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# Effect of the Solute Concentration on Hydraulic Properties of Unsaturated Porous Media

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### Abstract

In arid and semi-arid regions are characterized by the high evaporation rates which increases the solute accumulation in the unsaturated soils. Hydraulic properties are essential for modeling water flow and contaminant transport. In this paper, the effect of high solute concentration is studied in three different soils (Clay, Loam and Sand) through the measurement of the retention curves by a simple evaporation method using two water qualities (distilled water and water with a total solute concentration of 5 $g.l^{-1}$). The measured values were fitted on the van Genuchten model by the RETC software in order to obtain an estimation of the hydraulic parameters. The results show that there is a significant effect for the water retention curve of the clay soil which increases. On the contrary, for the sand and the loam soils the effect is not significant.

### Keywords

Unsaturated Soils, Hydraulic Properties, Parameter Optimization, RETC, Soil Retention Curve

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## 1. Introduction

The increasing demand for water and the degradation of its quality due to industrial, agricultural, anthropogenic and salinization activities have aroused great interest in understanding the hydraulic properties of soils, which are strongly influenced by soil structure and texture [1, 2] and the presence of solutes. These parameters are used as input in numerical simulation and solute transport models. The reliability of these methods depends on the accuracy of the measurements of the hydraulic parameters of the soil. Several direct methods of in situ and laboratory measurements have been developed, but most of these methods are costly, laborious, not very accurate and time-consuming [1, 3].

The use of indirect methods is an alternative for the estimation of soil hydraulic parameters. These theoretical methods are based on soil properties such as pore distribution and therefore the use of pedotransfer functions [3]. From simple measurement methods such as the evaporation method, they can be used to determine the retention curve in order to deduce that of hydraulic conductivity from analytical models [4]. Several empirical methods for estimating the retention curve and the hydraulic conductivity curve have been developed such as the models of: [6, 7, 8, 9, 10]. These models are simple to use and accurate for most textures; But are sometimes inaccurate especially for heavy soils.

The objective of this paper is to study the influence of a high solute concentration on the hydraulic properties of different soils by measuring the retention curves of three different soils using the evaporation method.

## 2. Materiel and Methods

### 2.1. Soil Columns and Measurements

Three types of soils were used: sandy (S), Loamy (L) and clayey (C). The soils were sampled from the region of

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Kairouan (Central Tunisia) for the sand, the region of Soukra (North Tunisia) for the loam and from the region of Cherfech (North Tunisia) for the clay. The soils cover a wide range of soils texture from Sandy to Clay in order to get significant variations in the measured water retention curves. The soil samples were crushed and then placed in small clear plastic containers. A tensiometer was implanted in the middle of each soil. As described in details by [5], the soils were saturated from the top with water and were left to evaporation. Monitoring volumetric water content (θ) was performed by gravimetric method (weighing scale) and the pressure head (h) by the tensiometer. In this study, two water qualities were used: distilled water (DW) and water with total solute concentration of 5 $g.l^{-1}$ (SW).

### 2.2. Parameters Estimation

The RETC software [1] was used to estimate the four parameters of the van Genuchten model.

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{1 + \left|\alpha h^n\right|^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \; ; \; m = 1 - \frac{1}{n} \qquad n > 1 \qquad (1)$$

where $\theta_r$ is the residual water content [L-3 L-3], $\theta_S$ is the saturated water content [L-3 L-3], h is the water pressure head [L], α [L-1] and n [-] are shape parameters. Their values were estimated by fitting the retention model to the measured data using the parameter optimization technique of Marquardt's maximum neighbourhood.

Initial values for the soil hydraulic parameters θr, θs, α and n were estimated with the ROSETTA [11] pedotransfer function using measured data of sand, silt, and clay contents (Table 1).

**Table 1.** Initial values of van Genuchten soil retention parameters estimated by Rosetta.

| Soil | $\theta_r$ ($cm.cm^{-3}$) | $\theta_s$ ($cm.cm^{-3}$) | α($cm^{-1}$) | n (-) | Ks ($cm.d^{-1}$) |
|---|---|---|---|---|---|
| C | 0.068 | 0.38 | 0.008 | 1.09 | 4.80 |
| S | 0.045 | 0.43 | 0.145 | 2.68 | 712.80 |
| L | 0.078 | 0.43 | 0.036 | 1.56 | 24.96 |

### 2.3. Statistical Evaluation

To evaluate fitted retention curves, two statistical parameters were used: the root mean square error (RMSE) and the geometric mean error ratio (GMER). These statistical parameters are calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(F_i - O_i)?}{j}} \times \frac{1}{\overline{O}} \qquad (2)$$

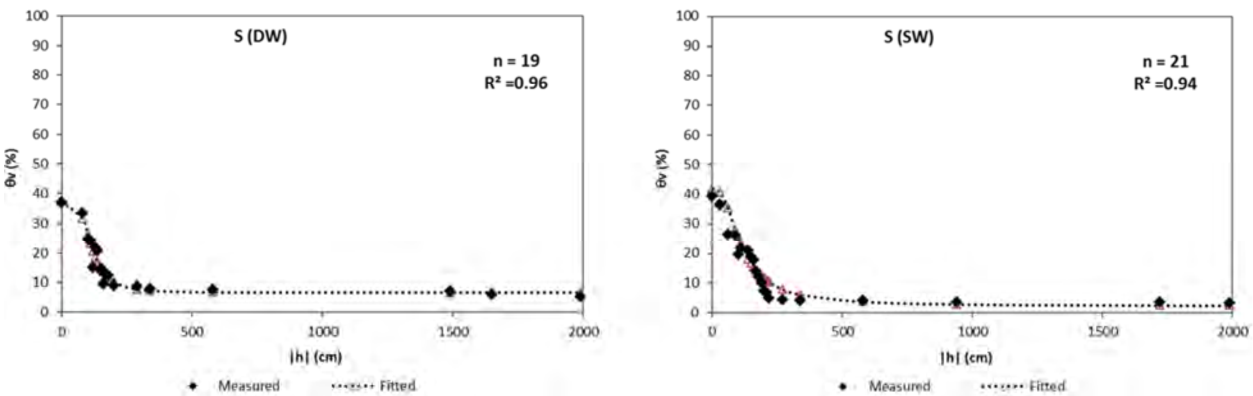
$$GMER = \exp\left[\frac{1}{j}\sum_{i=1}^{j}\ln\left(\frac{Fi}{Oi}\right)\right] \qquad (3)$$

where $F_i$ are the fitted values, $O_i$ are the observed values, $\overline{O}$ is the average value of observed data and $j$ is the number of observations. The RMSE and the GMER equal to 0 and to 1, respectively, correspond to an exact match between observed and fitted data. The GMER value less or greater to 1 indicates that the corresponding model underestimates or overestimates fitted data. The smaller (closer to 0) the RMSE value was, the better the model was.

## 3. Results and Discussion

### 3.1. Retention Curves

The volumetric water content θv (%) observed is plotted as a function of the absolute value of suction for the different types of textures in both cases (distilled water, high solute concentration) in figure 1. For each case, the curve of the volumetric water content is plotted alongside that of its fitted value as a function of the pressure head.



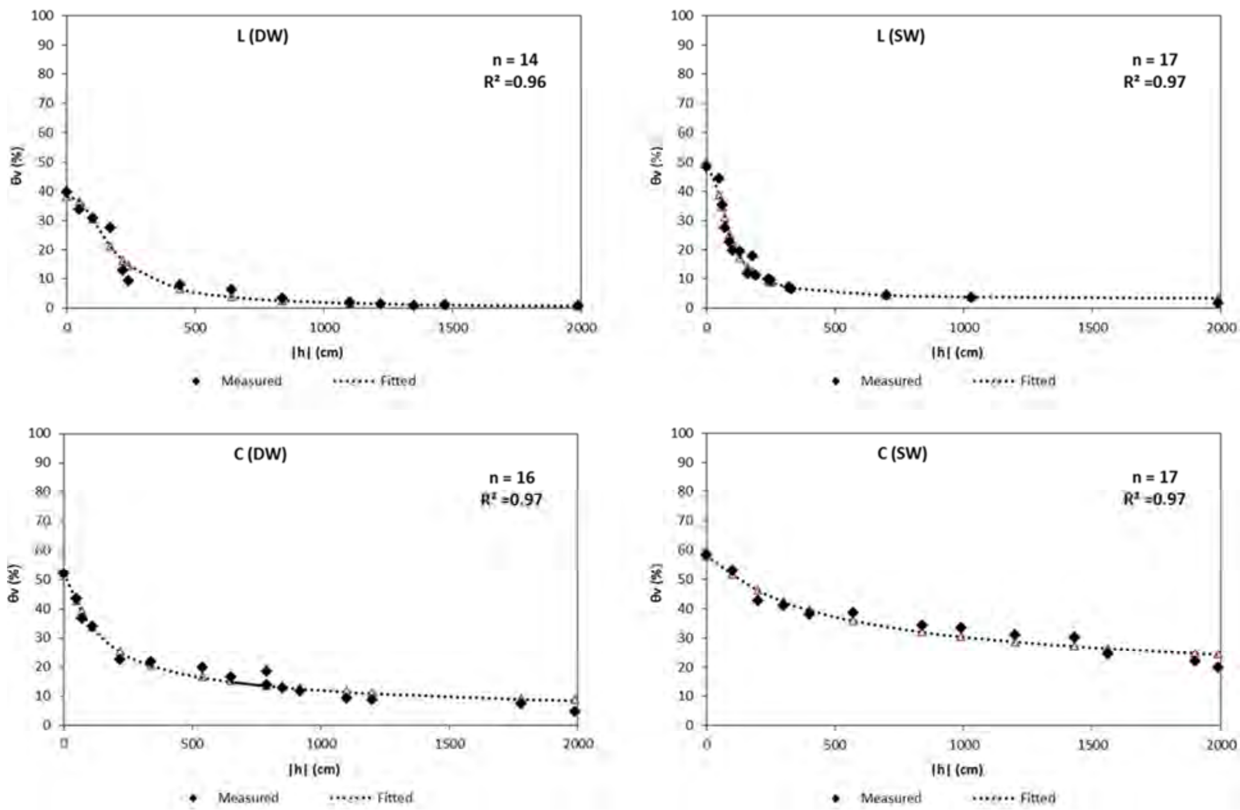



**Figure 1.** Measured and fitted retention curve of each soil.

A good correlation is found with values of $R^2$ varying between 0.94 and 0.97. The RMSE values are low and close to 0. The GMER values oscillate around 1 with three values slightly above 1. The statistical evaluation shows a good agreement between the estimated parameters and the measured values (Table 2).

**Table 2.** Statistical evaluation and estimated values of each soil.

| Soil | $R^2$ | RMSE | GMER | $\theta_s$ (cm.cm$^{-3}$) | $\theta_r$ (cm.cm$^{-3}$) | $\alpha$ (cm$^{-1}$) | n(-) |
|---|---|---|---|---|---|---|---|
| C (DW) | 0.97 | 0.10 | 1.04 | 1.03 | 0.00 | 0.01735 | 1.5121 |
| C (SW) | 0.94 | 0.07 | 1.00 | 0.75 | 0.00 | 0.00678 | 1.3294 |
| S (DW) | 0.96 | 0.14 | 1.01 | 0.74 | 0.13 | 0.00959 | 4.3443 |
| S (SW) | 0.94 | 0.18 | 0.99 | 0.83 | 0.04 | 0.01086 | 2.7524 |
| L (DW) | 0.96 | 0.20 | 0.96 | 0.66 | 0.00 | 0.00731 | 2.4817 |
| L (SW) | 0.97 | 0.14 | 1.03 | 0.99 | 0.06 | 0.01620 | 2.5019 |

## 3.2. Effect of the Solute Concentration

In order to highlight the effect of the soil texture and solute concentration on the retention curve, the values of the fitted water content were plotted as a function of the absolute value of the suction for the different soils (Figure 2).

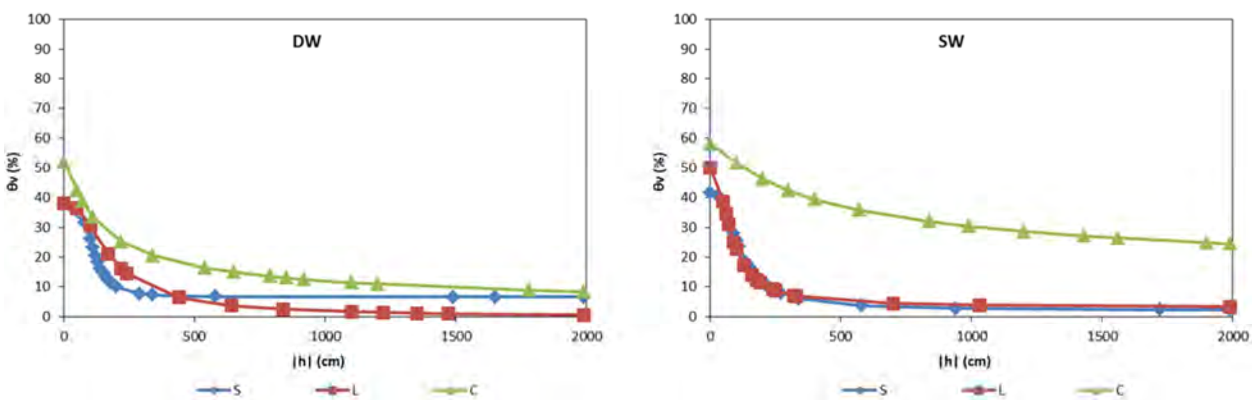



**Figure 2.** Effect of soil texture and solute concentration on retention curves.

According to figure 2:

- in the case of soils saturated with distilled water: the clay soil retains the most water with moisture at the end of the drying cycle around 20% whereas the sandy soil has the lowest values of moisture at saturation and at the end of drying. The loamy soil has an intermediate state. According to the literature, the more the soil is enriched with fine particles (Clay + Silt), the more its water retention capacity increases.

- In the case of soils saturated with high solute concentration water: water retention increased for clay soil with moisture at the end of the drying cycle around 25%, whereas it decreased slightly for the soil Sandy soil and has reached a water state very close to that of the loamy soil. The difference between the reaction of the clay and that of the sand is explained by the fact that the clay being a mineral colloid contains negative electric charges which make it possible to fix the cations dissolved in the water. A layer of exchangeable bases such as $Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $Na^{+}$ is formed around the particles. The solute thus acts on the organization of the structure, the texture which leads to a reduction of the spaces between the sheets, of the pores by adsorption thus leading to an increase in the retention of the water [12].

## 4. Conclusion

Hydraulic properties estimation of unsaturated porous media is an important step in the modeling of transport phenomena in soils. The difficulties of the measurements and their exorbitant cost led to the choice of indirect methods of PFTs and analytical models associated with the use of numerical software. Using a simple evaporation method, this study was used to determine the retention curve of different soil samples and to study the influence of soil and solute concentration on hydraulic properties. As long as the clay and silt content increase, the water retention capacity of soils increases too. However, several parameters seem to influence the hydraulic properties of soils, including organic matter and solute concentration. Soil saturation with salt water induced an increase in water retention for the case of clay then for other soils there is not much difference. Solute would certainly interact with the sandy and the loamy soil, but without significantly reducing or increasing retention. The geochemical characterization of soils and irrigation water during the drying cycle is essential to demonstrate the effect of the solute concentration on hydraulic properties. In future studies it will be considered.

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