Effect of the soil particle size on the water redistribution during the evaporation process through homogeneous sandy soil profiles

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1. Introduction

Over the past few decades, global warming has been a serious threat to our planet, causing a wide range of impacts that have led to various natural geo-disasters. Due to the increase in the average temperature and the evaporation rate that exceeds the precipitation rate, severe droughts induce land degradation that in turn leads to desertification, which is becoming one of the most alarming environmental problems in the world. The proper prediction of the water-flow and the soil-atmosphere fluxes in unsaturated soil profiles is of significant importance for combating desertification. Among those boundary fluxes, the evaporation flux, where water gets lost from soil pores into the atmosphere as a complex multiphase process, follows an ambiguous mechanism.

The evaporation process involves three stages in which the evaporation rate behavior and the water transport mechanisms differ. Stage 1 (SI), the constant rate stage, is characterized by a relatively high and constant evaporation rate in which water is supplied by capillary liquid flow to the evaporating surface from a receding drying front. At a certain drying depth, indicated by the characteristic length (L_c), the hydraulic continuity is disrupted marking the end of SI (Lehmann et al., 2008). This initial stage is followed by Stage 2 (SII), the falling rate stage, during which the evaporation continues with relatively lower evaporation rates from a secondary drying front (Shokri et al., 2009) where water transport mechanisms are considered to be coupled between capillary flow and diffusion. Lastly, Stage 3 (SIII), the residual stage, dominated by vapor diffusion transport as the evaporation reaches a constant low rate. In spite of the progress done in studying the actual evaporation rates (AE) through the evaporation stages from homogenous soil profiles, yet many questions remained widely opened. Through this paper, the effect of the soil effective size (D_{10}) on the water redistribution through homogenous sandy soil profiles will be discussed.

2. Methodology and materials

One-Dimensional homogeneous sandy soil drying column tests were conducted. 50 cm in height and 10 cm inner diameter acrylic-material columns were used. The Time Domain Reflectometry probes (TDR) were attached along the column to continuously measure the water content, in order to determine the water redistribution profile through the evaporation process. To facilitate the up-flow saturation process, a valve was installed at the base of the column with a porous plate to uniformly saturate the soil column by applying a head difference. 80 kPa vacuum pressure was additionally applied to the top and the bottom of the column to get rid of the entrapped air bubbles and to achieve high degrees of saturation. For testing, the soil columns were attached to the Climate Control Apparatus (CCA) to unify the evaporative demand, by maintaining the temperature (30±3℃), humidity (45±3%) and wind speed (1.8±1m/s). Fig. 1 illustrates the experimental setup that was used in this study.

Two different textures of silica sand, K-7 and K-4, were used for testing. The particle size distribution curves and the physical properties of the used materials are shown in Fig. 2 and Table 1, respectively. The soil columns were prepared by dry packing at a relative density of 80%, corresponding to the density, ρ_d, and the void ratio, e, shown in Table 1.

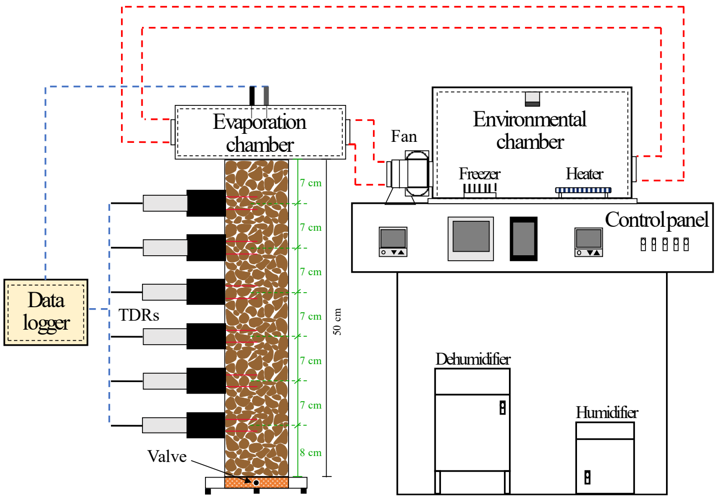

Fig. 1: Experimental setup (Schematic)

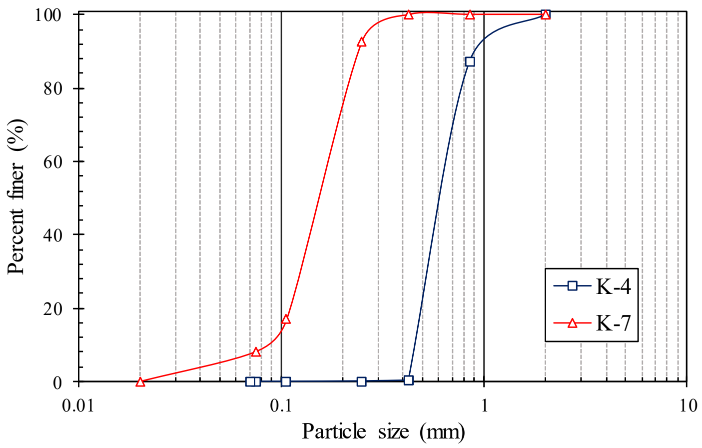

Fig. 2: Particle size distribution curves

Table 1: Soil physical and hydrological properties

		K-7	K-4
Specific gravity	[Gs]	2.647	2.651
Dry density	[ρ_d] (g/cm^3)	1.495	1.482
Void ratio	[e]	0.768	0.786
Effective size	[D_{10}] (mm)	0.087	0.455
Percentage of fines	(%)	15.4	0
Hydraulic conductivity	[k_s] (m/s)	1.14×10^{-5}	2.07×10^{-3}

3. Results

The data obtained from the TDRs was used to determine the degree of saturation. Fig. 3 and Fig. 4 illustrate the water redistribution profile subsequently at times 0, 3, 6, 9, 12, 15 and 18 days of the evaporation process for the K-7 and K-4 soil columns, respectively. In general, both soil samples have shown a dramatic decrease in the degree of saturation. At the early stages of evaporation, the first 3 days of testing, the top layer of the K-7 column has shown higher severity by losing around 43.4% of its saturation while K-4 column had lost around 24.2% of its top layer saturation. Evaporation continued with relatively lower rates for the K-7 to reach around 39.1% degree of saturation, while the K-4 has reached around 23.1% degree of saturation after 18 days of drying.

The characteristic length (L_c), that indicates the onset of SII, was determined by linearizing the Soil Water Characteristic Curve (SWCC), shown in Fig. 5, for both soil samples. The black dashed lines in Fig. 3 and Fig. 4 illustrate the depth of the L_c from the top of the soil surface, at 30.1 and 2.4 cm, for both K-7 and K-4, respectively. After the onset of SII the desaturated zone formed around 59.8% of the K-7 soil column, while it formed around 37% of the K-4 soil column. It can be observed that the water was lost from deeper layers in the K-7 column which makes the thickness of its unsaturated zone higher than that of the K-4 column, which can be attributed to the fines percentage that accounts for 15.4% for K-7 while K-4 includes 0%.

In order to study the influence of the soil particle size on the water redistribution during evaporation, D_{10} against the Deasaturtaed zone Severity Index (DSI) was plotted, as shown in Fig. 6. It must be noted that D_{10} is considered to be a good measure to estimate the hydraulic properties and drainage through soil profiles (Das, 2002). Moreover, the DSI was calculated by multiplying the Reduction in the degree of saturation (Red.Sr) by the Desaturated zone thickness (Desat.t). It can be observed that the smaller the D_{10} the more severe the vadose zone, and it gets more severe in late stages of evaporation (from 9 to 18 days).

Finally, it can be concluded that regardless of the climatic conditions, K-7 and K-4 desaturation profiles show significantly different patterns and consequently different amounts of water loss during the soil drying process. Moreover, K-7 and K-4 samples have the same mother material yet, the effective particle size (D_{10}) differ, where it significantly affects the water redistribution and the severity of the vadose zone in the soil profiles.

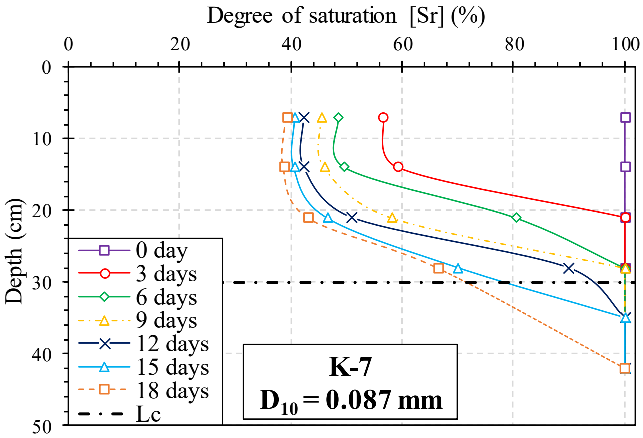

Fig. 3: K-7 water redistribution profile during evaporation

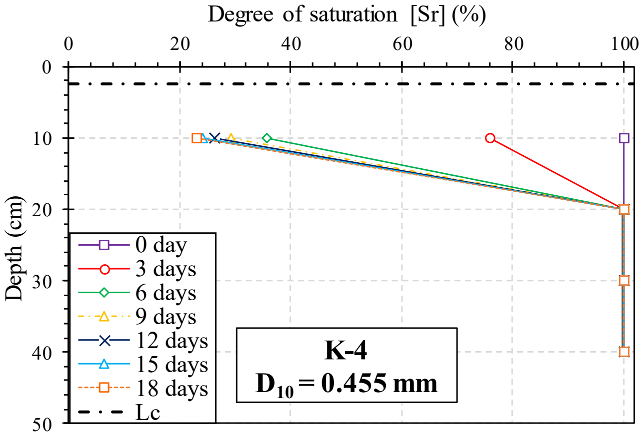

Fig. 4: K-4 water redistribution profile during evaporation

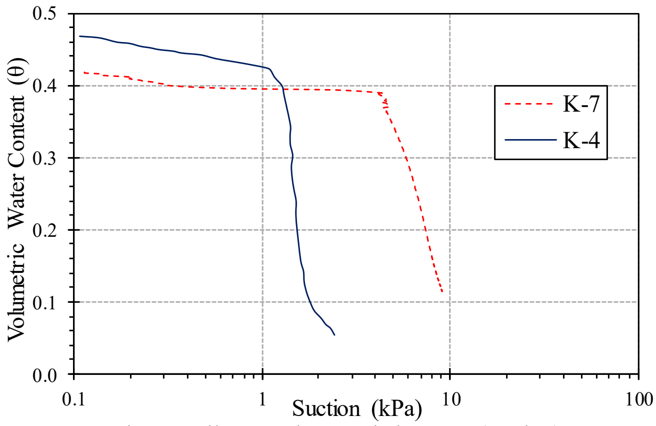

Fig. 5: Soil water characteristic curve (Drying)

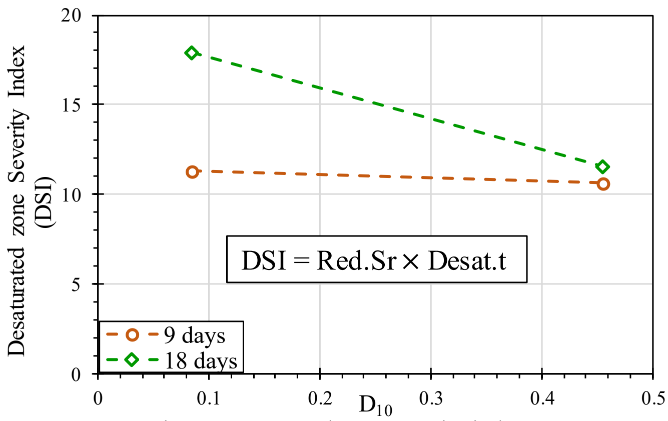

Fig. 6: Desaturated zone severity index

4. Conclusions

It was confirmed that regardless of the unified evaporative demand, the degree of saturation and water redistribution profile through the evaporation process is highly affected by the soil properties. It can be concluded that the smaller the D_{10} the more severe the vadose zone. Finally, in order to clearly study the effect of soil texture and the pore size distribution on the evaporation process further studies should be done on the actual evaporation from homogeneous soil profiles.

References

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