Significance of soil surface water content to determine evaporation

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1 INTRODUCTION

Evaporation from soil surface is a multi-phase transport process of soil water to evaporating surface. Due to the involvement of this complex process, it has been a challenge for accurate estimation evaporation from soil surface. However, it is essential for many disciplines, such as hydrology, meteorology, agriculture and geotechnical engineering (Blight 1997).

The potential evaporation (E_p) is explicit to evaluate, which occurs at water surface and is only related to the meteorological variables. However, how to extend to evaluate actual evaporation (E_a) from soil surface is still ambiguous. Many researchers directly expressed the ratio of actual to potential evaporation only as a function of surface water content. In addition, Mahfouf and Noilhan (1991) comprehensively overviewed this approach. Although researchers recently found that E_a / E_p is both related to atmosphere condition and soil water content (Yamanaka 1997), there is no clear consensus on the expression.

In this study, various evaporation tests were conducted to investigate the characteristics of evaporation process. Then, a simple model to parameterize evaporation from soil is proposed.

2 EVAPORATION EXPERIMENT

All the evaporation tests were conducted based on a climate control apparatus, in which the atmosphere conditions (temperature, relative humidity, wind speed) were controlled as shown in Table 1. temperature was maintained at 25 ℃ (±1.0 ℃); the relative humidity was controlled at three degrees of 40% (±2.37%), 60% (±3.24%), and 80% (±3.47%); wind speed was controlled at four degrees of 0.5 m/s (±0.09), 1.4 m/s (±0.13), 2.5 m/s (±0.21), and 3.6 m/s (±0.16). For each case, free water evaporation test to determine E_p and soil surface evaporation to determine E_a were carried out. Specimens were poured in cylindrical pans (Φ10 cm, thickness 1cm), the weight of the pan was measured every 10 minutes with a resolution of 0.1 g, then the evaporation rate can be calculated by the weight loss, and the average volumetric water content was determined using dry mass of soil and instantaneous masses monitored. The temperature of soil surface, air temperature was continuously monitored.

K-7 sand is known as standard silica sand for experiment in Japan. The physical properties of K-7 sand were summarized in Table 2. The sand was fully oven dried before the start of the experiment. After filling into the evaporation pan with identical density of 1.45 g/cm^3, the specimen was wetted to saturation using a fine uniform mist of distilled water. Because the experiments were performed indoors, there was no precipitation or radiation fluxes from the surface.

Table 1. Conditions of evaporation tests

	Wind speed m/s	Humidity %	Temperature ℃
C1	0.5	40	25
C2	1.4		
C3	2.5		
C4	3.6		
C5	0.5	60	25
C6	1.4		
C7	2.5		
C8	3.6		
C9	0.5	80	25
C10	1.4		
C11	2.5		
C12	3.6		

Table 2. Physical properties of K7 sand

Parameters	Value
Specific gravity	2.67 g/cm^3
D50	0.214 mm
Coefficient of curvature	1.20
Maximum dry density	1.58 g/cm^3
Minimum void ratio	0.69
Minimum dry density	1.38g/cm^3
Maximum void ratio	0.93

3 RESULT ANALYSIS AND DISCUSSION

The E_a / E_p versus drying time for different conditions of wind speed (C1, C2, C3 and C4) and humidity (C4, C8 and C12) were shown in Fig.1 and Fig.2, respectively. They suggest that the drying curves have the similar tendency for different conditions. It can be seen that the E_a / E_p is slightly greater than 1.0; this deviation can be attributed to slight variations in the wind speed in the air. Initially, evaporation occurs at a near potential rate and then starts to decline after a period of time. As shown in Fig.1, the time for evaporation rate changes to decrease seems proportionally increase with wind speed increases. However, evaporation rate at C12 condition is much lower than that of C4 and C8 conditions as expressed in Fig. 2. The evaporation rate for all conditions falls to zero after each soil specimen reaches an air-dry state.

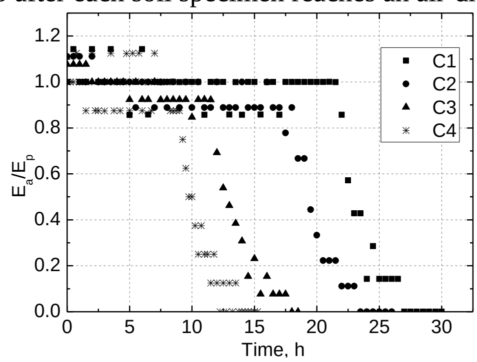

Figure 1. The relative evaporation versus drying time for C1, C2, C3 and C4 conditions.

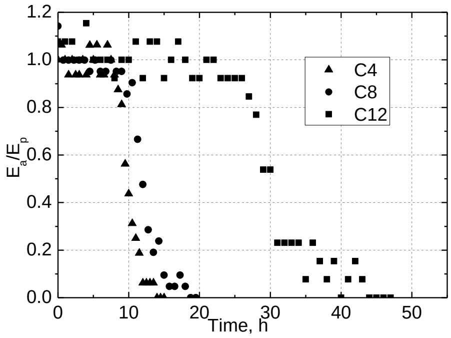

Figure 2. The relative evaporation versus drying time for C4, C8 and C12 conditions.

Here, we define critical water content θ_c, where the E_a/E_p starts to decline from 1.0 to zero. Fig. 4 and Fig. 5 show a plot of E_a/E_p versus water content for the conditions from C5 to C8 and C9 to C12. Due to E_a/E_p for the water content of greater than 14% is nearly constant to 1.0, it's not shown in the Figures. It can be seen that θ_c value increases along with the wind speed (in verse with aerodynamic resistance). According to other researchers, this value depends on soil texture, Here θ_{fc} , the field capacity, is adopted as common reference frame to eliminate the dependence on the soil texture.

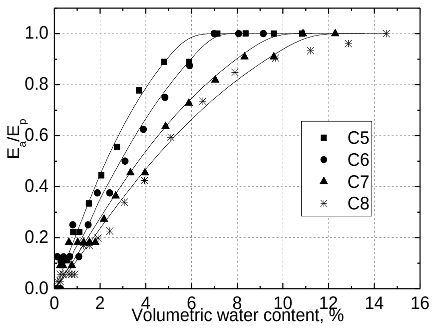

Figure 4. The relative evaporation versus volumetric water content for C5~C8 conditions. The solid line is from the proposed formula (1) and (2).

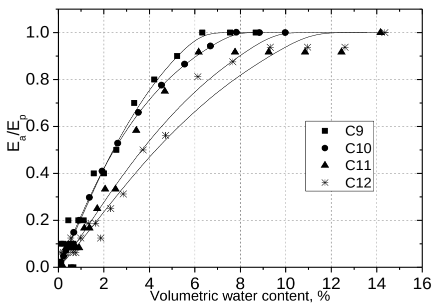

Figure 5. The relative evaporation versus volumetric water content for C9~C12 conditions. The solid line is from the proposed formula (1) and (2).

The above experiment result and analysis indicates that it is essential to formulate E_a/E_p considering the influence of aerodynamic resistance. it's feasible to clearly define the critical water content and adopt a piecewise function to describe the evaporation curve. For stage 1, E_a/E_p is nearly 1.0 that is uninfluenced by water content and r_a .Therefore, a simple empirical formula is proposed as

$$\beta = \begin{cases} 1 & \theta > \theta_c \\ \dfrac{1}{1+\sqrt{\dfrac{\theta_c}{\theta}}\left(\sqrt{\dfrac{\theta_c}{\theta}}-1\right)} & \theta \le \theta_c \end{cases} \qquad (1)$$

in which, θ_c is critical water content and expressed as

$$\theta_c = \left(\frac{73.10}{r_a} + 0.28\right)\theta_{fc} \qquad (2)$$

where, r_a is determined by wind speed. The field capacity is constant for certain soil textures.

Fig. 4 and Fig.5 shows the relative evaporation rate calculated by the proposed formulation compared with the experiment, which shows a good agreement. A linear relationship between critical water content and the reciprocal of aerodynamic resistance is clearly shown and expressed as Eqs.(2).

It should be noted that this paper discusses only the properties of soil surface that control evaporation process, and the thin soil specimen in the evaporation test is regarded as element section without considering the hydraulic conductivity in soil. For the analysis of evaporation from soil with enough thickness, it's essential to simulate the flow processes below soil surface.

5 CONCULATIONS

To parameterize the boundary of soil-atmosphere interaction during evaporation process, various pan evaporation tests are conducted under controlled conditions. Based on the result, a simple model for calculating relative evaporation rate from soil surface is proposed, which considers wind speed. Although this model agrees well with the experiment result, further calibration need to be conducted for different types of soils in the future.

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