MODELING SOIL WATER REDISTRIBUTION DURING SECOND STAGE EVAPORATION

A.A. Suleiman[1] and J.T. Ritchie[2]

1: Research Associate, Dept. of Civil & Environ. Eng., Bucknell Univ., asuleima@bucknell.edu

2: Professor, Nowlin Chair, Dept. of Crop & Soil Sciences, Michigan State Univ., ritchie@msu.edu.

Importance

Predicting the change of soil water content (θ) near the soil surface is needed for many management practices such as irrigation scheduling.

Modeling soil water evaporation (E_s) is required to find management strategies that minimize water losses

Definition

Soil evaporation is called second stage evaporation when it is less than potential evaporation. In this stage the evaporation rate is limited by the soil conditions (soil water content, matric potential gradient, hydraulic diffusivity etc.) which determine the rate at which the soil can release moisture towards the surface.

Objective

This study was carried out to develop a simple functional model to simulate soil water redistribution and evaporation rate during second stage evaporation. The developed model will be used in the water balance of SALUS crop simulation model.

Theory

On the basis of diffusivity theory, the quantity of water lost by evaporation (Q, cm) or cumulative evaporation (E_c, cm) during second stage evaporation is given by (Rose, 1968):

$$Q = E_c = \alpha\, t^{1/2}$$

$$\alpha = f(\lambda(\theta))$$

where z (cm): soil depth,

λ(θ): Boltzmann transform, and

θ_i, θ_{ad}, θ_{dul} initial, air dried, and drained upper limit soil water

Model Description

The daily change of soil water content (Δθ) at a certain depth during second stage evaporation is estimated as follows:

$$\Delta\theta = C\,(\theta_i - \theta_{ad})$$

where C (d^{-1}) is a constant and function of z (cm) as follows:

$$C = a z^n$$

where a and n are constants.

Data Analysis

Soil water content of loamy and sandy loam soils was monitored at 5 depths.

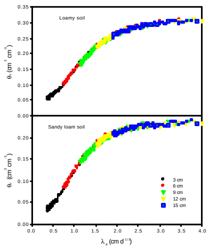
Numerical solutions were used to find α for the six different soils of Rose (1968) and the loamy and sandy loam soils.

Trial and error procedure was used to solve for n and a considering that 1) θ at all depths and at any time has a single function with Boltzmann transform and 2) α can be estimated from θ_{dul} as shown in Figure 2.

Results

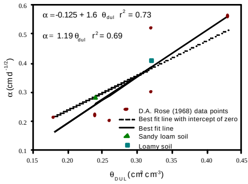
The diffusivity theory during second stage evaporation requires that θ at different soil depths and at any time has a unique function with the shown in Figure 1. This condition was met and shown in Figure 1. Volumetric soil water content at 3, 6, 9, 12, and 15 cm depths had the same relationship with λ(θ) for the loamy and sandy loam soils for about 60 days (Figure 1).

Figure 1. Relationship between θ and Boltzmann transform.



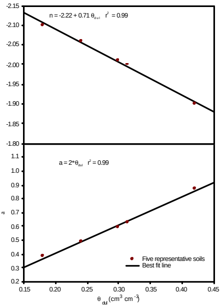
A linear relationship was found between α and θ_{dul} with r^2=0.73 for the best fit line and r^2=0.69 for the best fit line with an intercept of zero. Because no soil would have negative α, the best fit line with an intercept of zero was considered to be more realistic. The values of α ranged from 0.5 for soils with high θ_{dul} such as clayey soil to about 0.2 for soils with low θ_{dul} such as sandy soil (Figure 2). This is in agreement with (Ritchie, 1972; and Ritchie and Johnson, 1990).

Figure 2. Relationship between α and θ_{dul}.



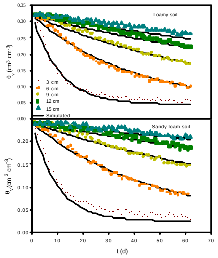
Linear relationships were found between both n and a and θ_{dul} with r^2 of 0.99. These relationships were evaluated and validated for soils whose θ_{dul} ranged from 0.15 to 0.45 cm^3 cm^{-3} (Figure 3). Both of n and a are related to α as well because α is related to θ_{dul}. The higher α the closer n to –1 and the greater a. That means that C at a certain depth is higher for soils with high θ_{dul} than for soils with low θ_{dul}.

Figure 3. Relationship between n and a with θ_{dul}.



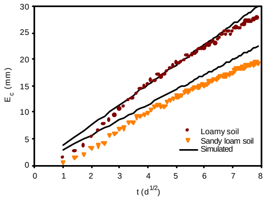
The modeled Soil water contents agreed well with the measured ones at 3, 6, 9, 12, and 15 cm depths for the loamy and sandy loam soils using n and a values estimated from θ_{dul} (Figure. 4). The change of soil water content was significantly high near the surface (at 3 and 6 cm) for both soils. This shows the importance of modeling soil water redistribution near the surface during second stage evaporation.

Figure 4. Measured and simulated soil water content.



E_c had a linear relationship with $t^{1/2}$ with zero intercept. This is another proof for the validity of the diffusivity theory and it demonstrate the soil evaporation was less than potential evaporation. E_c was estimated accurately for about 60 days using the values of n and a estimated from θ_{dul} (as shown in Figure 3). E_c of 60 days was about 28 mm for loamy soil and 18 mm for sandy loam soil (Figure 5).

Figure 5. Measured and simulated E_c.



Conclusions

The diffusivity theory was valid during second stage evaporation.

The developed model estimated soil water redistribution and cumulative evaporation accurately during second stage evaporation.

α, n, and a were soil specific. They could, however, be estimated accurately from θ_{dul}.

References

Ritchie, J.T. 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8:1204-1213.

Ritchie, J.T., and B.S. Johnson. 1990. Soil and plant factors affecting evaporation. ASA-CSSA-SSSA, 677 South Segoe, Madison, WI 53711, USA. Irrigation of Agricultural Crops-Agronomy Monograph no. 30:363-390.

Rose, D.A. 1968. Water movement in porous materials III. Evaporation of water from soil. Brit. J. Phys., Ser 2, Vol. 1:1779-1791.

Soil evaporation is called second stage evaporation when it is less than potential evaporation. In this stage the evaporation rate is limited by the soil conditions (soil water content, matric potential gradient, hydraulic diffusivity etc.) which determine the rate at which the soil can release moisture towards the surface.

The diffusivity theory was valid during second stage evaporation.

The developed model estimated soil water redistribution and cumulative evaporation accurately during second stage evaporation.

α, n, and a were soil specific. They could, however, be estimated accurately from θ_{dul}.