

SOIL TEMPERATURES - GILES, WESTERN AUSTRALIA⁺

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Abstract: Monthly mean soil temperatures at depths of 1 in., 4 in., 8 in., 20 in., and 40 in. at a desert station (Giles) during 1957 are presented. The diurnal variation, the direction of heat flow and the thermal diffusivity of the soil are discussed.

It is also shown that a rainfall of $4\frac{1}{2}$ in. in December would have had little effect on the regeneration of pastures due to the rapid drying out and the return of high temperatures in the top layers of the soil.

1. INTRODUCTION

The Giles Weather Station was established in 1956 at a spot about five miles south of the Rawlinson Ranges, just inside the Western Australian border and approximately 400 miles west of Finke. The height above mean sea level is 1990 feet; this height is subject to precise survey but 18 months experience with pressure data from the station indicates that this value is correct to within a few feet.

The country around the station is a typical desert scrub plain, very slightly undulating, with occasional quartz pebbly ridges some 10 to 20 feet above the general level. The whole area is covered with mulga scrub 8 to 15 ft high with some desert oaks, red gums and ghost gums; the understorey is mainly spinifex with some salt bush, cane grass and buck bush.

The soils are red desert clays, several feet thick in places but there are extensive areas, particularly along the ridges, where the soil is very pebbly, and only a few inches thick, and overlying a stony subsoil.

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The meteorological station is situated on one of these ridges, the instrument enclosure being at Lat. $25^{\circ} 02' 07''$ S, Long. $128^{\circ} 17' 59''$ E. There is a full programme of surface and upper air observations both visual and autographic. Soil temperatures are being measured at a depth of 1 in., 4 in. and 8 in. at 3 hourly intervals from 2.30 a.m. to 8.30 p.m., and at 20 in. and 40 in. at 8.30 a.m. daily. The thermometers at 1 in., 4 in., 8 in., are standard bent stem thermometers (H.M.S.O., 1956). Tests made during July, 1958, indicate that the readings at 4 in. and 8 in. are reliable. The 1 in. thermometer is quite accurate as a thermometer but the bulb is approximately $\frac{1}{4}$ in. long and at this depth the temperature gradient is so large that the $\frac{1}{4}$ in. length of the bulb leads to errors of possibly 10° F at high temperatures. For convenience the temperatures are listed as having been recorded at 1 in. depth; it should be kept in mind that this depth is not precise. The 20 in. and 40 in. thermometers are Symons earth thermometers (a) consisting of a mercury in glass thermometer imbedded in a layer of paraffin wax and suspended in a seamless, mild steel tubing of $1\frac{1}{4}$ in. bore with a cone of solid steel fitted to the lower end and a cap over the open tube. This tube will modify the surrounding earth temperature because of the greater thermal conductivity of the steel; the effect however is small, certainly less than half a degree (H.M.S.O., 1956).

Although the record is far too short to establish normals, it was considered that the 1957 data would prove of interest to geographers interested in the arid interior of Australia. The monthly mean temperatures for each depth at 8.30 a.m. are shown in Table 1, and the monthly mean temperatures at 1 in., 4 in., 8 in. at the 3 hourly observation times are shown in Table 2. In Table 3 some air temperature and rainfall data for 1957 are shown.

Table 1 - Monthly Mean Soil Temperatures ($^{\circ}$ F) - Giles 1957

(Observations taken at 0830 a.m.)

Depth (in.)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	86.4	79.8	75.7	70.3	56.2	53.1	41.8	51.9	62.1	74.6	83.3	80.4
4	87.1	81.4	80.5	75.5	62.3	57.4	47.5	56.7	64.9	74.6	81.5	81.4
8	92.4	86.0	86.1	79.5	69.8	62.8	52.7	62.2	70.9	79.3	87.5	86.2
20	95.9	91.1	90.5	86.4	75.9	69.2	61.3	66.6	73.9	82.7	90.2	90.3
40	94.2	91.0	90.0	86.9	79.6	73.1	66.2	67.6	73.5	79.9	86.5	88.8

Table 2 - Monthly Mean Soil Temperatures (°F) - Giles 1957

Depth (in).	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0230 83.0	79.0	76.1	71.9	57.7	56.0	45.4	52.8	61.1	70.0	76.3	76.2
	0530 79.2	75.5	72.4	68.7	55.0	54.8	42.9	49.9	59.6	66.8	71.9	73.6
	0830 86.4	79.8	75.7	70.3	56.2	53.1	41.8	51.9	62.1	74.6	83.3	80.4
	1130 117.4	105.4	106.5	97.4	81.2	70.2	63.1	78.9	92.4	106.9	116.6	108.8
	1430 134.5	119.2	125.9	115.6	95.8	82.0	78.5	95.7	110.9	122.7	136.6	121.3
	1730 123.6	109.4	114.6	102.6	85.8	75.0	68.6	82.7	99.0	109.7	122.9	111.0
	2030 98.7	90.1	90.6	83.5	67.7	63.4	56.0	64.5	74.1	84.9	94.1	89.7
4	0230 92.1	86.3	85.6	81.0	66.7	60.9	52.0	61.0	70.4	80.4	88.7	85.6
	0530 88.3	83.3	82.3	77.6	63.8	58.8	49.5	58.2	67.7	76.2	83.3	82.4
	0830 87.1	81.1	80.5	75.5	62.3	57.4	47.5	56.7	64.9	74.6	81.5	81.4
	1130 96.1	89.9	86.8	82.7	67.7	62.1	52.4	62.5	73.2	84.1	92.8	89.6
	1430 109.3	101.5	101.3	94.4	79.7	72.1	63.8	75.0	85.2	94.1	107.4	102.3
	1730 112.3	103.1	104.8	98.9	82.8	74.8	67.6	78.9	89.6	97.7	105.3	104.3
	2030 105.6	97.0	98.2	91.5	76.3	68.4	61.0	71.8	82.4	93.4	103.5	97.8
8	0230 96.9	90.9	90.7	83.3	73.4	66.2	55.3	65.3	75.5	83.7	92.4	90.2
	0530 94.3	88.7	88.2	81.0	71.4	64.8	53.8	63.9	73.3	81.2	89.7	88.3
	0830 92.4	86.0	86.1	79.5	69.8	62.8	52.7	62.2	70.9	79.3	87.5	86.2
	1130 93.4	87.6	86.8	79.4	70.1	63.6	55.8	61.8	71.8	80.4	88.2	87.3
	1430 98.1	92.7	90.9	83.8	73.0	66.4	61.3	67.3	75.5	85.1	92.8	91.6
	1730 102.8	96.2	94.8	86.5	76.2	69.8	63.5	69.8	79.8	88.6	97.5	95.4
	2030 102.7	95.8	95.6	87.1	76.7	69.8	61.1	70.6	80.3	89.1	97.3	95.2

Table 3 - Climatic Data - Giles 1957

Air Temp- erature (°F)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Mean	101.9	94.5	94.4	90.6	76.9	71.6	61.5	73.4	83.2	92.6	98.0	93.3	86.0
Maximum Absolute	109.5	104.2	100.3	98.9	87.1	80.1	70.2	84.0	94.7	103.0	105.9	106.0	
Minimum Absolute	76.4	71.3	68.0	65.6	52.2	52.3	42.9	47.7	56.1	65.1	69.3	70.6	61.5
Minimum Mean	66.0	61.6	59.3	51.8	37.3	37.3	33.1	35.8	41.2	52.1	58.2	54.3	
Temp.	89.1	82.9	81.2	78.1	64.5	61.9	52.2	60.5	69.7	78.9	83.7	81.9	73.7

Rainfall

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Total	139	90	13	37	33	61	77	2	10	12	0	460	934
No. of days of rain	8	8	3	2	1	7	2	1	2	3	0	12	51
No. days of rain more than 10 points	4	3	0	1	1	3	2	1	0	0	0	5	20
Wettest Day	62 on 25th	24 on 11th	9 on 9th	32 on 29th	33 on 31st	18 on 14th	66 on 13th	2 on 7th	8 on 30th	8 on 1st	0 on 29th	239 on 29th	239 on Dec

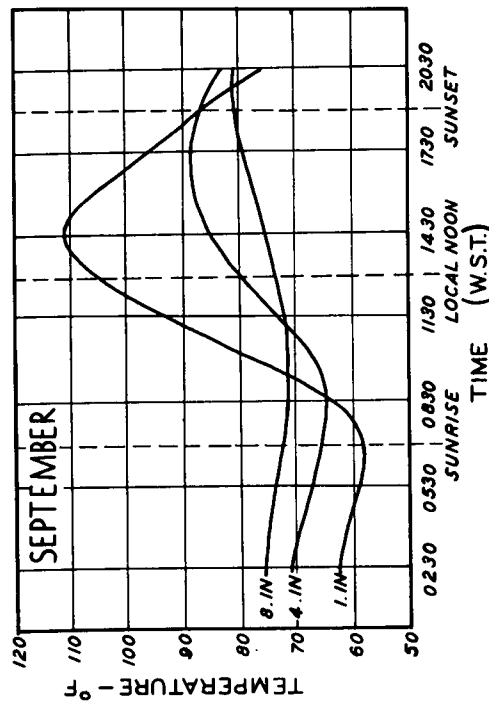
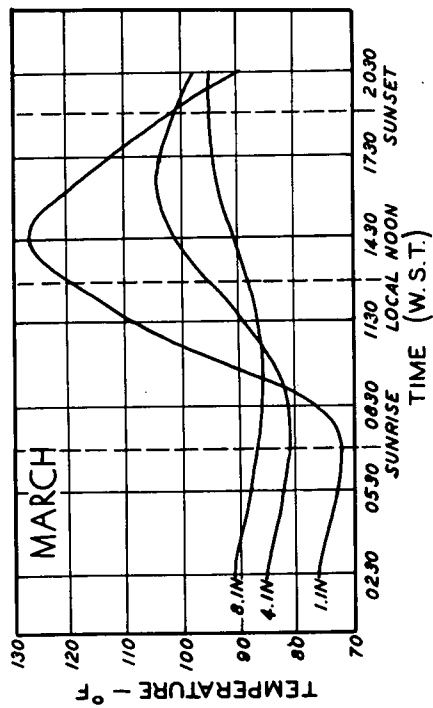
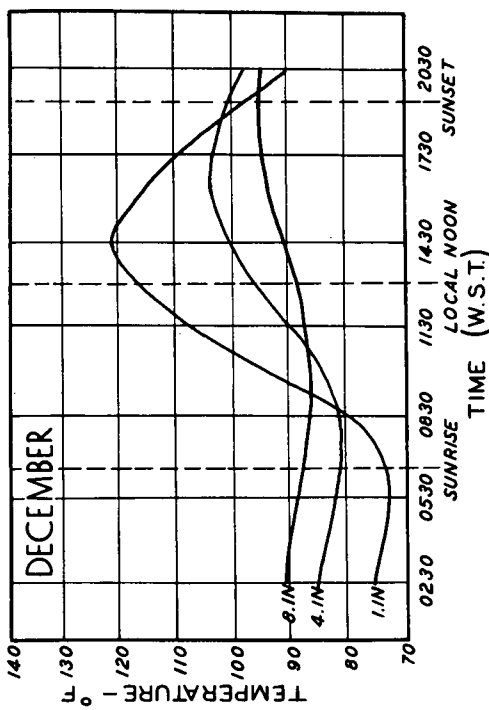
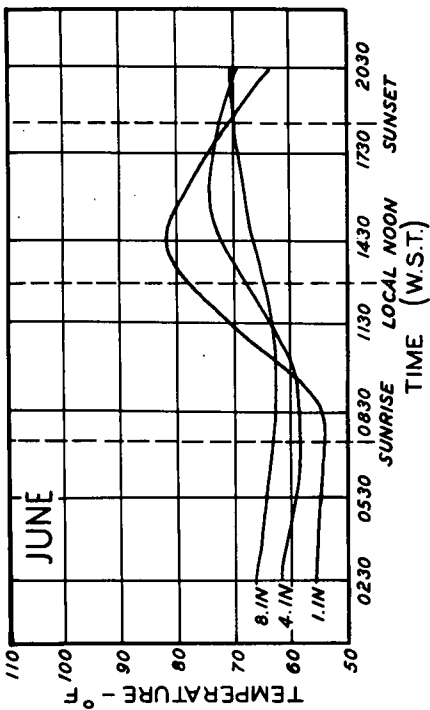


FIG. 1. DIURNAL SOIL TEMPERATURE VARIATION FOR DIFFERENT DEPTHS AT GILES 1957 - SELECTED MONTHS.

2. DIURNAL VARIATION

(1) With Time

The mean monthly temperatures for the four months March, June, September and December (equinoxes and solstices) for each time of observation at the 1 in., 4 in., 8 in., levels are plotted in Fig. 1. The local times of sunrise, sunset, and noon for the middle day of each month are also shown.

Theoretically the time of maximum temperature at the soil surface would be at local noon when the incoming radiation is a maximum. The time of maximum temperature should occur after noon at any depth, the time lag depending on the thermal diffusivity of the soil (see para. 4 below). At a depth of 1 in. the maximum temperature occurs approximately $1\frac{1}{2}$ hours after noon at each season of the year. At the 4 in. level the time lag has increased to about 4 hours and at the 8 in. level to $7\frac{1}{2}$ hours after local noon time.

The same lag but somewhat smaller is shown by the minimum temperatures. Again, the minimum temperature of the soil surface should occur theoretically near sunrise. At 1 in. the minimum occurs about half an hour after sunrise, at 4 in. about $1\frac{1}{2}$ hours and at 8 in. about $2\frac{1}{2}$ hours after sunrise.

(2) With Depth

The diurnal temperature wave is clearly defined at a depth of 8 in. The temperatures at 20 in. and 40 in. are only read once a day. The maximum interdiurnal variation during periods when there has been no rain is less than 1°F at 20 in. and less than 0.5°F at 40 in., indicating that the diurnal wave is probably barely noticeable at 20 in. and damped out or insignificant at 40 in. This agrees with observations made elsewhere. West (1952) reports that in a sandy loam at Griffiths, New South Wales, the daily wave is almost damped out at two feet. Guild (1950) reports that in a fine loose, sandy silt in the Arizona desert, the diurnal wave was almost entirely damped out at the 18 in. level. Fitton and Brooks (1931) report that "the diurnal range in soil temperatures extends to a depth of about 3 feet". (By comparison, the diurnal temperature variation of the sea surface temperature is only of the order of 0.5°F but the diurnal variation is still perceptible at 50 metres depth (Sverdrup, 1943).

3. DIRECTION OF HEAT FLOW

Reference to Tables 1 and 2 and Fig 1 shows that:

- (1) In the course of the day the heat flux between the 1 in. to the 4 in. levels is downwards from about $1\frac{1}{2}$ hours after sunrise to sunset or just slightly before sunset. Between the 4 in. and 8 in. levels the flux is downwards from about 4 hours after sunrise to 3 hours after sunset. Outside these hours the heat flux is towards the soil surface.
- (2) In the course of the year, the general direction of the heat flux at the 40 in. level is downwards between September and March and upwards between April and August.

4. HEAT CONDUCTIVITY OF SOIL

The classical treatment of the problem of heat diffusion in soil is given by Lettau (1951). With only one year of observations there is not sufficient data available to do a complete analysis of the soil temperature wave. However, Lettau's method can be used to give an estimate of the thermal diffusivity of the soil between 4 in. and 8 in. i.e. the soil horizon above the stony sub-surface layer. One is restricted to this layer because -

- (a) the 1 in. readings are not precise enough for this purpose
- (b) the 20 in. and 40 in. readings are only taken once daily.

By developing Lettau's treatment it can be shown that

$$T_2 = T_1 e^{-(x_1 - x_2) \sqrt{\frac{\pi C \rho}{\nu \lambda}}}$$

- where T_1 is the diurnal range of temperature at depth x_1
 T_2 is the diurnal range of temperature at depth x_2
 ν is the period of oscillation of the diurnal heat wave in seconds (86,400)
 ρ is the density of the soil
 C is the specific heat of the soil
 λ is the heat conductivity

The density and specific heat of the Giles desert clay has not been determined. In such a case, the thermal diffusivity defined as $\frac{\lambda}{\rho C}$ is calculated (dimensions cm^2/sec).

This was calculated for several days at each season of the year to produce a mean figure of .0045 cm²/sec. West (1952) analysed 8 years of record at Griffith by deriving the harmonics of the annual temperature wave at various depths and obtained a mean value of .00432 for the Griffith clay. Other figures for the thermal diffusivity quoted by Geiger (1950) are -

Granite (rock)	0.021 cm ² /sec	Wet marshy soil	0.003 cm ² /sec
Wet sandy soil	0.01 "	Dry sandy soil	0.0013 "

5. THE EFFECT OF RAIN

Probably of more interest to geographers is the effect of rainfall on the soil temperatures. With temperatures above 100°F for several hours each day in the top few inches of the soil, and reaching extreme values of 130°F to 145°F frequently in the surface layers, a newly germinated seed would face two hazards (a) the extremely high temperatures which would be lethal when the seed is turgid prior to shooting (b) the even higher temperature at the soil surface which would, in exposed situations, kill the emergent shoot.

When seeds are perfectly dry they can stand surprisingly high temperatures for long periods. Levitt (1956) has listed work done in this field by several workers and quotes cases of seeds surviving exposure to temperatures of over boiling point. In all cases the seeds must be dry. This would of course be the case for the hard-coated seeds of the desert plants. Once the seed becomes turgid (or even moist following the breaking of the hard surface tissue) temperatures over 100°F for periods up to an hour or so are lethal.

In the case of seedlings emerging from the soil, Julander (1945) shows that the stolons of range grasses are damaged at 118°F or higher. Since such temperatures are common and prolonged in the Giles area the possibility of damage is obvious.

How long then does the soil at Giles in a typical continental desert environment take to dry out after rain? In December, 1957, the rainfall at Giles was 460 points on twelve days, the totals for the 24 hours ending 9 a.m. being:-

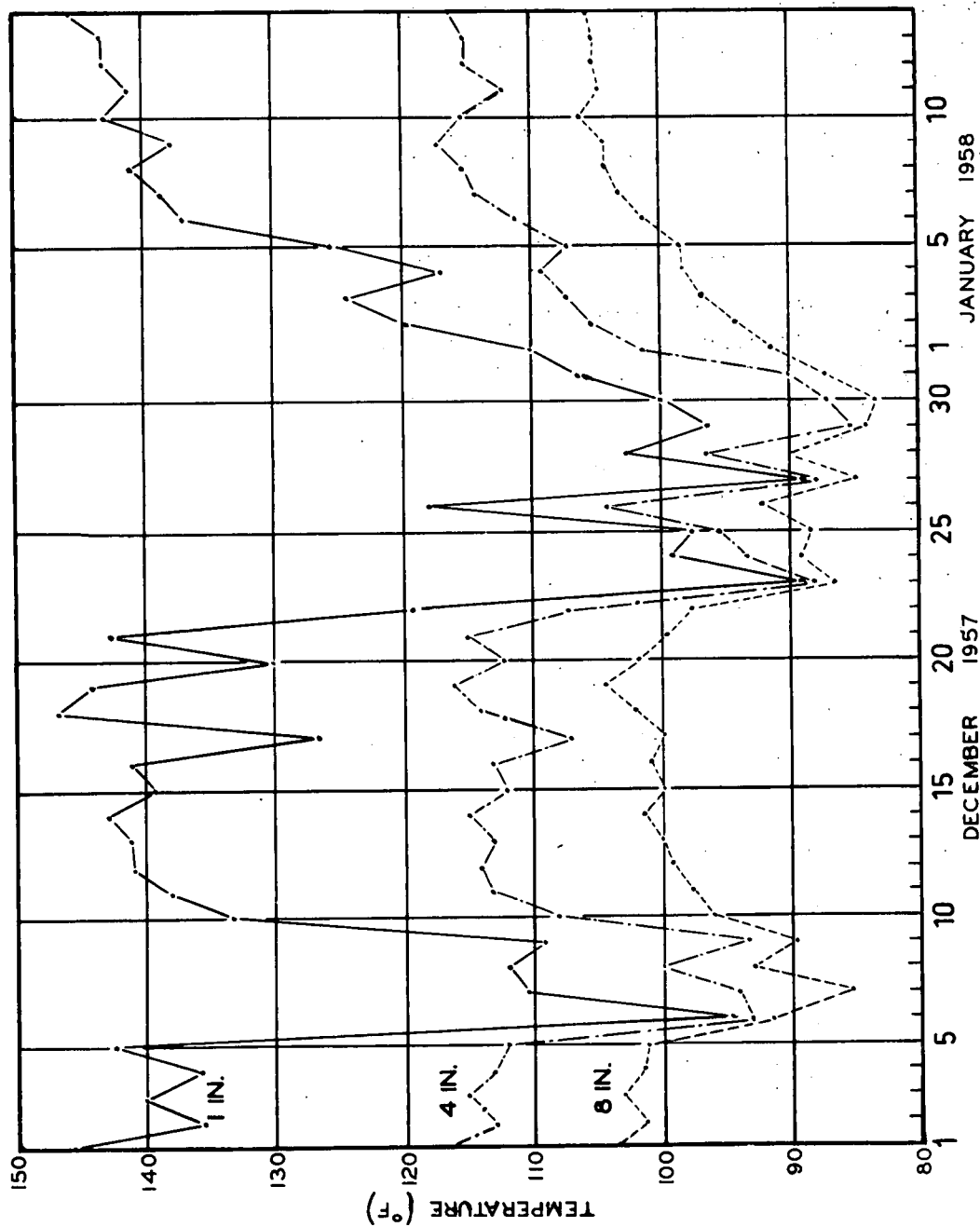


FIG 2. THE EFFECT OF RAIN ON SOIL TEMPERATURES AT GILES, DECEMBER 1957 AND JANUARY 1958.

6	December	4	points
7	"	6	"
8	"	1	"
10	"	2	"
22	"	4	"
23	"	19	"
24	"	90	"
25	"	44	"
26	"	8	"
27	"	40	"
28	"	3	"
29	"	239	"

Note that of the 460 points, 447 points fell in 8 successive days culminating in 239 points in the 24 hours ended 9 a.m. on the 29th. Now this must be regarded as an extremely good rainfall for this area, refilling water holes and of great value to the perennial herbs, shrubs and trees. What of the seeds? During the 8 successive wet days many of the seeds would germinate and hence become vulnerable to high temperatures. In Fig 2 the daily maximum temperatures at 1 in., 4 in., and 8 in. are plotted; most of the germinating seeds would be in this top 8 in. of the soil.

In the graph (Fig 2) it will be seen that the effect of the light rains in early December is transient, the temperatures even at 8 in. depth being over the 100°F again within 3 days. This rain would not be sufficient even to start germination. The effect of the 447 points at the end of the month can be seen quite clearly in the temperatures (in fact the effect can be detected at 40 in.). However, within 48 hours of the cessation of the rain the maximum temperature at 1 in. has already reached 106°F, within 4 days has reached 120°F and within a week is back to 140°F. At a depth of 4 in. the maximum temperature is over 100°F within 3 days and over 110°F within 8 days. At 8 in. the temperature has returned to over 100°F within 8 days.

The germinating seeds would probably survive at the 4 in. and 8 in. levels for seven to 10 days after the rain, but the shoots would then have to withstand the extreme temperatures at the soil surface.

Only those in shaded or otherwise favoured positions (drainage channels, etc) would survive to maturity. As far as the regeneration of pastures over the whole area is concerned even a good fall of 460 points can be non-effective in summer. If, however, a further 100 to 200 points had fallen about a week after the first falls to hold the soil temperatures down for a few more days and replace the moisture lost by evaporation from the top few inches then the new growth would have a much better chance of survival.

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