditions.

Table 4. Mean soil temperature in °C of 10, 25, and 50 cm depths for the plots, and the average monthly air temperature in °C (data from Tucson, Arizona Meteorological Network).

	Control		Buff Granite		White Marble		3.8 cm Green Waste		6.4 cm Green Waste		
Dates	Nat	Irrig	Nat	Irrig	Nat	Irrig	Nat	Irrig	Nat	Irrig	Air
Mar–98	19.2	17.3	20.5	18.8	16.5	15.6	16.6	15.8	16.2	16.1	13.3
Apr–98	20.0	18.1	21.3	19.7	17.1	16.1	17.0	15.7	16.5	16.0	16.1
May–98	25.9	23.2	27.2	25.1	23.0	21.4	21.9	20.1	21.2	21.0	22.2
Jun–98	30.1	27.6	32.1	30.0	27.7	26.4	26.2	24.0	25.0	24.9	27.2
Jul–98	31.7	29.4	33.5	32.3	28.7	28.2	28.7	27.5	28.4	27.8	30.0
Aug–98	31.1	30.3	33.1	32.2	29.1	28.7	28.5	28.1	28.9	28.8	29.4
Sep–98	29.4	27.3	30.3	29.1	27.1	26.4	26.8	26.0	27.1	26.9	27.8
Oct–98	24.6	22.4	25.9	24.1	22.9	21.8	23.0	21.4	23.0	22.2	20.6
Nov–98	17.6	14.9	18.6	16.6	15.9	14.4	17.1	15.6	17.5	16.2	13.9
Dec–98	10.6	9.6	11.4	10.7	9.7	9.4	11.0	10.5	12.1	11.1	9.5
Jan–99	11.7	9.7	12.5	11.1	10.2	9.6	11.2	10.1	11.8	10.7	10.0
	22.9	20.9	24.2	22.7	20.7	19.8	20.7	19.5	20.7	20.2	19.4
			(+6%)*	(+9%)*	(–10%)*	(–5%)*	(–10%)*	(–7%)*	(–10%)*	(–3%)*	

*Mean percentage increase or decrease in temperature compared to control plot for the two conditions.

all of the mulched plots; however, there was no significant temperature difference between the white marble rock and the two green waste plots.

On the irrigated plots the buff granite was 1.8°C (9%) warmer, and the white marble, green waste 3.8 cm, and green waste 6.4 cm were 1.1°C (5%), 1.4°C (7%), and 0.7°C (3%) cooler than the irrigated control plot, respectively. Statistical analysis also showed that the irrigated control plot was significantly different from all mulched plots; however, again there was no significant difference between the white marble rock and the two green waste plots.

Summary

All mulches in this study conserved soil moisture, but the amount of water conserved was different for the various mulch conditions. The temperature of soils is related to soil moisture, and three factors are usually listed that affect soil temperature: (a) the net amount of heat energy the soil absorbs, (b) the heat energy required to bring about a given change in soil temperature, and (c) the energy required for processes such as evaporation, which are constantly occurring at or near the soil surface. Solar radiation is the source of energy that heats soils, and the fraction of radiation that is reflected off the surface is called the albedo. Table 2 presents the albedo for the plots. The control and green wastes were comparable, ranging from 0.27 to 0.33; however, the buff granite and white marble were 0.17 and 0.41, respectively. This shows that the two rock types either absorbed or reflected the solar radiation differently than the bare soil and the green waste mulch. A cover on the soil surface, such as a mulch, significantly influences how much heat energy reaches the soil surface, because it shades the soil. Furthermore, rock and organic mulch have different abilities to conduct heat to the soil surface.

The thermal properties of soils are greatly affected by their moisture content. The heat capacity to raise the temperature of water 1°C is one calorie per gram, whereas dry soil is about 0.2 calories per gram. The heat capacity of rocks is about 0.5 calories per gram. Moist soils also use large amounts of heat to evaporate water from soil surfaces, measured as differences in temperature, and this too affects the temperature of the soil plots. Another factor is the thermal conductivity of materials, which refers to its ability to transmit heat. Soil air, a dry soil, a wet soil, rock, and organic mulches have very different abilities to conduct heat. All these factors have affected the results we measured in this experiment.

We conclude that both organic and rock mulches conserve soil moisture, as expected. The two rock types and the green waste treatments of 3.8 cm thickness were about the same. The 6.4 cm thick green waste conserved significantly more moisture. The soil temperature of the mulched plots was warmer for the buff granite and cooler for the white marble and green waste plots. Overall the irrigated plots were cooler than the natural rainfall plots.

References

Baver, L. D., and W. R. Gardner. 1972. Soil Physics. John Wiley and Sons, New York.

Copeland, S. M. 1989. Soil water potential as related to the crop water stress index of irrigated cotton. Mater's thesis, University of Arizona, Tucson.

Chung, S., and R. Horton. 1987. Soil heat and water flow with a partial surface mulch. Water Resources Res. 23: 2175–2186.

Corey, A. T., and W. D. Kemper. 1968. Conservation of soil water by gravel mulches. Hydrology Paper No. 30, Colorado State University, Fort Collins, CO.

Fairbourn, M. L., and C. B. Cluff. 1974. Gravel mulch to conserve scarce water. Crops and Soils Magazine, April–May.

Groenevelt, P. H., P. van Straaten, V. Rasiah, and J. Simpson. 1989. Modifications in evaporation parameters by rock mulches. Soil Technol. 2: 279–285.

Homburg, J. A., and J. A. Sander. 1997. Soil properties of ancient rock-mulch agricultural fields of Arizona. Poster presented at the 61st Annual Meeting of the Soil Science Society of America, Anaheim, CA.

Lal, R. 1978. Influence of within and between row mulching on soil temperature, soil moisture, root development and yield of maize (*Zea mays*) in a tropical soil. Field Crop Res. 1: 127–139.

Matthias, A. D., D. F. Post, L. Accioly, A. Fimbres, E. Sano, and A. K. Batchily. 1999. Measurement of albedos for small areas of soil. Soil Sci. 164: 293–301.

Modaihsh, A. S., R. Horton, and D. Kirkham. 1985. Soil water evaporation suppression by sand mulches. Soil Sci. 139: 357–361.

Post, D. F. 1981. Relationships of soil texture in the soil water content and soil porosity characteristics of Arizona soils. Hydrology and Water Resources, Arizona and the Southwest 11: 1–3.

SAS Institute. 1996. v. 6.11.

Schleusener, R. A. 1958. Factors affecting evaporation from soils in contact with a water table. Ph.D. dissertation, Colorado State University, Ft. Collins (diss. abstr. 58–02822).

Tolk, J. A., T. A. Howell, and S. R. Evett. 1999. Effect of mulch, irrigation, and soil type on water use and yield of maize. Soil and Tillage Research 50: 137–147.

Unger, P. W. 1971. Soil profile gravel layers: I. Effect on water storage, distribution and evaporation. Soil Sci. Am. Proc. 35: 631–634.

Van Wijk, W. R., and D. A. DeVries. 1963. Periodic temperature variations in a homogenous soil. Physics of Plant Environment.