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A PREDICTION OF THE MAIN WETTING CURVE (MWC) OF THE SOIL WATER CHARACTERISTIC CURVE BASED ON ITS MAIN DRYING CURVE (MDC) BY USING THE TWO POINTS METHOD

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Abstract

Direct measurements of the main wetting curve (MWC) of the soil-water characteristic curve are very hard compared to direct measurements of the main drying curve (MDC) of the soil-water characteristic. Both curves are important in agricultural and engineering applications. This study was conducted to predict main wetting curves (MWCs) from main drying curves (MDCs) using Feng and Fredlund (1999) equation by using the two points method for seven soil samples with a wide range of gypsum content including control treatment (0% gypsum). Both MDCs and MWCs were measured. Performed results showed that good fitting was obtained between measured and predicted value using the two points method by using quantitative statistical parameters: coefficient of determination (CD), coefficient of residual mass (CRM), error ratio (å), geometric mean of error ratio (GMSE) and geometric standard deviation of error ratio (GSDER) as well as 1:1 correlation which showed a high fitting between the measured and predicted points for the main wetting curve (MWC) of the soil-water characteristic curve. Feng and Fredlund (1999) is a simplified model for soil-water characteristic curves fitting as well as to predict main wetting curves (MWCs) from main drying curves (MDCs) by using the two points method with a wide range of gypsum in soil samples.

Key words : Main wetting curve (MWC), Main drying curve (MDC), gypsum, soil samples.

Introduction

The soil-water characteristic curve (SWCC) represents the relationship between the volumetric water content (θ) in pore space and the matric suction. The curve is also called the soil moisture characteristic curve (SMCC) or the soil water retention curve (SWRC) (Heshmati and Motahari, 2012; Albers, 2015). SMCC usually obtained by drying (drainage) or wetting (imbibition) a soil sample under constant stress while monitoring the changes of water content in the soil. Both methods gave two connected curves, but not identical, the volumetric water content in case of drying curve will be higher for same matric suction in case of a wetting curve, in other words, there are two different volumetric water content accrued at the same matric suction (Ebrahimi *et al*., 2007). This phenomenon known as soil hysteresis, in field often this process is clear in some of the complex processes when wetting and drying automatically or sequentially accrued during irrigation, as the predominance of soil moisturizing during the addition of water in surface and drip irrigation (Salim and Rasheed, 2015) and water capillary fluctuations (Alshammary and Salim, 2016) adding water then drying taken place with drainage, evapotranspiration or water uptake by plants (Salim and Khudair, 2015). Usually wetting and drying processes in the unsaturated zone (vadose zone) at the same time (Salim, 2003). The importance of this phenomenon in the applications mentioned before which depended on the relationship between the volumetric water content (θ) in pore space and the matric suction (ψ), soil water has different pathways which have led researchers to quantify and present several models to describe this phenomenon and predict soil behavior in which different paths are followed.

Most hysteresis models are categorized into two main groups: C.M and EM

Conceptual models

This approach based on the domain theory of capillary hysteresis (Izady *et al*., 2009), including the independent domain theory for water content-pressure head hysteresis as formulated by Everett (1954) dependents on two assumptions: first, that the pore space is made up of pores or domains, each defined by two pressure head values, one where the pore drains and one where it falls precipitously. The draining and filling of each pore take place at its defining pressure head values independent of the remaining pores in the system. Second, the water volume difference between the drained and filled states of each pore is independent of the pressure head. This explained by entrapped air phenomenon and dependent domain theories as formulated by Poulovassillis (1970) as models were taken into account the effect of pore blockage against water or air entry for drying and wetting processes assuming that there are two kinds of pore elements: when ψ_w values decreased but the values of q_d increased at which the process switches from wetting to drying and holding moisture amount when transition from wetting to drying takes place which is taken from independent domain theory. Model formulated by Parlange (1976), who developed the conceptual models similar to identical theory by relied on one boundary curve to predict the other curve.

Empirical model

Empirical models are based on an analysis of soil-water characteristic curve shape and properties, which can identify by interpolation model to calculate θ value for one crave from the matric section for the other curve (identical hypothesis theory), the linear model by calculating tendency for both main curves instead of interpolation model, the slope model approximates the scanning curves by a straight line spanning the main wetting and drying curves. In this model, the slope of the line is arbitrary with the only constraint that it be less than the slope of the main curves at the intersection. And the scaling-down model it is a simplified model for predicting scanning curves (Izady *et al*., 2009).

Feng and Fredlund (1999) model a simplify empirical models not based on a physical basis with less data needed for curve fitting as it described soil moisture characteristics apparently. The model used as a curve-fitting model using a soil characteristic curve-fitting equation to fit both main wetting and drying curves to obtain a high fitting between measured and predicted data (Pham, 2002). The model can be described as below:

$$w(\psi) = \frac{w_u b + c^d}{b + d} \tag{1}$$

Where,

b, c, d represent empirical fitting parameters. And w_u represents the water content at the soil matric suction of zero. c represents the water content at the high soil suction. d represents the slope of the curve and both parameters d and b represent the air entry value along the curve.

Project

According to difficulties associated with methodologic for the determination of the MWC compared with MDC and due to the simult occurrence of the wetting and drying cycles in the videos zone and and the … of MWC and MDC in soil water balance especially evaporation, evapotranspiration, contribution from the water table and deep percolation. This study performed to predict MWC from MDC according to the two point method described by Feng and fredlund (1994).

Materials and Methods

Soil material samples were taken from the fields of Agriculture, the University of Tikrit from different locations and depths to obtain soil material samples with different gypsum content. soil samples were dried up by air, ground and sifted with a sieve of 2mm diameter sieve's holes. Gypsum content for collected soil samples were 5, 15, 20 and 40%. Different proportions of soil materials have been mixed to obtain an approximate percentage of other required gypsum content according to the mixing equation as below:

$$(1 \times (CaSO_4.2H_20\%) = \left[\frac{c_1}{100} \times X\right] + \left[\frac{c_2}{100} \times (1 - X)\right] \tag{2}$$

Where,

$CaSO_4.2H_2O\%$ is required gypsum %.

X is gypsum % for soil samples.

c_1 and c_2 are gypsum % for both soil samples used in mixing.

Another sample was taken from Husseiniya area in Karbala governorate with 0% gypsum as a control treatment.

Soil textures were determined after the volumetric analysis of soil samples particles was conducted using the hydrometer method. Gypsum was also estimated by sedimentation method using Acetone according to the method described by Klute (1986). Some physical and chemical properties of soil samples have also been estimated according to methods described (Page and Kenny, 1982). Table 1 showed some of the physical and chemical characteristics for soil samples used in this study.

Drying and wetting curves of the SWRC were estimated. The relationship between volumetric water content (θ) and matric suction (ψ) were estimated for all soil samples. Soil samples were initially saturated with water and then subjected to drying; the drying curve of the SWRC was measured ûrst and the wetting curve was determined afterward starting from a soil water section in the range from 200 to 2000 cm using Hysteresis attachment model 1250 and water section in range 5-100 cm using a manometer. A pressure plate apparatus in the range between 3000-15000 cm were used. The relation between volumetric water content (θ) and matric suction (ψ) was described using Feng and Fredlund(1999) equation (Eq. 1) as a fitting model.

Feng and Fredlund(1999) theory to predict for the main wetting curve (MWC) using two points method

Feng and Fredlund (1999) theory are based on the following:

- Estimation of drying curve (MDC) and using Eq. 1 to describe the curve fitting.
- Using a and c to describe both MDC and MWC.
- To predict the other curve (MWC) required to determine two parameters b_w and d_w on MWC by identified two points on MWC.

P. Feng and Fredlund (1999) to calculate the two points

1. Two points selection: The relation between volumetric water content (θ) and matric suction (ψ) for MDC were described and fitting was performed using Feng and Fredlund (1999) equation (Eq.1) to obtain fitting parameter b_w and d_w as below:
   - The first additional point (ψ_1) can be chosen on the main wetting curve (MWC) at a soil suction is approximately equal to air entry value (AEV) for MDC and it will be approximately calculated as follows:

$$\psi_{ae} = \left(\frac{b}{10}\right)^{(1/d)} \tag{3}$$

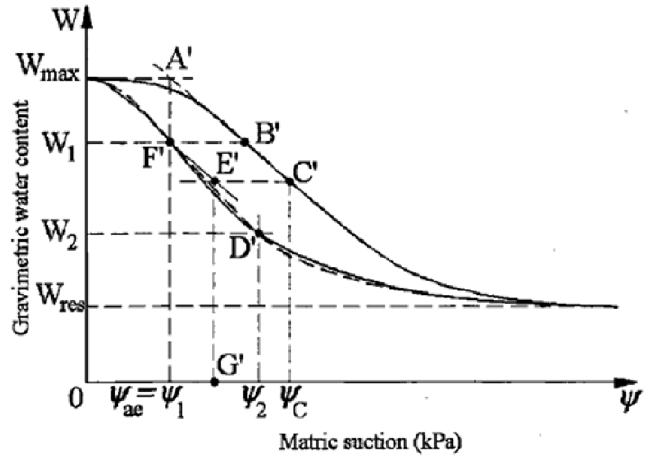

Fig. 1 : Schematic illustrations of procedures for predicting the main wetting curve using the Feng and M. Fredlund (1999) model (Pham, 2002).

Where, b and c fitting parameter for MDC by using Eq. 1.

- Determine the assumed inflection point on the main wetting curve E, which inparallel inflection point on the main drying curve.
- Assuming that the two curves are inparallel, soil suction value of the second point (ψ_2) on the main wetting curve which has been chosen according to first point, the second point on MWD has same section value for first chosen point on MDC by drawing upright line through the assumed inflection point on MWC in E as below:

$$|\psi_2 - \psi_E| = |\psi_1 - \psi_E| \tag{4}$$

Where, ψ_E soil suction at point E in fig. 1.

$$\psi_2 = \psi_1 - 2\left(\left(\frac{b(w_u - w_1)}{w_1 - c}\right)^{1/d} - b^{1/d}\right) \tag{5}$$

Where, w_u represents the water content at the soil matric suction of zero, b, c, d represent empirical fitting parameters for main drying curve, ψ_1 soil matric suction of first point and w_1 water content of first point.

- w_1 represents water content of first point on main wetting curve (MWD) with ψ_1 section at point (F), which can be calculated using Eq. (1).
- w_2 represents water content of second point on main wetting curve (MWD) with ψ_2 section at point (D) which can be calculated using Eq. 1. Fig. 1 showed how to estimate both points.

2. After the two point were determined on main wetting curve (MWC), now we can calculate the others points by estimation function and fitting parameters for main wetting curve (MWC) as presented in the two equations below:

$$d_w = \frac{log\left(A_1/A_2\right)}{log_{(2/1)}} \tag{6}$$

$$b_w = \frac{\left(w_1 - c\right)_1^{d_w}}{log_{(2/1)}} \tag{7}$$

A_1 and A_2 can be calculated as below:

$$A_1 = \frac{w_1 - c}{w_u - w_1} \tag{8}$$

$$A_2 = \frac{w_2 - c}{w_u - w_2} \tag{9}$$

Some other quantitative statistical parameters were calculated and analysis of residual errors, and differences between measured and predicted values to evaluate the accuracy of predicted results and reliability of predicted resultsby using Feng and Fredlund (1999) equation (Dirksen and Feddes, 2002; Khodaverdiloo *et al*., 2011; Naji, 2014; Mohamed and Sahli, 2006; Obiero, 2013; Reichle *et al*., 2004).

Results and Discussion

Fig. 2 showed soil moisture characteristic curves for drying (MDC) and wetting (MWC) curves for measured and fitted value by using Feng and Fredlund (1999) under different gypsum content and showed the two points required to predict MWC from MDC after determined both θ and q for each point were represented in Eq. 3, 4 and 1 respectively. The two points were in the same range for all soil samples. Also, fig. 2 showed main predicted wetting curves by using two points method and estimated function and fitting parameters bw and dw using eq. 5, 6, 7 and 8 respectively. Results revealed there are differences between measured and predicted values using the two points method, but the two curves took the same general shape according to Feng and Fredlund (1999) theory, approaching points and differences between measured and predicted wetting curves represented high fitting between measured and predicted values especially at section 0.1 and 15000 cm H_2O for all soil samples; also at section 50 and 330 cm

Table 1 : Some of physical and chemical characteristics for soil samples used in this study.

Soil Property	Control	5%	10%	15%	20%	30%	40%
Sand ($g.kg^{-1}$)	392	712	710	696	732	682	652
Silt($g.kg^{-1}$)	440	87	122	152	138	182	206
Clay ($g.kg^{-1}$)	168	201	168	152	130	136	124
Tex.	Loam	Sandy Clay Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
θ_s ($cm^3.cm^{-3}$)	0.45	0.39	0.398	0.401	0.41	0.414	0.424
θ_r ($cm^3.cm^{-3}$)	0.122	0.071	0.07	0.07	0.068	0.066	0.064
Bulk density	1.44	1.57	1.55	1.53	1.53	1.52	1.49
Real density	2.64	2.62	2.60	2.58	2.59	2.59	2.58
Porosity	0.452	0.400	0.403	0.406	0.409	0.413	0.422
pH	7.40	7.30	7.20	7.20	6.90	6.80	6.70
EC	1.70	2.00	2.20	2.40	2.50	2.50	2.60
CEC	20.00	14.00	11.70	10.20	9.00	7.80	6.70
O.M.	1.00	2.42	1.72	1.57	1.49	1.16	1.04

Table 2 : Quantitative statistical parameters to evaluate model performance and measured and predicted values.

Gypsum %	Parameters							
	R^2	$RMSE_\theta$	CD	EF	CRM	GMER	GSDER	$\varepsilon_{average}$
0	0.94710	0.02972	0.77820	-0.28502	0.07313	0.89644	1.13115	0.90276
5	0.96360	0.02076	0.82479	-0.21242	0.04529	0.91374	1.15268	0.92224
10	0.97900	0.01730	0.85180	-0.17398	-0.00197	0.96152	1.13598	0.96872
15	0.97630	0.01830	0.81866	-0.22151	0.00444	0.94976	1.13521	0.95680
20	0.98340	0.01672	0.95332	-0.04896	0.04531	0.91765	1.12711	0.92377
30	0.97870	0.01785	0.89556	-0.11662	0.05689	0.89473	1.14519	0.90234
40	0.97510	0.01967	0.90605	-0.10369	-0.00322	0.96029	1.16149	0.97033

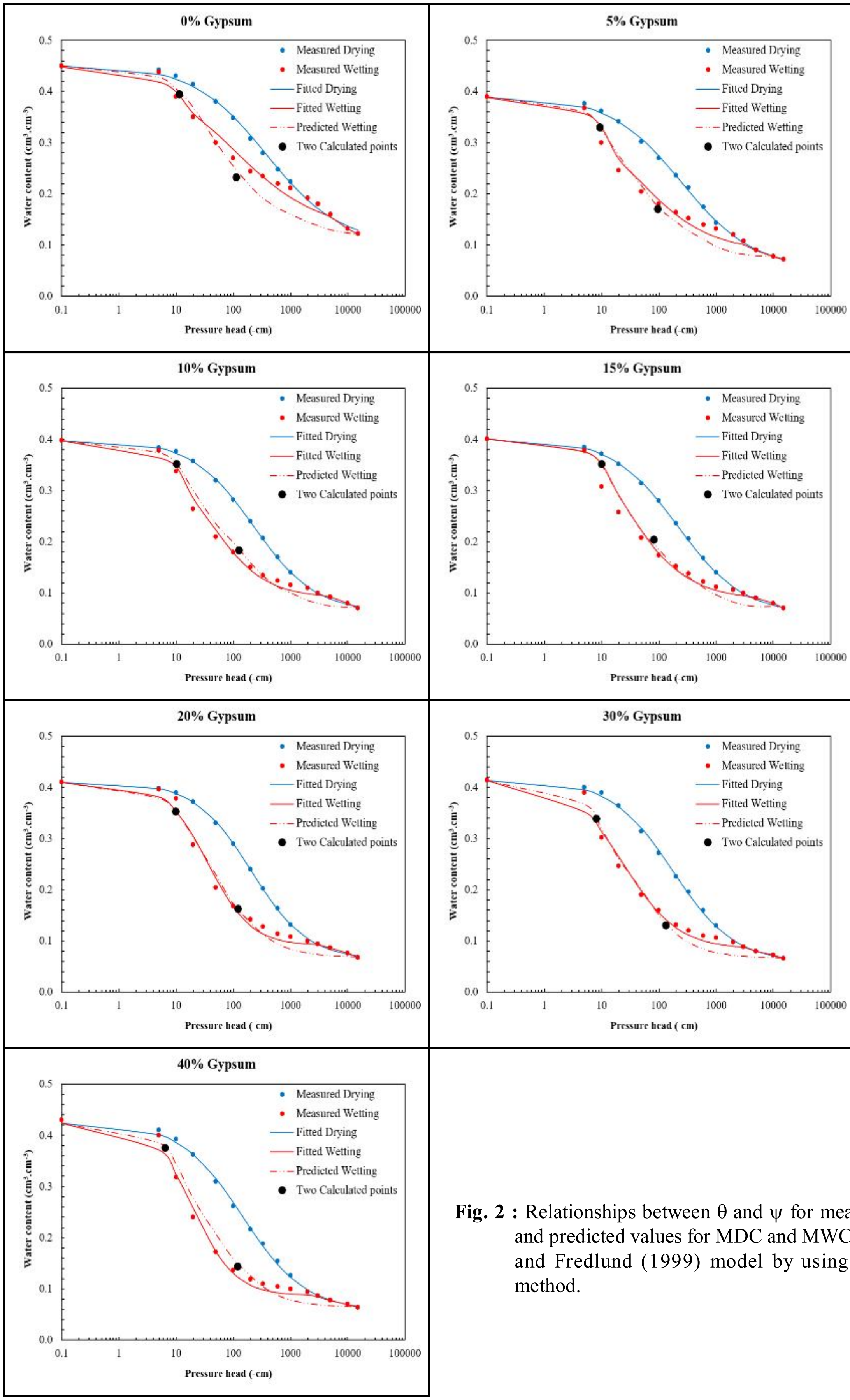

Fig. 2 : Relationships between θ and ψ for measured, fitted and predicted values for MDC and MWC using Feng and Fredlund (1999) model by using two points method.

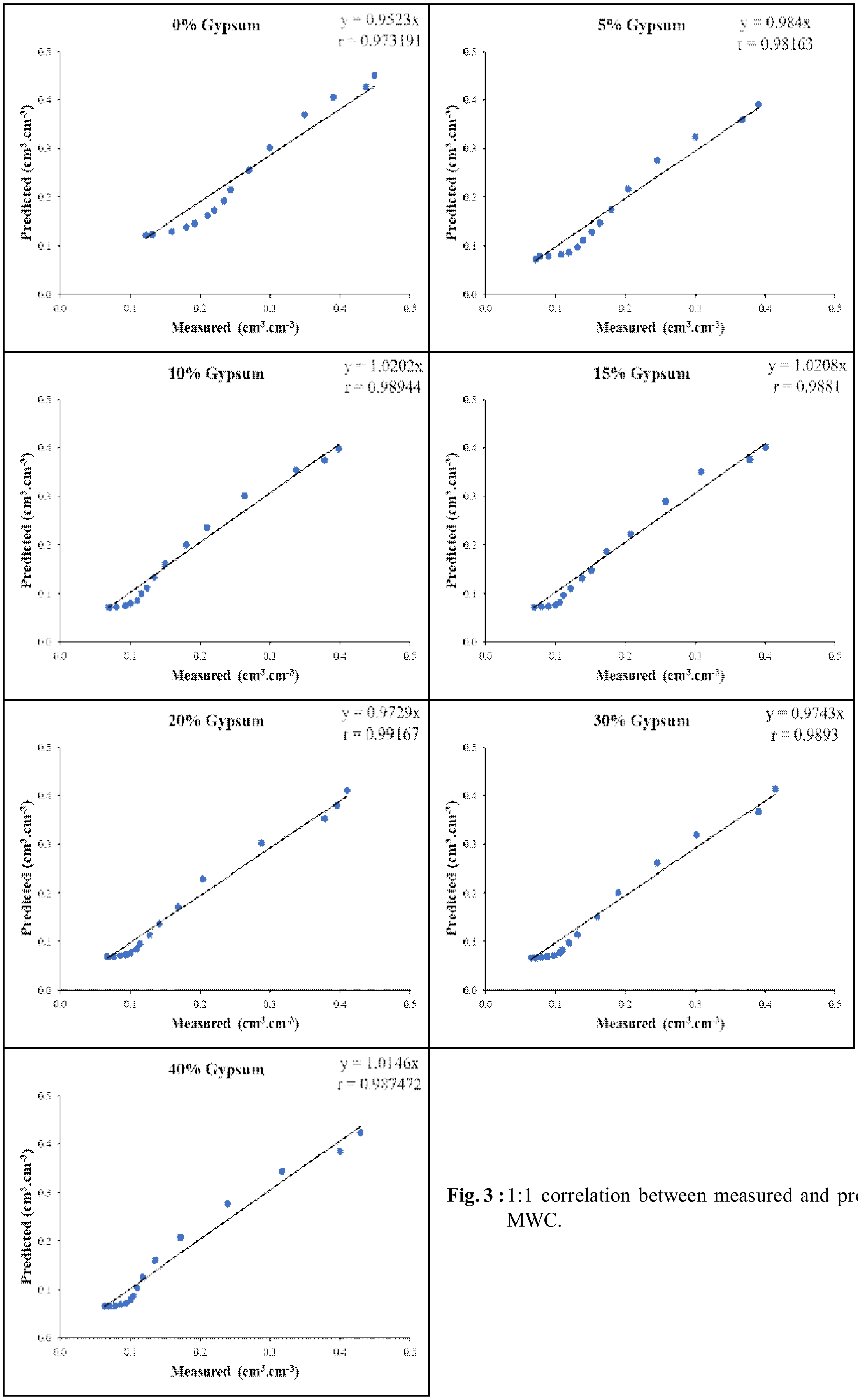

Fig. 3 : 1:1 correlation between measured and predicted for MWC.

H_2O in soil samples with 0 and 10% gypsum, respectively. Fig. 3 represented 1:1 correlation for main wetting curves which showed a good correlation between the measured and predicted points (calculated by using eq. 1) through high correlation coefficients for all soil samples. Correlation coefficients were 0.9732, 0.9816, 0.9894, 0.9881, 0.9917, 0.9887 and 0.9875 for soil samples 0, 5, 10, 15, 20, 30 and 40% Gypsum, respectively). Differences between measured and predicted points predicted points were higher than measured points in high range sections and lower in low sections.

Root Mean Squared Error of θ ($RMSE_\theta$) RMSE value shows how much the prediction overestimates or underestimate the measurements. $RMSE_\theta$ results gave very small values which indicated a high significant fitting between measured and predicted points for all soil samples (table 2). $RMSE_\theta$ showed the differences between measured and predicted points for all soil matric range of main wetting curve are very small and statistically insignificant, the smaller (closer to 0) the RMSE value was, the better the model was (Naji, 2014; Reichle *et al*., 2004; Khodaverdiloo *et al*., 2011; Jaiswal *et al*., 2013; Kang *et al*., 2014). Some other quantitative statistical parameters were calculated and analysis of residual errors, differences between measured and predicted values, the results showed in the table 2. The coefficient of determination (CD) gives the ratio between the scatter of the predicted values and of the measurements. CD results showed significant values in range 0.77820-0.95332 indicated highly significant fitting between measured and predicted points for all soil samples. Modeling efficiency (EF) value compares the predicted values to the averaged measured values. EF gave negative values for all soil samples, negative EF values indicate that the averaged measured values give a better estimate than the predicted values (Dirksen and Feddes, 2002; Khodaverdiloo *et al*., 2011), while Coefficient of residual mass (CRM) is a measure of the tendency of the model to overestimate or underestimate the measurements. CRM values were different with two negative values in soil samples 10 and 40% gypsum, respectively. The negative CRM showed a tendency to overestimate whereas the positive CRM indicate the showed a tendency to underestimate. Error ratio (ε) results showed all ε parameter values were less than 1. The geometric mean of error ratio (GMER) values were less than 1 indicates that the corresponding model overestimates fitted data. Geometric standard deviation of error ratio (GSDER) indicates deviation values of predicted values from measured values, all GSDER values were greater than 1 indicates that the corresponding model overestimates fitted data (table 2).

As a result, a high accordance between the measured and predicted values of the main wetting curve (MWC) and because of the predicted water content values for the main wetting curve (MWC) by using two-point method are lower than the measured values in the high sections and both MDC and MWC curves correspond at the end of the hysteresis loop at matric section 2 bar, which means ψ(θ) is the same for both curves. In this study, we suggest adding a third point of the line between the measured and predicted values of the main wetting curve (MWC) with the following boundary condition:

$$(\theta)\Big|_{MWC_{pre}} = -200 cm\, H_2\,) = (\theta)\Big|_{MWC_m} = (\theta)\Big|_{MDC_m}$$

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