Impact of Water Quality, Cultivation, and Cropping Systems on Infiltration and Physical Properties of an Arid Clay Soil

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Abstract

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Irrigation with treated wastewater is essential for increasing crop production in arid and semi arid regions. Field experiments were conducted on rainfed clayey soil to investigate the impact of water quality, cultivation, and different cropping systems on cumulative infiltration ($F_{(t)}$), field saturated hydraulic conductivity (HC_{fs}), penetration resistance (PR), and water stable aggregates (WSA). Treatments were: (1) barley fields tilled for the past 20 years (C_B-T), (2) olive tree fields tilled for the past 20 years (C_O-T), (3) non-cultivated field for 20 years, tilled for the last 2 years (NC-T_{2yr}), and (4) non-cultivated non-tilled field (NC-NT) for the past 20 years (control). Results indicated that $F_{(t)}$, HC_{fs}, PR, and WSA in NC-NT were significantly higher than in all other treatments. Compared to fresh water (FW), treated wastewater (TWW) significantly reduced $F_{(t)}$ and HC_{fs} in all treatments. This study showed that irrigation with TWW and protection of soil from any physical manipulation improved soil hydraulic and physical properties to acceptable levels. Therefore, application of such practices could be recommended in arid clayey soils.

Keywords: aggregate stability; crop cover; infiltration; tillage; wastewater

Water shortage is a major constraint for agricultural development in arid and semi-arid regions. As water scarcity is echoed in these regions, decision-makers and planners are considering the use of treated waste water (TWW) to reduce the gap between water supply and demand. Currently, the use of TWW for irrigation offers agricultural, environmental, and socio-economic benefits. Such benefits include: reduction of effluent disposal, supply of nutrients as fertilizers, and increase in crop production during dry seasons.

Many researchers suggested several mechanisms causing changes in soil hydraulic properties when TWW is applied. The total suspended solids in TWW effluent can clog water conducting pores; in addition, effluent quality can have a direct impact on soil chemical and physical properties. TWW are characterized by higher concentrations of soluble salts, sodium, and organic carbon than fresh water, which has an impact on the sodium adsorption ratio (SAR) and consequently on soil structure on the one hand and soil wettability on the other (Magesan *et al.* 2000; Gharaibeh *et al.* 2007; Vogeler 2009). Moreover, infiltration generally decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium. High sodium level in irrigation water decreases infiltration as a result of soil dispersion and structure breakdown (Shainberg & Letey 1984).

In addition, soil properties can also be influenced by tillage practices. The general purpose of tillage is to loosen the soil, decrease penetration resistance, and improve soil aeration and infiltration (Sharma & Abrol 2012). Results of tillage effect on soil physical and hydrological properties are conflicting. Pikul *et al.* (1990) reported that compared to non-tillage (NT), conventional tillage (CT) increased total porosity of soils. Pagliai *et al.* (1995) found that CT and NT had no effect on soil porosity. On the other hand, others (Azooz & Arshad 1996; Schwartz *et al.* 2010) reported that CT resulted in breakdown of soil aggregates and reduced water infiltration.

The reported effects of NT on water movement are inconsistent. Rasmussen (1999) observed decreased infiltration rates under NT treatments, while Nielsen *et al.* (2005) and Unger *et al.* (1991) observed the contrary. High infiltration rates in NT may be attributed to reduced soil disturbance and the presence of hidden cracks in soil profile, increased soil organic content, and stable soil aggregates (Arshad *et al.* 1990; Azooz & Arshad 1996; Franzluebbers 2002). On the other hand, slaking of aggregates, soil compaction, and the absence of macro- and bio-pores could reduce water movement in NT soils (Shukla *et al.* 2003).

Jordan is a region where competition for fresh water is growing and utilization of TWW in irrigated agriculture is an important step towards meeting crop requirements. The water situation is extremely difficult and it is expected to become worse in the near future.

The effects of TWW on infiltration in CT arid soils are not well documented. Hence, TWW should be evaluated and considered as supplementary source of irrigation water. Therefore, the main goal of this study is to evaluate the effect of water quality, cultivation, and cropping systems on some physical and hydrological properties of an arid clay soil.

MATERIAL AND METHODS

Site characterization. Field experiments were conducted at Ar-Ramtha agricultural station (32°29'33N latitude, 36°4'10E longitude), 70 km north of Amman, Jordan. The soil is clayey and classified as fine, mixed, thermic Typic Calcixeret. The climate is characterized by hot and dry summers and cold and wet winters. The mean annual precipitation is below 200 mm, and average temperature in summer is 24°C and in winter 12°C.

Experimental fields. Investigated fields were as follows: (1) barley fields tilled for the past 20 years (C_B-T), (2) olive tree fields tilled for the past 20 years (C_O-T), (3) non-cultivated field for 20 years, tilled for the last 2 years (NC-T_{2yr}), and (4) non-cultivated non-tilled field (control) for the past 20 years (NC-NT).

Barley (*Hordeum vulgare* L.) fields are cropped once a year and left fallow the following year. In the fallow year; the land is plowed twice: in April to clear out grass, and in December to increase the ability of soil to hold winter rain. In the following year (cropping year), the land is plowed three times: firstly in October, followed by harrowing in December to prepare the land for sowing, and thirdly in August after harvest to incorporate leftover hey into soil. Barley fields are occasionally and when needed sprayed with pesticide in February. Olive trees (*Olea europaea* L.) are usually localized-irrigated twice to three times in summer by applying about 100 mm of fresh water under the canopy of each tree. These fields are plowed three times a year. The first plowing is done in April to clear out winter grass, the second during July, and the third in December after harvest. A protected area classified as annual grassland with no tillage and any cultivation practices for the last 20 years was used as a control. A part of this field was tilled twice a year and only for two consecutive years (NC-T_{2yr}). Tillage was performed in April and November in order to study its short term effects on water infiltration and other soil physical properties.

Field and laboratory measurements. Infiltration was measured using fresh water (FW) and treated wastewater (TWW). Chemical characteristics of FW and TWW are shown in Table 1. In each field (four fields in total as described above), six infiltration runs were conducted per each water type (12 runs per field) for a total of 48 infiltration runs: (4 fields × 2 water types × 6 replicates per field). Infiltration was determined using 30-cm (inner) and 60-cm (outer) double-ring infiltrometer and the measurements were conducted according to ASTM D3385-03 standard test method. Measurements were continued until steady state was reached (approximately 5 h). Since the hydraulic gradient was close to unity and soil profile was homogeneous (no layering), the steady infiltration rate was approximately equal to the field saturated hydraulic conductivity (HC_{fs}). Water was maintained at constant head using Marriott siphon.

Table 1. Chemical properties of fresh water (FW) and treated wastewater (TWW) used in infiltration measurements

Parameter	FW	TWW
pH	7.4	7.3
EC (dS/m)	0.43	1.05
SAR	1	3.0
BOD (mg/l)	–	12
COD (mg/l)	–	47
Cations (mg/l)		
Na^+	43	135
Ca^{2+}	100	115
Mg^{2+}	19	22
Anions (mg/l)		
Cl^-	64	255
HCO_3^-	95	310
SO_4^{2-}	35	33

EC – electrical conductivity of water sample; SAR – sodium adsorption ratio; BOD – biological oxygen demand; COD – chemical oxygen demand

Cumulative ($F_{(t)}$) and average ($f_{(t)}$) infiltration rates were determined and modelled using the Kostiakov equation as follows:

$$F_{(t)} = \beta\, t^{\alpha} \qquad (1)$$

$$f_{(t)\,\mathrm{avg}} = \frac{F_{(t)}}{t} \qquad (2)$$

where:

$F_{(t)}$ – total (cumulative) infiltration depth (mm)
$f_{(t)\,\mathrm{avg}}$ – average infiltration rate (mm/h)
t – time in min in Eq. (1) and in h in Eq. (2)
α – empirically-determined exponent which is positive and always less than one
β – empirically-determined time parameter (infiltration at t = 1 min)

The term β has a physical significance which depicts the ability of soil to absorb infiltrated water. Both parameters (α and β) were determined by plotting Log $F_{(t)}$ versus Log t (h); the slope (α) and the inverse of Y-intercept (β) of the resulting straight line were found for each run. Cumulative ($F_{(t)}$) and average ($f_{(t)\mathrm{avg}}$) infiltrations were reported for relatively short time (3 h) ($F_{(3)}$, $f_{(3)\mathrm{avg}}$) and relatively long time (5 h) ($F_{(5)}$, $f_{(5)\mathrm{avg}}$).

Soil penetration resistance (PR) was measured using hand penetrometer (Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands) (Lowery & Morrison 2002). PR readings were taken in late winter when the whole profile was at field capacity and in early summer when the whole profile was at air dry conditions. Soil moisture content of core samples taken from each field showed similar moisture content among treatments. The penetrometer rod was driven in the soil and readings in kPa (1 kPa is equivalent to 1000 N/m^2) were recorded at 10 cm depth. The cone index values were likely to be quite variable; therefore multiple readings (> 10 readings) per 1000 m^2 (0.1 ha) were taken for each treatment. Duiker (2002) recommended taking at least three to four readings per acre (0.4 ha) to develop a solid recommendation.

A water stable aggregate (WSA) was determined from composite soil samples collected from each field. WSA was determined in triplicates using an Eijkelkamp wet sieving apparatus. Following the method of Kemper and Rosenau (1986), 4 g of soil composites (previously wetted by capillarity) were placed in 0.25 mm sieves. A total of eight sieves per run were then immersed in water filled cans and placed in the resisted holder of the sieving apparatus. The holder raised and lowered the samples in 1 cm vertical strokes for 5 min at a rate of 30 cycles per min. The remaining fraction in each sieve was dispersed in 2 g/l sodium hexametaphosphate solution, oven dried at 105°C, and reweighed to obtain sand mass (SM). The percentage of water stable aggregates (WSA) was calculated for composite soil samples in three replicates collected from each field as follows:

$$\mathrm{WSA} = [(\mathrm{SA} - \mathrm{SM})/(\mathrm{SOM} - \mathrm{SM})] \times 100$$

where:

WSA – water stable aggregate in soil (%)
SA – stable aggregate mass (g)
SM – sand mass (g)
SOM – soil original mass (g)

Particle size distribution was determined by the pipette method (Gee & Bauder 1986), bulk density by the clod method (Blake & Hartge 1986), pH and EC were measured in saturated paste extracts (McLean 1982; Rhoades 1982), and soil organic carbon (SOC) by wet oxidation method (Nelson & Sommers 1982).

Statistical analyses. Data were analyzed using the SPSS software, Version 17 (SPSS Inc., 2010). Two or One-Way ANOVA were used to analyze the effect of water quality and treatment on infiltration and other parameters, respectively. Differences were considered significant if $P < 0.05$. Data are presented as mean ± standard deviation (SD). Correlation analysis was employed to determine the relationship between PR-HC_{fs}, WSA-$F_{(t)}$, and PR-WSA.

RESULTS AND DISCUSSION

Selected soil properties of studied fields are listed in Table 2. Soil samples collected from all treatments showed a clayey texture with pH of 7.8, EC of 0.88 dS/m measured in saturated paste extract, calcium carbonate contents of about 15%, and bulk density of 1.3 kg/m^3. Organic matter content was very low in all fields (0.6%), however in protected fields it was relatively higher (1.3%). Statistical analyses demonstrated that water quality and treatments significantly affected cumulative infiltration ($F_{(t)}$) and field saturated hydraulic conductivity (HC_{fs}) with no interaction between water quality and treatments on the studied parameters.

Effect of water quality on infiltration and HC_{fs}. Water quality had significant effect on average infiltration rate ($f_{(t)\mathrm{avg}}$), cumulative infiltration ($F_{(t)}$), and field saturated hydraulic conductivity (HC_{fs}) (Table 3). The effects of water quality on $F_{(t)}$ and HC_{fs} are presented in Figures 1 and 2, respectively.

Table 2. Chemical and physical properties of soil in studied fields

	Value ± SD
Property	
pH	7.81 ± 0.03
EC_e (dS/m)	0.88 ± 0.15
Bulk density (kg/m^3)	1320 ± 7.00
Texture	
Sand (g/kg)	150 ± 14.0
Silt (g/kg)	390 ± 20.0
Clay (g/kg)	450 ± 14.0
Organic carbon (g/kg)	5.8 ± 1.0
$CaCO_3$ (g/kg)	155.5 ± 18.3

EC_e – electrical conductivity of saturated paste extract; SD – standard deviation

Infiltration and HC_{fs} were significantly higher in FW than TWW treatments ($P < 0.05$). Compared to FW, TWW reduced $F_{(t)}$ and HC_{fs} to half in all treatments (Figures 1 and 2). This is consistent with previous reports (Siegrist 1987; Magesan *et al.* 2000). TWW has higher sodium and suspended solids contents than fresh water. Sodium from TWW would be adsorbed on clay particles leading to soil swelling and dispersion. Infiltration and HC may be decreased either through blocking of soil pores by dispersed clay particles or by high loads of suspended solids during land application of wastewater (Magesan *et al.* 2000). Besides, the reduction in $F_{(t)}$ and HC_{fs} associated with the use of TWW may be due to the swelling of soil and reduction of surface cracks as a result of a higher sodium adsorption ratio (SAR) in TWW compared to FW. The SAR is commonly used as an index for evaluating sodium hazard in irrigation water and is defined by the following equation: SAR = Na/ÖCa + Mg, where all cation concentrations are expressed in mmol/l.

Siegrist (1987) suggested that accumulation of suspended solids at the soil surface caused diminution of soil pore-size via two mechanisms: partial retention of dissolved organic matter (DOM) and swelling and dispersion of clay particles. Additionally Vandevivere and Baveye (1992) suggested biological partial pore clogging through increased biomass amount (mainly algae, bacteria, and their products) in TWW. Moreover, organic matter (OM) in TWW tends to complex soluble Ca^{2+} and Mg^{2+} ions thereby increasing SAR of irrigation water and subsequently soil solution (Metzger *et al.* 1983; Nelson *et al.* 1999). In molecular dynamics computations of the interaction of OM with soluble cations (Na^+, Mg^{2+}, and Ca^{2+}) Kalinichev and Kirkpatrick (2007) showed that Na^+ forms only a very weak complex with organic matter and remains almost entirely in the solution and fully hydrated by water molecules, whereas Mg^{2+} interacts little with the organic mat-

Table 3. Infiltration and field saturated hydraulic conductivity for fresh water (FW) and treated wastewater (TWW) under different cultivation and cropping systems

Treatment	$F_{(3)}$	$F_{(5)}$	HC_{fs}	$f_{(3)avg}$	$f_{(5)avg}$
	(mm)		(mm/h)		
FW					
C_O-T	151.0^a ± 6.6	203.2^a ± 5.6	25.0^a ± 2.7	50.3^a ± 2.2	40.7^a ± 1.1
C_B-T	156.8^a ± 10.1	215.2^b ± 13.7	27.8^a ± 4.9	52.3^a ± 3.4	43.0^b ± 4.9
NC-T_{2yr}	195.6^b ± 7.4	271.4^c ± 5.1	36.2^b ± 3.7	65.2^b ± 2.5	54.3^c ± 1.0
NC-NT	248.3^c ± 11.9	347.9^d ± 17.3	47.7^c ± 3.8	82.8^c ± 4.0	69.6^d ± 3.4
LSD	8.60	10.45	3.60	2.97	2.23
TWW					
C_O-T	87.7^a ± 9.9	113.0^a ± 14.5	12.0^a ± 2.6	29.2^a ± 2.6	22.6^a ± 2.9
C_B-T	101.4^b ± 4.9	132.0^b ± 7.6	14.0^{ab} ± 3.4	33.8^b ± 1.6	26.4^b ± 1.5
NC-T_{2yr}	112.2^c ± 10.1	146.7^c ± 10.7	16.2^b ± 1.5	37.4^c ± 3.3	29.3^c ± 2.1
NC-NT	156.4^d ± 3.7	209.5^d ± 5.7	25.1^c ± 2.9	52.1^d ± 1.2	41.9^d ± 1.1
LSD	7.13	9.19	2.90	2.5	2.05

C_O-T – olive tree fields tilled for the past 20 years; C_B-T – barley fields tilled for the past 20 years; NC-T_{2yr} – non-cultivated field for 20 years, tilled for the last 2 years; NC-NT – non-cultivated non-tilled field for the past 20 years; superscripts indicate significant differences ($P < 0.05$) between treatments

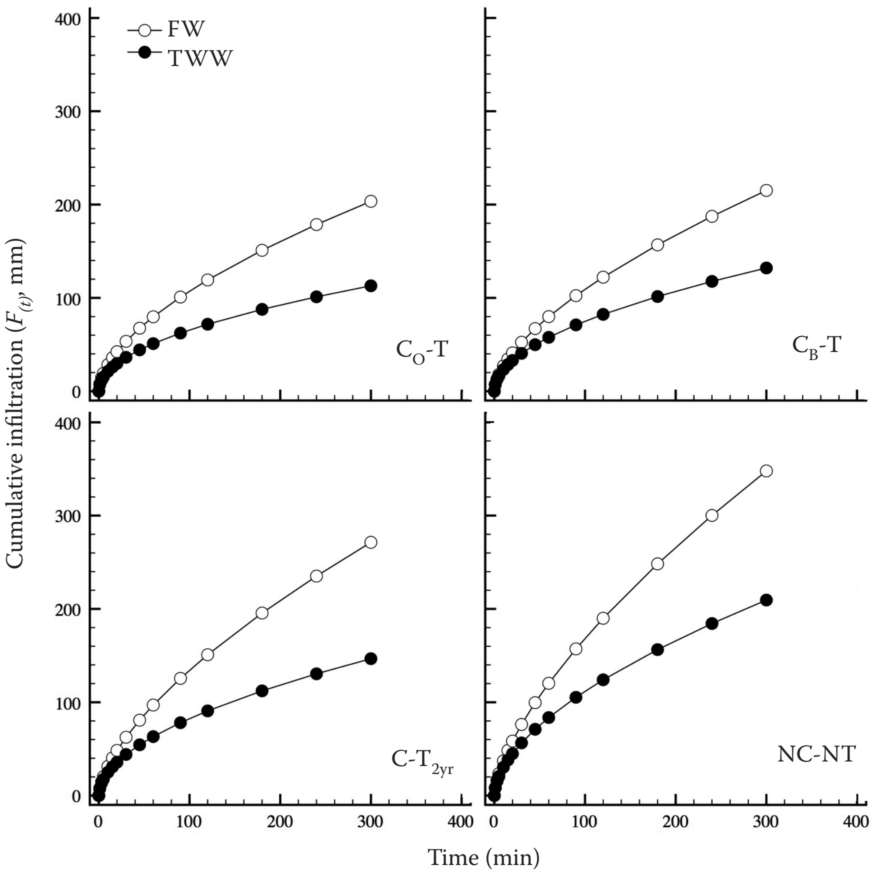

Figure 1. Effect of treatments and water quality on cumulative infiltration ($F_{(t)}$) calculated by Kostiakov equation; values are average of six runs (n = 6)
C_O-T – olive tree fields tilled for the past 20 years; C_B-T – barley fields tilled for the past 20 years; NC-T_{2yr} – non-cultivated field for 20 years, tilled for the last 2 years; NC-NT – non-cultivated non-tilled field for the past 20 years

ter due to its strongly held hydration shell. In the same study, they showed that Ca^{2+} has the strongest association with organic matter and forms a strong complex with the organic matter carboxylate groups. Overall, the relative strength of such a complexation is best interpreted in terms of simple electrostatic considerations as described by the charge/radius ratio of the cations. For example, Ca^{2+} is nearly the size of Na^+ but interacts more strongly with the organic matter carboxylate groups due to its larger charge/radius ratio.

Sposito *et al.* (1978) reported that the increase in SAR was due to functional groups of OM that forms relatively strong ion pairs primarily with Ca^{2+}, and to the exchange of Ca^{2+} with protons (H^+) on undissociated functional groups. Moreover, Sumner (1993) reported that OM has greater preference for Ca^{2+} than soil clay minerals. This preference would create a non uniform distribution of Ca^{2+} relative to Na^+ on organic and inorganic soil colloids. As a result, compared to the inorganic fraction, higher sodium levels present in the organic fraction would promote dispersion.

The complexity of Vertisols, and the role of OM in altering the sodicity of wastewater makes the

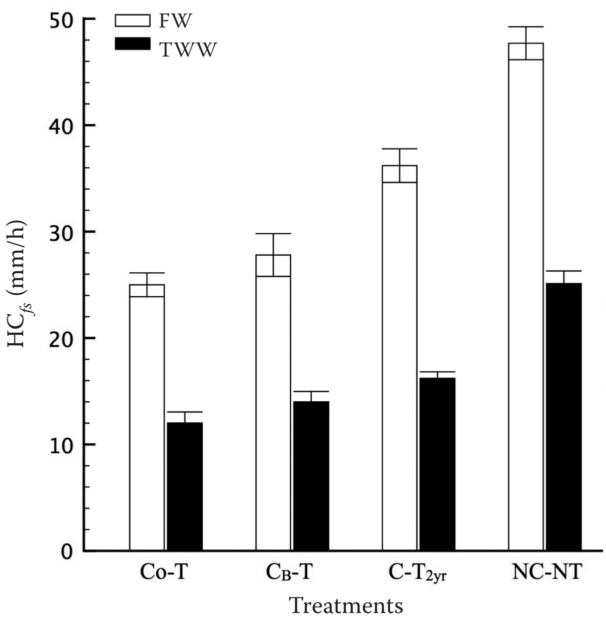

Figure 2. Effect of treatments and water quality on field saturated hydraulic conductivity HC_{fs} (mm/h)
C_O-T – olive tree fields tilled for the past 20 years; C_B-T – barley fields tilled for the past 20 years; NC-T_{2yr} – non-cultivated field for 20 years, tilled for the last 2 years; NC-NT – non-cultivated non-tilled field for the past 20 years

prediction of infiltration very difficult under tillage operation.

The effects of water quality on Kostiakov equation parameters (α and β) are shown in Table 4. Results showed that with TWW use, α was significantly reduced by water quality.

Effect of treatments on infiltration and HC_{fs}. The effect of treatments on $F_{(t)}$ and HC_{fs} are presented in Figures 1 and 2, respectively. Statistical analyses showed that $F_{(t)}$ $f_{(t)\text{avg}}$, and HC_{fs} were significantly higher ($P > 0.05$) in the NC-NT than in all other treatments irrespective of water quality. Cropping had significant effect on water infiltration but not on HC_{fs}. Barley cropped fields had significantly higher $F_{(5)}$, and $f_{(5)}$ than olive cropped fields using both water types. Both NC-NT and NC-T_{2yr} had significantly higher $F_{(t)}$ and HC_{fs} than cropped treatments. Using TWW, the highest $F_{(t)}$ and HC_{fs} values were observed in NC-NT treatment (209 mm, 25 mm/h), while the lowest value was observed in C_O-T treatment (113 mm, 12 mm/h) (Table 3). Effect of treatments on infiltration and HC_{fs} followed the same trend when FW was used. In the current study, NC-NT fields were characterized by the presence of surface cracks that probably encouraged preferential flow. These cracks were smaller as consecutive tillage operations were performed in the other treatments, therefore water flow was reduced.

Table 4. Parameters of Kostiakov equation (β, α) under different water types, cultivation, and cropping systems

Treatment	β	α
FW		
C_O-T	$7.331^a \pm 2.88$	$0.589^a \pm 0.061$
C_B-T	$6.886^a \pm 2.63$	$0.619^{ab} \pm 0.096$
NC-T_{2yr}	$7.422^a \pm 3.10$	$0.642^b \pm 0.064$
NC-NT	$8.167^a \pm 1.42$	$0.660^b \pm 0.036$
LSD	1.854	0.046
TWW		
C_O-T	$6.996^a \pm 1.99$	$0.493^a \pm 0.062$
C_B-T	$7.354^a \pm 2.58$	$0.516^a \pm 0.069$
NC-T_{2yr}	$7.630^a \pm 2.66$	$0.527^{ab} \pm 0.055$
NC-NT	$8.353^a \pm 2.60$	$0.572^b \pm 0.060$
LSD	2.1	0.053

C_O-T – olive tree fields tilled for the past 20 years; C_B-T – barley fields tilled for the past 20 years; NC-T_{2yr} – non-cultivated field for 20 years, tilled for the last 2 years; NC-NT – non-cultivated non-tilled field for the past 20 years; superscripts indicate significant differences ($P < 0.05$) between treatments

Higher infiltration in NC-NT treatment may also be attributed to the influence of perennial grasses on soil macroporosity and aggregate stability and to a long period of NT practice. Sauer *et al.* (1990) indicated that even though NT soils had higher bulk density than tilled ones; infiltration was higher in these soils due to more stable soil structure and increased number of continuous earthworm channels. In addition, higher infiltration in NT could be attributed to water flow through macropores and reduced surface sealing (Meek *et al.* 1990). Furthermore, the lower infiltration rates in tilled treatments were probably due to the collapse of aggregates and the formation of surface crusts caused by direct raindrop impact. In fact, differences in HC_{fs} among treatments suggest greater porosity, less tortuous paths, and better pore continuity in NC-NT compared to other treatments.

In addition, higher infiltration in C_B-T compared to C_O-T could be attributed to the presence of leftover hay on soil surface. As tillage is practiced, leftover hay is incorporated into the soil and decomposed with time. Therefore, promoted infiltration could be related to addition of OM. Its content was 1.1% and 1.0% for C_B-T and C_O-T, respectively, data was not included. Lado *et al.* (2004) indicated that soil OM binds soil particles to form stable aggregate. Upon wetting, soil structure is maintained and water infiltration is improved.

The effects of treatments on Kostiakov equation parameters (β and α) are shown in Table 4. Results showed that treatments had no significant effect on β and weak non-significant effect on α parameter. Barley fields had greater (non-significant) α values compared to olive fields.

PR and WSA and their effect on $F_{(t)}$ and HC_{fs}. The field experiments were conducted to study the relationship between penetration resistance (PR) and water stable aggregates (WSA), and water movement ($F_{(t)}$ and HC_{fs}). For all treatments, PR was around 500 kPa and over 2000 kPa at field capacity and air dry conditions, respectively (Table 5). These results are in agreement with Ghuman and Lal (1984) who reported that PR decreases with increasing soil moisture content. In addition, PR values below 2000 kPa indicate no root-limiting compaction (Duiker 2002). At field, capacity treatments had no significant effect on PR and this could be attributed to the clayey nature of the studied soils. Once wetted, these soils become very soft and possess low resistance to penetration. The highest PR values were observed in the cropped treatments (C_B-T and C_O-T) and the lowest was observed in NT-NC treatment. Moreover, treatments had significant effect on WSA; the highest was observed in NT-NC and the lowest in C_O-T treatment.

Table 5. Effect of treatments on penetration resistance (PR) and water stable aggregates (WSA) in rainfed conditions (FW)

Treatment	PR (kPa)		WSA (%)
	FC	Dry	
C_O-T	$500^a \pm 0.029$	$7800^c \pm 0.325$	$25^a \pm 2.0$
C_B-T	$500^a \pm 0.048$	$7200^{bc} \pm 0.485$	$37^b \pm 3.6$
NC-T_{2yr}	$490^a \pm 0.050$	$6500^b \pm 0.670$	$38^b \pm 2.6$
NC-NT	$485^a \pm 0.039$	$5400^a \pm 0.760$	$43^{c+} \pm 3.5$
LSD	70	972	3.9

C_O-T – olive tree fields tilled for the past 20 years; C_B-T – barley fields tilled for the past 20 years; NC-T_{2yr} – non-cultivated field for 20 years, tilled for the last 2 years; NC-NT – non-cultivated non-tilled field for the past 20 years; FC – penetration resistance at field capacity; dry– penetration resistance at air dry conditions; superscripts indicate significant differences ($P < 0.05$) between treatments

Strong negative correlation was observed between PR-HC_{fs} ($r = -0.86$) and PR-$F_{(t)}$ ($r = -0.95$). On the contrary, moderate positive correlation was observed between WSA and HC_{fs} ($r = 0.65$), and strong positive correlation between WSA and HC_{fs} ($r = 0.78$). Field experiments also showed that HC_{fs} coincided directly with PR results. The lowest PR (485 kPa FC, 5400 kPa air dry) and the highest WSA values (43%) were observed in NC-NT, both values coincided with the highest $F_{(t)}$ (348 mm) and HC_{fs} (47.7 mm/h) values (Table 3 and 5). This is consistent with the findings of McConkey *et al.* (2002) who reported that higher organic matter in NT provided favourable environment for aggregate formation compared to CT treatments. Moreover, the lower WSA and the relatively higher PR values in cropped treatments (C_B-T and C_O-T) may be due to the effect of primary and secondary tillage. Such practices may reduce water movement as a result of disruption and breakdown of soil aggregates. WSA and $F_{(t)}$ but not PR and HC values were significantly different between the cropped treatments (C_B-T and C_O-T) (Table 5). However, C_O-T treatment had a numerically higher dry PR value than C_B-T treatment. The highest PR values in C_O-T treatment were associated with the lowest HC_{fs} and $F_{(t)}$ values. Apparently, no tillage treatment reduced pore disruption and significantly increased water movement as compared with all treatments (Table 3 and 5). Using TWW reduced $F_{(t)}$ and HC_{fs} in all treatments. Cropped treatments (C_B-T and C_O-T) exhibited similar PR values with slight differences in HC_{fs} and infiltration.

According to the soil survey manual (Soil Survey Division Staff 1993), HC_{fs} values in NC-NT using both water types (FW and TWW) are classified as moderate (15–50 mm/h). Although the HC_{fs} values in TWW were reduced, they actually lie within the acceptable range of a good water movement in soils. This study showed that irrigation with TWW and protection of soil from any physical manipulation improved soil hydraulic properties. Therefore, such practices could be recommended in arid clayey soils.

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