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Soil Water Retention Curve and Specific Water Capacity for Three Different-Textured Soils

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Abstract: *A laboratory experiment was carried out to study some hydraulic properties such as soil water retention curve (SWRC), pore size distribution (PSD), and specific water capacity (SWC), for three different-textured soils (sandy loam (SL), silt loam (SiL), and silt clay loam(SiCL)). The SWRC was estimated, and the equation of van Genuchten was used to determine the best-fit parameter α, n, and m for experimental data of water content- pressure head [θ(h)] which have nonlinear relationship. This study includes an experimental investigation of the effect of soil particles on PSD. The change in water content θ of soil per unit change in pressure head h was used to estimate SWC. The capillary rise equation (Jurin equation) was used to estimate the effective pore diameter (D). The results show that pore space was affected by experimental soil samples. Air pores (>30 μm) increased with increasing sand content at the same time capillary pores filled with water (<30 μm) increased with increasing clay content. The relative of water volume to total soil volume ranged between 0.41 and 0.79* cm^3cm^{-3} *for soil samples. At pressure head 100 cm the amount of water lost increased with sand content, where soil sample SL lost water more than SiCL by 54%. The percentage of pores (<30 μm) ranged from 41% to 79% and the pores (>30 μm) ranged from 59% to 21%. The parameters of van Genuchten equation considered very important to calculating the SWC from the differential relation, and the amount of retained or lost water has been estimated at various water potential.*

Key words: *capillary rise equation, pore size distribution, differential water capacity, pore diameter, van Genuchten equation.*

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I. Introduction

Soil texture effects on hydro physical properties of soil, and make environmental changes in which reflected on the growth and the production of plant [1]. The presence of clay affect in soil water properties such as the ability to hold water, total porosity and pores size distribution [2]. The effect of soil structure and texture is considered by changing hydraulic conductivity, water retention, root growth and transformation of the chemicals [3]. However the porous system of soil have been effect by particle size distribution, the shape of particles, cementing, and packing density [4]. Pore space was the soil voids that can be filled by water and, or air, it is effect by the soil texture. All operations and reactions occur through pore space such as the movement of water and air, dilution and sedimentation [5, 6]. The soil pore space characterized in to two features porosity and pore size distribution. The pore size distribution considered the most important feature for it's complicated and strong relation with other soil characterize especially with soil structure, stability of aggregates and texture [7, 8]. The pore size distribution controlling fluid movement and storage in soil and provides a space within the void occupied by air that is important for activity in rhizosphere zone[9]. The Pore size distribution is affected by many factors and the most important of them are the way of packing, layering and soil particle distribution. However pore space is always continuous change because of the effect of outside and inside stresses of the soil [10]. The pore space can be divided in to two volumetric groups. Macropores defined as the air pores and the micropores which known as capillary pores. The activities are affected by pores size distribution in which the capillary forces dominate such as cohesion, adhesion and the capability of water retention in micropores to become a source providing water and dissolved materials, while macropores was important to ventilate the soil [4, 9]. Amer, [11] used capillary rise equation to determined pore size, the equivalent pressure ranges of 0-10, 10-33, 10-1500, 33-1500, and > 1500 Kps, are roughly corresponding to rapidly draining pores, slowly draining pores, coarse capillary pores, water holding pores, and fine capillary pores diameters. Classes can be combined into total draining pores (0-33 Kps), and total water storage pores (>33 Kps),as well as into macropores (<10 Kps) and soil matrix pores (>10 Kps). Goncalvesa et al. [12] mentioned three volumetric categories of pore space depending on active porosity concept: cryptopores (<0.2 μm in diameter), micropores (0.2–50 μm capillary forces dominate in it), and macropores (>50 μm water moves easily through it).

The water content in an unsaturated soil is a function of the suction present in the soil, the relation between soil water content (θ)-pressure head (h), [θ(h)] is nonlinear relationship which is known soil water retention curve (SWRC) and it is important to understand the soil water properties [13]. From the SWRC a few parameters can be defined: the saturated volumetric water content, the residual volumetric water content, the air-entry value or bubbling pressure, and the residual air content [14]. A number of equations have been suggested for the SWRC and almost all the equations were suggested based on the shape of the SWRC, the general shape of the SWRC is nonlinear (sigmoid curve), which have empirical parameter. The equation that provide a sigmoid curve are the equations of van Genuchten [15], and Fredlund and Xing [16], [17]. The SWRC was used for determining the soil hydraulic properties such as unsaturated hydraulic conductivity, soil water diffusivity, porosity and pore size distribution, and specific (or differential) water capacity, both SWRC and unsaturated hydraulic conductivity are often necessary for solving unsaturated flow problems [18, 19]. The SWRC is strongly related with soil pores size distribution which was considered a traditional way to evaluation and measuring pores size distribution [20]. Nimmo [4] had reviewed modalities of measuring the sizes of soil pores and showed that the most used method was water retention curves which explains the behavior and liquid content of unsaturated porous media by adopting the idea of effective capillary size which gain or lose a certain volume of liquid from pores by the drying curve or wetting curve that showed by a diagram between θ and h where the volumetric moisture content is a function of pressure head [θ(h)]. The objective of this research was to evaluate the soil pores system for soil samples which had different texture by the function of pores size distribution.

II. Materials And Methods

Three different-texture soil samples, sandy loam (SL), silty loam (SiL), and silt clay loam(SiCL) were used in this experiment. All sample of disturbed soil were taken from the A_p horizon (0-30 cm) of representative sites of the fields a region located in west part of Baghdad (longitude 43° 45' 34'' E, latitude 33° 72' 78'' N, altitude 33 m above sea level), Iraq. The soil material has dried by air in the laboratory, crushed and sieved through a 2 mm screen. Some of physical and chemical properties have been estimated for the soil material before the experiment procedure and table 1 shown the analysis results.

Table 1. Physical, chemical and hydraulic properties of the soil

Parameter	Soil sample		
	Sandy loam	silt loam	Silt clay loam
Sand (g kg^{-1})	721	258	187
Silt (g kg^{-1})	174	538	446
Clay (g kg^{-1})	105	204	367
Bulk Density (Mg m^{-3})	1.61	1.33	1.11
Volumetric water content at 33 Kps (cm^3 cm^{-3})	0.106	0.224	0.370
Volumetric water content at 1500 Kps (cm^3 cm^{-3})	0.095	0.138	0.196
Available water (cm^3 cm^{-3})	0.011	0.086	0.174
Saturated hydraulic conductivity (cm day^{-1})	14.22	9.57	4.61
Electrical Conductivity (dSm^{-1})	2.1	1.7	1.6
pH	7.61	7.53	7.8
CEC ($Cmol_c$ kg^{-1} soil)	16.34	21.79	34.11

* Properties were estimated according to methods described in [21, 22].

The relation estimated between volumetric water content θ and pressure head h for the soil samples. A Tempe cells have been used with a specification soil moisture equipment group (Tempe cell No. 1400B0.5M2-3) to measure the moisture content at water potentials between -1 to-100 Kps, and a pressure plate apparatus in the range -250 to -1500 Kps. The soil water functions were described using the van Genuchten equations [15]. Equation 1 was used to describe the relation between θ and h.

$$\theta=\theta_r+(\theta_s-\theta_r)[1+(\alpha h)^n]^{-m} \qquad (1)$$

Where θ is volumetric water content (cm^3 cm^{-3}) at any value of h, θ_s and θ_r are the saturated and residual volumetric water content of soil, respectively (cm^3 cm^{-3}), h pressure head (cm), and α (related to the inverse of the air-entry value) and n (related to the slope of moisture retention curve which depends on pores size distribution), and m, are the fitting parameters of van Genuchten's model.

The differential of eq.1 was used to find the slope of SWRC ($\frac{d\theta}{dh}$), it is called differential water capacity or specific water capacity (SWC). The differential formula of SWC is:

$$\frac{d\theta}{dh}=\frac{-\alpha n m(\theta_s-\theta_r)(\alpha|h|)^{n-1}}{[1+(\alpha|h|)^n]^{m+1}} \qquad (2)$$

To evaluate the diameter (D) of pores sizes, can be calculated by the equation of Jurin equation eq. 2 [20].

$$D = \frac{4\sigma \cos\beta}{\rho_W g \tau} \quad (3)$$

Where D is effective pore diameter (cm) and it's a function of pore volume, σ is a water surface tension (at 20°C= 72.7 g s^{-2}), cosβ= 1, (β is contact angle between soil pore wall and water its 0 for a wetted surface), ρ_w water density (at 20°C= 0.998 g cm^{-3}), and g is the acceleration due to gravity (980 cm s^{-2}). When substituting the values above in eq. 2, eq. 3 produced to evaluate effective pore diameter.

$$D = \frac{0.298}{\psi} \quad (4)$$

III. Results and discussion

Fig. 1 shows the soil moisture retention curves (SWRC) of soil samples that have different texture sandy loam (SL), silt loam (SiL), and silt clay loam (SiCL), (Table 1). There were differences between the curves of the moisture retention for different soil sample. The ability of soil samples to retained water increase by the increasing of clay contents at different pressure head level (from zero to 15000 cm). The amount of retained water at lower pressure head (10 cm) decreased with the increasing sand, the volumetric water content (θ) was 0.589, 0.496, and 0.375 cm^3 cm^{-3} for SiCL, SiL, and SL respectively. Water content has changed at pressure head 100 cm for soil samples which decreased to 0.468, 0.306, and 0.154 cm^3 cm^{-3} for soil samples respectively. The moisture content at pressure head 15000 cm got the same behavior which the residual water content θ_r decreased with the increasing of sand from 0.196 to 0.138, and 0.095 cm^3 cm^{-3} for soil samples respectively. The solid line in the fig. 1 refer to the best fitting of data of pressure head (h) against θ according to van Genuchten equation (eq.1). Eq. 1 shows good fitting between the observed data and fitted data, the determination coefficient (R^2) value was more than 0.997 for soil samples, and declines the residual man square of θ (RMSθ), it was less than 1.5×10^{-5} (cm^3 cm^{-3})^2, table 2 shows eq. 1 parameters which are θ_s, θ_r, α, n, and m.

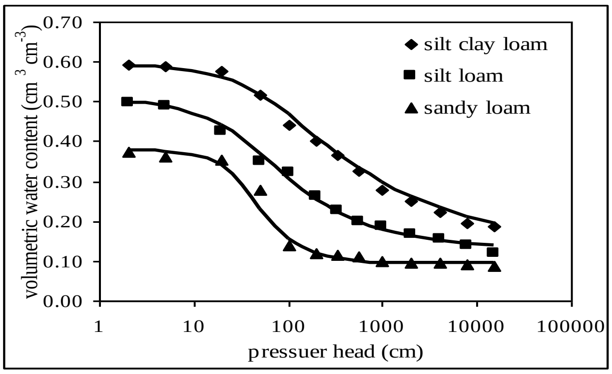

Fig. 1. Soil water retention curves for silt clay loam, silt loam, and sandy loam

Table 2. the values of van Genuchten equation parameters (θ_s, θ_r, α, n, and m) for soil water retention curves of soil samples (SiCL, SiL, and SL), and the values of best fitting parameters (R^2, RMSθ)

Soil samples	θ_s cm^3 cm^{-3}	θ_r cm^3 cm^{-3}	α cm^{-1}	n	m	R^2	RMSθ (cm^3 cm^{-3})^2
Silt clay loam	0.592	0.196	0.019	1.342	0.255	0.998**	1.15×10^{-5}
Silt loam	0.497	0.138	0.035	1.538	0.350	0.997**	1.50×10^{-5}
Sandy loam	0.377	0.095	0.029	2.427	0.588	0.998**	1.45×10^{-5}

** significance at 0.01

The difference of water content between pressure head zero and 100 cm represents soil air-filled porosity which is pores having size more than 30 μm as effective pores diameter (eq. 3), while the water content difference between pressure head 100 and 15000 cm which is water-filled porosity and their size less than 30 μm and it is defined as water holding capacity or available water or field capacity [9, 14]. Fig 2 shows ratio of pores volume which is filled by air, water and residual water content to bulk soil volume of different texture soils. It is seemed that the volume ratio of air-filled porosity declines with increase clay content and the soil sample SiCL had lowest air-filled pores ratio (0.121 cm^3 cm^{-3}), while the SL soil had the highest air-filled pores ratio (0.223 cm^3 cm^{-3}), this means that the SL soil has an increase by 1.8 times of the air-filled pores volume. The water-filled pores ratio was low in SL soil sample (0.059 cm^3 cm^{-3}) and it increased in the SiCL soil sample to be the highest water-filled pores ratio (0.272 cm^3 cm^{-3}), and this means that soil ability to lose water increases with increase of sand content and this may attributed to ability of these samples to release more water quantity than the samples that have less sand content at the same water potentials. This can be interpreted by using the slope of water retention curves (SWC). The residual volumetric water content (θ_r) of soil samples increased with increasing of clay content, in this case the volume of retained water depending on the specific surface area of soil particle and the clay had highest specific surface area (table 2).

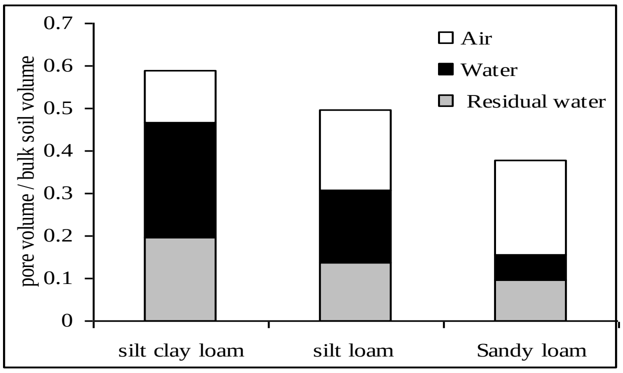

Fig. 2. Air and water distribution in three soil sample, Air-filled pore volume (pores >30 µm diam.) and water-filled pore volume (pores < 30 µm diam., water + residual water).

The relationship between absolute value of SWRC slope ($\left|\frac{d\theta}{dh}\right|$, SWC) and pressure head for three experimental soils are shown in fig. 3. It can be noticed that the SWC increases with pressure head increase till reaching the highest slope peak, and this was taken place at 30-50 cm pressure head of soil samples. The maximum values of SWC was 3.6×10^{-3}, 3×10^{-3}, and 1.4×10^{-3} for SL, SiL, and SiCL respectively. The SiCL soil sample showed slight change in SWC values starting from zero to 50 cm pressure head, after that the values of SWC decreased with increasing pressure head and reach the minimum values at pressure head 15000 cm. This decline included all soil samples. The change taken place in the absolute value of SWRC slope and the obtained change in peak of SWC was a result of effect of soil texture on pores volume distribution and this shows progressive curvature in curve peaks with sand content increase. For this reason, the soil sample content high sand was more ability to lose water when it was subjected to applied pressure head. Fig. 4 shows the relationship between effective pore diameter (D) and SWC values, this relationship called pore size frequency distribution function. From the figure the pore size ranged from 0.2 to the 149.0 µm according to the eq. 4 for all soil samples. The peak of the relationship refer to the pore size at 100 µm, this pores size and more lose water at pressure head ranged between 50-80 cm, and the soil sample had the maximum values of SWC quickly lose water from pores size > 100 µm, so the experimental soil samples lose water according to the order in follows SL > SiL > SiCL.

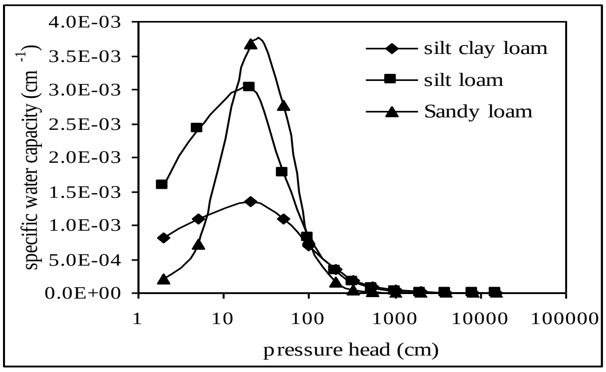

Fig. 3. The relationship of SWC (cm^{-1}) with pressure head (cm) for silt clay loam, silt loam, and sandy loam

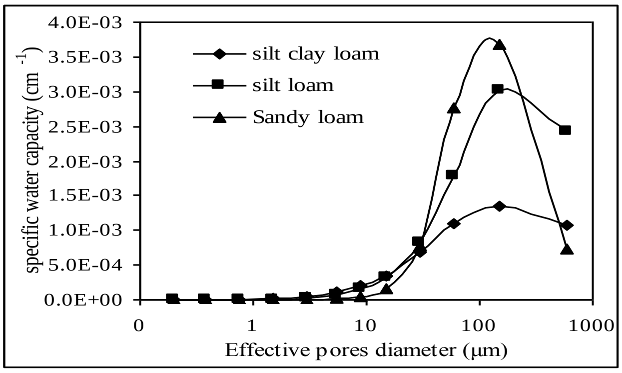

Fig. 4. The relationship of SWC (cm^{-1}) with effective pores diameter (μm) for silt clay loam, silt loam, and sandy loam

One of the soil pores size distribution evidence is the relationship between α (cm^{-1}), and the maximum absolute value of SWC (cm^{-1}). Kind of this is shown in fig. 5 which indicated presence linear positive relation between α and maximum value of SWC, the agreement was good as indicated the correlation coefficient (r= 0.788). The increase of maximum value of SWC and value of α increased in all of experimental soil samples. As it is lastly known that increase of maximum value of SWC of water retention curves was correlated with increase of sand content, and α values also were correlated with increase of their values with sand content (Table 2). So the linear positive relation was obtained between α and maximum value of SWC, and this emphasized that the soil porous system and the pores size distribution were affected by the primary soil particles content and, this was reflected on available water and the amount of water holding when soil was subjected to applied water potential and the quantity of the hold water is considered as function of effective pores diameter at the applied water potential.

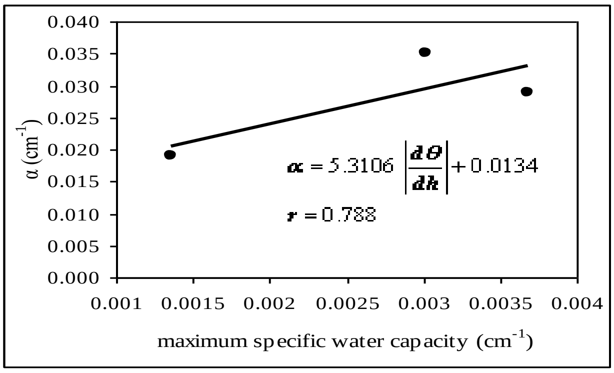

Fig. 5. The relationship of maximum SWC (cm^{-1}) with α (cm^{-1}) for silt clay loam, silt loam, and sandy loam

The relation of effective pores diameter that estimated from eq. 4 with the volumetric water content for experimental soil samples was shown in fig. 6. It was noticed that increase of the effective pores diameter caused increase of soil water content. When the effective pores diameter is less than 30 μm, the soil water content increases with decrease of the sand content, and it may be due to that the water content in these circumstances is connected with the pore size distribution and with the specific surface area. With increase of the effective pores diameter (from 50 to 150 μm), the water content increased with clay content increase, the reason of that was due to soil porosity increase (Table 1). The represents curve of pore size distribution noticed that pore volume increase strongly with decrease of pore diameter and it may be concluded on pore volume in soil samples from soil water quantity which is maintained by soil when specific water potential is applied and this represents soil pores having less than 30 μm in diameter. The ratio of the pore volume that keeping water when soil samples were subjected to pressure head 100 cm was 0.41, 0.62, and 0.79 as the ratio water content ($\Theta = \dfrac{\theta - \theta_r}{\theta_s - \theta_r}$), where $0 < \Theta < 1$ for soil samples contained clay 105, 204 and 367 g kg^{-1} respectively. The pore volume ratio that had active diameter more than 30 μm ranged between 0.59 to 0.21, and this was equals ($1 - \dfrac{\theta - \theta_r}{\theta_s - \theta_r}$) for soil samples respectively. The air-filled pores system was as mesopores kind which are water transporting pores [14] and water may be drained when soil exposed to pressure head 100 cm. while the water stored pores which are keeping water when they are exposed to pressure head 100 cm it is micropores kind. This pores size distribution of soil pores is important to determine the biological and aqueous soil environment as soil samples had good ratio of the transporting water pores and it is important for water movement and diffusion in soil, so the samples with high sand content characterized by good water diffusion and conductivity due to increase of the transporting water pores which were more than half of the porous system volume of SL soil sample. The experimental soil samples SiCL and SiL had little macro pores and it can be known from the slope of SWRC till 100 cm pressure head was small slope due to flat state of the curve at low water potential, especially at saturated conditions.

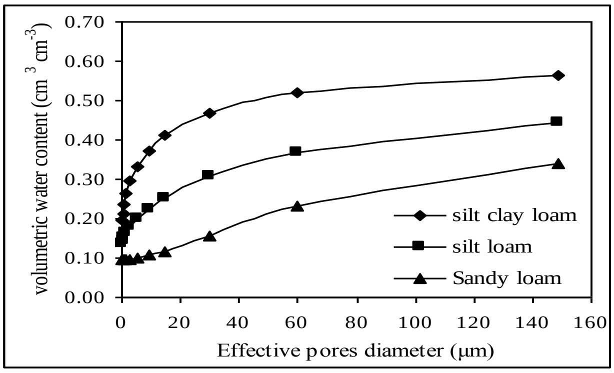

Fig. 6. Relationship between effective pores diameter D and water content θ for silt clay loam, silt loam, and sandy loam

IV. Conclusion

The behavior of SWC mostly depends on particle size distribution, total porosity, pore size distribution, and water content. The maximum values of SWC increase with increasing sand content. The pores system of the experimental soil samples have effected by primary soil particles content so that the ability of soil samples to retained water increase by the increasing of clay contents at different pressure head. The increase occurred in air pores (greater than 30 μm) with the increasing of sand content while the water filled pores (less than 30 μm) increase with clay increased. When soil samples exposed to pressure head about 100 cm, the soil sample SL lost water more than SiCL by 50%.

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