Influence of top layer density on the actual evaporation rate and water storage through coarse overlying fine sand profiles

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1. Introduction

Evaporation is considered as main reason for water losses from natural and irrigated soil profiles. Optimizing adaptations and evaluation of actual evaporation and water redistribution through layered soil profiles are of particular interest for many geotechnical and geo-environmental problems such as design of soil cover systems in mining and landfill, prediction of expansive soils behavior and so on (3). A key element is to minimize the actual evaporation rate and maximize the water storage through the soil profiles. The evaporation process occurs in two distinct stages as shown in Fig.1: 1) Constant rate stage (stage I), when the soil surface is saturated or nearly saturated. 2) Falling rate stage, divided into two sub-stages: Stage II [considerable water loss] and Stage III [negligible] (1).

Most of the existing studies focus on the evaporation from layered soil systems without considering the effect of individual layer properties. This study aims to evaluate the effect of the top layer density on the actual evaporation rate and water storage through double layered soil system without water table [coarse overlying fine sand].

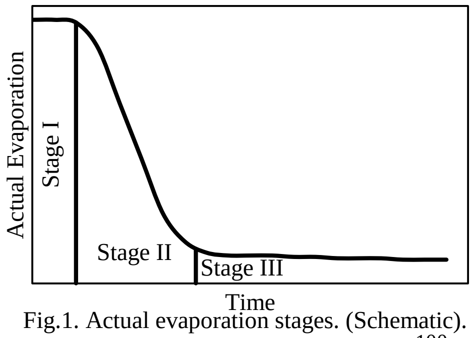


Fig.1. Actual evaporation stages. (Schematic).

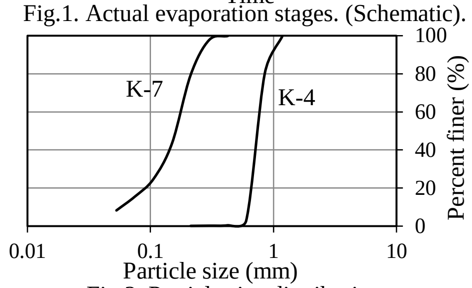
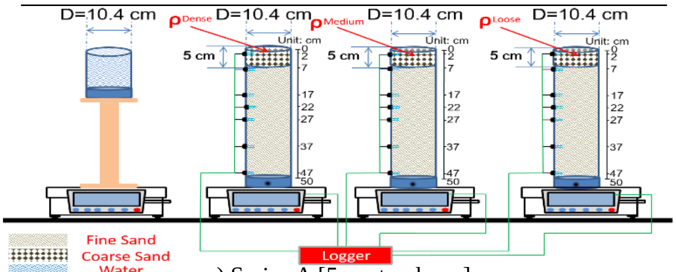


Fig.2. Particle size distribution.

2. Materials and experimental setup

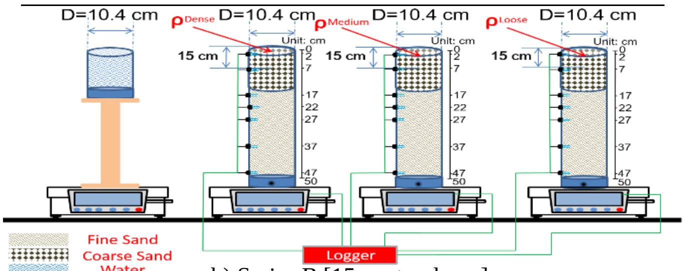
Tests were conducted using silica sand provided by KUMAMOTO –Silica Mining co., Ltd, Japan. Two texturally distinct soils were used K-7 (fine silica sand) and K-4 (coarse silica sand). Summary of soil properties and the particle size distribution curves are shown in Fig.2 and Fig.3.

Configuration	C1 [Dense]	C2 [Medium]	C3 [Loose]	Bottom layer [K-7]
ρ (g/cm^3)	1.561	1.429	1.335	1.618
S.G	2.655	2.655	2.655	2.657
θ_i	0.410	0.460	0.496	0.389
D_{50} (mm)	0.740	0.740	0.740	0.161
Uc	1.222	1.222	1.222	3.061
Initial condition	Saturated	Saturated	Saturated	Saturated



a) Series A [5 cm top layer].

Configuration	C1 [Dense]	C2 [Medium]	C3 [Loose]	Bottom layer [K-7]
ρ (g/cm^3)	1.561	1.429	1.320	1.618
S.G	2.655	2.655	2.655	2.657
θ_i	0.410	0.460	0.501	0.389
D_{50} (mm)	0.740	0.740	0.740	0.161
Uc	1.222	1.222	1.222	3.061
Initial condition	Saturated	Saturated	Saturated	Saturated



b) Series B [15 cm top layer].

Fig.3. Experimental configurations.

Two testing series were carried out [5 and 15 cm top layer], where in each series three configurations were adopted with various top layer densities as shown in Fig.3. The columns were constructed using a 10.4 cm in diameter Acrylic material. A valve was installed to the base for saturation purposes. Each column was instrumented with moisture sensors installed through drilled ports as shown in Fig. 3. The actual evaporation rate from each column was continuously obtained by independently measuring the mass of each column using a balance with 31 kg capacity and ±1 g resolution. The potential evaporation rate was measured using an evaporation pan placed adjacent to the soil columns and subjected to the same testing conditions. The pan was frequently replenished in order to keep the water surface at the same elevation. In order to increase the evaporation rate, a heater lamp in addition to a fan were installed above the soil surface of each column as shown in Fig. 4. A hygrometer was installed 15 cm above the experimental setup which allows continuous recording of relative humidity and temperature of the experimental zone. Soil was filled in separated layers where all the layers were placed using identical placement techniques. The columns were filled in lifts of 3-6 cm and tapped with rubber hammer to disturb the soil in order to obtain consistent and uniform densities. A constant water head was applied to the columns through the water inlet valve in the base. The water supply was kept till the columns achieved fully saturation through the whole soil profile. Then the water valves were closed and the water head was removed. Through the whole testing period the evaporation rate, saturation profile, relative humidity and temperature were continuously measured with a constant interval of 15 minutes. The evaporation tests were shut down when the evaporation rate of all columns achieved the residual stage where the evaporation rate becomes low and stable.

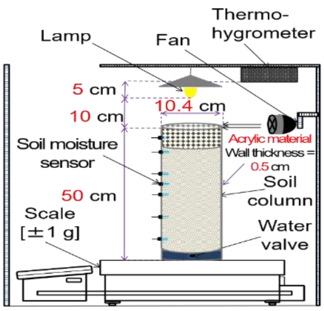


Fig.4. Experimental setup.

Keywords: Evaporation, Water storage, Unsaturated layered soil profile.
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3. Results and discussion

Fig.5 shows the actual evaporation curves for the three tested configurations through series A. It can be observed that the top layer density has weak influence on the actual evaporation curve where the three configurations showed almost identical curves with almost the same time needed to achieve the residual evaporation stage [Stage III].

Fig.6 shows the saturation profile for the three column configurations, where the results agree with the results of (Huang M. et al., 2012); almost all of the water removed by evaporation came from the coarse sand (top layer). By the end of the experiment, the overlying coarse sand layer had undergone extensive drying while the fine sand layer remained close to saturation.

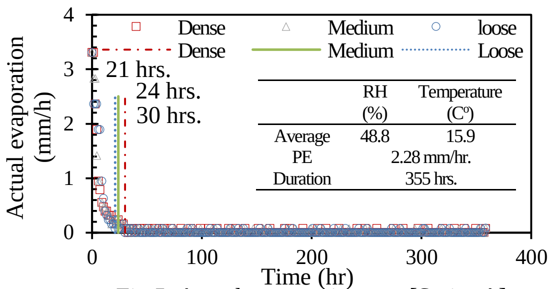

Fig.5. Actual evaporation rate [Series A].

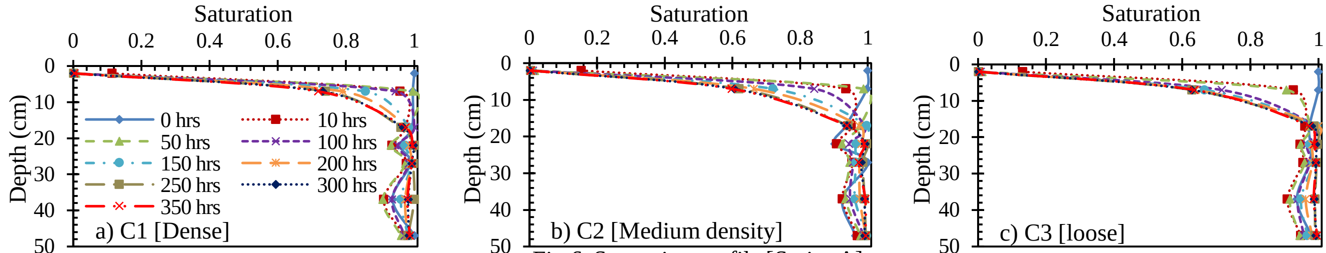

Fig.6. Saturation profile [Series A].

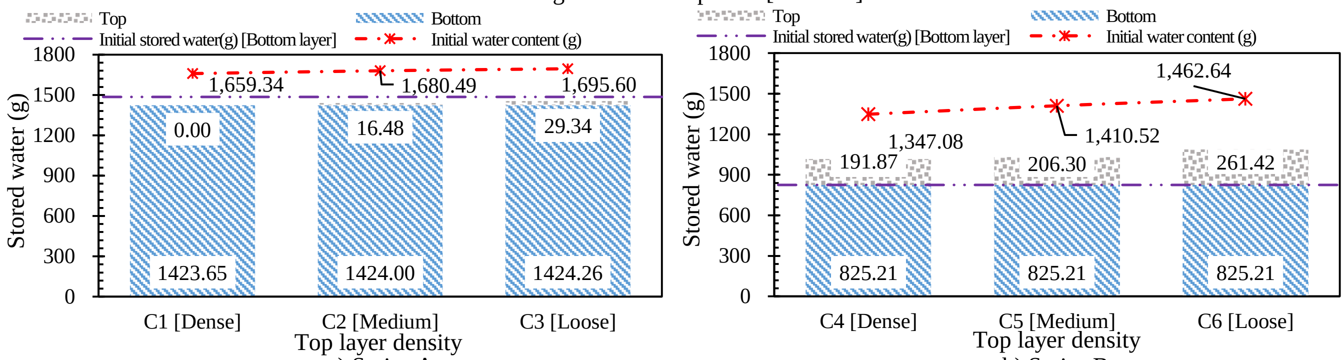

Fig.7. Lost water distribution.

This trend can be justified to be a result of water content discontinuities and preferential fluid transport pathways through the soil profile as a result of the textural contrast configuration. The water redistribution through the soil profile exhibited almost identical trend for the three tested configurations. Thus it can be concluded that the density of the top coarse sand layer has weak influence on the water redistribution through the whole soil profile. For the 15 cm top layer [Series B], the same trend was observed where changing the top layer density has weak influence on the actual evaporation curve and water redistribution through the soil profile.

Fig.7 shows the contribution of bottom and top layer in the total water lost by evaporation for series A and B respectively, where the results agree with the results of (ALOWAISY A. and YASUFUKU N., 2016); for coarse overlying fine sand profiles an optimum top layer thickness was observed [15 cm], where larger than this value the bottom layer water content is slightly affected by the evaporation process.

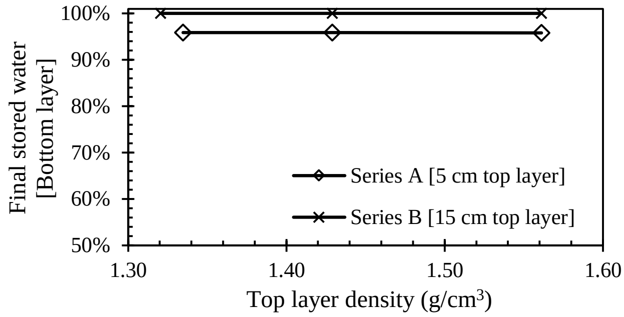

Fig.8. Water storage [Bottom layer].

Fig.8 demonstrates the water storage through the bottom fine sand layer at the end of the test, it can be concluded that the top coarse sand layer density influence on the water storage through the bottom fine sand layer is weak and can be neglected for both series A and B.

Conclusions

An experimental study aiming to evaluate the influence of the top layer density on the actual evaporation and water storage through coarse overlying fine soil profile was carried out. It can be concluded that the density of the top coarse sand layer has weak influence on the actual evaporation curve and water redistribution through the whole soil profile. Therefore, the influence of the top coarse sand layer density on the water storage through the bottom fine sand layer is too small and thus can be neglected. [refer to Fig.8]

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