The Estimation of Diffusion-dispersion Coefficient and Retardation Factor of Salt Solution Transported through Saline Soil by Capillary Force

การหาสัมประสิทธิ์การแพร่กระจายและค่าตัวประกอบความหน่วงของการเคลื่อนที่ของสารละลายเกลือผ่านชั้นดินเค็มด้วยแรงแคพิลลารี

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ABSTRACT

The purpose of this study is to determine the upward diffusion-dispersion coefficient and retardation factor in salt affected area. The study was performed by simulate salt solution upwards flow to soil pores in the unsaturated soil column driven by capillary force with water table at 90 cm below the surface. The soil samples were packed into a PVC tube with bulk density of 1.58 g/cm^3. The initial concentration of solution is 150 mS/cm. During experiments, soil moisture content and electrical conductivity were measured at 1, 3, 7, 14, 21 and 28 days every 5 cm interval. The parameters were fitted by the solute transport equation of Danckwerts. The upward diffusion-dispersion coefficient (D_u) and retardation factor (R) in sandy loam soil are ranging from 0.003 to 0.0285 m^2/day and 0.1 to 0.7, respectively. The results indicated that when water content increased the values of D_u and R are tend to decrease.

บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อประเมินค่าสัมประสิทธิ์การแพร่กระจายและค่าตัวประกอบความหน่วงของดินในพื้นที่ดินเค็ม ดำเนินการศึกษาโดยการจำลองการเคลื่อนที่ของสารละลายเกลือขึ้นไปตามช่องว่างเม็ดดินในแท่งดินที่ไม่อิ่มตัวด้วยแรงแคพิลลารี ระดับน้ำใต้ดินที่ 90 เซนติเมตร ตัวอย่างดินบรรจุลงในท่อพีวิซีด้วยความหนาแน่นรวมเท่ากับ 1.58 กรัมต่อลูกบาศก์เซนติเมตร สารละลายเกลือที่ใช้แทนน้ำเค็มมีค่าความเค็มเริ่มต้น 150 มิลลิซีเมนต์ต่อเซนติเมตร ในระหว่างการทดลองทำการวัดค่าความชื้นและค่าการนำไฟฟ้าช่วงระยะเวลา 1, 3, 7, 14, 21 และ 28 วัน ที่ทุก ๆ 5 เซนติเมตร นำค่าตัวแปรมาเทียบกับเส้นโค้งด้วยสมการการหาความเข้มข้นของสารละลายของ Danckwerts ค่าสัมประสิทธิ์การแพร่กระจายและค่าตัวประกอบความหน่วงของดินร่วนปนทรายมีค่าอยู่ในช่วง 0.003-0.0285 ตารางเมตรต่อวัน และ 0.1-0.7 ตามลำดับ ผลการศึกษาบ่งชี้ว่าเมื่อดินมีความชื้นเพิ่มมากขึ้นค่าตัวแปรทั้งสองมีแนวโน้มลดลง

Keywords: Diffusion-dispersion coefficient, Salt solution transport, Saline soil

คำสำคัญ: สัมประสิทธิ์การแพร่กระจาย การเคลื่อนที่ของสารละลายเกลือ ดินเค็ม

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Introduction

The total salt-affected areas in Thailand are 2.302 million ha and about 1.841 million ha are distributed in the Northeastern region (Arunin and Pongwichian 2015). The soil salinity has been a serious environmental problem which is a major cause to soil degradation and reduce crop yields. A main source of salinity is dissolved sodium chloride from the rock salt in the Mahasarakham Formation leading to saline groundwater. The movement of shallow saline groundwater above water table to the ground surface as well as unsaturated zone leads to salt accumulation at the soil surface driven by capillary force and evaporation process. The calculation and prediction models of solute transport in unsaturated soil have been essentially established for the study soil salinization.

The mass of solute transport in porous media is relate to three processes i.e. advection, molecular diffusion and hydrodynamic dispersion. Equation of advection-dispersion has to know average velocity of solution, diffusion-dispersion (D_u) coefficient and retardation factor (R). The velocity can be calculated from applied Darcy's law and water balance equation (Chalongchan, 2003). The D and R parameters were obtained from the experimental of simulation salt mass transport in soil column by capillary effect (Konyai, 2007).

In the present study, laboratory experiments were specifically designed to simulate salt solution transport through saline soil by capillary effect. These laboratory investigations aimed to evaluate diffusion-dispersion coefficient and retardation factor from shallow saline groundwater in unconfined aquifer.

Objectives of the study

The objective of this study was to determine of upward diffusion-dispersion coefficient and retardation factor in salt solution transport through saline soil.

Methodology

Materials

The salt affected soil was collected from Ban Thum, Mueang KhonKaen district, Khon Kaen province. The soil sample was brought to laboratory for physical and chemical properties analyses as summarized in Table 1. They were air-dried and sieved by passing through a 2 millimeters grid (sieve no.10) and was packed without any condition treatment. Saline water is used as the simulated saline groundwater which was prepared by dissolving sodium chloride (NaCl) with tap water to make up the concentration of 150 dS/cm.

Experiment and procedure

The experiment was carried out to simulate capillary rise of salt mass transport and measured rising heights for evaluating D_u and R. The dried soil samples were packed as uniform as possible with the bulk density of 1.58 g/cm^3 into six PVC tubes, 100 cm in length and 5.0 cm in diameter for the column. A filter membrane was placed at the bottom of column to prevent soil particles move through the bottom and a cap was placed at the top to prevent the evaporation process. During experiments, the water table was maintained constant at 90 cm from the ground surface and performed in room temperature (25±2°C).

Each experiment, soil water content and electrical conductivity (EC) was measured at 1, 3, 7, 14, 21 and 28 days every 5 cm interval. The moisture content was determined by weight of wet and oven-dried soil samples, and then dried soil samples were mixed with deionized water in a 1:5 soil/water fraction to measure EC.

Data analysis

The water balance equation was applied to calculate the flux velocity that is a change in water storage is equal to water content at *t*:

$$I_n - O_n = \frac{(\theta_{n,t} - \theta_{n,0})A\Delta x}{\Delta t} \quad (1)$$

where I_n is the rate of flux inflow (L^3T^{-1}), o_n is the rate of flux outflow (L^3T^{-1}), θ is the water content, A is the cross section area (L^3), Δx is the distance and Δt is the time (T).

The water inflow in section *n* is equal to water outflow in section *n-1*, so the rate of flux was calculated following the equation:

$$\bar{q}_n = \frac{(q_{in,n} + q_{out,n})}{2} \quad (2)$$

where $\bar{q}_n$ is the flux velocity in section (LT^{-1})

Then, the average velocity in soil column at each layer was calculated from the following the equation:

$$v = \frac{\bar{q}_n}{n} \quad (3)$$

where v is the velocity in section (LT^{-1}) and n is porosity

The upward diffusion-dispersion coefficients (D_u) and retardation factor (R) were fitted by using the solution transport equation of Danckwerts (1953) that describes the steady flow of a fluid through solid particles, given as:

$$c*_{(x,t)} = \frac{1}{2} erfc\left[\frac{Rx - vt}{2(D_u Rt)^{0.5}}\right] \quad (4)$$

The relative concentration in soil column at time $c_{(x,t)}$ was calculated using the following equation:

$$c_{(x,t)} = \frac{C_{(x,t)} - C_i}{C_0 - C_i} \quad (5)$$

where $C_{(x,t)}$ is concentration in soil column at time, C_i is initial concentration in soil column, C_0 is concentration of solution and $erfc$ is complement error function

Results

Soil moisture content and electrical conductivity (EC)

The initial soil moisture for simulation of mass solute transport by induced saline water rise into soil column from the capillary effect is 0.082. The soil section every 5 cm interval, the water content was measured for calculate velocity of salt mass rising and electrical conductivity was measured for calculate D_u and R. The results are presented in Figure 1. For the soil moisture, the maximum of moisture content is 0.23 that is not exceed the porosity of soil.

From Figure 1a, it can be measured the height of capillary of 50 cm for day 1 and 60 cm for day 3, respectively. In 7, 14, 21 and 28 day as show in Figure 1b, the capillary heights are over 95 cm due to salt solution can be moved upward to top of soil column. From Figure 1 and Figure 2, it can be seen that the rapid increase of moisture and EC within 20 cm above water table. Mostly, they are tend to decrease when increasing of distance from the water table. However, in each soil section, they are increase with time.

Determination of the parameters

The values of upward diffusion-dispersion coefficient and retardation factor are listed in Table 2 and the relative concentrations were plotted Figure 3. The correlation coefficients were calculated by least square error method. The maximum of D_u and R show in day 1 are 0.0285 m^2/day and 0.7, respectively and the minimum values presented in day 28. This result suggests that the D_u and R are decline when increasing time.

Discussion and Conclusions

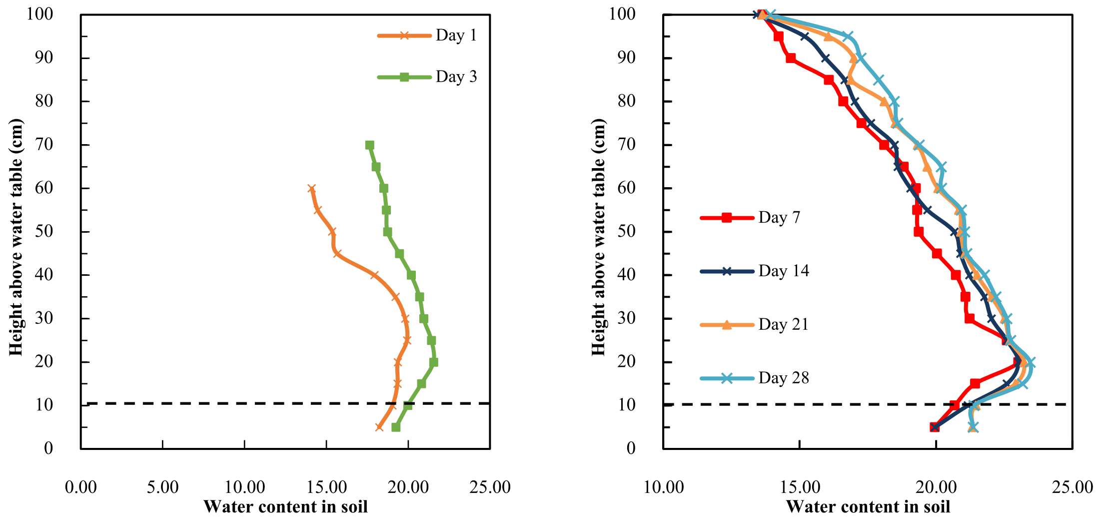
The results from the experiments such as soil moisture contents and electrical conductivity values of soil sections from the column were used to calculate the velocity of mass solution transport and to evaluate the values of D_u and R. The flux velocity in unsaturated soil is decreased when the distances rise from the surface due to the upward movement from capillary force is against gravity force. In fine textured soils, upward diffusion-dispersion coefficient and retardation factor are low compared to previous study (Chalongchan, 2003 & Konyai, 2007), but the height of capillary fringe is higher than coarse textured soils. The effect of clay particles in the soil is inducing the salt solution moves higher than non-saline solution due to a cohesion force between anion on clay surface and cation in solution. The parameters are also decreased because of the velocity of water is slower than that of salt solution ($R = v_{solvent}/v_{solution}$).

Table 1 Summary of physical and chemical properties of samples

Properties	Particle size distribution			Texture (USDA)	Bulk density (g/cm^3)	porosity	initial water content	salinity (mS/cm)
	sand	silt	clay					
soil sample	73.78	19.06	7.16	Sandy Loam	1.58	0.38	0.082	11.47

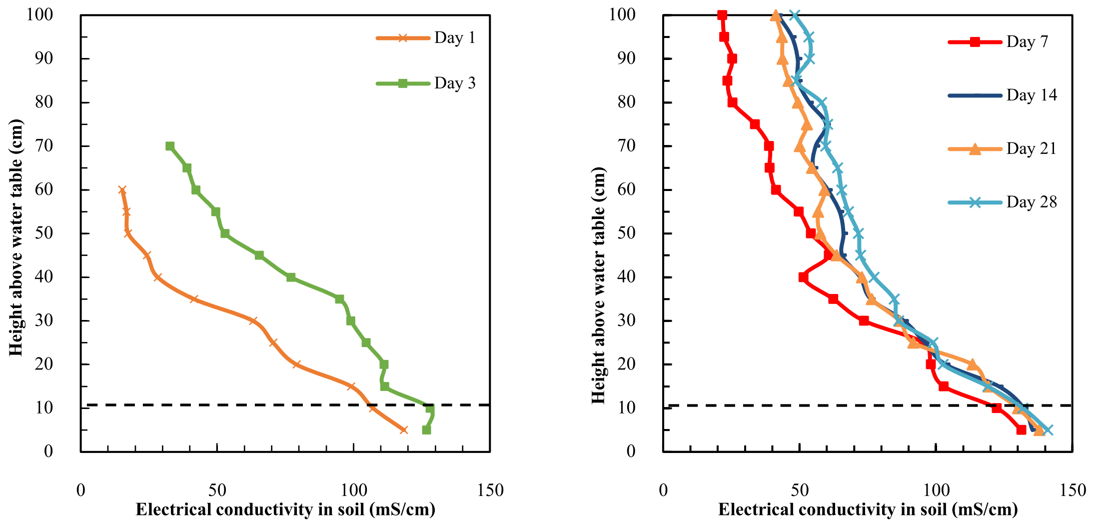
Table 2 Summary values of diffusion-dispersion coefficient and retardation factor

Time (day)	1	3	7	14	21	28
D_u (m^2/day)	0.0285	0.02	0.006	0.0054	0.0045	0.003
R	0.7	0.375	0.295	0.245	0.225	0.1



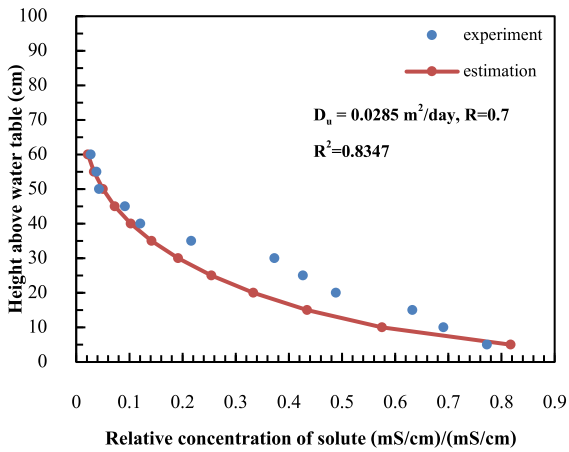
(a) (b)

Figure 1 Soil moisture content in column with every 5 cm interval by (a) day 1 and day 3 and (b) day 7, 14, 14 and day 28.

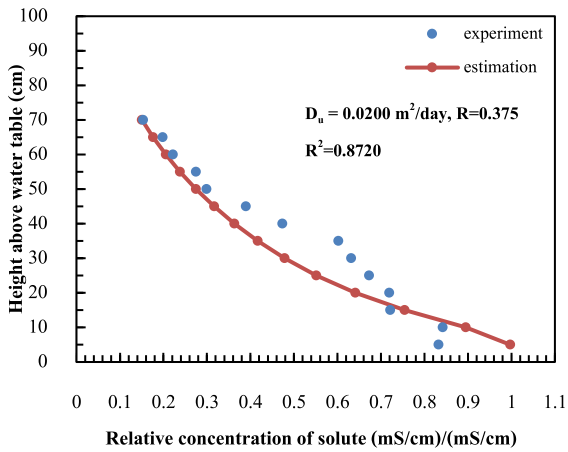


(a) (b)

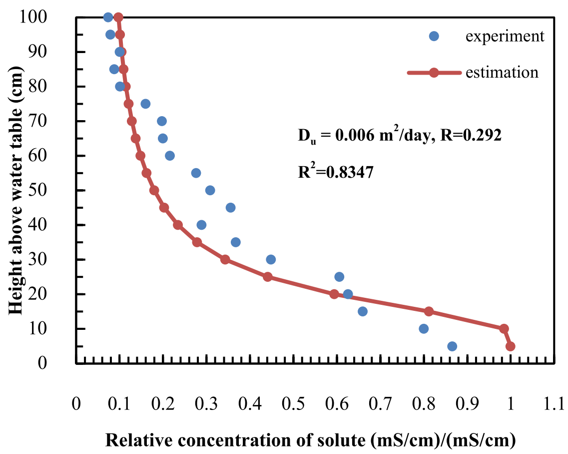
Figure 2 Electrical conductivity in column with every 5 cm interval by (a) day 1 and day 3 and (b) day 7, 14, 14 and day 28.



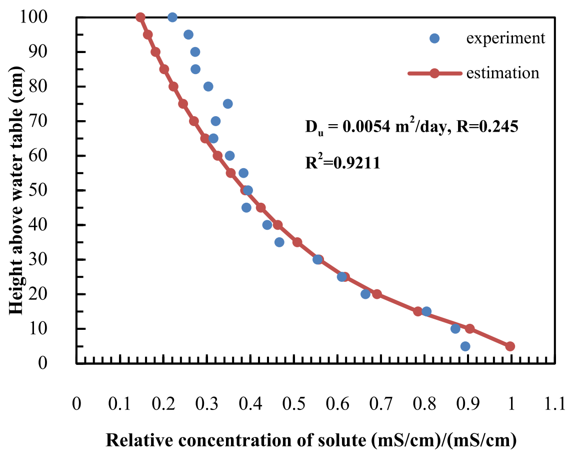
(a) day 1



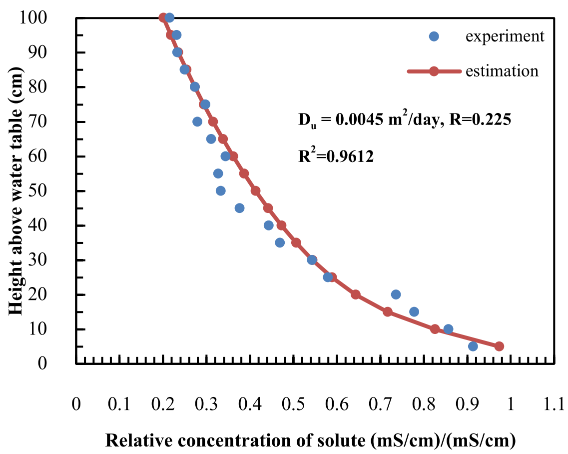
(b) day 3



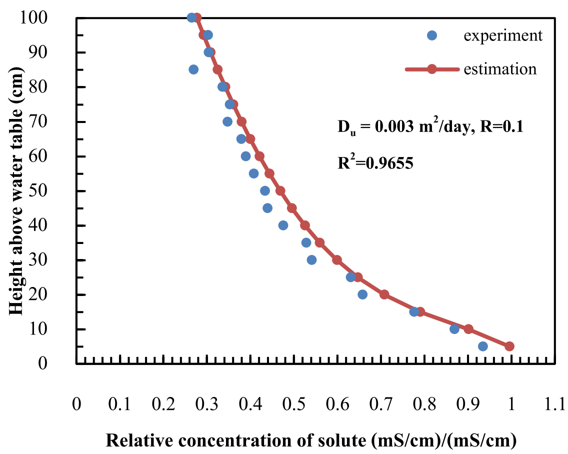
(c) day 7



(d) day 14



(e) day 21



(f) day 28

Figure 3 The parameters were obtained from comparison between simulation and experimental relative concentrations

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