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Short Communications

Improvements in E-DiGOR Model: Quantifying the Water Balance Components of Bare Soils

Mehmet Aydin[1*]

[1]*Visiting Professor, Department of Biological Environment, Kangwon National University, Chuncheon 200-701, Korea*

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Quantification of water loss through evaporation and drainage from bare soils in rainfed-agriculture is very important for an effective soil-water management. In many regions, evaporation from the soil surface constitutes a large fraction of the total water loss not only from bare soils but also from cropped fields. It has been reported that direct evaporation from the soil surface ranged from 30 to more than 80% of the total rainfall (Onder et al., 2009). However, quantifying the components of water balance is of major importance in the assessment of soil hydrology under bare-field conditions.

In general, soil evaporation is modeled by limiting potential evaporation (e.g., from Penman-Monteith equation) with a surface resistance of zero (Allen et al., 1994; Wallace et al., 1999; Aydin et al., 2005):

$$E_p = \frac{\Delta(R_n - G_s) + 86.4 c_p \rho \delta / r_a}{\lambda(\Delta + \gamma)} \qquad (1)$$

where E_p is potential soil evaporation (E_p = kg/m$^{2/}$day ≈ mm/day), Δ is the slope of vapor pressure-temperature curve (kPa/^{o}C), R_n is the net radiation (MJ/m^2/day), G_s is the soil heat flux (MJ/m^2/day), ρ is the air density (kg/m^3), c_p is the specific heat of air (kJ/kg/^{o}C=1.013), δ is the vapor pressure deficit of the air (kPa), r_a is the aerodynamic resistance (s/m), λ is the latent heat of vaporization (MJ/kg), γ is the psychrometric constant (kPa/^{o}C), and 86.4 is the factor for conversion from kJ/s to MJ/day.

A simplified model originally proposed by Aydin (1998), referred as Aydin equation, for estimating actual evaporation from bare soils was tested by Aydin et al. (2005) under different environmental conditions:

$$E_a = \frac{Log|\psi| - Log|\psi_{ad}|}{Log|\psi_{tp}| - Log|\psi_{ad}|} E_p \qquad (2)$$

If $|\psi| \le |\psi_{tp}|$ *then* $E_a = E_p$ *or* $E_a/E_p = 1$

For $|\psi| \ge |\psi_{ad}|$, $E_a = 0$.

Remember that $E_p \ge 0$.

where E_a and E_p are actual and potential evaporation rates (mm/day), respectively, ψ_{tp} is the absolute value of soil water potential (matric potential) at which actual evaporation starts to drop below potential one (cm of water), ψ_{ad} is the absolute value of soil water potential at air-dryness (cm), and ψ is the absolute value of soil water potential at the surface layer (cm).

Aydin equation could derive soil evaporation successfully from soil water potential (Aydin et al., 2005; Falge et al., 2005). This approach was based on energy fluxes and soil properties, and experimental data were used to define a threshold separating the two stages of evaporation (Quevedo and Frances, 2007; Romano and Giudici, 2007). Although the equation appeared to be useful; however, the objective measurement of soil water potential near the surface of the profile was difficult, especially for drier upper layer. In order to overcome such difficulties, Aydin and Uygur (2006) devised a simple model for predicting soil water potential at the top surface layer:

$$\psi = -\left[(1/\alpha)(10\sum E_p)^3 / 2(\theta_{fc} - \theta_{ad})(D_{av} t / \pi)^{1/2}\right] \qquad (3)$$

where ψ is soil water potential (cm of water) at the top surface layer, α is a soil specific parameter (cm) related to flow path tortuosity in the soil, ΣE_p is cumulative potential

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*Corresponding Author: Mehmet Aydin (E-mail: maydin08@yahoo.com) soil evaporation (cm), θ_{fc} and θ_{ad} are volumetric water content (cm^3/cm^3) at field capacity and air-dryness, respectively, D_{av} is average hydraulic diffusivity (cm^2/day) determined experimentally, t is time (day) and π is 3.1416.

During a drying period, the top surface layer of the soil may dry out eventually to air-dry wetness and the soil then no longer evaporates at a considerable rate, except water transport through the slow process of moisture diffusion. Assuming that the water potential at dry soil surface is at equilibrium with the atmosphere, the minimum water potential can be derived from the Kelvin equation (Brown and Oosterhuis, 1992; Aydin et al., 2005; Aydin, 2008):

$$\psi_{ad} = \frac{R_g T}{mg} \ln H_r \tag{4}$$

where ψ_{ad} is the water potential for air-dry conditions (cm of water), T is the absolute temperature (K), g is the acceleration due to gravity (981 cm/s^2), m is the molecular weight of water (0.01802 kg/mol), H_r is the relative humidity of the air (fraction), and R_g is the universal gas constant (8.3143×10^4 kg cm^2/s^2/mol/K).

The model had been validated for actual evaporation by Aydin et al. (2008) and Onder et al. (2009) based on the combination of Aydin (1998) and Aydin and Uygur (2006) equations. Recently, Aydin (2008) proposed an interactive way (called E-DiGOR model by the author) for predicting daily actual soil evaporation, soil water storage and drainage rates.

The soil water storage (S) on any day can be imposed on the difference between rainfall (P, in case) and actual evaporation on the consecutive day. Symbolizing this produced variable as W, and assuming a negligible runoff from nearly level soils, the following expression can be written (Aydin, 2008):

$$W^{(j)} = S^{(j-1)} + P^{(j)} - E_a^{(j)} \tag{5}$$

If $W^{(j)} < \theta_{fc} Z$, then $S^{(j)} = W^{(j)}$

If $W^{(j)} \geq \theta_{fc} Z$, then $S^{(j)} = \theta_{fc} Z$.

In practice, soil water storage between the soil surface (0) and a given depth (Z) is calculated by integrating water content of individual soil layers ($\int_0^z \theta_i dz$).

Drainage is simply calculated by the mass balance. The cumulative drainage until day j can be expressed as follows (Aydin, 2008):

$$\left[\sum D\right]^{(j)} = \int_0^z \theta_i dz + \left[\sum P\right]^{(j)} - \left[\sum E_a\right]^{(j)} - S^{(j)} \tag{6}$$

where ΣD is cumulative drainage (mm) out of storage depth since the first day of simulation period, ΣP is total rainfall (mm), and ΣE_a is cumulative actual soil evaporation (mm). Thus, from the differences between the consecutive days, drainage rates (D = mm/day) can be easily calculated, if any:

$$D^{(j)} = \left[\sum D\right]^{(j)} - \left[\sum D\right]^{(j-1)}$$

Aydin and Polat (2010) developed a computer program for a functional implementation of the E-DiGOR model. The sensitivity analysis of soil evaporation module of the E-DiGOR model was carried out by Aydin and Kececioglu (2010). More recently, Kurt (2011) tested the model in olive plantations in a Mediterranean environment and concluded that the model could successfully quantify the components of soil water balance in orchards.

Although the E-DiGOR model could provide detailed descriptions of water balance components at plot scale, there was still a need to improve the model since it lacked the estimation of runoff. The model is additionally updated to provide a method of assessing runoff losses with an acronym DERSim (Aydin, 2010):

$$Q = P \times \{1/2 \times [Log\sqrt{S_p} + Exp(-D_s / P)]\}^{(Ks/\mathrm{Im})} \tag{7}$$

where Q is runoff (mm), P is rainfall (mm), S_p is slope steepness (%), K_s is saturated hydraulic conductivity (mm/h), I_m is maximum intensity of rainfall (mm/h) and D_s is deficit of saturation (mm) which means saturated water amount minus the antecedent water amount.

In order to give an idea to the readers about the performance of E-DiGOR model, the statistical relationships between

Table 1. Statistical relationships between measured and simulated data of actual soil evaporation (Ea), drainage rates (D) and soil water storage (S)

Variable	Number of pairs (n)	Calculated coefficient of determination (R^2)	Level of significance	Reference
E_a	70	0.915	$P < 0.01$	Aydin et al. (2005)
E_a	122	0.940	$P < 0.001$	Aydin et al. (2008)
E_a	53	0.914	$P < 0.01$	Aydin (2008)
E_a_plot1	65	0.694	$P < 0.01$	Kurt (2011)
E_a_plot2	65	0.615	$P < 0.01$	Kurt (2011)
D	20	0.885	$P < 0.01$	Aydin (2008)
D_plot1	22	0.964	$P < 0.01$	Kurt (2011)
D_plot2	22	0.982	$P < 0.01$	Kurt (2011)
S	22	0.897	$P < 0.01$	Aydin (2008)
S_plot1	105	0.919	$P < 0.01$	Kurt (2011)
S_plot2	109	0.917	$P < 0.01$	Kurt (2011)

measured and simulated data compiled from the literature are summarized in Table 1. In spite of several limitations such as neglected upward flux from deeper layers into the considered profile zone, preferential flow and surface roughness, the performance of the model is still sufficient to estimate the water balance components of bare soils.

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