THE EXPERIMENT
INTERNATIONAL JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN-2319-2119

RESEARCH ARTICLE

*Sabri Kanzari et al*, The *Experiment, 2014., Vol. 26(4), 1834-1843*

# SIMPLE EVAPORATION METHOD FOR ESTIMATING SOIL WATER RETENTION PROPERTIES OF AN UNSATURATED ZONE IN BOUHAJLA (KAIROUAN - CENTRAL TUNISIA)

## ABSTRACT

Soil hydraulic properties are important parameters for modeling water flow and solute transport in the vadose zone. However, direct measurement of this characteristic in field conditions is tedious, time consuming and expensive. A simple evaporation method has been used to characterize soil water retention properties of 18 layers, constituting the unsaturated zone of a land parcel in the region of Bouhajla (Central Tunisia). This experiment requires measuring volumetric water content by the gravimetric method and pressure head by a Watermark sensor, of a small disturbed soil core, during a drying cycle under the effect of evaporation. Measured retention curves were fitted to the analytical model of van Genuchten with RETC software to estimate residual water content ($\theta_r$), saturated water content ($\theta_s$) and the two shape parameters α and n. Estimation results were evaluated by calculating the mean square error (RMSE) and the geometric mean error ratio (GMER). Statistical analysis has proved the success of the evaporation method for estimating van Genuchten soil retention parameters of the studied unsaturated zone.

**Keywords**: Evaporation method, Parameter optimization, RETC, Soil retention curve, Tunisia

## INTRODUCTION

Salinization risk assessment of soils and aquifers in arid and semi-arid regions require knowledge of the evolution of water movement and solute transport in the subsurface. During the last decades, a large number of numerical models have been developed for the simulation of water flow and solute transport in the unsaturated zone. Nevertheless, their use in field conditions is often limited by the lack of characterization of hydraulic properties, which include retention curve and unsaturated hydraulic conductivity. In situ field measurements of hydraulic properties are tedious, costly, time consuming and are not accurate because of experiment shortcoming and high spatial and temporal variability. Therefore, the hydraulic properties of unsaturated soils are often estimated indirectly from other soil properties using pedotransfer functions (PTFs) (Schaap et al., 2001; Ungaro et al., 2001; Romano et al., 2002; Ghanbarlan-Alavijeh et al.,2010; Abbasi et al., 2011) or determined in the laboratory (Granier et al., 2004: Meadows et al., 2005; Simunek et al., 2005; Wesseling et al., 2009), which allow higher spatial and temporal resolution. Among the most widely used and easily methods to determine the retention curve and hydraulic conductivity of unsaturated soils is the evaporation method. This method is based on measuring both soil moisture and pressure head during a soil drying cycle under the effect of evaporation. The method was developed by Wind (1968) which introduced an iterative graphical procedure to estimate, firstly, the water retention curve from average soil moisture and pressure head readings, and then determined hydraulic conductivities from measured pressure head profile and variations in water content distribution. In general, five tensiometers, in a measuring range from -50 cm to -700 cm, are used in evaporation methods, several authors have proposed to reduce the number of tensiometers to 2 (Fujimaki and Inoue, 2003; Peters and Durner, 2008; Schindler et al., 2010; Schelle et al., 2010). Wessolek et al. (1994) and Simunek et al. (1998) have used only one tensiometer in small soil cores and showed that this method is able accurately to estimate soil hydraulic characteristics. Furthermore, as an alternative to Wind Algorithm, the analysis of water flow during an evaporation experiment can be performed by using optimization algorithms. RETC software (van Gencuhten et al., 1991), which is based on the Levenberg-Marquardt optimization algorithm is often used for estimating soil hydraulic parameters by fitting analytical models to measured data. Among the most popular closed-form analytical expression for hydraulic properties is that of van Genuchten (1980), which is able to predict hydraulic conductivity from the retention curve and is more convenient for numerical models of water flow in the unsaturated zone.

The overall objective of our study is the numerical simulation of water movement and salts transfer in Bouhajla (Central Tunisia), characterized by saline soils, to try to assess groundwater contamination risk. The specific objective of this paper is to estimate soil water retention properties of an unsaturated zone of Bouhajla by a simple evaporation method in the laboratory. This method is to monitor the water content by the gravimetric method and the pressure head by a Watermark sensor, which allows a wider measuring range than the conventional tensiometer (0 cm to -1990 cm), during a drying cycle, of a small soil core under the effect of evaporation and using the RETC program to estimate the van Genuchten model parameters from measured retention curves.

## Material and Methods

### Mathematical description of soil water retention curve

The analytic model of van Genuchten (1980) was used to set the water retention curve $\theta(h)$, which relates the volumetric water θ content in pressure potential $h$. The equation of van Genuchten (1980) for the retention curve is:

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

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.

Equation (1) contains up to four independent coefficients, represented by the parameter vector b = {$\theta_r$, $\theta_s$, α, n}. The different parameters are essentially empirical coefficients without much physical significance (Kool et al., 1985). Their values were estimated by fitting the retention model to the observed data using the parameter optimisation RETC (van Genuchten et al., 1991). This program uses Marquardt's maximum neighbourhood method to minimize the objective function, O(b):

$$\overset{\min}{b}\; O(b) = \sum_{i=1}^{N} \left[\left(\theta_i - \hat{\theta}_i(b)\right)\right]^2 \qquad (2)$$

where $\theta_i$ and $\hat{\theta}_i$ are the observed and fitted water contents, respectively, and N is the number of retention data. Initial values for the soil hydraulic parameters θr, θs, α and n were estimated with the ROSETTA (Schaap et al., 2001) pedotransfer function using measured data of sand, silt, and clay contents (Table 1; Table 2).

### Evaporation experiment

A land parcel (35°15'47.58''N; 10°4'17.16''E) was selected from a farmer about 9 kms south of the village of Bouhajla (Central Tunisia). A piezometer dug in the land parcel indicated that the groundwater level varies around 550 cm. Soil sampling was done every 30 cm at in a depth of 540 cm to characterize the entire unsaturated zone. Soil particle size analysis of each soil layer is given in Table 1. The eighteen soil samples have been leached from salts, crushed and dried and then placed in small clear plastic containers. Watermark sensor (Irrometer Inc.,USA) was implanted in the middle of each soil layer (Figure 1). Each soil was saturated from the top with distilled water and was left to evaporation. During the drying cycle, no device has been used to accelerate evaporation. Monitoring volumetric water content was performed by gravimetric method (weighing scale) and the pressure head by dielectric method (Watermark sensor). Upon conversion of gravimetric water content to volumetric humidity, the value of bulk density used was 1.5 $g.cm^{-3}$, since we used disturbed soil samples and leached from their salts. The measurements were made daily until the digital meter indicates h = -1 990 cm, which corresponds to the Watermark sensor limit.

**Statistical Analysis**

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:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(F_i - O_i)^2}{j}} \times \frac{1}{\overline{O}} \tag{3}$$

$$GMER = \exp\left[\frac{1}{j}\sum_{i=1}^{j}\ln\left(\frac{Fi}{Oi}\right)\right] \tag{4}$$

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.

## RESULTS

Measured water retention curves are represented in Figure 2 for all the layers of the unsaturated zone, from 0 cm to 540 cm. During their drying cycle, the pressure head (h) has varied from a saturated state (h = 0 cm) to a completely dry state (h = -1990 cm) for all the layers. However, the values of volumetric water content ($\theta_v$) at saturation and at the end of the drying cycle are different between layers. The sandy surface layer of 0-30 cm has the lowest values of $\theta_v$ at saturation and at the end of drying. Soil water retention has increased with soil enrichment by fine particles (clay + silt). Soil water retention curves of the sandy clay layers have shown higher values of $\theta_v$ at saturation and at drying and dry while silt-sandy layers have shown an intermediate moisture state between them and the surface layer. Soil layers that lie below 420 cm depth have begun their drying cycle from a state of saturation close to 100% and have finished it by about 50% of $\theta_v$. These layers set up the area called capillary fringe above the aquifer, which explains their great ability to retain water.
Measured water retention data obtained from evaporation method were fitted by RETC to estimate the van Genuchten equation parameters (Figure 2). Strong correlations were noticed between measured and fitted curves, $r^2$ has ranged between 0.84 and 0.99. The values of van Genuchten's equation parameters and the values of the objective function O(b) were assigned in Table 3. The values of these parameters are very heterogeneous between the different layers of the unsaturated zone. The layers 300-330 cm and 150-180 cm have the highest values of n and α, the most sensitive parameters to water flow (Lu and Zhang, 2002). These layers may be particular areas for water movement and solute transport in the unsaturated zone of Bouhajla. For the other layers, the values of n varied between 1.11 and 2.98537, and the values of α varied between 0.00237 and 0.37048. The sandy layers have the smaller values of $\theta_r$. The last four layers have the highest values of θs, 95% for the layer 480-510 cm.

The RMSE and GMER calculated for the different layers are close to 0 and 1, respectively, and show a strong agreement between measured values of the retention curve by evaporation method and the adjusted values to van Genuchten's equation by RETC (Table 4). GMER values were greater than 1 for most of the layers. The proposed evaporation method may slightly overestimate the soil water retention curve.

## DISCUSSION

The evaporation method is a widespread experimentation for estimating soil hydraulic properties. In this research, we have demonstrated the success of estimating soil retention parameters by RETC from an evaporation experiment on small soil cores and using a single sensor for measuring pressure head such as Simunek et al. (1998) and Wessoleck et al. (1994), and we have extended the range of measurement to -1990 cm. Estimated values of van Genuchten equation parameters, especially α and n, are of the same order as the parameters estimated by other authors from evaporation method, as Bruckler et al. (2002) and Fujimaki and Inoue (2003) for sandy loam soils and Basile et al. (2006) for sandy clay soils. However, the hydraulic conductivity curve has not been determined assuming that it can be estimated from the equation of van Genuchten (1980). Simultaneous estimation of the retention curve and unsaturated hydraulic conductivity by Wind algorithm (1968) could be an interesting perspective of this study. According to Abbasi et al. (2011) salinity affects indirectly soil hydraulic properties by acting on the porosity and permeability, the study of the effect of salts on these properties is recommended.

Finally, Levenberg-Marquardt optimization algorithm implemented in RETC presents some difficulties to optimize certain parameters of water content and hydraulic conductivity from collected data in field conditions (Wesseling et al., 2008), use of other optimization methods is also suggested. All these recommendations will be taken into consideration in future work.

## CONCLUSION

A simple evaporation method was advanced in this study for estimating soil water retention proprieties of an unsaturated zone. The obtained estimation results are acceptable and have shown that the van Genuchten retention curve parameters are very heterogeneous from one layer to another. However, these results allowed us to get an idea of the range of these parameters for each soil layer, especially for shape parameters α and n. These results are essential for modeling of water flow and salts transfer in Bouhajla vadose zone.

## ACKNOWLEDGMENTS

This study was done under the support of INRGREF/ACSAD project “Technology Transfer of Brackish/Saline Waters for Farmers” and the PISEAU project “Salinity Management for Small Farmers and Long-term Salinization Risk in Central Tunisia”.

| Layer (cm) | Clay (gkg$^{-1}$) | Loam (gkg$^{-1}$) | Sand (gkg$^{-1}$) | Texture |
|---|---|---|---|---|
| 0-30 | 9.5 | 4.5 | 85 | Sand |
| 30-60 | 11.5 | 5.5 | 83 | Sandy Loam |
| 60-90 | 12.5 | 6.5 | 80 | Sandy Clay Loam |
| 90-120 | 11 | 6 | 82 | Sandy Clay Loam |
| 120-150 | 15 | 8 | 76 | Sandy Clay |
| 150-180 | 13 | 6.5 | 79.5 | Sandy Clay |
| 180-210 | 15 | 8 | 76 | Sandy Clay |
| 210-240 | 15 | 8 | 76 | Sandy Clay |
| 240-270 | 10 | 14 | 76 | Sandy Loam |
| 270-300 | 8 | 8 | 84 | Sandy Loam |
| 300-330 | 9 | 10 | 80 | Sandy Loam |
| 330-360 | 1 | 29 | 69 | Sandy Loam |
| 360-390 | 17 | 22.7 | 59.5 | Clay Loam |
| 390-420 | 10.5 | 10 | 78.5 | Sandy Clay Loam |
| 420-450 | 11 | 11 | 77.5 | Sandy Clay Loam |
| 450-480 | 10 | 10.5 | 79 | Sandy Clay Loam |
| 480-510 | 10.5 | 8 | 82.5 | Sandy Clay Loam |
| 510-540 | 28.5 | 18 | 52 | Clay Loam |

**Table 1. Soil particle size analysis of the parcel.**

| Layer (cm) | $\theta_r$ (cm$^3$ cm$^{-3}$) | $\theta_s$ (cm$^3$ cm$^{-3}$) | $\alpha$ (cm$^{-1}$) | n (-) | $K_s$ (cm d$^{-1}$) |
|---|---|---|---|---|---|
| 0-30 | 0.0547 | 0.372 | 0.0298 | 1.8898 | 129.67 |
| 30-60 | 0.0551 | 0.3732 | 0.0299 | 1.7062 | 84.59 |
| 60-90 | 0.0541 | 0.3727 | 0.0301 | 1.587 | 62.98 |
| 90-120 | 0.0536 | 0.3729 | 0.0304 | 1.6895 | 85.07 |
| 120-150 | 0.055 | 0.3732 | 0.0299 | 1.4608 | 39.84 |
| 150-180 | 0.0545 | 0.3725 | 0.0299 | 1.5638 | 57.8 |
| 180-210 | 0.0556 | 0.3758 | 0.0306 | 1.4837 | 42.96 |
| 210-240 | 0.0556 | 0.3758 | 0.0306 | 1.4837 | 42.96 |
| 240-270 | 0.0454 | 0.3816 | 0.0363 | 1.5087 | 59.69 |
| 270-300 | 0.0495 | 0.378 | 0.0342 | 1.8468 | 126.31 |
| 300-330 | 0.0476 | 0.3778 | 0.0348 | 1.6469 | 86.71 |
| 330-360 | 0.0265 | 0.402 | 0.0418 | 1.4594 | 86.09 |
| 360-390 | 0.0548 | 0.3858 | 0.025 | 1.3761 | 22.94 |
| 390-420 | 0.049 | 0.3769 | 0.0337 | 1.5735 | 70.26 |
| 420-450 | 0.0487 | 0.3781 | 0.0341 | 1.535 | 62.52 |
| 450-480 | 0.0482 | 0.3783 | 0.0346 | 1.5899 | 73.84 |
| 480-510 | 0.0518 | 0.3778 | 0.0329 | 1.6923 | 87.11 |
| 510-540 | 0.0718 | 0.3948 | 0.0237 | 1.3124 | 9.84 |

**Table 2. Initial values of van Genuchten soil retention parameters estimated by Rosetta.**

| Layer (cm) | $\theta_r$ (cm$^3$ cm$^{-3}$) | $\theta_s$ (cm$^3$ cm$^{-3}$) | $\alpha$ (cm$^{-1}$) | n (-) | $r^2$ | $O(b)10^4$ |
|---|---|---|---|---|---|---|
| 0-30 | 0.01678 | 0.25305 | 0.0104 | 2.62368 | 0.94 | 38.20 |
| 30-60 | 0.0000 | 0.32812 | 0.08369 | 1.3141 | 0.92 | 135.10 |
| 60-90 | 0.0093 | 0.39429 | 0.00854 | 1.71022 | 0.97 | 69.90 |
| 90-120 | 0.0000 | 0.35373 | 0.00699 | 1.73213 | 0.96 | 72.50 |
| 120-150 | 0.0177 | 0.2220 | 0.02326 | 1.95435 | 0.96 | 29.70 |
| 150-180 | 0.3733 | 0.45964 | 0.01893 | 3.78153 | 0.93 | 49.70 |
| 180-210 | 0.0000 | 0.28179 | 0.00237 | 2.36118 | 0.95 | 92.70 |
| 210-240 | 0.0000 | 0.38912 | 0.00759 | 1.69582 | 0.98 | 34.70 |
| 240-270 | 0.0000 | 0.40726 | 0.01226 | 1.88077 | 0.97 | 35.70 |
| 270-300 | 0.0000 | 0.28755 | 0.02817 | 1.73985 | 0.97 | 35.90 |
| 300-330 | 0.20708 | 0.46226 | 0.03654 | 5.33151 | 0.84 | 355.10 |
| 330-360 | 0.20436 | 0.41129 | 0.03364 | 2.40498 | 0.87 | 185.30 |
| 360-390 | 0.23402 | 0.49134 | 0.00697 | 2.57708 | 0.99 | 22.20 |
| 390-420 | 0.000 | 0.32677 | 0.00839 | 1.86114 | 0.98 | 58.50 |
| 420-450 | 0.29616 | 0.66347 | 0.00495 | 2.98537 | 0.98 | 60.20 |
| 450-480 | 0.3268 | 0.8180 | 0.00743 | 2.22736 | 0.94 | 627.50 |
| 480-510 | 0.0000 | 0.95618 | 0.37048 | 1.11148 | 0.94 | 323.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 510-540 | 0.39614 | 0.74794 | 0.03282 | 1.67468 | 0.98 | 41.80 |

**Table 3. Estimated van Genuchten soil retention proprieties and values the objective function.**

| Layer (cm) | RMSE (%) | GMER |
|---|---|---|
| 0-30 | 23.58 | 1.05 |
| 30-60 | 13.34 | 1.01 |
| 60-90 | 9.31 | 1.00 |
| 90-120 | 9.63 | 0.99 |
| 120-150 | 13.73 | 1.00 |
| 150-180 | 4.01 | 0.99 |
| 180-210 | 15.61 | 1.01 |
| 210-240 | 8.15 | 1.00 |
| 240-270 | 13.69 | 1.01 |
| 270-300 | 16.81 | 1.21 |
| 300-330 | 11.92 | 1.00 |
| 330-360 | 9.1 | 1.00 |
| 360-390 | 2.54 | 1.00 |
| 390-420 | 9.14 | 0.94 |
| 420-450 | 3.33 | 1.00 |
| 450-480 | 7.69 | 1.00 |
| 480-510 | 5.44 | 0.99 |
| 510-540 | 5.33 | 1.00 |

**Table 4. Calculated statistical parameters for estimating soil retention curve using RETC.**

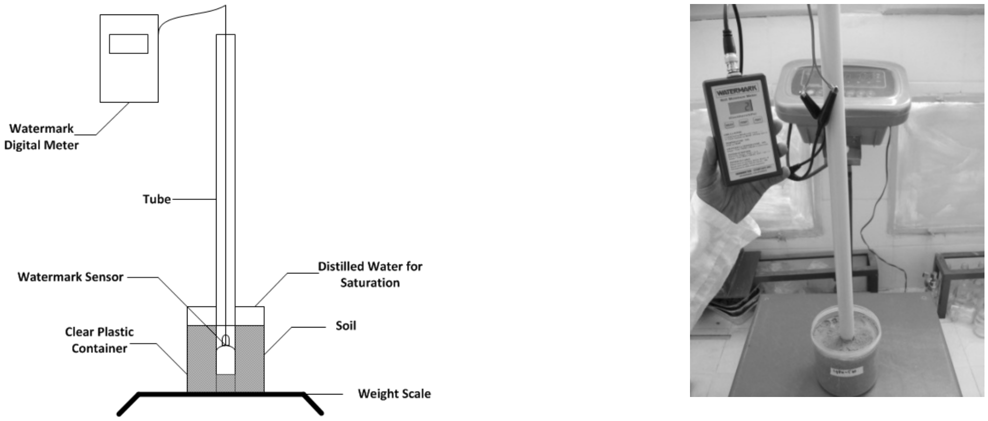

**Figure 1. Schematic and photo of soil evaporation experiment.**

INTERNATIONAL JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN-2319-2119

RESEARCH ARTICLE

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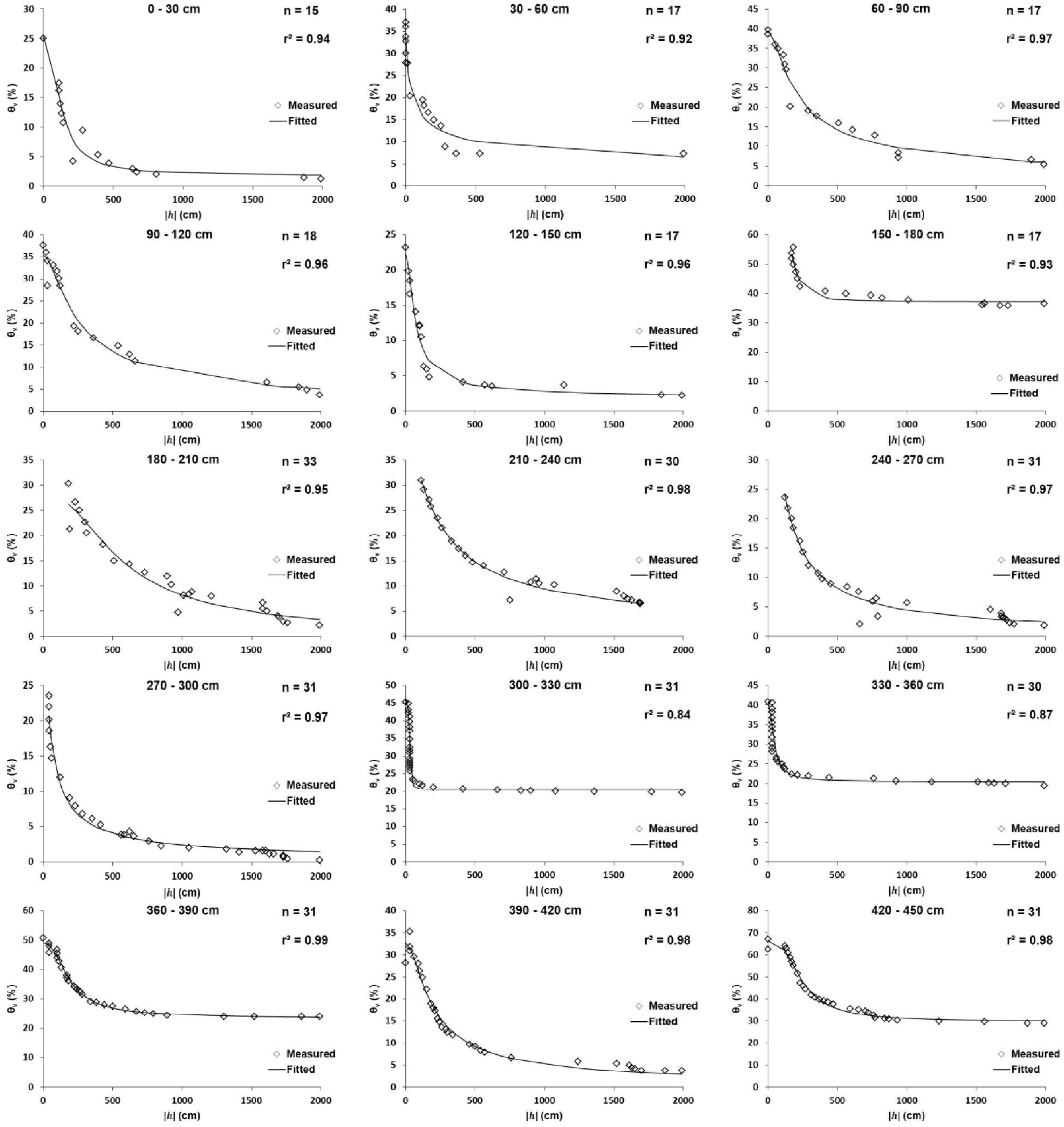

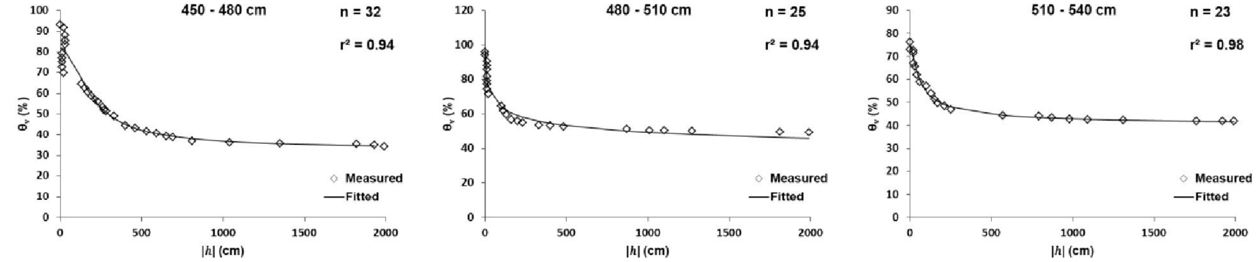

**Figure 2. Measured and fitted soil retention curves of Bouhajla unsaturated layers.**

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