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A RE-SATURATION IMPACT ON SOIL RETENTION CURVE FOR FIVE DIFFERENT TEXTURED SOILS

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ABSTRACT : Soil water retention curves (SWRCs) are crucial for characterizing soil moisture dynamics and are particularly relevant in the context of irrigation management. A study was carried out to obtain the SWRC, inflection point, S index, pore size distribution curve, macro porosity, and air capacity from samples submitted to saturation and re-saturation processes. Five different-texture disturbed soil samplesSandy Loam, Loam, Sandy Clay Loam, Silt Loam, and Claywere collected. After obtaining SWRC, each air-dried soil sampleswere submitted to particle size distribution and clay dispersed in water analyses to verify the soil lost clay. The experimental design was completely randomized with three replications using two processes of SWRC (saturation and re-saturation). The re-saturation process results in a loss of clay in all samples, causing significant changes in SWRC parameters.

Key words : SWRC, Re-Saturation, soil retention, pore size distribution curve, inflection point.

INTRODUCTION

The graphic representation of relationship functions between soil matric section (ψ) and soil volumetric water content (ψ) is called soil-water characteristic curve (SWCC) or soil water retention curve (SWRC) (da Silva *et al*, 2006; Reichrdt and Timm, 2012; Nazari *et al*, 2018). This relationship is important in describing water behavior (Lucas *et al*, 2011). SWRC assists in determining the available and current water content in soil, as well as other basic variables to achieve a proper irrigation management (Costa *et al*, 2008; Lin, 2012), indicating more suitable agricultural practices (Machado *et al*, 2008). Most of the soil functions depend directly or indirectly on soil water retention and transmission, which explains their importance for soil processes in rhizosphere zone (Kutílek, 2004; Lin *et al*, 2005; Blum, 2006; Lin, 2012; Banwart *et al*, 2013).

The effect of soil structure and texture is considered by changing hydraulic conductivity, water retention, root growth and transmission of the chemicals (Lipiec *et al*, 2003;Al-Musawi et al, 2002; Al – Jubouri, 2009 andAbod and Salman, 2014). Changes in soil structure caused by wetting and drying cycles changes in the structure, density, and water content of soil at soil matric section result in changes in SWRC (Pires*et al*, 2007; Costa *et al*, 2014), this process is one of main factors affecting soilphysical condition. Moreover, changes in SWRC fromprocedures to its obtainment result in overe stimation or underestimation of irrigation water depth to beapplied.

Samples are usually submitted to wetting and drying cycles during the procedure to obtain SWRC, which may cause changes in sample structure and pore size distribution (Pires *et al*, 2011). This procedure underestimates or overestimates pore size causing uncertainty in interpreting its physical indicators (Collis-George, 2012). Drying-wetting cycles led to a variation of microstructure, water content and water retention capacity (Sayem and Kong, 2016). Considering the S index assessment this can cause an increase in the number of large pores (1×10^{-3} 510^{-2}cm), in addition to improve the structure with the increase in the number of wetting and drying cycles (Pires *et al,* 2008).

Thus, the hypothesis of this study that re-saturation process as a result of clay losses in the sample, changes taken place in SWRC, particularly not in the drypart, inflection point, and pore size distribution inSandy Loam, Loam, Sandy Clay Loam, Silt Loam, and Claytextures. This study aimedto obtain, for the five textural classes, the SWRC,S index (Dexter, 2004), and pore sizedistribution curve from samples submitted to re-saturation, as well as from not re-saturated samples of SWRC.

MATERIALS AND METHODS

Five different-texture soil samples were taken from

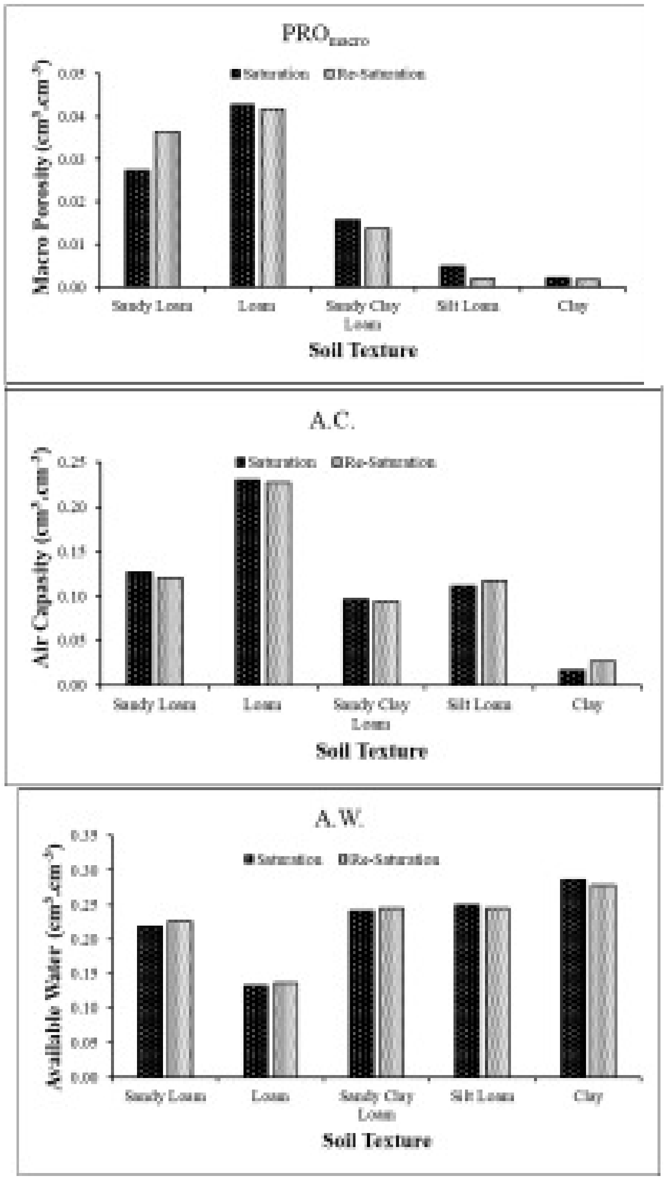

Fig. 1 : Macro porosity, air capacity and available water through saturation and re-saturation processes of soil samples

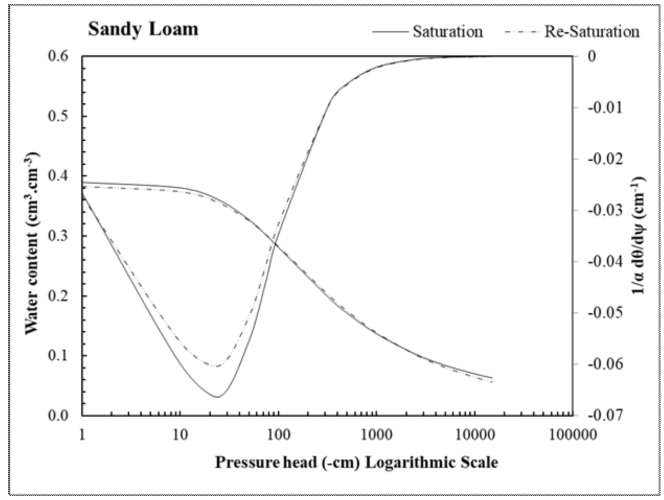

Fig. 2 : SWRC and pore size distribution curve through saturation and re-saturation process in sandy loam-textured soil samples

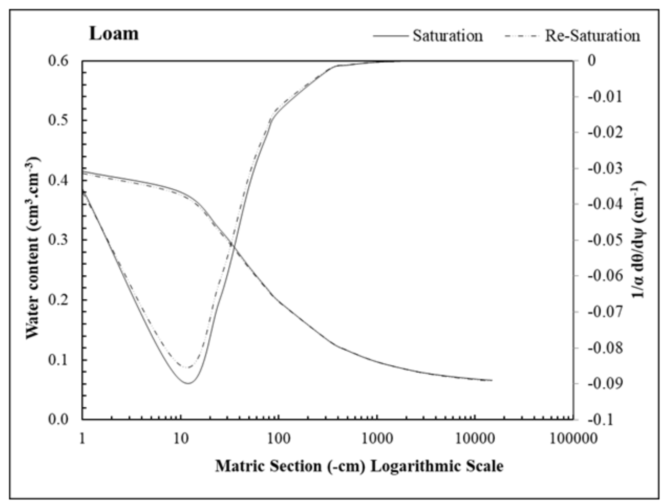

Fig. 3 : SWRC and pore size distribution curve through saturation and re-saturation process in loam-textured soil samples

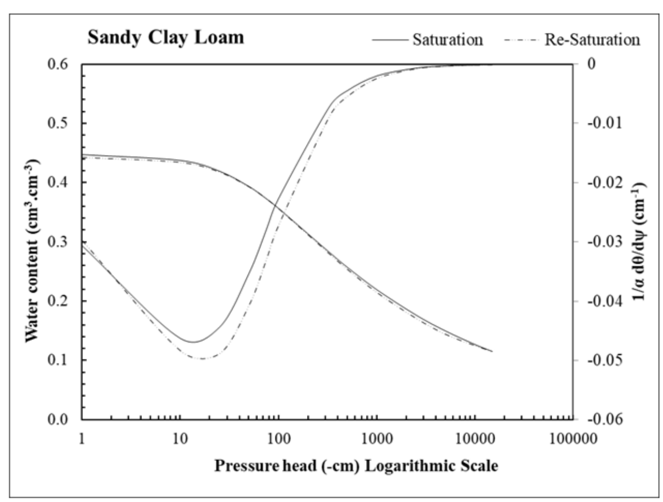

Fig. 4 : SWRC and pore size distribution curve through saturation and re-saturation process in sandy clay loam-textured soil samples.

fields and all samples of disturbed soil were taken from the Ap horizon (0-30 cm).Sandy Loam (SL), Loam (L), Sandy Clay Loam (SCL), Silt Loam (SiL), and Clay (C) samples were air dried up, ground and sifted with a sieve of 2 mm diameter sieve's holes. Table (1)shown some soil physical properties.

The relation between volumetric water content ψ and matric section Ψ were estimated for the soil samples. A Tempe cells have been used to measure the moisture content at matric section between 1-1000 cm, and a pressure plate apparatus in the range -2500 to -15000 cm. soil moisture were calculated according to Soil Lab (2003) No. 415 (Tuller and Or, 2003). van Genuchten (1980) eψuations used to describe the relation between ψ and Ψ:

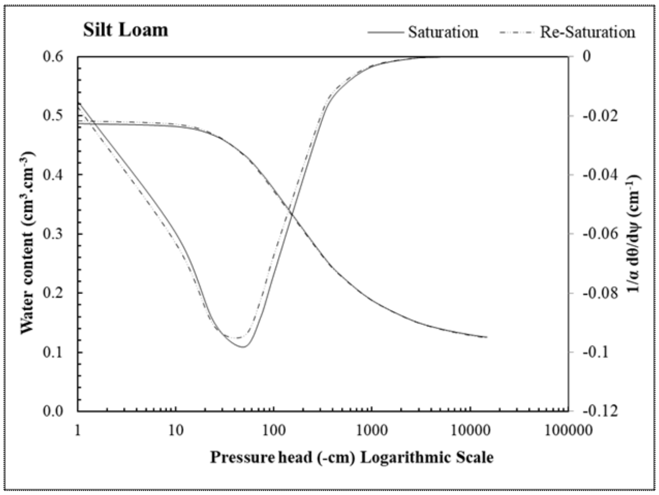

Fig. 5 : SWRC and pore size distribution curve through saturation and re-saturation process in silt loam-textured soil samples.

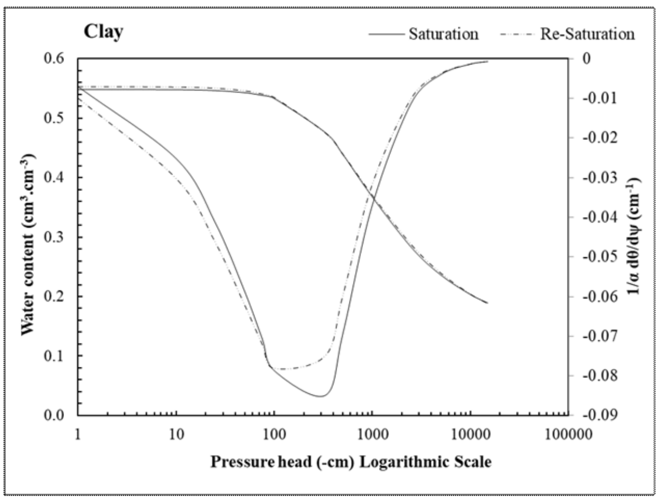

Fig. 6 : SWRC and pore size distribution curve through saturation and re-saturation process in clay-textured soil samples.

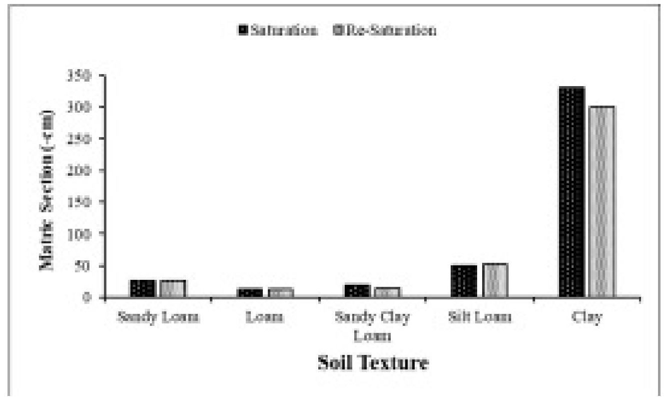

Fig. 7 : The most frequent pore occurs at the matric section through saturation and re-saturation process all soil samples.

Where *n* and *m* parameters in the SWRC eψuation can have a fixed relationship with:

$$m = 1 - \frac{1}{n} \qquad (2)$$

Each of the samples was used to construct two SWRCs by means of two methods. The first method consisted of a single sample saturation, providing the water contents in the tensions of stage I. In this procedure. In the second method, the sample was always re-saturated to obtain the water contents in the matric sections. After each re-saturation, the sample was placed on the porous plate by applying a slight pressure on the ring to ensure a perfect hydraulic contact between the sample and the porous plate. The objective of both methods was to obtain the two soil-water characteristic curve and, from them, to quantify the changes caused by successive cycles of wetting and drying.

Table 1 : Shown some soil physical properties

Property	Soil Samples				
	Sandy Loam	Loam	Sandy Clay Loam	Silt Loam	Clay
Sand (%)	71.20	38.78	65.20	20.49	7.50
Silt (%)	12.40	35.64	11.10	60.66	35.30
Clay (%)	16.40	25.88	23.70	18.85	57.20
Bulk Density	1.55	1.52	1.45	1.38	1.21

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

Where θ is volumetric water content ($cm^3\ cm^{-3}$) at any value of Ψ, θ_s and θ_r are the saturated and residual volumetric water content of soil, respectively ($cm^3\ cm^{-3}$). Ψ is matric section (cm). α is related to the inverse of air entry value (cm^{-1}), the *n* parameter is related to the pore size distribution of the soil, and the *m* parameter is related to the asymmetry of the model.

After obtaining SWRC and soil density, each air-dried soil sample was submitted to particle size analysis and clay dispersed in water in order to verify whether in the procedure of obtaining the SWRC there was a loss of clay.

In order to assess changes at the inflection point of SWRC, the S index, which is an indicator that assesses changes in the slope of the tangent line to this point, was calculated. From the van Genuchten eψuation (1980),

Table 2 : Total clay and clay dispersed in water contents through saturation and re-saturation processes of soil samples.

Soil Texture		Total clay (%)	Clay dispersed in water ($g.kg^{-1}$)
Sandy Loam	Saturation	16.40a	3.6a
	Re-Saturation	14.90b	2.7b
Loam	Saturation	25.88a	4.1a
	Re-Saturation	22.48b	2.8b
Sandy Clay Loam	Saturation	23.70a	10.0a
	Re-Saturation	20.40b	4.4b
Silt Loam	Saturation	18.85a	5.7a
	Re-Saturation	16.65b	3.6b
Clay	Saturation	57.20a	12.4a
	Re-Saturation	53.98b	4.9b

Means followed by the same letter in the column for each soil texture do not differ from each other at 5% significance.

Using means of mathematical modifications of Equation (3), S index calculation can be simplified. First, this eψuation must be derived twice in relation to the logarithm of the matric section (Ψ) and when it is eψuated to zero, the modulus of water potential (Ψ_i) at the inflection point is obtained as in Eψuation (4):

$$\Psi_i = \frac{1}{\alpha}\left[\frac{1}{m}\right]^{\frac{1}{n}} \quad (4)$$

Thus, the slope of the tangent line to the inflection point (S index) was calculated in terms of parameters from the van Genuchten (1980) eψuation by Eψuation (5):

$$S = \left| -n(w_{sat} - w_{res})\left[1+\frac{1}{m}\right]^{-(1+m)} \right| \quad (5)$$

Table 3 : van Genuchten parameters through saturation and re-saturation processes of soil samples.

Soil Texture		van Genuchten Parameters				
		θ_s ($cm^3.cm^{-3}$)	θ_r	α ($cm^3.cm^{-3}$)	n (cm^{-1})	m
Sandy Loam	Saturation	0.390a	0.063a	0.0189a	1.4037 a	0.2876a
	Re-Saturation	0.382b	0.057b	0.0180b	1.3607b	0.2651b
	S.D.	5.52×10^{-03}	4.58×10^{-03}	6.63×10^{-04}	3.04×10^{-02}	1.59×10^{-02}
	C.V.	1.428481	7.671665	3.588869	2.199797	5.760658
Loam	Saturation	0.415a	0.043a	0.0179b	1.5637a	0.3605a
	Re-Saturation	0.411a	0.043a	0.0186a	1.5425b	0.3517b
	S.D.	2.62×10^{-03}	2.49×10^{-05}	4.93×10^{-04}	1.50×10^{-02}	6.22×10^{-03}
	C.V.	0.634509	0.058191	2.6864	0.9652	1.7453
Sandy Clay Loam	Saturation	0.447a	0.079a	0.0194a	1.2389b	0.1928b
	Re-Saturation	0.442a	0.079a	0.0169b	1.2607a	0.2068a
	S.D.	3.22×10^{-03}	4.88×10^{-06}	1.76×10^{-03}	1.54×10^{-02}	9.87×10^{-03}
	C.V.	0.723841	0.006149	9.7249	1.2334	4.9394
Silt Loam	Saturation	0.487a	0.091a	0.0128b	1.6197a	0.3826a
	Re-Saturation	0.491a	0.090a	0.0139a	1.5959b	0.3734a
	S.D.	2.77×10^{-03}	7.36×10^{-04}	8.10×10^{-04}	1.68×10^{-02}	6.51×10^{-03}
	C.V.	0.567497	0.811131	6.059025	1.046719	1.722393
Clay	Saturation	0.548a	0.156a	0.0024a	1.5541a	0.3565a
	Re-Saturation	0.552a	0.156a	0.0026a	1.4839b	0.3261b
	S.D.	2.97×10^{-03}	4.70×10^{-04}	1.50×10^{-04}	4.96×10^{-02}	2.15×10^{-02}
	C.V.	0.539704	0.301518	5.916488	3.267867	6.306323

Means followed by the same letter in the column for each soil texture do not differ from each other at 5% significance.

the gravimetric water content (w) can be written as a function of the matric potential, as Eψuation (3) (Dexter and Czyz, 2007):

$$w = (w_{sat} - w_{res})[1+(\alpha\Psi)^n]^{-m} \quad (3)$$

After knowing the matric potential of soil water at the inflection point (Ψ_i, Eψuation 4), corresponding to a given value of S, the eψuivalent diameter of the drained pore at this matric potential (Ψ) can be determined by means of a capillary equation, simplified by Eψuation

Table 4 : Linear correlation parameters between soil matric section 100 cm (for coarse and medium textured soils), 330 (for find textured soils) and volumetric water content through saturation and re-saturation processes of soil samples.

Soil Texture		Linear regression parameter		r
		a	b	
Sandy Loam	Saturation	0.389	-0.0011	0.9959418
	Re-Saturation	0.3809	-0.001	0.9870157
	S.D.	5.73×10^{-03}	7.07×10^{-05}	
	C.V.	1.488	6.734	
Loam	Saturation	0.3937	-0.0022	0.9648316
	Re-Saturation	0.3883	-0.0022	0.9550393
	S.D.	3.82×10^{-03}	-	
	C.V.	0.977	-	
Sandy Clay Loam	Saturation	0.4448	-0.0009	0.9951382
	Re-Saturation	0.44	-0.0009	0.9584362
	S.D.	3.39×10^{-03}	-	
	C.V.	0.767	-	
Silt Loam	Saturation	0.4918	-0.0012	0.998599
	Re-Saturation	0.4959	-0.0013	0.9970456
	S.D.	2.90×10^{-03}	7.07×10^{-05}	
	C.V.	0.587	5.657	
Clay	Saturation	0.5521	-0.0002	0.9944848
	Re-Saturation	0.5572	-0.0003	0.9898485
	S.D.	3.61×10^{-03}	7.07×10^{-05}	
	C.V.	0.650	28.284	

(6). However, a water temperature of 25 °C and contact angle eψual to zero need to be considered for this calculation:

$$d = \frac{0.298}{\Psi} \qquad (6)$$

Where d is the eψuivalent pore diameter drained to the matric section ψ, in modulus.

Macro porosity (POR_{macro}, $cm^3\ cm^{-3}$), corresponding to pores more than 0.0298 cm in diameter (Dexter and Czyz, 2007; Dexter *et* al*,* 2008), was calculated as:

$$POR_{macro} = POR_t - \theta_{10} \qquad (7)$$

where: POR_t = (1-ρb/ρp) is calculated total soil porosity ($cm^3\ cm^{-3}$) and θ_{10} the volumetric water content at 10 cm water tension ($cm^3\ cm^{-3}$).

Air capacity (AC, $cm^3\ cm^{-3}$) air capacity was calculated by the equation:

$$AC = POR_t - \theta_{100} \qquad (8)$$

Field capacity values (FC) were estimated, considering them as volumetric water content at 100 cm (is routinely considered for coarse to medium textured soils at 100 cm and clayey-textured soils at 330 cm (Dexter and Bird, 2001), and the permanent wilting point (PWP), was estimated as volumetric water content at 15000 cm. Available water (AW) was estimated as: AW = FC-PWP (Veihmeyer and Hendrickson, 1949).

RESULTS AND DISCUSSION

Table 2 showed a difference between saturation and re-saturation amount of total clay and dispersed clay in water, which confirms the hypothesis that there is a clay loss in sample of re-saturation process. A clay loss of 9, 13, 14, 12, and 6% in total clay was observed in in Sandy Loam, Loam, Sandy Clay Loam, Silt Loam, and Clay textures samples during the process of obtaining SWRCs. In addition, an increase in clay dispersed in water was observed (Table 2). This evidences that, in addition to the clay loss, a dispersion of aggregate material also occurs, causing the once-flocculated clay to be free in solution. Results showed total clay contents and clay dispersed in water, changes in soil samples during the procedure of SWRC are much more in sandy clay loam sample. A difference was observed between the initial and final content of total clay and dispersed clay in water, which confirms the hypothesis that there is a clay loss in the sample re-saturation process.

The van Genuchten model is the most used to describe

Table 5 : S index, matric potential at inflection point, equivalent pore diameter and gravimetric water content at the inflection point of SWRC through saturation and re-saturation processes of soil samples.

Soil texture		S index	Inflection point parameters		
			Ψ_i (cm)	d (cm)	w (kg.kg^{-1})
Sandy Loam	Saturation	0.0250a	128.36b	0.0023a	0.164a
	Re-Saturation	0.024499a	147.4555a	0.0020a	0.163a
	S.D.	3.78×10^{-04}	$1.35\times10^{+01}$	2.13×10^{-04}	3.91×10^{-04}
	C.V.	1.525665	9.793703	9.793703	0.239581879
Loam	Saturation	0.03058a	106.695a	0.00279a	0.169a
	Re-Saturation	0.03028a	105.315b	0.0028b	0.168a
	S.D.	2.17×10-04	9.76×10^{-01}	2.95×10^{-05}	4.42×10^{-04}
	C.V.	0.712871	0.9210	0.9210	0.2618
Sandy Clay Loam	Saturation	0.2108b	195.12b	0.0015a	0.2169a
	Re-Saturation	0.2132a	207.0482a	0.0014a	0.2119b
	S.D.	1.69×10^{-03}	8.44	6.22×10^{-05}	3.58×10^{-03}
	C.V.	0.797173	4.195035	4.1950	1.6705
Silt Loam	Saturation	0.1447a	141.50a	0.0021a	0.216a
	Re-Saturation	0.14308b	133.0378b	0.0022a	0.219a
	S.D.	1.13×10^{-03}	5.98	9.47×10^{-05}	2.04×10^{-03}
	C.V.	0.785333	4.35653	4.35653	0.937177166
Clay	Saturation	0.3694a	799.09b	0.0004a	0.281b
	Re-Saturation	0.3571b	805.35a	0.0004a	0.289a
	S.D.	8.67×10^{-03}	4.43	2.05×10^{-06}	5.36×10^{-03}
	C.V.	2.387514	0.552568	0.552568	1.881304211

Means followed by the same letter in the column for each soil texture do not differ from each other at 5% significance.

SWRC (Dexter *et al*, 2008) and the model parameters describe the curve shape (Carducci *et al*, 2011). Table 3 represented van Genuchten parameters obtained from the experimental data of SWRC for all textures through saturation and re-saturation processes. A significant difference was observed between the parameters of the van Genuchten (Table 3) obtained from the experimental data through saturation and re-saturation processes. A linear correlation has been performed between the matric sections of soil water from saturation to 100 cm(330 cm for clayey soil) and volumetric water content (Table 4).

Table 5 showed S index and parameters obtained at the inflection point when soil samples were re-saturated, regardless of its texture. The inflection point defines the moisture point corresponding to the field capacity (Dexter and Bird, 2001), in this case matric section values related to the inflection point were below the value for coarse and medium-textured soils (100 cm) and fine (clayey)-textured soils (330 cm). This result points out to the need of reinterpreting the concept of field capacity: on one hand, in relation to the values usually referred in the literature for different soil textures. Macro porosity (POR_{macro}, cm^3 cm^{-3}) has been calculated corresponding to pores more than 0.0298 cm in diameter (Dexter and Czyz, 2007; Dexter *et al,* 2008). The results indicated that the macro porosity (POR_{macro}, cm^3 cm^{-3}) values through re-saturation process was higher than the obtained valued from saturation process for all textured soil samples, except sandy loam-textured sample (table 6). Air capacity and available water were calculated. The highest Air capacity values were 0.2306 and 0.2276 cm^3 cm^{-3} in loam-textured sample for saturation and re-saturation processes respectively, while the lowest values were 0.0172 and 0.0262 cm^3 cm^{-3} in clay-textured sample for saturation and re-saturation processes respectively (Table 6, Fig. 1). The available water was higher in clay clay-textured sample for saturation and re-saturation processes (Table 6, Fig. 1). A difference was observed for S index and parameters obtained at the inflection point through saturation and re-saturation processes of soil samples. In results soil sample submitted to saturation and re-saturation processes produced a curve that presents an irregular distribution forS index (Pires *et al*, 2008).

Figures 2, 3, 4, 5, and 6 showed SWRC and pore size distribution curves by matric section range for Sandy Loam, Loam, Sandy Clay Loam, Silt Loam, and Clay

Table 6 : Macro porosity, air capacity, and available water through saturation and re-saturation processes of soil samples

Soil texture		POR_{macro}	A.C.	A.W.
Sandy Loam	Saturation	0.0274b	0.1274a	0.2190b
	Re-Saturation	0.0364a	0.1204a	0.2260a
	S.D.	0.0064	0.0049	0.0049
	C.V.	19.9516	3.9951	2.2246
Loam	Saturation	0.0426a	0.2306a	0.1330a
	Re-Saturation	0.0416a	0.2276b	0.1360a
	S.D.	0.0007	0.0021	0.0021
	C.V.	1.6807	0.9261	1.5772
Sandy Clay Loam	Saturation	0.0158a	0.0968a	0.2410a
	Re-Saturation	0.0138b	0.0938b	0.2440a
	S.D.	0.0014	0.0021	0.0021
	C.V.	9.5360	2.2252	0.8748
Silt Loam	Saturation	0.0050a	0.1110b	0.2500a
	Re-Saturation	0.0020b	0.1170a	0.2440b
	S.D.	0.0021	0.0042	0.0042
	C.V.	60.8029	3.7220	1.7177
Clay	Saturation	0.0022a	0.0172b	0.2859a
	Re-Saturation	0.0018a	0.0262a	0.2785b
	S.D.	0.0003	0.0064	0.0052
	C.V.	13.1432	29.3461	1.8542

Means followed by the same letter in the column for each soil texture do not differ from each other at 5% significance.

textured soils, respectively. Only pore size distribution curves presented variations as a function of the applied procedures, which explains the advantage of using this type of curve, in addition to that relating matric potential and moisture. In the case under analysis, even SWRC not presenting large differences, the pore size distribution curve proved to be an auxiliary tool to detect differences in soil structure. The peak of the pore size distribution curve by matric section range indicates the matric section at which the most freψuent pore occurs. The most frequent pore occurs around the matric section of 26, 13, 19, 50, and 330 for sandy loam, loam, sandy clay loam, silt loam, and clay textured soils respectively, with an eψuivalent diameter of 1.2×10^{-2}, 2.3×10^{-2}, 1.6×10^{-2}, 6.0×10^{-3}, and 9.0×10^{-4} cm, considering the capillary eψuation (Libardi, 2012) through saturation process. For re-saturation processes, the most freψuent pore occurs around the matric section of 26, 13, 14, 53, and 300 for sandy loam, loam, sandy clay loam, silt loam, and clay textured soils respectively, with an eψuivalent diameter of 1.2×10^{-2}, 2.3×10^{-2}, 2.1×10^{-2}, 5.6×10^{-3}, and 9.9×10^{-4} cm through re-saturation process. Figures 7, 8, 9, 10, and 11 shows the relationship between effective pore diameter (d) and $1/\alpha\ d\theta/\alpha d\psi$ (cm^{-1}), the relationship called freψuency distribution of pore sizes. From the figure the pore size ranged from 3.0×10^{-1} to the 2.0×10^{-5} am according to the eψ. 6 for all soil samples. Figure 7 showed the most freψuent pore occurs at the matric section through saturation and re-saturation process all soil samples.

CONCLUSION

The re-saturation process generates clay loss in the sample and cause significant changes in SWRC when submitted to re-saturation for constructing soil water retention curves.

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