



Capillary rise simulation of saline waters of different concentrations in sandy soils

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Abstract

Soil salinity causes corrosion of engineering structures worldwide. The main cause of soil salinization is capillary rise of saline groundwater. Soil salinity can be mitigated if the capillary rise of saline groundwater in soils is understood. The objective of this paper is to present experimental results of the capillary rise rates of water with different salt concentrations in three sandy soils. Each sample was comprised of a soil column 300-mm height and 50-mm in diameter steeped in a 25 mm deep saline water pool for a time period to allow for capillary action to develop. The salinity varied from fresh water, EC = 2 dS/m, to medium salinity (50, 100, and 150 dS/m), and to high salinity water (200 dS/m). It was found that the highest rate of capillary rise occurred in medium salinity waters, while the lowest was in fresh water. Very saline water had a lower rate of capillary rise than medium salinity, but higher than for fresh water.

Keywords: Capillary rise, Saline water, Soil salinization, Sandy soil

1. Introduction

Soil salinization has been spreading and intensifying worldwide recently including in Northeastern Thailand [1-2]. This is the results of anthropogenic activities such as deforestation, irrigation, land modification, leakage from nuclear spend and carbon storage in rocksalt or brine reservoirs, and sea level rising [2-3]. Salinization causes damage to engineering structures such as construction buildings, roads, irrigation channels [4-5]. Causes of salinity is saline groundwater originated from rocksalt such as the Mahasarakham rocksalt in Northeast Thailand [6] and sea water intrusion as in the South of Thailand [1], [7] for example. Capillary action induces saline groundwater from aquifers to rise up to the soil surface [8]. In order to control soil salinization, the capillary mechanism of saline water must be thoroughly understood.

The theory of capillary rise of fresh water in a uniform micro-tube appears in every Fluid Mechanics text [9-10]. The height of capillary rise is derived from balancing of capillary force and the weight of capillary water (Figure 1) as:

$$h_c = 2T \cos \alpha / r \rho_w g \quad (1)$$

where h_c = capillary height, T = surface tension, α = wetting angle, r = radius of micro- tube, ρ_w = water density, and g = gravity.

The capillary theory of fresh water rising in soils is discussed in most Soil Physics [11-12] and Unsaturated Soil Mechanics [13-14] texts. Since the distribution of pores in bulk soil is complex and varies in sizes, the water content of

soil varies with depth (or height). Typically, it is saturated at the water table and water content decreases with the height of soil. However, the decreasing of water content with height in different soils (such as clay, loam, and sandy soils) are different (Figure 2). Two types of forces concern capillary mechanism namely cohesive and adhesive forces. The two forces of saline water acting on the soils are not the same as that of fresh water acting [15], especially in sandy soil [16]. Therefore, the capillary rising of saline water in soil is not the same as that of fresh water. Various concentrations of water salinity are likely to affect the capillary rising rate in various degrees.

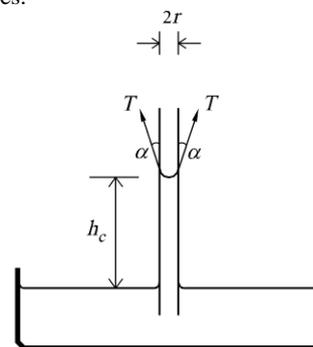


Figure 1 Capillary rise of fresh water in a micro-tube

Sandy soil is the majority of soil in the Northeast of Thailand. It is derived from the parent materials of Khorat Group sandstone [17]. The complexity and instability of pore structure of sandy soil increases the difficulty in capillary understanding. The objective of this paper is therefore to

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present a physical simulation of various concentration of saline water capillary rise in sandy soils.

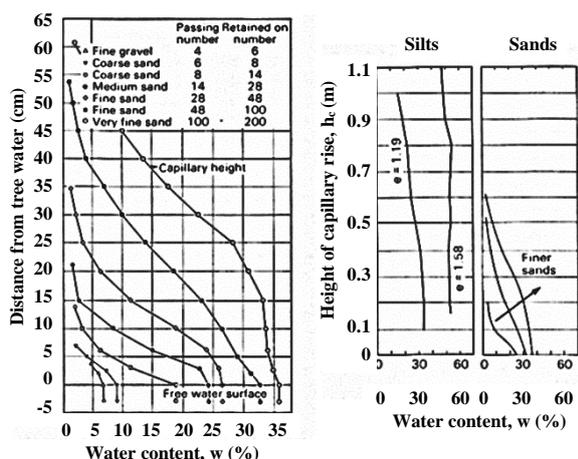


Figure 2 Capillary rises in different soils [20], [21]

2. Materials and methods

2.1 Sandy soil samples

The soil sampling location was at Ban Khi, Tumbon Khaow Yai, Kantravichai District, Maharakham Province, Thailand. There were three different sites, namely upslope, midslope, and downslope which are identified by St1, St2, and St3, respectively. The soil samples were collected by both disturbed and undisturbed methods. The undisturbed samples were collected using a stainless steel tube with nominal diameter of 50 mm. and length of also 50 mm and open on both ends. The tube was pushed vertically into the soil, then the tube with soil was dug out then smooth and capped at both ends. The disturbed samples were collected in plastic bags. All soil samples were collected at 50 mm. below the soil surface and taken back to the Soil Laboratory, Faculty of Engineering, Maharakham University.

Several physical properties of the soil samples were measured in this study. Particle size distributions were evaluated using sieve analysis for the three sampling sites. The results are shown in Figure 3. By deducing percentage of sand, silt, and clay particles from Figure 1, the textures of all soil samples were determined to be sandy soil. Some physical properties such as porosity, residual water content, bulk density, saturated hydraulic conductivity, and van Genuchten parameters are presented in Table 1.

2.2 Capillary rise experiments

Dry repacking soil samples in six stainless steel tubes from each site were connected lengthwise into a column of 300 mm. long. The disturbed soil samples were used to ensure their moisture content and density being constant for

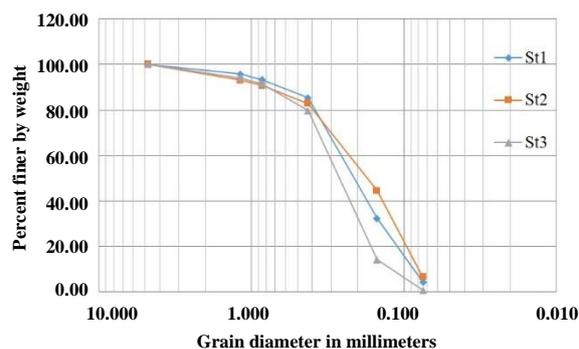


Figure 3 Particle size distributions of the soil samples

each of the sampling sites. Their initial moisture content must be at the residual values (Table 1). The joints between consecutive tubes were treated with care and sealed to prevent discontinuity and leaking. (The limit of capillary height in fine sand is about 300 mm.) The dry soil column was steeped into a pool of saline water and let the capillary rise to take place for a period of time (Figure 4). The pool of saline water was controlled for both water level and salt concentration. Then the partially wet soil column was taken out from the pool of water and was split into individual tubes. Immediately the water content of soil sample in each tube was evaluated by gravimetric method. Therefore, each soil column rendered 6 water content values ranging from the first tube which was immersed half way below water surface up to the sixth (last) one at the column top. We tested the capillary rise for 5 different salinity concentrations with electrical conductivities (EC) of 2, 50, 100, 150, and 200 dS/m called EC2, EC50, EC100, EC150, and EC200, respectively. The time periods allowed for capillary to rise were varied from 1, 2, 3, 4, and 6 hours. There were 2 repetitions for each experimental site.



Figure 4 Experimental set up

Table 1 Some physical properties of the soil samples

Soil samples	Textures	Soil particles %			θ_r	θ_s	ρ_b (g/cm ³)
		Clay	Silt	Sand			
St1 (upslope)	Sandy	0	0.4	99.6	0.014	0.408	1.65
St2 (midslope)	Sandy	0	0.2	99.8	0.020	0.383	1.63
St3 (downslope)	Sandy	0	2.3	97.7	0.030	0.377	1.62

3. Results and discussion

There were 3 site samplings involved in this study, namely upslope (St1), midslope (St2), and downslope (St3). For each site sampling, we performed twice experimental repetitions. For example, at the upslope site (St1) we would have 2 sets of experiment on saline water of 50 dS/m for a period of 1 hour. Then the experimental values from these 2 sets were averaged into 1 set for comparisons. Two types of results are presented here. The first one we see the temporal development of capillary rises in the whole soil column. In the second, the temporal variations of water contents at points are scrutinized.

3.1 Capillary rise in the whole soil column

Figures 5, 6, and 7 illustrate the capillary rises in sandy soils for the sampling sites at upslope (St1), midslope (St2), and downslope (St3), respectively. Each figure, such as Figure 5 compares the developments of capillary rises of 5 different salt concentration waters in the upslope soil. Figures 5a, 5b, 5c, 5d, and 5e present the capillary rises in the upslope soil at 1, 2, 3, 4, and 6 hours, respectively.

Let us first consider the movement of wetting fronts in St1, St2, and St3 soils, in Figures 5, 6, and 7, respectively. At 1 hour of the performance, the wetting fronts of all waters reach the height of 125 mm for St1 and St3. However, St2 shows all waters reach 125 mm in 1 hour with the exception of EC2 which reaches only 75 mm. This illustrates that wetting fronts of all waters with different concentrations moved upward from the water table at the same speed, except the water of EC2 rising in St2 was slower than the others. At 4 hours, the wetting fronts of all waters moved upward to 175 mm height with the exception of EC2 of St1 and St2 which were lagging at 125 mm. The waters of EC50 and EC100 rose up to the height of 225 mm for all sites at the 6th hour time. Interestingly, the water of EC200 only moved to the height of 175 mm for all sites at 6 hours which shows slower rate than that of EC50 and EC100. The capillary actions of the water EC150 are not mentioned due to ambiguous and anomalous results.

It can be concluded that the wetting front of all waters with different concentrations (EC2 to EC200) moved up with the same speed at the beginning then only the water of EC2 was slowed down, and finally both EC50 and EC100 won over the others.

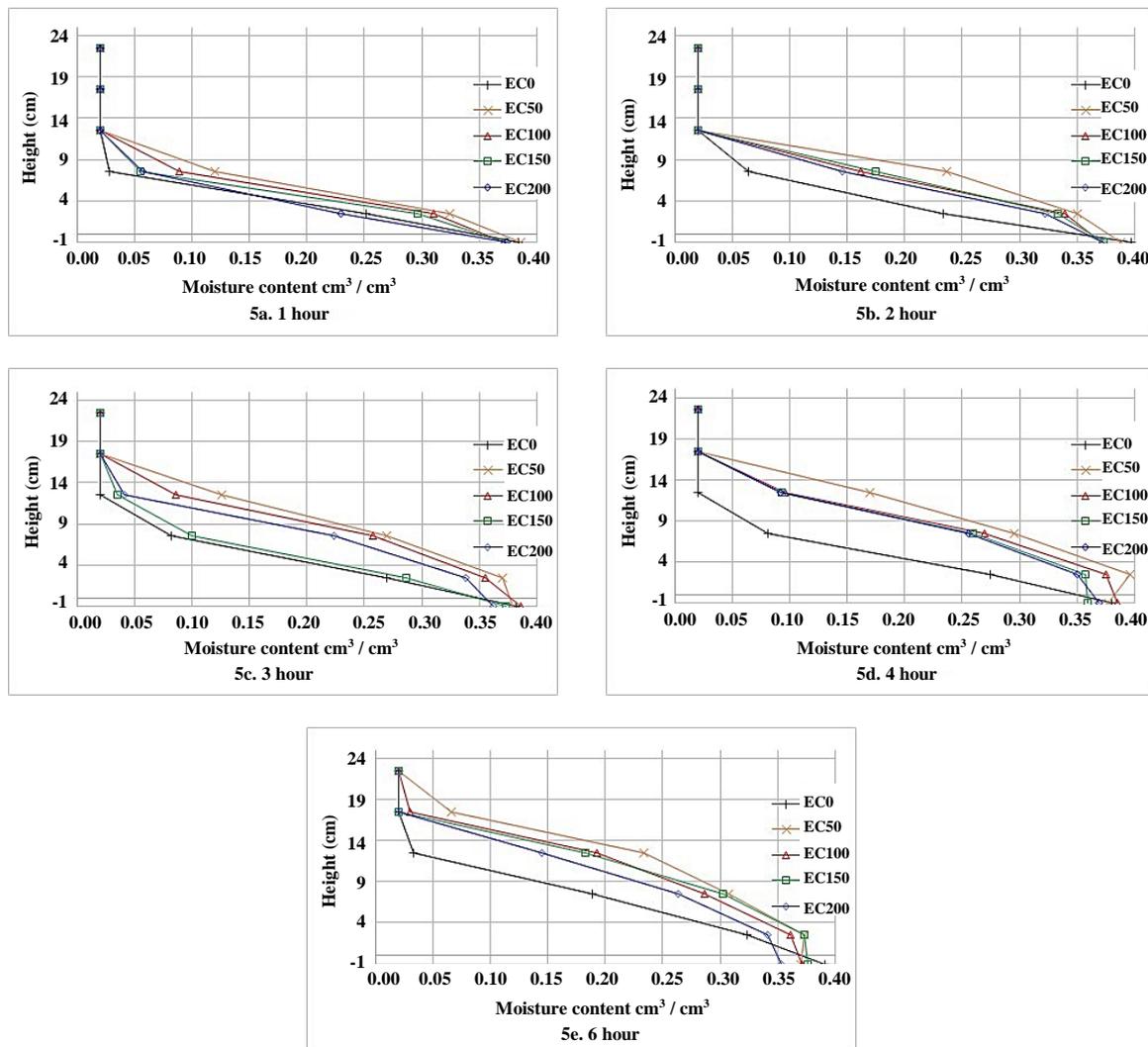


Figure 5 Comparisons of capillary rises of 5 saline concentration waters in upslope soil, (a) at 1hr, (b) 2 hrs, (c) 3 hrs, (d) 4 hrs, and (e) 6 hrs.

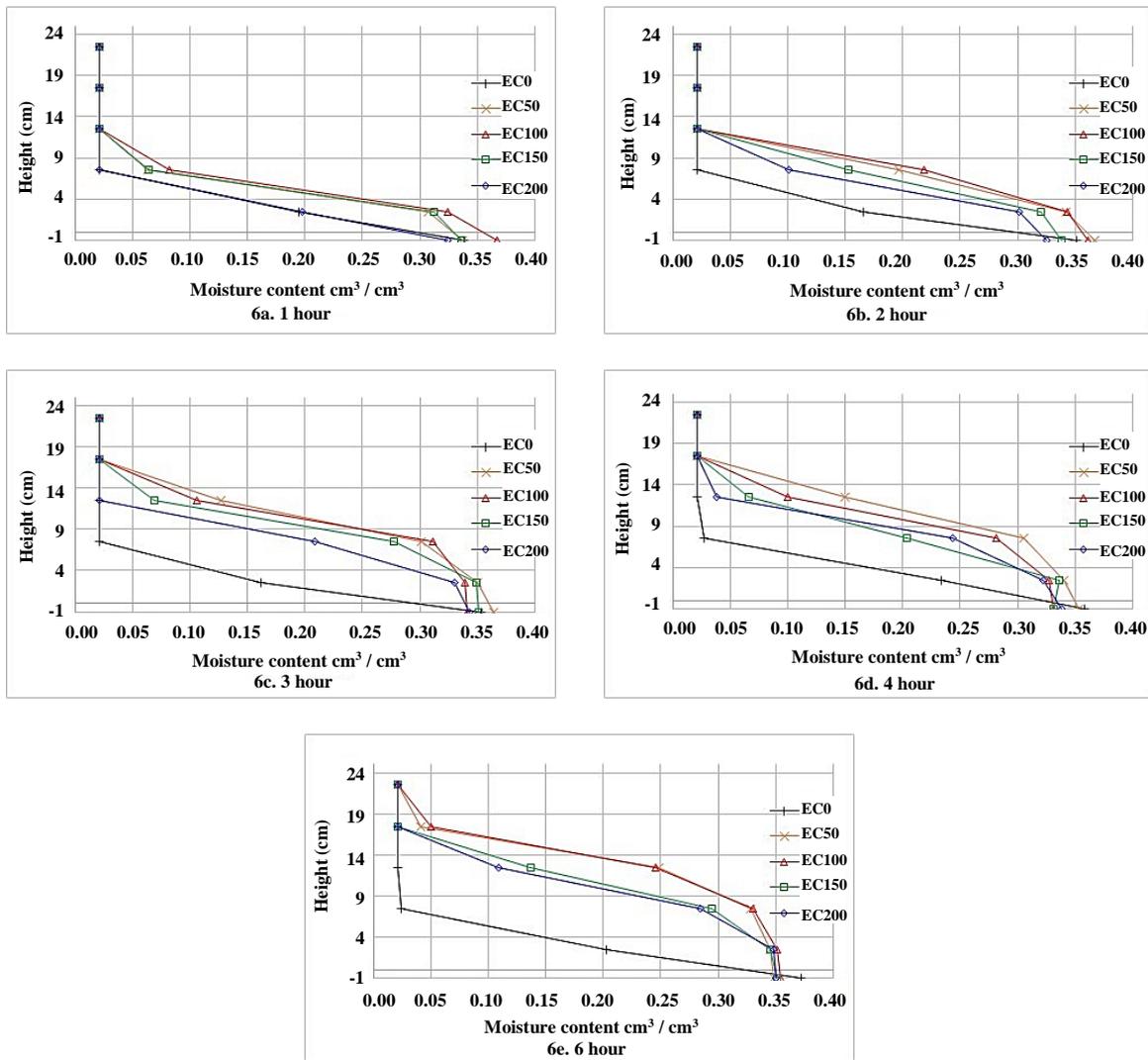


Figure 6 Comparisons of capillary rises of 5 saline concentration waters in midslope soil, (a) at 1hr, (b) 2 hrs, (c) 3 hrs, (d) 4 hrs, and (e) 6 hrs.

Now we consider the rates of capillary rises, by scrutinizing the development of water content values with heights in Figures 5, 6, and 7. The waters of EC50 and EC100 show higher flux velocity than the rest for all sites (St1, St2, and St3). By neglecting the results of EC150, the waters of EC2 and EC200 have lower capillary flux velocity than the others. We may conclude here that the lowest and highest EC waters produce smaller capillary rise, while the waters of EC50 and EC100, and probably EC150 heightens the capillary action.

The difference of capillary flux among the different salt concentration solutions is due to the capacity of saline water to breakdown the soil structure [15], [18]. Saline water when flowing through soil can breakdown the soil structure by separating the fine aggregates from the coarse ones. This can promote the blocking of the macro-pore of the soil mass reducing its saturated hydraulic conductivity [18]. However, the unsaturated hydraulic conductivity is a different story since unsaturated flow is caused by capillary force whereas saturated flow being caused by gravitational force. The different degree of concentration can produce different intensity of breaking down of soil structure. At present, we do not fully understand the relationship between degree of saline concentration and the intensity of structure collapsing.

What we have found is that fresh water and high salinity water (EC200) result in smaller capillary rate while medium salinities (EC50, EC100, and probably EC150) increase capillary rising rate.

3.2 Capillary rate of rise considering at points

Now, we consider the changes of water contents of each soil column at 25, 75, and 125 mm. above the water table. Figures 8, 9, and 10 show the development of water contents at the heights of 25, 75, and 125 mm. from the water tables for the sites St1, St2, and St3, respectively.

It is obvious that the results of the water EC150 is anomalous, therefore it is neglected in most of our discussions. The cause of the anomalous was naturally and probably the experimental random errors. This can be overcome by repeating the EC150 experiments in the future. The fresh water (EC2) illustrates the slowest capillary rate of all heights and sites. This is very interesting and contrasting to Eq. 1, for that the density, ρ_w , of fresh water must be smaller than those of saline waters, therefore the height, h_c , of fresh water should be higher than the saline waters. In our case, the Eq. 1 is not valid if we assume the pore size, r , and the surface tension, T , being constant. Due to the collapsing

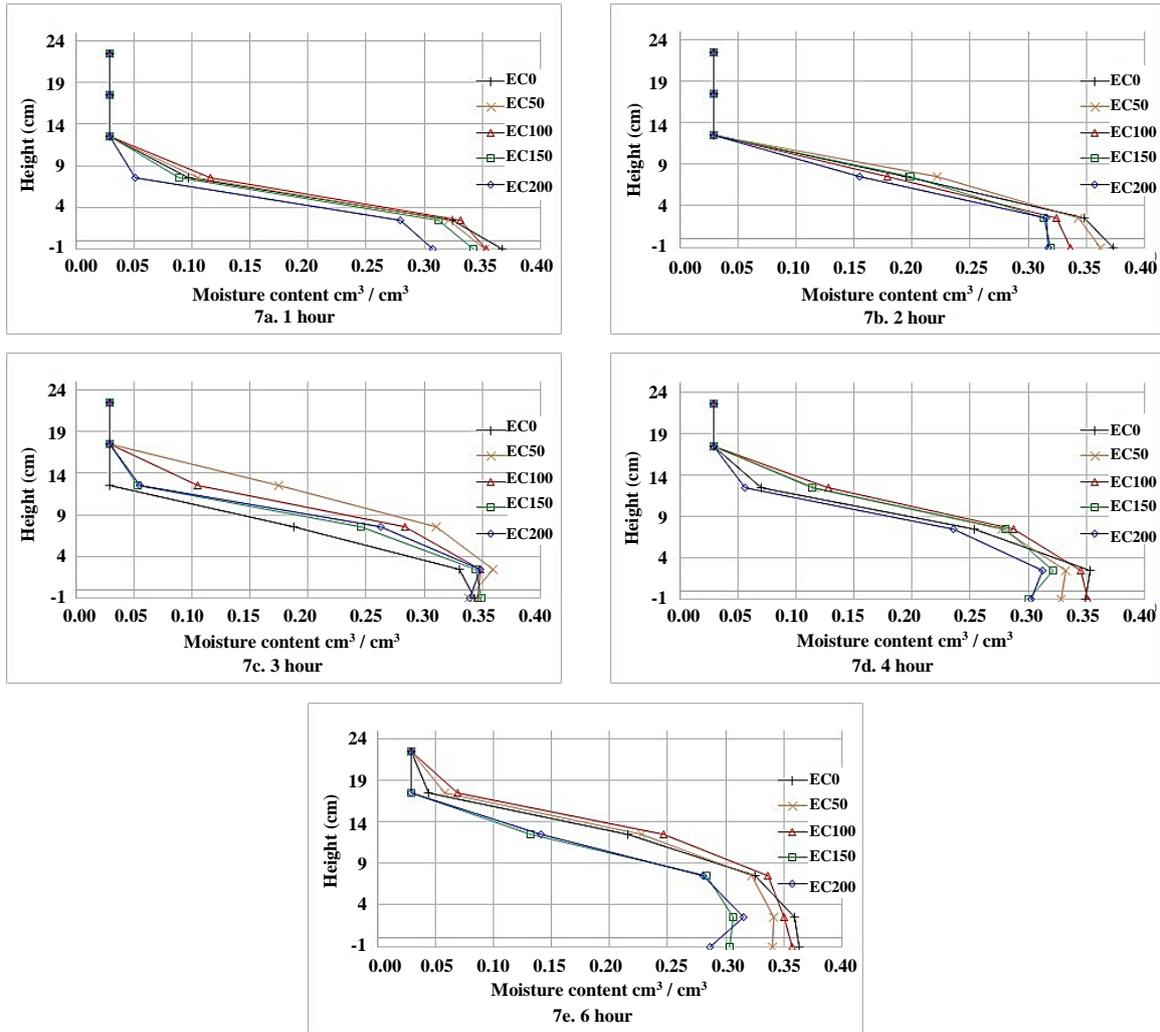


Figure 7 Comparisons of capillary rises of 5 saline concentration waters in downslope soil, (a) at 1hr, (b) 2 hrs, (c) 3 hrs, (d) 4 hrs, and (e) 6 hrs.

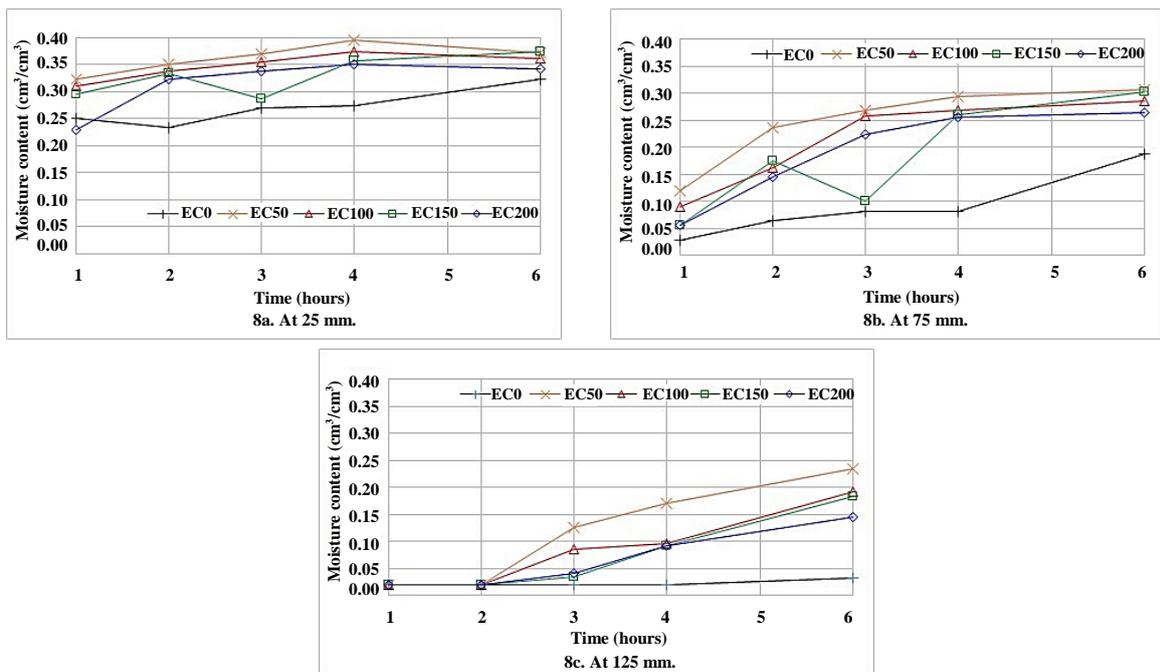


Figure 8 Temporal water contents at 25 (a), 75 (b), and 125 mm (c) for the site St1

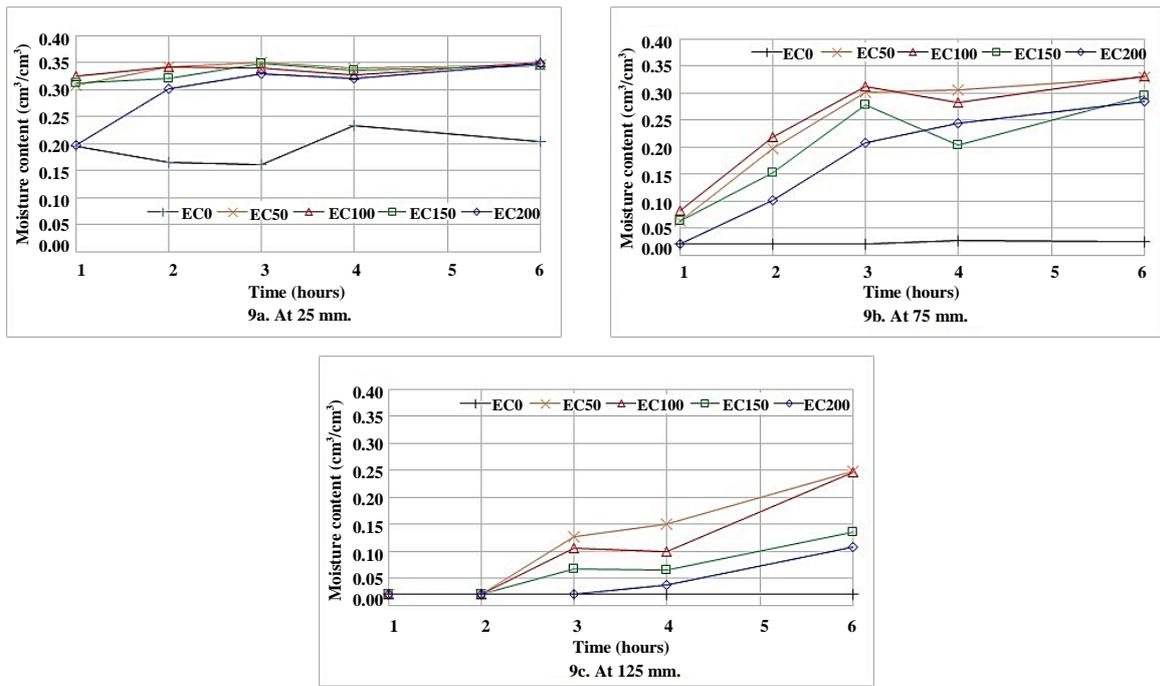


Figure 9 Temporal water contents at 25 (a), 75(b), and 125 mm (c) for the site St2

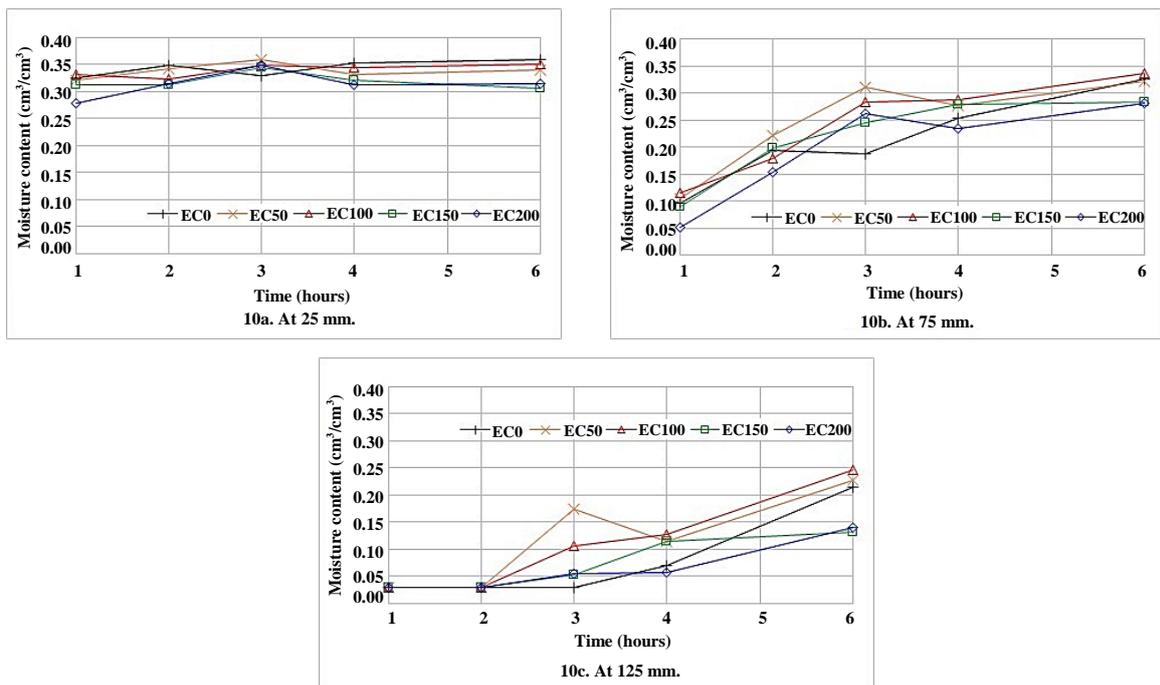


Figure 10 Temporal water contents at 25 (a), 75 (b), and 125 mm (c) for the site St3

of soil structures during capillary action, the representative r is reduced renders increasing in capillary rising rate for saline water. It is also well-known that surface tension increases with salinity [19]. These two reasons explain the highest rate of capillary rises for the waters of EC50 and EC100 for all sites. Another interesting result is that the water of EC200, which is the highest salinity in this study, becomes the second slowest for the capillary rise. A reason for this is that when the representative pore size becomes too small, the

capillary rate of rise is slowed down though the rising height gets higher due to the above.

4. Conclusions

We performed the experiment of capillary rises of saline waters of different concentrations, ranging from fresh water with the EC of 2 dS/m to the very saline of 200 dS/m. in sandy soils of a location of 3 different sites the upslope,

midslope, and downslope. The results can be concluded as follows.

1. The fresh water sample has the slowest capillary rising rate of all.

2. The medium saline water namely the EC of 50 and 100 dS/m shows highest rate of capillary rise.

3. The saline water with the highest EC of 200 dS/m renders slower rate than the medium salinity but faster than the fresh water.

4. These phenomena occurs as a result of soil structure modification through the segregation of fine particles from the soil mass due to interaction of saline water with the soil mass.

5. Further researches are recommended to investigate the impact of increase of surface tension due to salinity on the variation of capillary rates.

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