A Study of Local Evapotranspiration (I)
- Daily Soil Water Contents from Energy Balance-Water Budget with Eddy Correlation Approach and TDR -

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1. Introduction

The selected experimental watersheds located in the southwest of the United State represent typical semiarid land. Since the vegetation in semiarid rangelands is fairly sparse compared to humid regions, the soil plays a major role in the radiative and hydrologic balance (Kustus et al., 1991). In terms of the hydrologic cycle, the condition of the soil surface influences the magnitude of the runoff component. This is especially evident in semiarid and arid rangelands, where infiltration may be one of the most important factors in determining the amount of runoff (Keppel and Renard, 1962). Antecedent soil moisture is certainly an important factor in the amount of runoff at the watershed scale in this area (Hino et al., 1988; Logue and Freeze, 1985).

The daily soil water contents were estimated from the energy balance-water budget approach with the eddy correlation at semiarid watersheds of Lucky Hills and Kendall during the summer rainy period. This daily estimated soil water contents were compared with the measured soil water contents using time domain reflectometry (TDR) at watershed scale. The comparison is valuable to evaluate the accuracy of current soil water content measuring system using TDR and sensible heat flux measurement using eddy correlation method at small watershed.

2. Method and Results

The site chosen for the experiment is the well-instrumented Walnut Gulch experimental

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watershed (31° 43'N, 110° 41'W) operated by the Southwest Watershed Research Center of the U.S. Department of Agriculture's Agricultural Research Service (ARS). It is located in southwestern Arizona about 120 km southeast of Tucson, Arizona. Data used for this study were measured from Monsoon 90 experiment (Kustus et al., 1991) during the summer rainy period from DOY (Day of Year) 90198 through DOY 90227 at Lucky Hills subwatershed, and from DOY 90202 through DOY 90223 at Kendall subwatershed (Fig. 1).

Lucky Hills has an area of 8.09 ha nestled in the western portion of the Walnut Gulch watershed, having smoother topography. The dominant vegetation type is shrub. The Kendall subwatershed has an area of 48.56 ha nestled in the eastern portion of the Walnut Gulch watershed. It is typical of southwestern rangeland where cattle grazes on gentle hillslopes dominated by grasses.

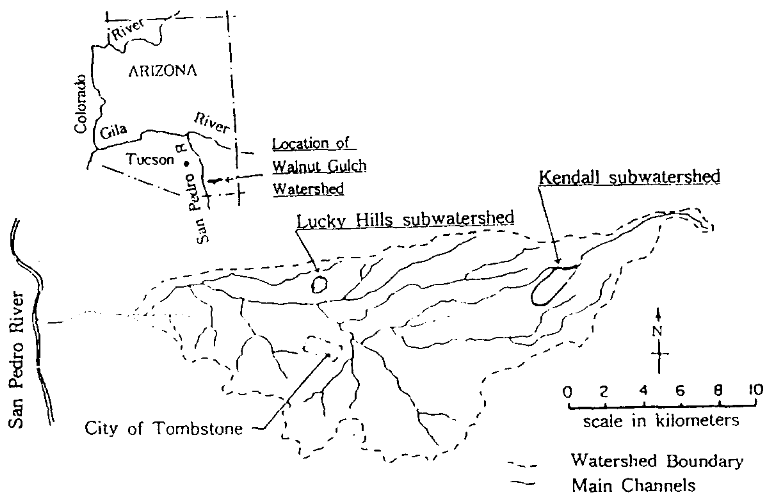

Fig. 1. USDA-ARS Walnut Gulch Experimental Watershed Location Map.

2.1 Flux Measurements

Latent heat flux (Q_{LE}) was estimated from easily measured fluxes [net radiation(Q_n), sensible heat flux(Q_h) and ground heat flux(Q_g)], based on energy balance approach ($Q_{LE} = -Q_n - Q_h - Q_g$). Daily evapotranspiration (ET) was obtained by summing the hourly ET for each day. Actual ET differs from latent energy (Q_{LE}) only in units. ET is the "depth equivalent" of evaporated water (in mm per period) while Q_{LE} is in W/m^2.

Net radiation was measured with a REBS Q*6 net radiometers at 2.5 m above ground level. The net radiation (Q_n) is the driving factor for energy exchange because in most systems it represents the net energy available from sources and sinks.

Soil heat flux (Q_g) is the combination of heat flux (Q_{gh}) at soil heat flux plate with 5 cm depth and thermal energy (Q_{gs}) stored in the soil layer above the sensor. Therefore, soil heat flux is $Q_g = Q_{gh} + Q_{gs}$. At 5 cm depth, Q_{gh} was measured directly with soil heat flux plates at 3 sites in each watershed. The mean Q_{gh} was calculated from the measured values. The hourly energy used for ground heat storage above the sensors (Q_{gs}) was estimated from the change in mean temperature of the 0-5 cm soil layer. The mean temperature of this layer was determined by averaging soil temperatures obtained at the 2.5 cm and 5 cm depths. The averaged ground temperature was used to obtain the Q_{gs}. Therefore,

$$Q_{gs} = 0.01\, \Delta T_s C_s\, \Delta z / \Delta t \tag{1}$$

where C_s is volumetric heat capacity of the soil [= 1.5(MJ/m^3/K)]; ΔT_s is the soil temperature difference between T_{si} and T_{si-1}; T_{si} is the average soil temperature at time i (hr); T_{si-1} is the average soil temperature at time i-1 (hr); 0.01 is unit conversion coefficient (m/cm); Δt is the one hour time interval (= 3600 s); and Δz is the thickness of soil layer (= 5 cm).

Sensible heat flux (Q_h) was estimated by eddy correlation (EC) during rainy periods in summer of 1990. The EC values of Q_h were calculated from air temperature, T_a, and vertical wind speed, w, both measured at 9 m above ground level and both sampled at 4 Hz over periods of 20 min. The flux was calculated as

$$Q_h = -\rho_a \cdot c_p \cdot \overline{w' T_a'} \tag{2}$$

where ρ_a is air density (kg/m^3), c_p is specific heat of air (J/kg/K), primes denote deviations from period means, and overbars denote period means (Businger et al., 1967). The Q_h measurement is based upon the mean covariance of temperature and vertical wind speed [cov(w · T_a)] over the measurement period.

2.2 Soil Moisture Measurements

The data on the vertical distribution of soil moisture was collected using the time domain reflectometry (TDR) method at Lucky Hills and Kendall watersheds (Goodrich et al., 1994).

The TDR sensors were positioned at 6 different depths about from 0 to 60 cm, which represents the total rooting depth of each watershed. The total water content for 60 cm depth was estimated from the TDR volumetric soil water content by summing the TDR estimates for each layer in the profile.

The TDR measurements at Lucky Hills were made between and underneath brush (three replications each), and at six locations adjacent to recording raingages in the Lucky Hills watershed which were an average of about 130 m apart. The TDR measurements at Kendall were made on north- and south-facing slopes midway between the stream channel and ridge, and in grazed and ungrazed areas (three replications each). The average of the TDR replications in each watershed was used to represent the soil water content.

2.3 Daily Soil Moisture Estimation

The daily soil water content was estimated from the energy balance-water budget approaches with eddy correlation at Lucky Hills and Kendall watersheds during the summer rainy period. The TDR measurements of soil water on DOY 90198 and DOY 90207 defined the initial soil water content for Lucky Hills and Kendall watersheds, respectively. The water balance is then given by:

$$\Delta SM = \Delta P - \Delta ET - \Delta RO \quad (3)$$

where ΔP is the net daily precipitation (mm/day); ΔET is the net daily evapotranspiration (mm/day); ΔRO is the net daily runoff (mm/day); and ΔSM is the net change in soil moisture content (mm/day).

2.4 Correlation between Measured and Estimated Soil Water Contents

The water balance estimates of soil water were compared with measured soil water content during the study period. The estimated and measured soil water content showed good agreement during the study period at Lucky Hills and Kendall watersheds (Figs. 2, 3, 4 and 5).

The degree of similarity between the regressions of the two methods of measuring soil water content (energy balance-water budget approach with eddy correlation and TDR) was explained by determining the correlations between these methods at Lucky Hills and Kendall watersheds during the summer rainy period (Table 1).

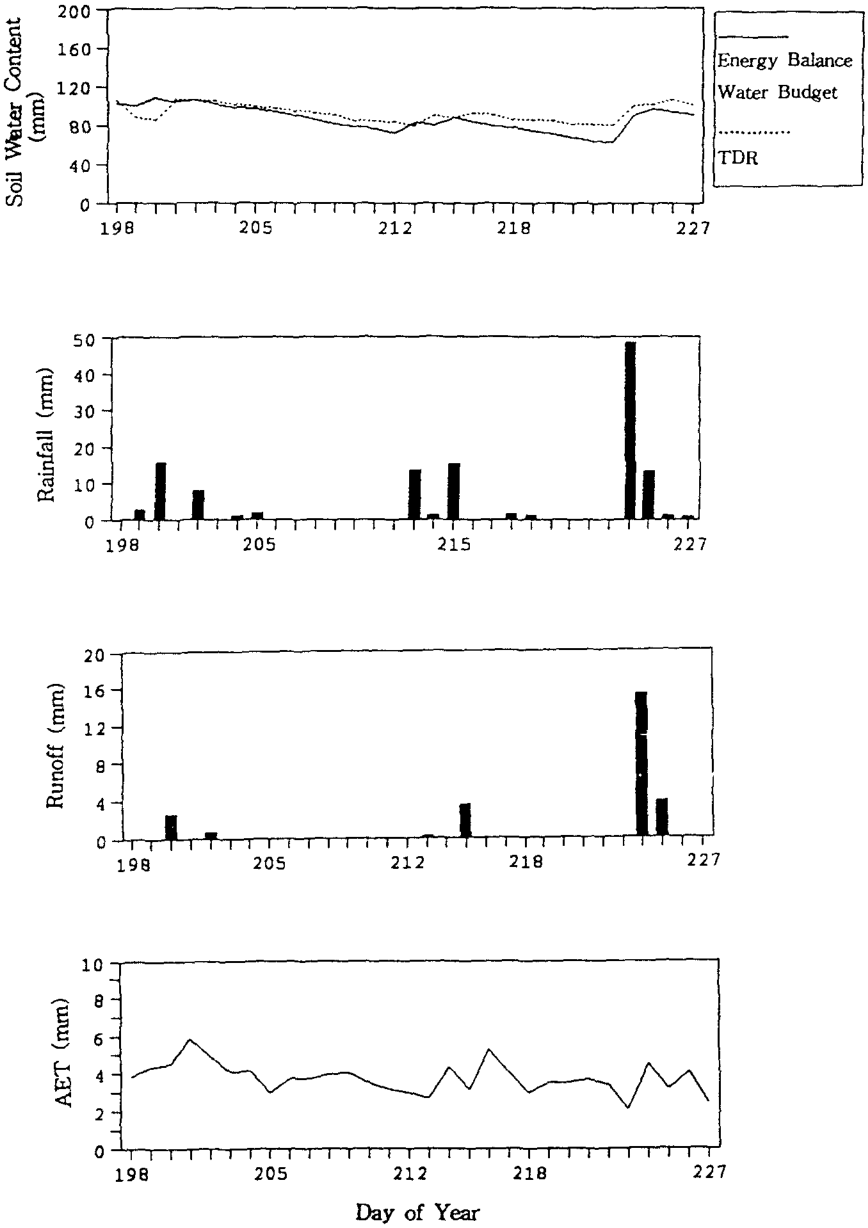

Fig. 2. Water Balance at Lucky Hills Watershed.

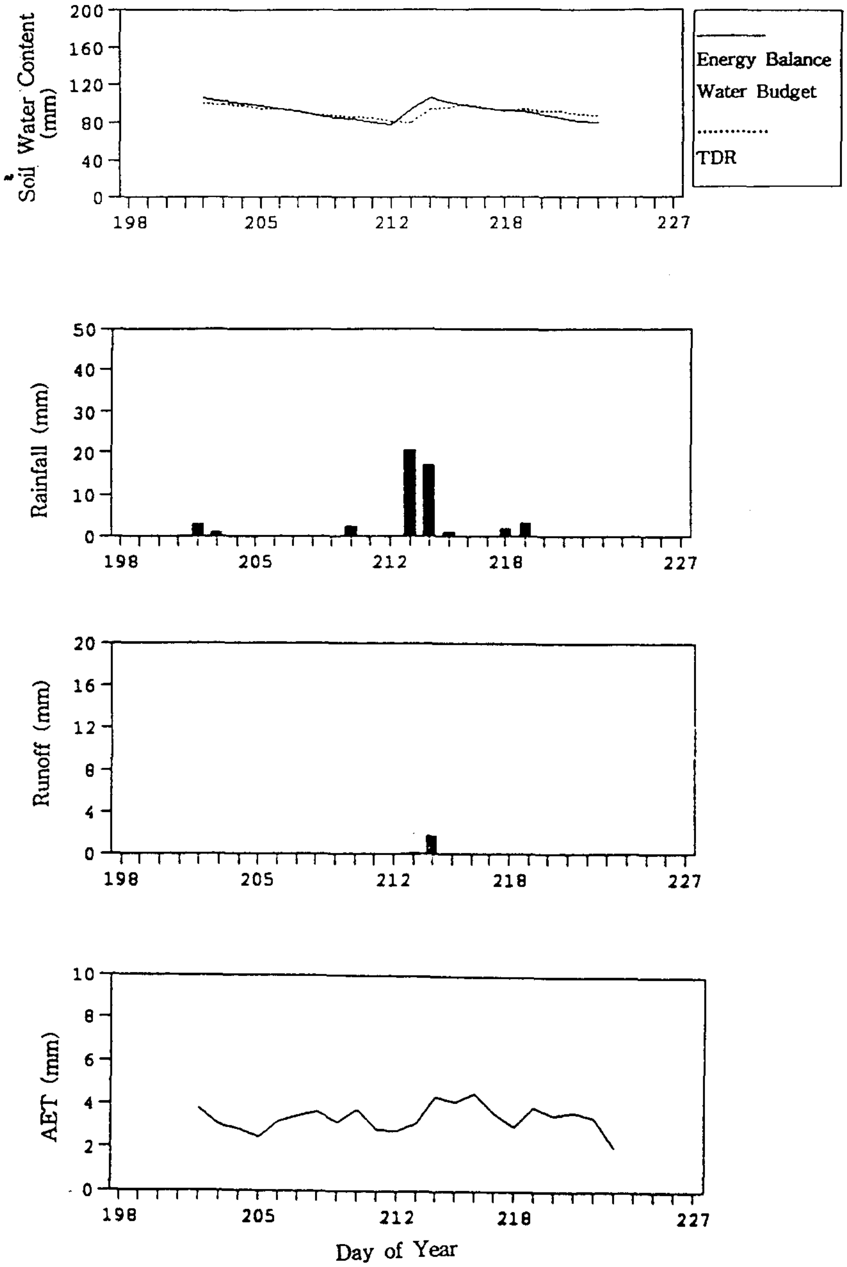

Fig. 3. Water Balance at Kendall Watershed.

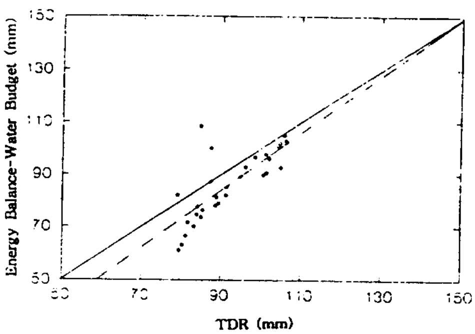

Fig. 4. Simple Linear Regression for Daily Soil Moisture Measurements between the Energy Balance-Water Budget with Eddy Correlation and TDR at Lucky Hills Watershed during the Summer Rainy Period (1990).

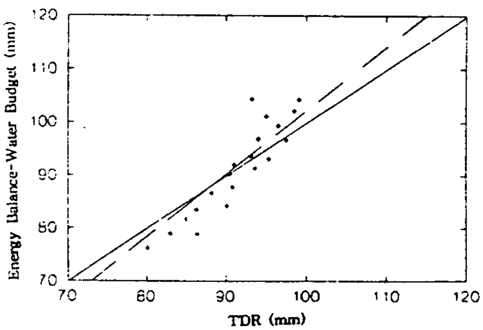

Fig. 5. Simple Linear Regression for Daily Soil Moisture Measurements between the Energy Balance-Water Budget with Eddy Correlation and TDR at Kendall Watershed during the Summer Rainy Period (1990).

Table 1. Simple Linear Regressions between the Two Measurements of Daily Soil Water Contents at Lucky Hills and Kendall Watersheds during the Summer Rainy Period (1990).

No	Regression Equations	r^2	SEE	MSM_{EW}	MSM_{TDR}	n
1	$SM_{EW} = -14.058 + 1.089SM_{TDR}$	0.584	8.51	85.73	91.68	30
2	$SM_{EW} = -16.910 + 1.191SM_{TDR}$	0.630	5.34	91.28	90.81	21

(All the regressions are significant at $P < 0.001$)
1) : Lucky Hills watershed
2) : Kendall watershed
SM_{EW} : daily soil water based energy balance-water budget approach (mm)
SM_{TDR} : daily soil water based on TDR (mm)
MSM_{EW} : mean of SM_{EW} (mm)
MSM_{TDR} : mean of SM_{TDR} (mm)
n : sample size
r^2 : coefficient of simple determination
SEE : standard error of the regression (mm)

3. Conclusions

The degree of similarity between the regressions of two methods (energy balance-water budget approach with eddy correlation and TDR) of measuring soil water content was explained by determining the correlations between these methods. Simple linear regression analyses showed that soil water content measured from TDR method was responsible for 58 % and 63 % of the variations estimated from energy balance-water budget approach with eddy correlation at Lucky Hills and Kendall, respectively. The scatter plots and the regression analyses revealed that two different approaches for soil water content measurement at small watershed scale have no significant difference. The comparison tested the accuracy of current soil water content measuring system using TDR and energy balance-water budget approach using eddy correlation method at small watershed scale.

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