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Soil Properties Affecting Rainfall Water Use Efficiency (RWUE) in Wheat Dry-Farming Lands, NW Iran

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Abstract

Effective use of rainfall water is a key issue in agricultural development in the arid and semi-arid regions since rainfall water is a precondition for crop production there. This study was conducted in a semi-arid agricultural region with 900 km^2 in area in Hashtroud, northwest of Iran to determine the relationship between rainwater use efficiency (RWUE) and soil properties. Winter wheat yield and soil properties were determined at 108 plots (40.41 m^2 in area) installed in thirty six dry-farming lands. RWUE of each plot obtained from the ratio of crop dry matter per unit of abstracted rainfall water volume (ARWV). ARWV was computed from deduction of the rainfall and runoff volume during a two-growth period. Runoff data for each land was obtained from field measurements at the plots under natural rainfalls. Analysis of rainfalls uniformity using four rain gauge stations data showed that spatial distributions of rainfalls were homogeneous in the area. The RWUE values in the lands were ranged from 0.35 kg m^{-3} to 1.49 kg m^{-3} with an average of 0.84 kg m^{-3}. Soil properties which considerably affected either the infiltration capacity or the available water controlled the RWUE in the study area. Multi-regression analysis indicated that the RWUE significantly related to silt, organic matter and lime (R^2=0.82, $p < 0.001$). Maintaining crop residues and incorporating with the soil can be proper techniques and sustainable strategies to improve the soil properties and enhance the RWUE in the dry-farming lands.

Keywords: available water, infiltration capacity, semi-arid region, natural rainfall, winter wheat

1. Introduction

Precipitation is one of the most important factors affecting agricultural productions, especially in the arid and semi-arid regions. Water from precipitation must be captured and retained in soil and used efficiently for optimum yield production (Morell et al., 2011). Effective use of rainfall water is a key issue in agricultural development in the arid and semi-arid regions since rainfall water is a precondition for crop production there. RWUE is the ratio of crop dry matter per unit of abstracted rainfall water volume (ARWV). The abstracted rainfall water volume is a part of precipitation that could be stored in soil. The RWUE is often considered an important determinant of yield under stress and even as a component of crop drought resistance. It has been used to imply that rainfed plant production can be increased per unit water used, resulting in ‘‘more crop per drop’’ (Blum, 2009).

A major research challenge is to investigate methods that maximize wheat yield and the RWUE. It has been concluded that most of the agronomic options for improving RWUE in rainfed agricultural systems decrease water losses by declining soil evaporation, runoff, through flow, deep drainage, and competing weeds, thereby making more water available for increased water use by the crop (Asseng et al., 2001; Turner, 2004). Soil properties are one of the most important factors influencing crop water availability due to their effects on the water holding capacity, evaporation, and runoff generation. Rainfall water use efficiency (RWUE) decreases when both plant water supplying in the soil decreases and runoff generation increases. The supplied water for the plant (available water, AW) is that portion of water held in soil that can be absorbed by plant roots (Richards & Wadleigh, 1952). AW is the amount of water between the field capacity (FC) and the permanent wilting point (PWP) (Veihmeyer & Hendrickson, 1927) that may strongly affected by some soil properties particularly texture and structure. Soil properties also affect on runoff rate in the land. Runoff occurs only when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the soil (Schwab et al., 1993). Runoff more commonly occurs in the arid and semi-arid regions, where rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing, or in paved areas. The rate of infiltration of water into the soil depends on several soil properties, particularly physical characteristics of the soil (Ghawi & Battikhi, 1986).

Almost 39 percent of Iran (642797 km^2) has a semi-arid climate condition, with an annual precipitation between 200 and 500 mm. East-Azarbijan province located in north west of Iran is one of the typical semi-arid regions, with an mean annual precipitation of 300 mm (Modarres, 2006). On average, precipitation has a nonuniform annual distribution, with the major part occurring in early spring (37%), middle autumn (26%) and early winter (31%) and little precipitation in summer (6%) (Anonymous, 2011). The arable area is estimated to be about 1220980 ha (27 percent of total surface area). Farming is mostly done in rainfed condition (813119 ha) and water is the principal limiting factor for agriculture development (Shefaat, 2006). Wheat is the main crop in the region with a mean yield of 650 kg ha^{-1} (Iranian Agriculture Ministry, 2009). It is widely adopted as a monoculture crop, with the growing period between March and July, and October and July for spring and winter-sown, respectively.

Improving water use efficiency has been an urgent issue in the region as ecological water demand has been increasingly concerned. Determining factors affecting the RWUE and quantification their effects value are important to model the RWUE and predict crop yield in the area. Some authors have investigated various factors influencing the RWUE, which include cropping systems (Kar et al., 2006; Rao, 2008), fertilization (Rao et al., 2010), mulch (Rehman et al., 2009) and tillage (Ronner, 2011), previously. Up to now, the effect of soil properties on the RWUE has not been quantitatively investigated; therefore, the objective of this work was to quantify the influence of soil properties on the RWUE and model it in dry-farming lands of the semi-arid region.

2. Materials and Methods

2.1 Study Area

The study was carried out in a semi-arid area of northwest of Iran located in Hashtroud township (southern part of East Azarbyjan province) from March 2005 to March 2006. The study zone was 900 km^2 in area located between 37° 18' 49" and 37° 35' 0" N latitude, and 46° 46' 5" and 47° 6' 5" E longitude (Figure 1). The climate is semi-arid with an average annual precipitation of 322 mm, mostly falling as snow in the winter and autumn and as rain in the spring, and a mean annual temperature of 13°C. Agricultural soils located mostly in 5-15% slopes (Hakimi, 1986) and mainly are utilized for wheat production under rainfed condition. Soils according to USDA Soil Taxonomy classification system (Soil Survey Staff, 1975) were classified as calcixerepts (Banaee, 1999). Soils were mostly tilled and planted in slope direction. So, as noted by Blanco and Lal (2008) surface runoff rapidly concentrates in furrows and immediately flows up- and down-slope direction.

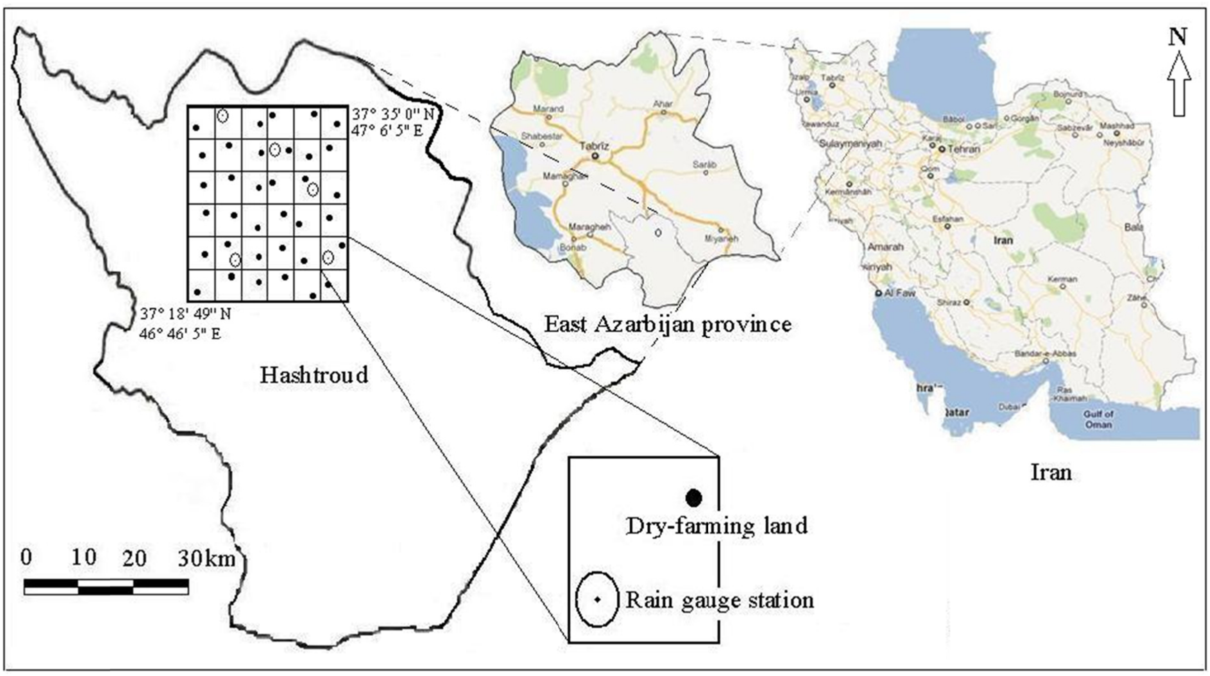

Figure 1. Location of the study area, dry-farming lands and rain gauge stations

2.2 Determination of the RWUE

Based on the water use efficiency definition that refers to the ratio of economic yield to water consumed by the crop (Katerji et al., 2008), rainwater use efficiency (RWUE) obtained from the ratio of crop dry matter (CDM) per unit of the abstracted rainwater volume (ARWV) as fallowing:

$$RWUE = \frac{CDM}{ARWV} \tag{1}$$

where RWUE was in kg m^{-3}, CDM was in kg and ARWV was in m^3. The abstracted rainfall volume (ARWV) obtained from differentiation of the rainfall volume (m^3) and runoff volume (m^3) during a two-growth period.

2.2.1 Installation of the Crop and Runoff Plots

Thirty six dry-farming lands were considered in the study area to installation of crop plots and runoff plots (Figure 1). The crop plots and runoff plots were separately installed in a 200 m^2 area at three replications beside together in each dry land at the same time. In fact crop yield and runoff volume were separately determined at 108 plots during a two-growth period for a two-study period (2005-2007). The crop and runoff plots were established based on USLE standard/unit plots (Wischmeier & Smith, 1978) with 22.1 m length in slope direction and 1.83 m width and a buffer bed about 1.2 m between two plots. The plots were plowed and accordingly disked up to down slope at middle October 2005. For providing similar conditions between the crop plots and runoff plots, was avoided from fertilizer application to enhance crop yield in the planted area.

2.2.2 Determination of Wheat Yield

The Sardary winter wheat variety, normally grown for bread, was planted at the crop plots by a drill in depth of 4-6 cm, with 20 cm row spacing and 5 cm plant spacing right after plowing at last October 2005. Length of growing period of the winter wheat was about eight months and on July 25, the crop was harvested for determining grain yield. Plant samples were randomly taken from three 1 m^2 locations from each plot area by clipping the plants at the soil surface and accordingly mean grain yield of each plot was computed. Mean grain yield and mean dry matter of each dry-farming land (kg ha^{-1}) were calculated from averaging the yield and biomass values of its three plots, respectively. The mean wheat yield and dry matter for a two-year study period were computed based on the yield and biomass values of the first and second year (kg ha^{-1}).

2.2.3 Determination of Surface Runoff Volume

Surface runoff caused by natural rainfalls was measured at the lower parts of the runoff plots during a two-growth period for a two-study period (2005-2007). The plots were surrounded using 30 cm ridges and runoff-collecting installations consisted of gutter pipes, pipes and 70-1 tanks were established at their lower parts. After each natural rainfall event producing runoff at the plots, total contents (runoff-sediment) mass in the collecting tank was measured. Then, the tanks contents were mixed thoroughly and a 0.5 kg homogeneous sample was taken to determination of runoff mass. In the laboratory, the samples were weighed and evaporated on a hot plate then weighed again to determine runoff mass. Water loss of each plot was determined based on multiplying total contents mass of the tank by mass percentage of water in its sample. Annual surface runoff was also computed from summation of total surface runoffs produced in different rainstorms for a two-growth period.

2.2.4 Determination of Rainfall Volume

Rainfall volume (m^3) was calculated from multiplying the rainfall depth (m) and plot area (40.44 m^2). Rainfall data were taken from five rain gauge stations located in the study area (Figure 1). Four standard rainfall gauges located in the grids 2, 10, 27 and 30 were used to manually measure the depth of rain after occurring the runoff at the plots. An automatic rain gauge station located in the grid 17 was also used to determine intensity of rainfall events. Rainfall data for a two- growth period was also used to determine spatial variations of the rainfall amounts in the study area.

2.3 Determination of Soil Properties

To determine soil properties in each dry-farming land, soil samples (0-30 cm depth) were taken randomly from three locations within each plot before plowing. Then, the samples were mixed together to provide a representative sample from each plot. After being dried, the soil samples were grounded to pass a 2 mm sieve and stored in sealed polyethylene bags in a cool and dry place until the chemical analysis in the laboratory. The particle size distribution consisted of sand (0.05-2 mm), silt (0.002-0.05) and clay (<0.002 mm) was determined by the Robinson's pipette method (SSEW, 1982). Gravel (2-8 mm) was determined using the weighting method (Gee & Bauder, 1980). The total soil organic carbon was measured by the Walkley-Black wet dichromate oxidation method (Nelson & Somers, 1982) and converted to organic matter through multiplying it by 1.724. To determine soils carbonates (lime), the total neutralizing value (TNV) on the basis of calcium carbonate was measured using acid acetic volume consumed to neutralization of carbonates (Goh, Arnaud, & Mermut, 1993). The aggregate stability was determined using the wet-sieving method based on the mean weight diameter (MWD) as proposed by Angers and Mehuys (1993). The water-stable aggregates were determined by placing 100 g soil surface aggregates with diameter larger than six mm on the top of sieves set and moved up to down in a water cylinder for one minute. Soil infiltration capacity was determined by measuring the one-dimensional water flow into the soil per unit time by double-ring infiltrometer (Bouwer, 1986) at four to six replications at the plots during dry period (in July 2005). Available water (AW) for each soil obtained from difference of mass soil moisture contents between the holding capacity (FC) and permanent wilting point (PWP). Soil moisture content by mass at FC (-30 kPa matric potential) and PWP (-1500 kPa matric potential) were measured using a pressure plate and pressure membrane apparatus, respectively (Hillel, 1982).

2.4 Statistical Analysis

Soil, rainfall and runoff data were assessed for normality using the Kolmogorov-Smirnov test before analysis. Differences in rainfall amounts among rain gauge stations were analyzed using one-way ANOVA. Relationship between runoff and rainfall was extracted using the different equations based on the highest determination coefficient (R^2). Runoff and RWUE difference among the plots was analyzed using Duncan's parametric test. Soil properties influencing the RWUE were extracted based on bivariate Pearson's correlation matrix. A stepwise multiple regression analysis was applied to develop a relationship between the RWUE and the effective soil properties. SPSS 18 software was used, and the significance level was 95% ($p < 0.05$) in all statistical analyses.

3. Results and Discussion

3.1 Rainfall Characteristics

Annual rainfall amount in the first and second study year was 249.3 mm and 159.5 mm, respectively. Thirty six and twenty seven natural rainfall events occurred in the study area during the growth period in the first and second study year, respectively. Table 1 shows the statistical characteristics of the rainfall events in the first and second study year. Rainfall intensity in the first year varied from 0.1 to 13.78 mm h^{-1} with an average of 3.25 mm h^{-1}. Rainfall intensity in the second year was between 0.31 to 8.20 mm h^{-1} with an average of 2.57 mm h^{-1}. Total rainfall height during the growth period in the first and second year was 151.41 mm and 93.95 mm, respectively. There was no significant difference among the rainfall depth values in different rain gauge stations ($F = 0.03$, p-value = 0.99). In fact, spatial variations of the rainfall events were uniform in the study area.

Table 1. The statistical characteristics of the rainfall events in the growth period in the first and second study year

Growth Periods	Height (mm)		Intensity (mm h^{-1})	
	Mean	StD.	Mean	StD.
2005	4.21	4.52	3.25	2.81
2006	3.48	2.84	2.57	1.99

3.2 Runoff and RWUE

Nineteen rainfall events and thirteen rainfall events produced runoff at the plots in the first and second growth period, respectively. Table 2 shows rainfall height and runoff depth in the rainstorms in the first and second growth period in the study area.

Mean surface runoff during the growth period in the first study year varied from 2.15 lit to 49.37 lit with an average of 17.13 lit. It was between 1.79 lit and 27.67 lit with an average of 10.63 lit in the second growth period. The abstracted rainfall water volume (ARWV) values were ranged from 74.36 lit to 696.83 lit and from 127.38 lit to 485.95 lit in the first and the second growth period, respectively.

Runoff depth significantly affected by rainfall height ($R^2 = 0.70$, $p < 0.001$). With an increasing rainfall height, runoff remarkably increased (Figure 2). Rainfall having a height of 17.1 mm had the highest potential to generate runoff in the study area. The highest productive runoff had a height of 17.1 mm that could produce 0.8 mm runoff in the study plots. Rainfalls that had a height value lower than 1.7 mm did not had any potential in runoff production in the study area. The abstracted rainfall significantly correlated with the rainfall ($R^2 = 0.99$, $p < 0.001$).

Table 2. Rainfall height and runoff depth in the rainstorms in the first and second growth period

Growth Periods					
2005			2006		
Date	Rainfall (mm)	Runoff (mm)	Date	Rainfall (mm)	Runoff (mm)
April 2	2.5	0.053	March 29	5.3	0.130
April 3	3.65	0.106	April 5	4.2	0.082
April 15	13.7	0.803	April 7	6.7	0.093
April 16	2.7	0.103	April 17	12.7	0.684
April 17	4.8	0.231	April 24	4.2	0.168
April 18	3.7	0.181	April 25	3.3	0.150
April 26	17.8	0.620	April 26	5.6	0.369
April 27	2.8	0.314	may 3	8.1	0.499
May 3	8.3	0.412	May 4	4	0.350
May 4	2	0.085	May 5	3.4	0.193
May 5	2.5	0.234	May 6	4.8	0.268
May 6	4.2	0.302	May 10	6.8	0.385
May 14	11.9	0.982	June 25	4.1	0.044
May 15	12.4	1.221			
May 16	8.1	0.698			
May 19	12.5	0.557			
May 20	10.4	0.717			
May 31	3.5	0.365			
June 2	1.9	0.061			

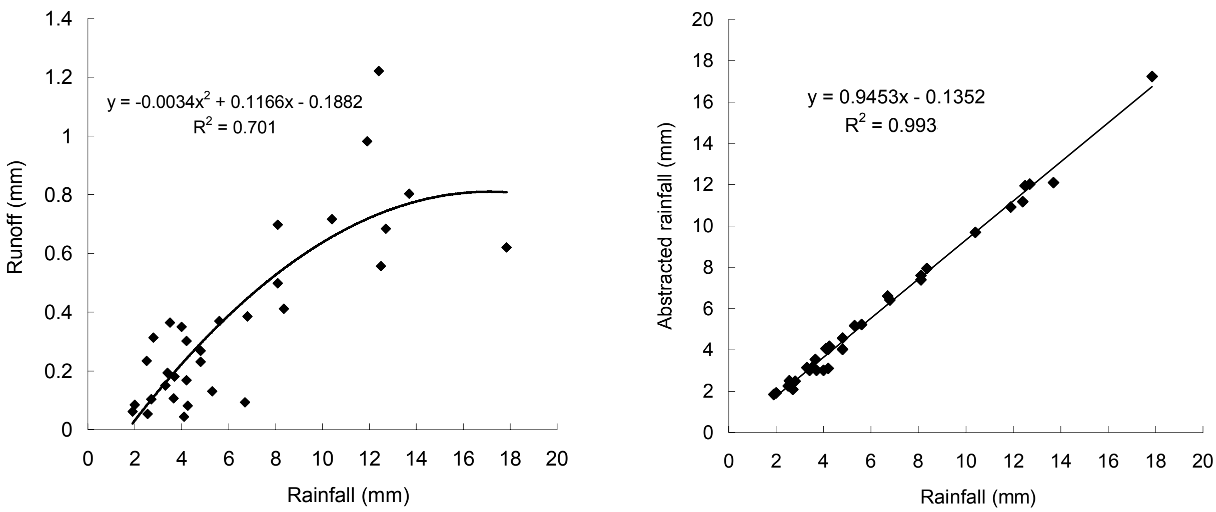

Figure 2. Relationship between runoff and abstracted rainfall, and rainfall during a two-growth period

Both runoff and the abstracted rainfall water volume (ARWV) significantly ($p < 0.001$) varied among the plots installed in 36 dry farming lands (Table 3). Since the spatial distribution of the rainfalls were uniform in the study area, differences of the runoff and ARWV among the dry-farming lands directly related to soil properties.

Table 3. Analysis of variance of mean runoff and ARWV in the dry-farming lands

Variable	Sum of squares	DF	Mean square	F	Significant level
Runoff	421190.955	35	12034.027	45.531	0.000
ARWV	609780.425	35	17422.298	62.609	0.000

3.3 Wheat Yield and RWUE

Mean annual wheat grain yield values in the dry-farming lands were ranged from 801.4 kg ha^{-1} to 3484.3 kg ha^{-1} with an average of 1937.8 kg ha^{-1}. Mean annual rainfall water use efficiency (RWUE) values were between 0.72 and 3.13 kg m^{-3}. Table 4 shows mean annual wheat grain yield and RWUE in 36 dry farming lands. Both wheat yield and RWUE considerably ($p < 0.001$) varied among the dry farming lands (Table 5). Difference of the yield among dry-lands was only due to variations of the soil properties in dry-farming lands.

Table 4. Mean wheat grain yield and RWUE in 36 dry farming lands in the study area

Land No.	Wheat yield (kg ha^{-1})	RWUE (kg m^{-3})	Land No.	Wheat yield (kg ha^{-1})	RWUE (kg m^{-3})	Land No.	Wheat yield (kg ha^{-1})	RWUE (kg m^{-3})
1	801.4	0.72	13	1559.0	1.41	25	1376.3	1.24
2	1125.4	1.01	14	2118.6	1.92	26	2970.3	2.66
3	834.6	0.75	15	1445.4	1.31	27	3476.5	3.13
4	2540.3	2.28	16	3263.7	2.81	28	1187.5	1.07
5	1130.3	1.02	17	3396.0	2.91	29	1846.7	1.66
6	2641. 7	2.35	18	1724.3	1.48	30	1202.7	1.09
7	1256.7	1.12	19	1234.5	1.07	31	2340.8	2.14
8	3484.3	3.12	20	2443.3	2.14	32	3316.4	3.02
9	1265.7	1.13	21	3470.9	3.03	33	1484.5	1.33
10	1176.9	1.05	22	1757.8	1.53	34	2174.4	1.89
11	1364.5	1.22	23	1017.8	0.88	35	1446.6	1.25
12	3017.7	2.67	24	1543.7	1.33	36	1323.2	1.15

Table 5. Analysis of variance of wheat grain yield and RWUE in the dry-farming lands

Variable	Sum of squares	DF	Mean square	F	Significant level
Wheat yield	$5.711*10^7$	35	1631653.076	71.413	0.000
RWUE	$56.394*10^7$	35	1.611	67.591	0.000

3.4 Soil Properties

Soil physicochemical analysis indicated that the soils were mainly clay loam having 36.7% sand, 31.6% silt and 32.0% clay (Table 6). Soils had inherently low amount of organic matter (1.1%) due to low plant growth caused by water stress and frequency cultivation without considering fallow condition. Soils were calcareous/limy with a relatively high value of carbonates (about 13% equivalent calcium carbonate /lime). Soil aggregates were mainly granular and mean wheat diameter of the water-stable aggregates was very low (1.13 mm). The soils based on the SCS method (USDA, SCS, 1991) were mostly classified in C hydrological grope with a mean infiltration capacity of 3.5 cm h^{-1}.

Table 6. Soil properties in the study area

Soil property	Mean	St.D.
Sand	36.72	6.69
Silt	31.59	7.12
Clay	31.69	5.75
Gravel	9.89	2.37
Organic matter	1.09	0.25
Carbonates/lime / (%)	12.66	5.25
Porosity	0.46	0.06
Aggregate stability in Water, (mm)	1.13	0.44
Infiltration capacity (cm h^{-1})	3.56	1.17
Available water (%)	8.31	2.70

3.5 Relationship between the RWUE and Soil Properties

As shown in Table 7, the RWUE significantly correlated with silt ($r = -0.62$, $p< 0.01$), clay ($r = 0.52$, $p < 0.01$), pH ($r = 0.44$, $p < 0.01$), organic matter ($r = 0.68$, $p < 0.01$), Nitrogen ($r = 0.28$, $p < 0.05$), aggregate stability ($r = 0.61$, $p < 0.01$), infiltration capacity ($r = 0.68$, $p < 0.01$) and available water ($r = 0.41$, $p < 0.05$). With an increasing in clay, pH, organic matter, Nitrogen, aggregate stability, infiltration capacity and available water, the RWUE remarkably improved. Aggregate stability, infiltration capacity and available water were the dependent soil variables that were affected by some independent soil properties. Aggregate stability positively correlated with clay, organic matter and lime, whereas sand as resulted by Moreno-de and Heras (2009) negatively affected it. Clay and organic matter as cementation collides encouraged soil particles to stick together and form the stable aggregates in the soils. Presence Ca^{2+} ion in the limey soil matrix also stimulated flocculation of soil colloids (Charman & Murphy, 2000) and increased the aggregate stability. In some dry-lands, presence of the stable aggregates in the soil surface decreased runoff generation, and probably roots aeration due to enhancing resistance of the aggregates against the impact of raindrops and finally soil crusting. Other authors also found significant negative relationships between the aggregate stability and susceptibility to runoff (Reichert & Norton, 1994; Amezketa, Singer, & Le Bissonnais, 1996). Cantón et al. (2009) showed that the stability of topsoil aggregates can be a valuable indicator of field assessed runoff of sandy loam range soils under semiarid conditions. Infiltration capacity had the highest correlation with the RWUE because of its direct influence on the runoff generation. This result was in accord with Gómez et al. (2001), who found that approximately 50% of variability of runoff in fallow plots, can be explained by the final infiltration rate. Infiltration capacity increased with an increase in sand, organic matter and lime. Despite presence sand particles in soil decreased soil porosity, it caused more large pores (macropores) which allowed rapid entry of water into the soil. Organic matter increased water infiltration rate in the soil due to promoting aggregates formation and increasing macrospores proportion in the soil. Studies by Brakensiek and Rawls (1994) and Maestre and Cortina (2002) also indicated that spatial variability of the soil infiltration capacity is related to the high spatial variability of soil properties (organic matter content, structure) that affect the runoff generation in the hillslopes. The presence of organic matter in the soil also improved the soil-water availability due to increasing the water holding capacity (FC) of the soil as a result of the aggregates formation. In many studies, the effect of organic matter in improving the physical properties of soil, such as soil porosity, structure and water-holding capacity were well known (Oades, 1984; Lal, 1986; Lavelle, 1988). While findings of Katerji and Mastrorilli (2006) showed that the WUE was reduced significantly when crops (potato, corn, sunflower, and sugar beet) were grown in clay soil, in the present study clay positively affect on the RWUE. This result was due to strong role of clay in enhancing the stability of soil structure. While findings by Xiaoyan et al. (2002) showed that surface gravel mulch could negatively affect the runoff generation, gravel presence in soil matrix had no significant effect on the soil physical properties and in consequent the RWUE. Nevertheless, in some studies (Li et al., 2000) benefits of Nitrogen (N) was a dependent element to organic matter which improves the crop yield and the RWUE. Deng et al. (2006) also reported that the use of nitrogen fertilizers was one of reasons of increasing the water use efficiency (WUE) in China from 1949 to 1996. Lime has been recognized as an important factor controlling runoff in the soils because Ca^{2+} cations could bind soil particles and improves the aggregates stability (Pepper & Morrissey, 1985).

Table 7. The correlation matrix of the RWUE and physicochemical soil properties in the study area

	Gr	Sa	Si	Cl	F	pH	EC	OM	Li	N	K	AS	If	AW	RWUE
Gr	1														
Sa	0.02	1													
Si	0.02	-0.68**	1												
Cl	-0.06	-0.38*	-0.41*	1											
F	-0.04	-0.39*	-0.09	0.61**	1										
pH	-0.02	-0.16	0-.21	0.44**	0.09	1									
EC	-0.07	-0.35*	0.41*	-0.11	-0.09	-0.03	1								
OM	0.16	0.06	-0.23	0.21	0.29*	0.06	0.02	1							
Li	-0.03	-0.27	0.17	0.03	0.02	0.47**	0.36*	0.05	1						
N	0.13	-0.03	-0.09	0.24	0.55**	-0.08	-0.06	0.60**	-0.24	1					
K	0.09	-0.08	-0.18	0.31*	0.16	0.19	-0.15	0.06	-0.09	-0.07	1				
AS	-0.09	-0.46**	-0.12	0.70**	0.48**	0.56**	0.24	0.29*	0.48**	0.22	0.22	1			
If	0.09	0.57**	-0.55**	-0.07	-0.16	0.26	-0.14	0.54**	0.29*	0.11	0.08	0.13	1		
AW	0.22	0.26	-0.18	-0.07	0.27	-0.01	-0.04	0.55**	-0.10	0.55**	-0.08	0.10	0.33*	1	
RWUE	0.04	0.19	-0.62**	0.52**	0.23	0.44**	-0.03	0.68**	0.30*	0.28*	0.16	0.61**	0.68**	0.41*	1

Gr: gravel; Sa: sand; Si: silt; Cl: clay; F: porosity; pH: potential of hydronium ions; EC: electrical conductivity; OM: organic matter; Li: lime (carbonates); N: nitrogen; K: potassium; AS: aggregate stability; If: infiltration capacity; AW: available water; RWUE: rainfall water use efficiency.

The stepwise multiple regression analysis of the relationship between the RWUE and soil properties showed that the RWUE significantly ($R^2 = 0.85$, $p < 0.001$) related to silt, organic matter and lime (Table 8). Organic matter and lime contrary to silt improved the RWUE in the dry-farming lands. These properties considerably enhanced either the soil infiltration capacity or the soil available water. As well known by Hartanto et al. (2003) and Zhang et al. (2007b), organic matter was the most important binding and bridging agent in enhancing the soil's structural stability, infiltration capacity, and in consequence reducing runoff in the study area. Besides this, organic matter was only effective factor influencing the soil available water and plant growth (Zhang et al., 2007a). Since the soil organic matter is strongly affected by tillage methods such as crop residues and cultivation systems, it can be considered the only management soil factor influencing the RWUE in the study area. Thus, adding organic matter to the soil through maintaining crop residues is a proper technique and sustainable strategy to improve the soil properties (Shaver, 2010), prevention of the excessive soil water evaporation (Howell et al., 1990), decline runoff (Freebairn & Boughton, 1985) and enhance the RWUE in the dry-farming lands. Contour farming is another effective method to prevent runoff generation (Blanco & Lal, 2008; Gebreegziabher et al., 2009) and soil nutrients loss and promote soil physicochemical properties in order to the effective use from rain waters in the sloped dry-farming lands.

Table 8. The multi-regression analysis of the relationship between RWUE and some dependent soil properties

Model variable	Unstandardized coefficients		Standardized coefficient	t-level	p-level
	Model coefficients	Standard error			
Constant	-2.563	0.316		-8.101	p< 0.001
1/Silt	-56.458	6.754	0.588	8.360	p< 0.001
Organic matter	1.582	0.210	0.523	7.523	p< 0.001
Lime	0.054	0.010	0.367	5.370	p< 0.001

A regression equation was developed based on the relationship between the RWUE and the effective soil properties:

$$RWUE = -56.458/Silt + 1.582\ OM + 0.054\ Lime \quad (2)$$

where the RWUE was in kg m^{-3}, silt, OM and lime were in percent.

4. Conclusions

The study indicated that the RWUE (Rainfall water use efficiency) in rainfed conditions remarkably affected by soil properties in the dry-farming lands. Soil properties which considerably enhanced either the water infiltration rate into the soil or the water availability to plant could also improve the RWUE in the study area. The RWUE significantly ($R^2 = 0.85$, $p < 0.001$) related to silt, organic matter and lime. Organic matter and lime positively affected on the soil structure, water infiltration rate and water-holding capacity, while silt inversely affected these soil physical parameters and in consequence the RWUE in the study area. A regression equation was developed based on theses soil properties to predict the RWUE in the study area. Organic matter was only the most important management factor influencing the physic-chemical properties and controlling the RWUE in the study area. Therefore, adding organic matter to the soil through maintaining crop residues is a proper technique and sustainable strategy to improve the soil physic-chemical properties and enhance the RWUE in the dry-farming lands. Contour farming is another effective approach to prevent runoff generation, conserve soil and nutrients, and promote soil physicochemical properties to the effective use of rains in the sloping fields.

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