ASSESSING SOIL-WATER STATUS VIA ALBEDO MEASUREMENT[1/]

by

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INTRODUCTION

To evaluate the water balance of a watershed, rainfall, runoff, evaporation, transpiration, deep percolation, and storage must be known. The rates of change of all of these factors (except rainfall) depend to some degree on the soil-water status. Runoff is related to the infiltration rate, which is dependent on antecedent moisture; while evaporation and transpiration are governed by the amount and distribution of soil-water, as are deep percolation and storage. Thus, to make accurate water balance studies of watersheds, good information on soil-water status is required. This knowledge is also required to ascertain the survival probabilities of various types of vegetation between rainfalls in low rainfall areas, and to determine the susceptibility of the uppermost soil particles to wind erosion.

Several techniques have been proposed to measure continuously the soil-water content of large watersheds. These techniques range from nuclear radiation methods (Kirkham and Corey, 1973; Sammis, et al. 1972; Smith, 1967) to microwave radiometry from satellites (Schmugge, et al., 1974). Because of manpower, money, and machinery limitations, broad and routine attempts to implement these procedures have been frustrated, however; and a need still exists for a straightforward, inexpensive, and accurate method for assessing soil-water status.

Recent work by Idso, et al. (1974a, b) suggests that simple solarimeters may help to accomplish this objective. They showed that bare soil albedo (defined as the ratio of reflected to incoming solar radiation) was a linear function of the water content of a very thin surface layer of soil, and that albedo correlated well with the water contents of thicker soil layers. In addition, they showed that albedo measurements could be used to delineate the three classical stages of soil drying. This paper considers the possibilities of utilizing albedo measurement as a simple means of assessing the soil-water status of sparsely vegetated watersheds, where plants do not play a dominant role.

OVERVIEW OF EXPERIMENTS

Six individual drying experiments provided the data for the analyses of Idso, et al. (1974a, b). They were conducted on a smooth bare field of

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Avondale clay loam (a fine-loamy, mixed, hyperthermic, Torrifluvent) at Phoenix, Arizona, in July 1970, March 1971, August 1972, and May, September, and December 1973. In each experiment, the 72- × 90-m field was flood irrigated with about 10 cm of water and then allowed to dry. During these drying periods, at either 20- or 30-min intervals, incoming and reflected solar radiation were measured with upright and inverted solarimeters as were other meteorological factors and evaporation via two weighing lysimeters. On certain days, soil water contents were also measured at 20-min intervals, at six sites in the field, at depth increments of 0 to 0.2, 0 to 0.5, 0 to 1, 1 to 2, 2 to 4, 4 to 6, 6 to 8, and 8 to 10 cm. Details of this procedure are provided by Jackson, et al. (1973).

These basic experiments were extended in early 1974, to include photographs of the drying field soil and measurements of evaporation from small pots receiving from 0.5 to 3.0 cm of water. The pots of Avondale clay loam were sunk in the field and removed hourly for weighing to determine cumulative evaporation. Each treatment had three replications.

ALBEDO VARIATIONS DURING A DRYING CYCLE

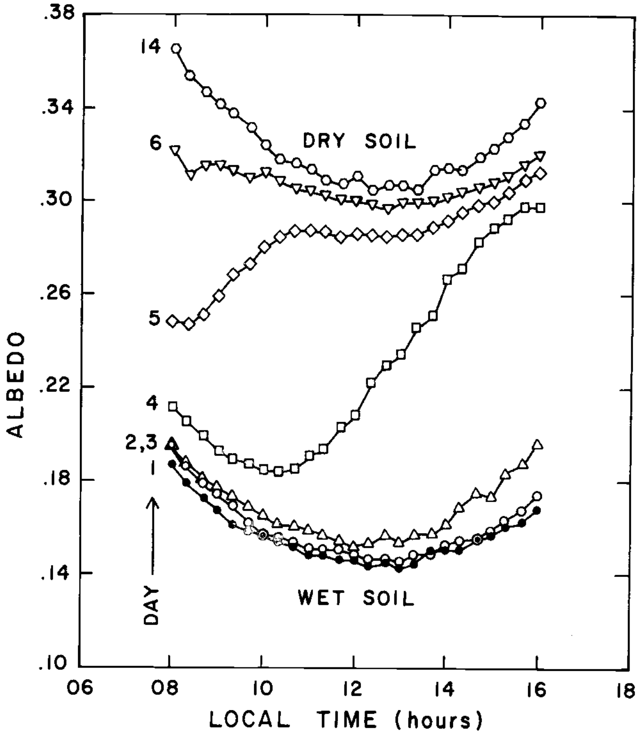
An example of the type of albedo data obtained in all seasons of the year is presented in Fig. 1 for September. The transition from low to high values occurred more rapidly during warmer seasons, but followed the same basic pattern in all experiments. There was an initial period of low values that were symmetrical about solar noon, followed by a period of rapidly rising nonsymmetrical values that led into another set of symmetrical values at the high end of the range.

After introducing a normalizing factor to remove solar zenith angle effects, the data of Fig. 1 were transformed into the parameterization portrayed in Fig. 2. Operating upon all of the data in this fashion, it was found that in all experiments the normalized albedo had an initial value of 0.14 on day 1 after irrigation, and a limiting value of 0.305 when the soil was very dry.

To see how this range of albedo variation with water content compared with that of other soils, a search of the literature was made, the results of which are listed in Table 1. For all soils, the characterizations of "wet" and "dry" were somewhat arbitrary, but as far as could be determined, they represented nearly saturated and air-dry conditions, respectively. For most soils, the wet soil albedo was generally about half that of the dry soil albedo.

ALBEDO-WATER CONTENT RELATIONS

When normalized albedo values, obtained in the 1973 experiments, were plotted against the measured volumetric water contents of nine depth intervals, (from the soil surface to the 10-cm depth) the family of curves in Fig. 3 was obtained. The linear surface relation obviously was not measured directly, but extrapolated from the trends indicated by the other curves. This linearity of the surface relation is probably a characteristic of all soils. Tests of other soils would be valuable in determining the validity of this assumption.



ALBEDO
LOCAL TIME (hours)
DRY SOIL
WET SOIL
DAY
14
6
5
4
2,3
1
.38
.34
.30
.26
.22
.18
.14
.10
06
08
10
12
14
16
18

Figure 1

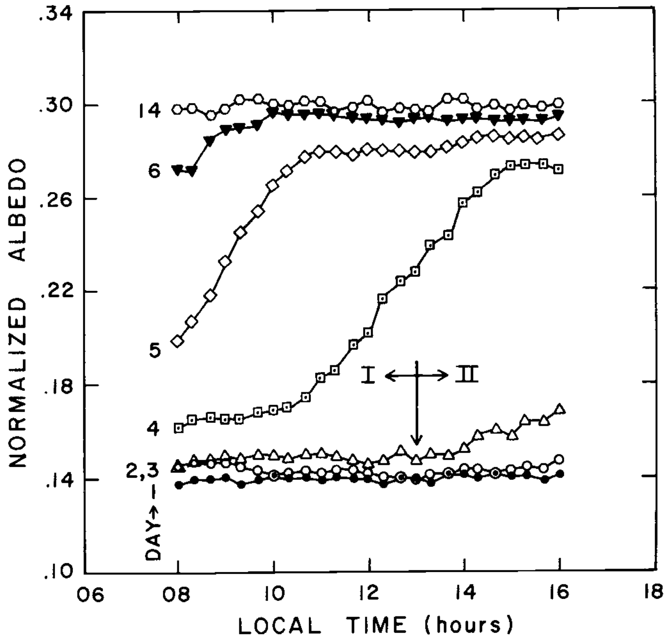

.34
.30
.26
.22
.18
.14
.10
NORMALIZED ALBEDO
14
6
5
4
2,3
DAY→ 1
I ← → II
06
08
10
12
14
16
18
LOCAL TIME (hours)

Figure 2

From Fig. 3, it can be seen that the curves for all depth intervals converge at the maximum albedo value at a very low soil-water content approaching zero, and at the minimum albedo value at some greater soil-water content. From the water characteristic curve for Avondale clay loam, this upper water content value (minimum albedo) occurs at about -300 mb soil-water pressure, or what has historically been referred to as field capacity. Although no other sets of curves like Fig. 3 are known to exist in the literature, Robinson (1966) presents a single curve for sand taken from Kondrat'ev (1954) that shows the point of maximum curvature leading to this lower albedo convergence point to occur at a much lower water content value than that of our soil. Thus, the water content corresponding to field capacity may represent a common location for this lower convergence point. Additional work on wide color and textural ranges of soils is required to substantiate this hypothesis.

ALBEDO - EVAPORATION RELATIONS

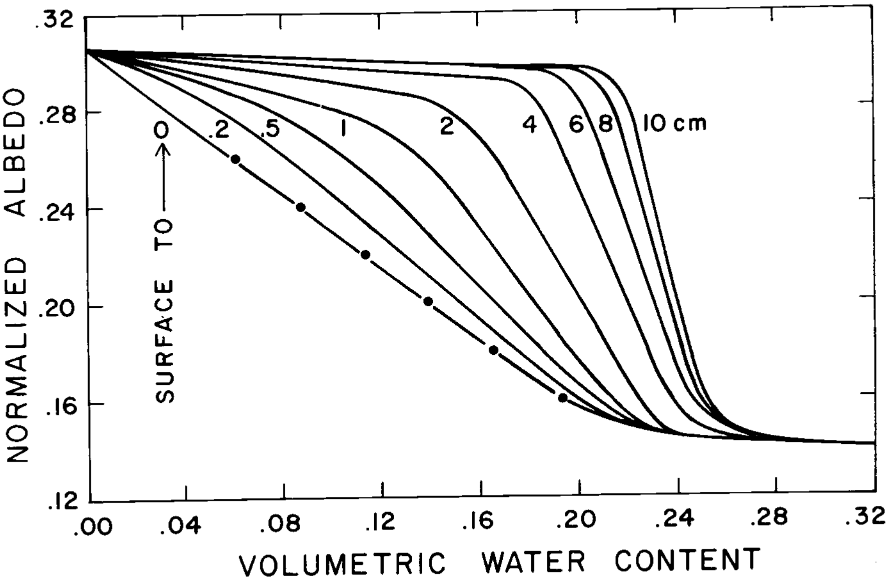
DIFFERENTIATING EVAPORATION REGIMES

An example of the type of evaporation data obtained in each experiment is presented for September 1973 in Fig. 4. It shows very nearly identical rates for days 1 and 2 after irrigation and for the first 11 hours of day 3. From that point on, however, it is greatly reduced. In considering all of the data obtained in all seasons of the year, Idso et al. (1974b) determined that evaporation up to this point of variation was essentially potential evaporation (denoted State I), and that the evaporation beyond this point was the falling rate evaporation phase, composed of the classical Stages II and III.

In looking back at Fig. 2, it is noted that the normalized albedo for September begins to break away from its initial, near constant value at about 1300 on day 3, just 2 hours after the initiation of Stage II drying, determined from the evaporation data of Fig. 4. To see how good an indicator albedo variations of this nature are in determining this breaking point in evaporation characteristics, we compared the length of time of Stage I drying, determined by both lysimeter and albedo data, for four of the drying experiments (Table 2). May 1973 is excluded because of loss of albedo data on the afternoon of day 2; and December 1973 is excluded because of extremely low evaporation rates that approached the sensitivity limits of the lysimeters. This table shows that the normalized albedo is indeed a good indicator of the end of Stage I and beginning of Stage II evaporation.

EVALUATING STAGE I EVAPORATION FROM LYSIMETER DATA

Using the finding of the preceding section, we determined the total evaporation that occurred during Stage I of each of our experiments for which both albedo and lysimeter data existed. We also made similar evaluations for some rainstorms and irrigations that occurred about 12 years ago, when our experimental field was in a similar nonvegetated condition, and both albedo and lysimeter data were routinely recorded. The results are portrayed in Fig. 5. Regardless of how much water was applied to the soil by either rainfall or irrigation, between 20 to 25% of



NORMALIZED ALBEDO
.32
.28
.24
.20
.16
.12
.00
.04
.08
.12
.16
.20
.24
.28
.32
VOLUMETRIC WATER CONTENT
SURFACE TO
0
.2
.5
1
2
4
6
8
10 cm

Figure 3

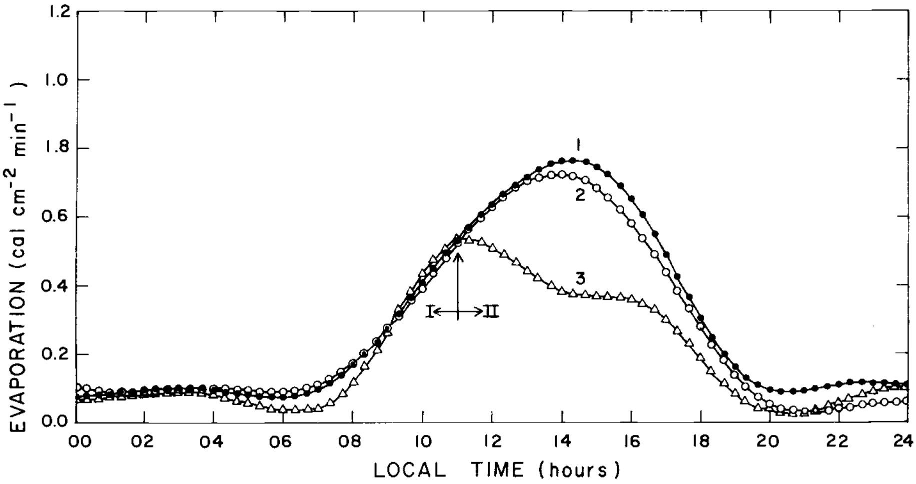

EVAPORATION (cal cm⁻² min⁻¹)
1.2
1.0
1.8
0.6
0.4
0.2
0.0
00
02
04
06
08
10
12
14
16
18
20
22
24
LOCAL TIME (hours)
1
2
3
I
II

Figure 4

the amount applied was always lost by Stage I potential evaporation before the surface dried, which raised the albedo and initiated the falling rate phase of evaporation.

DIFFERENTIATING EVAPORATION REGIMES BY SIGHT

In early 1974, a small portion of the field was given a light irrigation, and photographic records of the visual appearances of dry, drying, and moist soil were obtained every 20 min. Simultaneous albedo measurements were obtained over both the continuously dry and the drying sections. Figure 6 shows the combined results. As is readily apparent, the end of Stage I potential evaporation signified by the sharp increase in drying soil albedo at about 1130 is easily detected by sight.

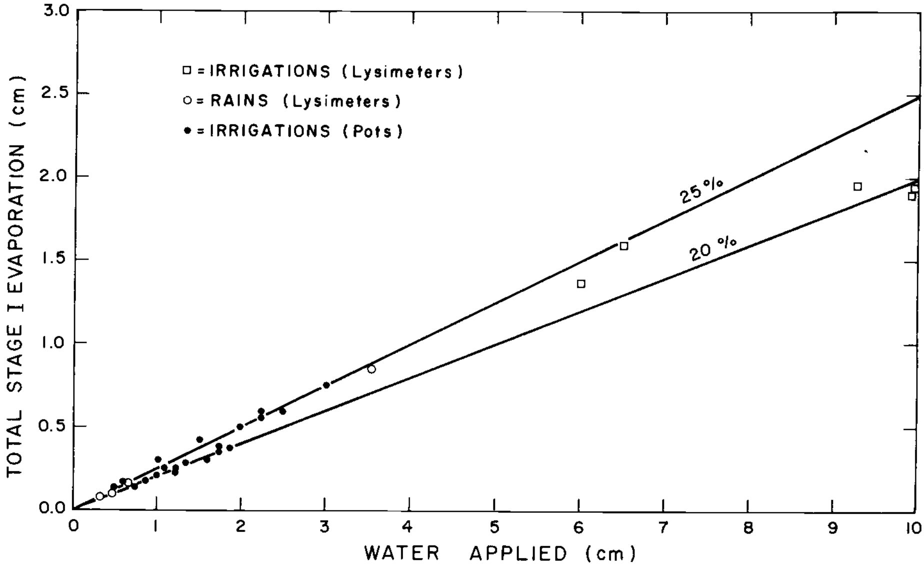
EVALUATING STAGE I EVAPORATION FROM SMALL POTS

Several small pots (16 cm diameter, 18 cm deep) were filled with Avondale clay loam and packed to uniform bulk density at air-dry water content. From 0.5 to 3.0 cm of water were then added, after which they were weighed and set in retaining holes dug in the field. When the visual appearance of each small pot indicated that Stage I evaporation had ceased, the pots were weighed again. The results (Fig. 5) were essentially the same as those obtained with lysimeters for the irrigations and rains: between 20 to 25% of the water added was lost by potential evaporation during Stage I.

CONCLUDING DISCUSSION

This paper indicates that albedo variations of many soils are significant over the soil-water content range from air dry to field capacity, and that albedo may be used to estimate the surface water content of soils in this range. Albedo may also be used to differentiate between the initial potential rate phase of evaporation following an application of water, and the succeeding falling rate phase. Our results of applying this technique to a field of Avondale clay loam indicate that 20 to 25% of the water applied by either irrigation or rain will be lost by Stage I potential evaporation, independent of seasonal variations in evaporative demand. Since the visual appearance of the soil changed significantly with the transition from Stage I to II, we developed a simple technique using sunken pots to determine total Stage I evaporation. Its agreement with the albedo-lysimeter results indicates that it may be a useful technique for calibrating watershed soils in the field.

Presently, the techniques we have developed are applicable only to bare soil surfaces. When vegetation is present, we have the complication of water being extracted from the volume of soil infused by roots in addition to the loss from the soil-air interface. It is possible, however, that our techniques may be used in conjunction with miniature solarimeters to separately evaluate the evaporative water loss from a vegetated watershed via these two separate pathways. Our approach may then provide useful input data for more comprehensive hydrologic models. Thus, the technique of assessing soil-water status via albedo measurement is not yet ready for routine field use in most natural situations, but it



3.0
2.5
2.0
1.5
1.0
0.5
0.0
TOTAL STAGE I EVAPORATION (cm)
□ = IRRIGATIONS (Lysimeters)
○ = RAINS (Lysimeters)
• = IRRIGATIONS (Pots)
25 %
20 %
0
1
2
3
4
5
6
7
8
9
10
WATER APPLIED (cm)

Figure 5

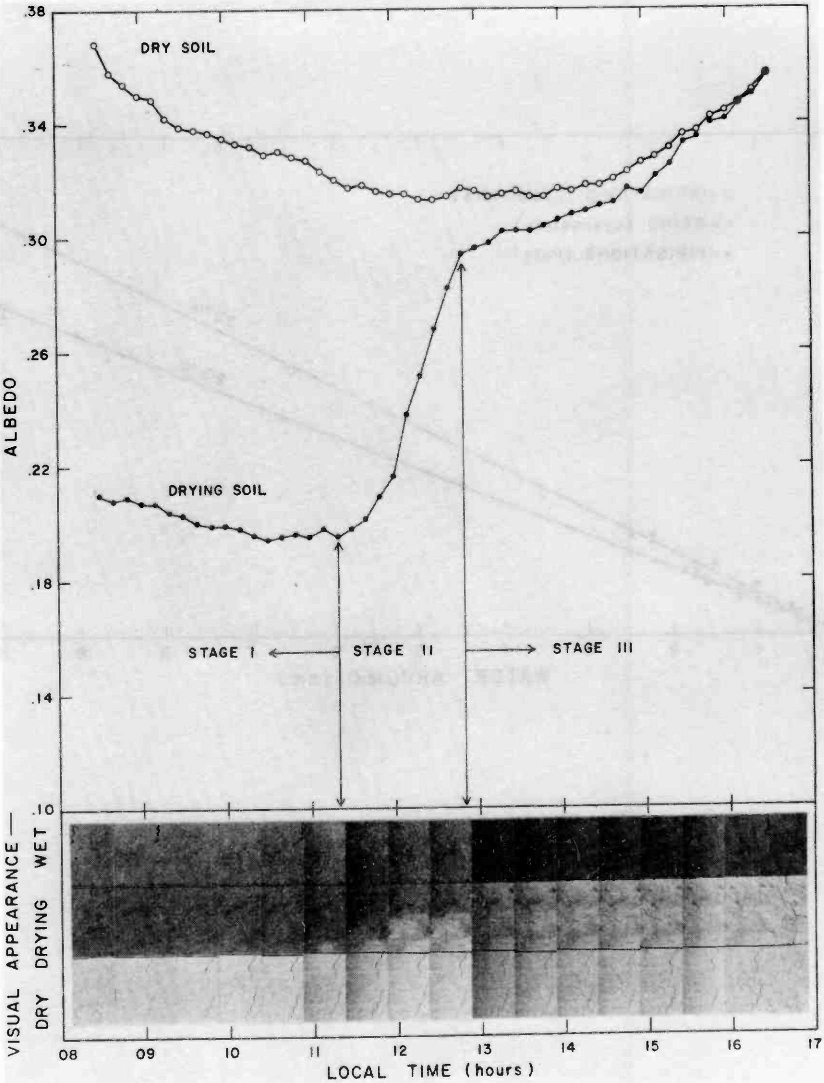

.38
.34
.30
.26
.22
.18
.14
.10
ALBEDO
DRY SOIL
DRYING SOIL
STAGE I
STAGE II
STAGE III
VISUAL APPEARANCE—
DRY DRYING WET
08
09
10
11
12
13
14
15
16
17
LOCAL TIME (hours)

Figure 6

seems to hold promise for the future. To bring it to fruition, additional work is needed on albedo-water content relations of other soils, albedo-evaporation relations of other soils - including extensions to Stages II and III - and, finally, integration with plants in a more complete system of the type commonly encountered on most watersheds.

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TABLE 1. Albedos (nonnormalized) of wet and dry soils and their ratios.

Reference Source	Type of Soil	Wet	Dry	Wet/Dry
Van Wijk (1963)	Dark clay	0.05	0.16	0.31
Portman (1954)	Unspecified	.06	.16	.38
Chia (1967)	Black soil	.07	.14	.50
Kondrat'ev (1954)	Black soil	.08	.14	.57
Ekern (1965)	Bare latosol	.08	.14	.57
Angstrom (1925)	Black mould	.08	.14	.57
Angstrom (1925)	Grey sand	.09	.18	.50
Piggin & Schwerdtfeger (1973)	Red-brown clay loam	.10	.20	.50
Kondrat'ev (1954)	Grey soil	.11	.27	.41
Monteith (1959)	Clay loam with flints	.11	.18	.61
Rijks (1967)	Dark brown clay	.11	.17	.65
Graham & King (1961)	Grey brown loam	.12	.21	.57
Idso, et al. (1974a)	Avondale clay loam	.14	.30	.47
Kalma & Bredham (1972)	Tippera clay loam (red)	.14	.23	.61
Budyko (1958)	Grey soil	.15	.27	.56
Kondrat'ev (1954)	Blue loam	.16	.23	.70
Buttner & Sutter (1935)	Dune sand	.24	.37	.65
Average	All types	0.111	0.205	0.537

TABLE 2. The time required to reach Stage II of soil drying.

Experiment	Time to Reach Stage II Determined:	
	From Lysimeter Data	From Albedo Data
July 1970	46 hours	46 hours
March 1971	96 hours	95 hours
August 1972	51 hours	51 hours
September 1973	74 hours	76 hours
Average	66.8 hours	67.0 hours