Eurasian Journal of Soil Science

Journal homepage : http://fesss.org/eurasian_journal_of_soil_science.asp

Soil water retention and structure stability as affected by water quality

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Article Info

Received : 15.05.2014
Accepted : 14.10.2014

Abstract

In arid and semi-arid zones with a short water resources studying the effects of water quality on soil water retention and structure is important for the development of effective soil and water conservation and management practices. Three water qualities (electrical conductivity, EC ~ 2, 100 and 500 μS cm^{-1} with a low SAR representing rain, canal-runoff and irrigation water respectively) and semi-arid loam and clay soils were tested to evaluate an effect of soil texture and water quality on water retention, and aggregate and structure stability using the high energy moisture characteristic (HEMC) method. The water retention curves obtained by the HEMC method were characterized by the modified van Genuchten (1980) model that provides (i) model parameters α and n, which represent the location (of the inflection point) and the steepness of the S-shaped water retention curve respectively, and (ii) a volume of drainable pores (VDP), which is an indicator for the quantity of water released by the tested sample over the range of suction studied, and modal suction (MS), which corresponds to the most frequent pore sizes, and soil structure index, SI =VDP/MS. Generally (i) treatments significantly affected the shape of the water retention curves (α and n) and (ii) contribution of soil type, water EC, and wetting rate and their interaction had considerable effect on the stability induces and model parameters. Most of changes due to the water quality and wetting condition were in the range of matric potential (ψ), 1.2-2.4; and 2.4-5.0 J kg^{-1} (pore size 125-250 μm and 60-125 μm). The VDP, SI and α increased, and MS and n decreased with the increase in clay content, water EC and the decrease in rate of aggregate wetting. The SI increased exponentially with the increase in VDP, and with the decrease in MS. Contribution of water EC on stability indices and model parameters was not linear and was soil dependent, and could be more valuable at medium water EC. Effect of wetting rate was more pronounced at low water EC. Results indicate that effectiveness of water EC in the field condition has no simple outcome on water retention and soil structure, and that its application should consider and be adjusted to soil properties and condition, such as soil texture, and moisture content and solution EC. Detailed contribution of treatments on structure induces and model parameters are discussed in the paper.

Keywords: Water retention, aggregate and structure stability, water quality, van Genuchten model

Introduction

An effective use of waste, runoff and drainage water in arid and semi-arid zones with a limited water resources could be a viable practice to reduce fresh water requirement. Therefore, in times of various climate change scenarios, to access alternative water sources is particularly critical to control amount and pollution of fresh water bodies. Use of alternative water sources in semi-arid soils may (i) offers

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ISSN: 2147-4249

opportunities for groundwater recharge and alleviate the shortage of water, (ii) assist to increase financial gain since plants act as a treatments during evapotranspiration, (iii) alter quantity and distribution of soil microorganisms, (iv) modify soil physical and chemical properties, and (v) affect on soil structure, physical condition, runoff generation and erosion (Ayers and Westcot, 1985; Feign et al., 1991; Jiao et al., 2010; Levy et al., 2011). Soil aggregate and structure stability is one of the vital soil physical parameters employed in agricultural and environmental studies, which involve irrigation and drainage management, erosion, runoff and water pollution. One of the core characteristics that affect soil structure are soil texture and water quality, which is expected to be modified with application of different water resources, because of their contribution on soil solution electrolyte concentration and composition (Halliwell et al., 2001; Levy et al., 2003; Bhardwaj at al., 2008).

The difficulty to quantify the impact of soil properties and water type on soil structure stability has been commonly recognized. The effects of water quality on structure and macrospores continuity of soils with different texture and properties are not clearly understood (Connolly, 1998; Bronick and Lal, 2005; Levy et al., 2003). This difficulty could be associated with a variety of physical and physicochemical mechanisms of soil aggregates breakdown by water such as: (i) slaking, breakdown caused by compression of entrapped air during fast wetting, (ii) breakdown by differential swelling, (iii) breakdown by impact of raindrops, and (iv) physicochemical dispersion because of osmotic stress upon wetting with low electrolyte water (Le Bisonnais, 1996). These mechanisms differ in the type of energy involved in aggregate disruption and in the aggregate size distribution of the disrupted products, and hence in the type of soils and soil properties affecting the mechanisms. Changes in the macropores system of the soils appear to be the prevailing factor for soil physical properties, infiltration and hydraulic conductivity decline, and sealing and runoff generation during irrigation and precipitation. Soil structure deterioration and decreases in infiltration may result in surface runoff, which lead to surface contamination by the effluents and soil erosion. Most of the studies mention a significant decrease in soil permeability after the application of rain, runoff or waste water (Magesan et al. 1999; Halliwell et al., 2001; Green et al., 2003; Shainberg et al., 2002; Mamedov et al., 2002).

Several available aggregate stability measurements methods employing diverse primary breakdown mechanisms makes the comparison of the results difficult. Wet sieving is the mostly used method, but results obtained with this technique are difficult to reproduce (Amazetka, 1999). The new approach, high energy moisture characteristic (HEMC) method had been tested in numerous studies. This method is sensitive of detecting even small changes in aggregate and structure stability of a range of soils from arid zones, and may link its indices to management evaluation (Levy and Mamedov, 2002; Mamedov and Levy, 2014). The objective of our study was to evaluate the impacts of soil texture and water quality on water retention, and aggregate and structure stability of soils using the high energy moisture characteristic (HEMC) method.

Material and Methods

Soil and water samples

To evaluate an effect of soil texture and water quality on water retention, and aggregate and structure stability of soils were tested using the modified HEMC method (Levy and Mamedov, 2002). Three water qualities (electrical conductivity, EC ~ 2, 100 and 500 µS cm^{-1} with a low SAR (< 3) representing rain, canal (runoff) and irrigation water respectively) and semi-arid loam and clay soils were used. Soil samples from the 0-20 cm layer were brought from the various fields to the laboratory, air-dried and passed through a 2 mm sieve. Soil properties are presented in Table 1.

Table 1. Some physical and chemical properties of the soils studied

Soil	Particles (%)			CEC	$CaCO_3$	OM	pH	EC
	Sand	Silt	Clay	$cmol_c\ kg^{-1}$	(%)	(%)		µS/cm
Loam	44.3	29.1	26.6	25.2	12.8	0.92	7.94	378
Clay	26.8	25.4	47.8	45.1	17.6	1.42	7.96	443

CEC - cation exchange capacity; OM - organic matter; EC-electrical conductivity.

Aggregate stability test

In HEMC method, energy of hydration and entrapped air are the main forces responsible for breaking down of aggregates. In brief, 15 g of macroaggregates (0.5-1.0 mm) were placed (~5 mm thickness) in a 60 mm I.D. funnel with a fritted disc of 40-60 µm pore size. The aggregates were wetted from the bottom at a controlled manner (slow or fast: 2 or 100 mm h^{-1}) with a peristaltic pump, and then a soil water retention curve at high energies of matric potential (ψ) from 0 to -5.0 J kg^{-1} (0-50 cm H_2O), corresponding to drainable pores of > 60 µm, with small steps of 0.1-0.2 J kg^{-1}, was performed (Figure 1a,b). Each treatment was duplicated.

Aggregate and structure stability indices were inferred from differences among the water retention curves of the treatments, using the modified van Genuchten (1980) model and its $d\theta/d\psi$ differentiating. The water retention and the specific water capacity curves were described with the following two equations:

$$\theta = \theta_r + (\theta_s - \theta_r)\left[1 + (\alpha\,\psi)^n\right]^{(1/n-1)} + A\psi^2 + B\psi + C \quad [1]$$

$$d\theta/d\psi = (\theta_s - \theta_r)\left[1 + (\alpha\,\psi)^n\right]^{(1/n-1)}(1/n - 1)(\alpha\,\psi)^n n/\left[\psi(1 + (\alpha\,\psi)^n)\right] + 2A\psi + B \quad [2]$$

where θ_r and θ_s are the residual and saturated water content; α (m^{-1}) and *n* represent the location of the inflection point and the steepness of the water retention curve; A, B and C are the coefficients.

Analysis of water retention curves yield two soil structure indices: the volume of drainable pores (VDP), defined as the integral of the area under the specific water capacity curve ($d\theta/d\psi$), and the modal suction (MS), which is the matric potential at the peak of the specific water capacity curve and corresponds to the most frequent pore size; the higher the value of the MS, the smaller the size of the most frequent pore (Figure 1b). A structural index (SI), defined as the ratio of the VDP to the MS, is then used to quantitatively evaluate structure stability of the samples. The higher the value of SI the greater the stability of aggregates (0 < SR < 1).

Volume of the drainable pores were divided to three groups: macropores (>250 µm), mesopores (125-250 µm), and micropores (60-125 µm) which empty under suction of 0-12, 12-24, and 24-50 cm respectively. As a result of the link between aggregate size and pore size, observed differences between water retention curves can be used to identify which group size of pores, and thus the accompanying apparent aggregates' size, had been affected by a given management treatment.

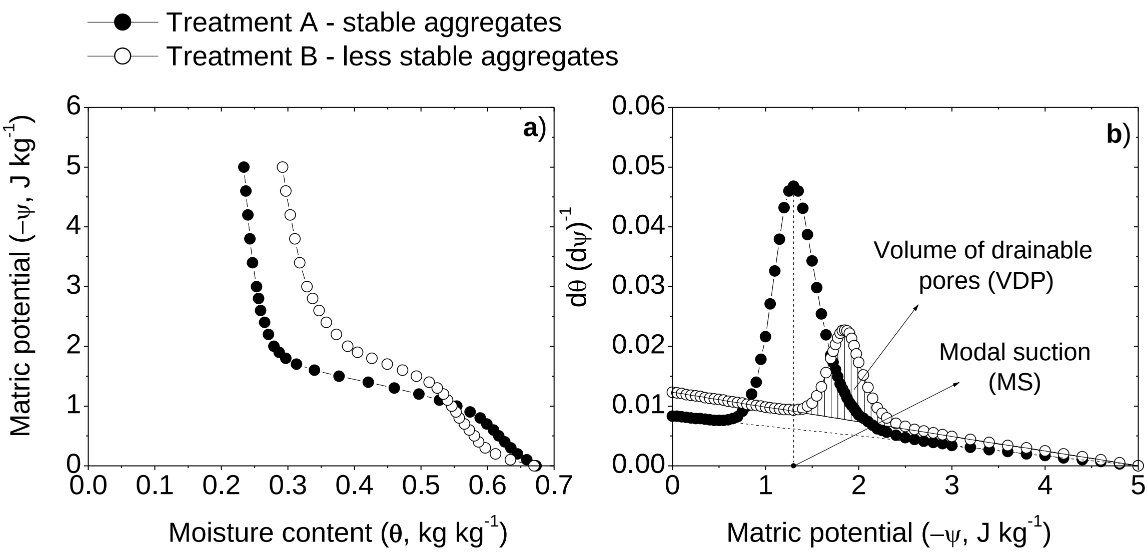

Figure 1.(a) water retention, and (b) specific water capacity curves of the clay soil aggregates subjected to fast wetting. The dashed baseline in the specific water capacity curve represents soil shrinkage line.

Statistical Analysis

The ANOVA (SAS Institute Inc. 1995) was used to determine significant effects of soil type (loam and clay), wetting rate (slow and fast) and water quality (rain, channel and fresh water with EC ~ 2, 100 and 500 µS cm^{-1} accordingly) factors (treatments) and their interaction on various indices, e.g. VDP, MS, SI, α and *n*. Significant effects were identified at the $P < 0.05$ probability level and comparisons between mean values were based on the Turkey-Kramer HSD test.

Results and Discussion

Soil texture and the electrolyte concentration of the soil solution play a significant role in resistance of soil aggregates to wetting and determining soil physico-chemical properties. Treatments significantly influenced the shape of the water retention curves (Figure 2 and 3). A summary of significant variable effects and their interaction on studied indices (VDP, MS, SI, *n* and α parameters is presented in Table 2. Except Soil x WR effect on all indices, and Soil x EC on MS and α, treatments (soil, WR and EC) and their two or three interactions significantly affected the results presented below.

Table 2. Significant effects of treatments on the stability indices tested

Source	DF	VDP g/g	MS cm	SI 1/cm	n	α 1/cm
Soil	1	***	***	***	***	***
EC	2	***	***	***	***	***
Soil x EC	2	**	ns	*	*	ns
WR	1	***	***	***	***	***
Soil x WR	1	ns	ns	ns	ns	ns
EC x WR	2	***	**	***	***	***
Soil x EC x WR	2	**	**	**	***	**

VDP, volume of drainable pores; MS modal suction; SI structural index; α and *n* the location of the inflection point and the steepness of the water retention curve;
ns , non significant; *, **, *** significant at <0.05, <0.01 and <0.001 level

Analysis of the water retention curves suggests that in the absence of stabilizing agents (e.g., low level of organic matter), contribution of wetting rate and water EC had considerable more effect on the shape of the water retention curves and hence on the stability induces and model parameters of loam soils (Tables 2 and 3, Figure 2-4). In slow wetted loam aggregates in opposite to clay soil in the range of 0-12 cm, water retention curves of samples treated with channel and fresh water were located in the left side of water retention curve of the sample treated with the rain water, whereas in 24-50 cm range the opposite were observed. Nevertheless in fast wetted samples in the range of 12-50 cm the water retention curves of aggregates treated with channel and fresh water are located in the left side of sample treated with rain water (Figure 2 and 3).

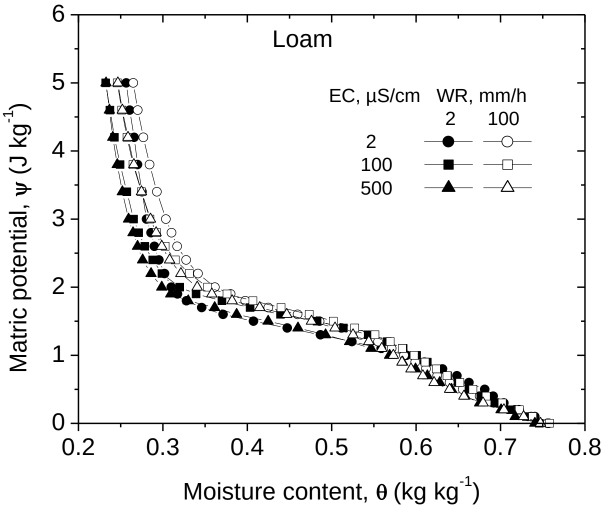

Figure 2. Water retention, of the loam soil aggregates wetted with different water quality.

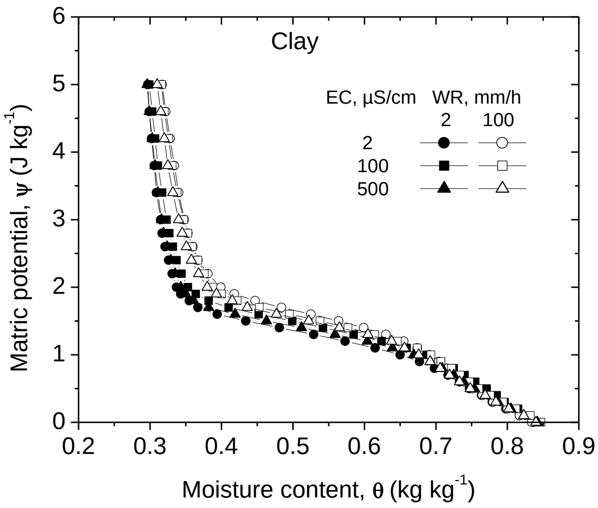

Figure 3. Water retention, of the clay soil aggregates wetted with different water quality.

Generally, susceptibility of aggregates to disintegration increases with the decrease in soil clay content and the decrease in solution salinity (Levy et al., 2003), however distribution of macro pore size (> 60 µn) and associated aggregate size may not have known range (Levy and Mamedov, 2014). As it appear from Tables 3 and Figure 4 (i) VDP and SI and α were considerable higher and MS and *n* were lower in clay soil than in loam soil, and (ii) for both soil the VDP, SI and α increased with increase in water EC, however for MS an *n* these trend was conflicting. Contribution of treatments were associated with soil properties, their sensitivity to swelling and dispersion and hence high level of soil carbonate, all mutually affecting concentration and composition of soil solution (Levy et al., 2003).

The aggregates wetted with fresh water were more stable because use of fresh water decreased the effect of differential swelling on aggregate slaking during the wetting of the aggregates (Levy et al., 2003). Manipulation of the chemo-physical properties of the clay size fraction in the aggregates, by changing water quality used in the aggregate stability test, seems to affect the stability and size fraction of the apparent meso- and micro-aggregates (60-250 µm). Thus, some changes in the aggregate and structure stability of irrigated soils are also to be expected even when water quality is good (Levy and Mamedov, 2014). However, the essential trial should be taken to schedule uniform application of water with low quality, during vegetation (Levy and Mamedov, 2013).

Table 3. Effect of fast wetted treatments on aggregate and structure stability indices and model parameters.Columns labeled with same letter do not differ at $P < 0.05$

Soil	Water EC dS/cm	VDP g/g		MS cm		n		α 1/cm	
Loam	2	0.141	c	14.9	ab	10.7	ab	0.066	ab
	100	0.146	c	15.4	a	12.1	a	0.064	b
	500	0.163	b	15.6	a	10.8	ab	0.063	b
Clay	2	0.234	a	14.9	ab	10.4	b	0.066	ab
	100	0.234	a	14.1	b	10.5	b	0.070	a
	500	0.254	a	14.0	b	9.5	b	0.072	a

VDP, volume of drainable pores; MS modal suction; SI structural index; α and *n* the location of the inflection point and the steepness of the water retention curve;

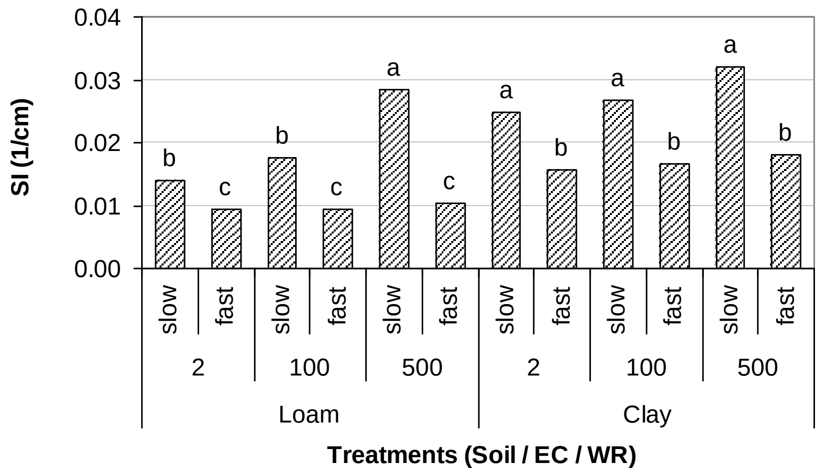

Figure 3. Structural index (SI) of the soils as affected by the treatments (EC-electrical conductivity, WR-wetting rate)

Conclusion

Soil quality, aggregate stability and pore structure of cultivated soils can be influenced by management, but the manipulability of this structure largely depends on soil properties and used water quality (e.g. EC). Effect of three water qualities representing rain, canal-runoff and irrigation water and soil texture were tested to evaluate an effect of soil type and water quality on water retention, and aggregate and structure stability. Irrigation with different water quality had the capacity to change soil properties. Soil structural alteration was predictable where salinity is involved. Generally irrigated soils may have less swelling and shrinking and less wetting and drying and these are both important physical processes for the creation of soil structure.

For the tested soils the VDP, SI and α increased, and MS and *n* decreased with the increase in clay content, water EC and the decrease in rate of aggregate wetting. The SI increased with the increase in VDP, and with the decrease in MS. Contribution of water EC on stability indices and model parameters was soil dependent.

Effect of wetting rate and water quality was more pronounced at low water EC in loam soil. Results indicate that effectiveness of water quality in the field condition has no simple ending on water retention and soil structure. Application of water with different quality should consider and be adjusted to soil properties and condition, such as soil texture, carbonates and moisture content and solution EC. Most of the changes in soil produced by irrigation with low EC water would probably be negative ones. However, increased soil water content may increase the activity of soil microbiology, fauna and plant roots and positively affect on soil structure. The structural state of irrigated soils reflects the balance between these processes.

Acknowledgements

Dr. A.I. Mamedov is thankful to TUBITAK Turkey for providing him a Visiting Scientist fund that enables him to contribute to this work.

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