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THE EFFECTS OF IRRIGATION AND CULTIVATION ON THE QUALITY OF DESERT SOIL IN CENTRAL IRAN

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ABSTRACT

Cultivation of irrigated desert soils in Central Iran is one way of utilizing under-exploited land to produce more food. This study explores the value of soil quality indicators as measures when converting desert to croplands. Soil samples from unfarmed desert, wheat and alfalfa sites in the Abarkooh Plain (Central Iran) were taken from 0–10, 10–20 and 20–30 cm depths. Soil quality indicators including organic carbon, total nitrogen, carbohydrate, particulate organic carbon (POC) in aggregate fractions, and aggregate water-stability were determined. The desert soils contained organic carbon of 0·26–0·56 g kg^{-1}, total nitrogen of 0·05–0·08 g kg^{-1} and carbohydrate of 0·03–0·11 g kg^{-1} at 0–30 cm depth. Across this depth, the contents of organic carbon, total nitrogen and carbohydrate in wheat were about 3–7, 2–3 and 6–26-times higher than those of desert soils, respectively. These values for alfalfa were 5–12, 3–4 and 7–35 times, respectively. The POC (near zero in desert soils) and generally other soil quality indicators showed greater improvement in alfalfa than in wheat fields. The results indicated a significant decrease in proportion of the fraction $<$0·05 mm in cultivated soils, whereas the proportion of the large aggregate size classes (2–4 and 1–2 mm) was increased by irrigation and cultivation. A significant improvement in aggregate water-stability was observed in cultivated soils. At all depths, a large portion of the total soil organic carbon was stored in the fractions $<$0·05 mm for desert and macroaggregates (0·25–2 mm) for cultivated soils.

KEY WORDS: central Iran; desert; irrigation; particulate organic carbon (POC); soil quality

INTRODUCTION

Soil organic matter (SOM) is a major indicator of soil quality (Piccolo, 1996) and it is also a main source for atmospheric CO_2 and other greenhouse gases (Lal, 2004). Nonetheless, particulate organic carbon (POC) can be a more appropriate indicator of soil quality rather total SOM (Chan, 1997) because POC is preferentially lost when pasture soils are converted to cultivated fields (Chan, 2001). In addition, the POC can improve soil aggregation due to forming an organic core surrounded by soil particles (clay and silt), and aggregates (Jastrow and Miller, 1997). Soil aggregate structure and stability are important factors that contribute to sustainable soil quality (Shepherd *et al.,* 2002). It is reported that macroaggregates contain more organic carbon (OC) than microaggregates (Cambardella and Elliot, 1993; John *et al.,* 2005). However, the amount of information on soil quality and aggregation in arid regions is limited.

Approximately 90 per cent of land in Iran is arid or semiarid (Qadir *et al.,* 2008), and estimates suggest that salt-affected soils in the Country cover more than 34 million ha (FAO, 2000). In the central part of the Country, soils with low OC (Hajabbasi and Hemmat, 2000) and high salinity levels are prevalent (Qadir *et al.,* 2008). Leaching of soluble salts is a viable technique for reclamation of salt-affected soils and crop production (Ayers and Wescot, 1985). In Ningxia, China, Fullen *et al.* (1995) reported that the use of irrigation water resulted in distinct improvements in the chemical and physical properties of reclaimed desert soils. In arid regions, irrigation is essential for crop production in order to increase the water availability in the soil (Feng *et al.*, 2005).

Winter wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) are widely grown in central Iran. Alfalfa is not only a high quality forage crop, but also a plant species which can ameliorate soil properties (Bai and Li, 2003). Indeed, alfalfa by symbiotic fixation of nitrogen expect to have a concomitant positive effect on both OC and total nitrogen (TN) added to the soil (Wu *et al.,* 2006). Drinkwater *et al.* (1998) also reported that legume cropping systems could help retention OC and nitrogen in soil.

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Data regarding soil quality and storage of OC in aggregates of desert and the cultivated desert soils in Iran is scarce. Thus, the main objective of this study was to analyse the effects of converting desert to irrigated cropland (alfalfa and wheat) on soil quality indicators and OC storage in different aggregate size classes.

METHODS AND MATERIALS

Study Area

The study area is Abarkooh Plain, with a flat topography and an elevation of around 1500 m above sea-level, nearly 140 km southwest of Yazd, Central Iran (31° 18′ N, 53° 17′ E). The climate of this area is arid with a mean annual precipitation of 60 mm, potential evapotranspiration of 2800 mm, and the temperatures ranging from 40 °C in summer to –13 °C in winter. In the southeast Abarkooh plain, groundwater is saline (1700–2500 μmho cm^{-1}), though it could be exploited to meet crop water requirement. Prior to 1980s the desert has not been used in any way. The cultivation (land preparation for cropping) started about 30 years ago. A flood-irrigation system was developed during 1979–1981 to reduce salinity levels in the root zone and also to provide water for cropping. For the purposes of this study, three adjacent sites with relatively similar properties (soil and parent materials) were chosen including (1) virgin desert, (2) alfalfa (*Medicago sativa* L.) in rotation with wheat and (3) wheat (*Triticum aestivum* L.) in rotation with fallow and barley. The desert is covered by a low coverage of *Tamarix hispida*. Alfalfa was irrigated at 25800 m^3 ha^{-1} from May to November. Wheat was sown in mid-November and was irrigated at 13200 m^3 ha^{-1} from November to May (except January and February). In the cropland, mineral N (as urea) and P (as di-ammonium phosphate) fertilizers are usually applied to improve soil productivity. In these sites, soils usually are cultivated by mouldboard-plough and disc-plough.

Soil Sampling and Analysis

In June 2008, soil samples from desert (area wholly devoid of visible vegetation over an area of at least 100 m from sample site), wheat, and alfalfa sites were taken at 0–10, 10–20 and 20–30 cm depths (the approximate plow layer is 0–30 cm). From each depth, 27 soil samples were taken and mixed to obtain nine composite soil samples (each three soil samples were mixed as a composite sample). Overall, 81 composite soil samples (i.e. 3 sites × 9 composite soil samples in each depth × 3 depths) were prepared for physical and chemical analyses. After air-drying, soil samples were sieved through 4 mm sieve size for aggregate fractionation and separation of POC, and the remaining was sieved through 2 mm sieve size for chemical analysis and particle size distribution. Soil particle size analysis was performed using the pipette method (Gee and Bauder, 1986). Soil pH was measured in the soil saturation paste and electrical conductivity (EC) in saturated extracts. Total OC (the Walkley and Black method), TN (the Kejldahl method), available K (with ammonium acetate) and available P (the Olsen's method) were determined via procedures described in Baruah and Barthakur (1997). Calcium carbonate equivalent was determined using the methods suggested by US Department of Agriculture, Soil Conservation Service, Soil Survey Staff. (1992). The concentration of dilute acid-hydrolysable carbohydrate (CH_{da}) in whole soils was determined by the phenol-sulphuric acid procedure (Dubois *et al.,* 1956).

Fractionation of Water-Stable Aggregates and Separation of POC

The procedure described by Cambardella and Elliot (1993) was used to separate water-stable aggregates. The size distribution of soil aggregates was measured by wet sieving through a series of sieves (2, 1, 0·5, 0·25 and 0·05 mm). A 70 g sample of air-dried soil (<4 mm) was spread on the top of a 2 mm sieve submerged in a bucket of distilled water. Soils were sieved by moving the sieve 3 cm vertically 50 times during a period of 2 min. Materials that passed through the sieve were poured on to the next finer sieve and the process was repeated. The material passing the 0·05 mm sieve (<0·05 mm) was also collected. The aggregates were dried in the oven at 50 °C and weighed. The percentage ratio of the aggregates in each sieve represents the aggregates of size classes: 2–4, 1–2, 0·5–1, 0·25–0·5, 0·05–0·25 and <0·05 mm.

For the separation of particulate organic matter (POM), aggregate fractions were combined into two groups: macroaggregate (0·25–2 mm) and microaggregate (0·05–0·25 mm). The soil macro- and microaggregate fractions were dried (50 °C) in the oven overnight and cooled in a decicator to room temperature. The separation of POM by Loss on Ignition (LOI) was done following the procedure of Cambardella *et al.* (2001). Ten grams of each aggregate fraction was dispersed in 30 ml sodium hexametaphosphate (5 per cent) for 16 h on a reciprocating shaker at 120 strokes per minute. After dispersion, the suspensions were sieved through 0·05 mm sieve to separate sand particles + POM. The collected sand particles + POM were dried at 55 °C to constant weight, and then subjected to 450 °C for 4 h to measure POM by LOI method and POC estimated by multiplying the mass difference by 0·58. Thus, by this procedure the POC in macroaggregate (POC_{mac}) and microaggregate (POC_{mic}) were separately determined.

OC concentration in the sandfree aggregates (sandfree $OC_{fraction}$) was calculated as Six *et al*. (1998):

$$\text{Sandfree } OC_{fraction} = OC_{fraction}/(1-\text{sand proportion}_{fraction})$$

where $OC_{fraction}$ was the concentration of OC in the respective aggregate fraction and sand $\text{proportion}_{fraction}$ was the relative proportion of sand particles in the aggregate fraction. The mean weight diameter (MWD) of the soil aggregates was calculated through the following equation:

$$MWD = \sum_{i=1}^{n} X_i W_i$$

where X_i is the mean diameter of the *i*th sieve size and W_i the proportion of the total aggregates in the *i*th fraction.

Statistical Analysis

The physical and chemical properties in the whole soils and aggregate fractions were repeated nine and three times, respectively. The effect of cultivation of desert on soil and aggregate variables was determined by two-way analysis of variance (ANOVA). Means were compared by least significant difference (LSD). Statistical procedures were carried out using the software package SAS 9·1 for Windows.

RESULTS AND DISCUSSION

Basic Soil Properties

Table I presents some of basic soil characteristics for the studied area. The means of the particle size (sand, silt, and clay fractions) distribution of the desert and cultivated soils were not statistically different and classified as clay loam at all depths. All soils were basic ($8·1 > pH > 7·7$) and there was no significant effect of cultivation on soil pH. Soils in the study area are calcareous (Calcic Haplosalids) with high calcium carbonate contents (32–34 per cent of soil). Desert soils showed the highest EC at all depths (Table I). In these soils, water evaporation is much higher than rainfall thus soluble salts move upward and accumulate in surface layers of soil. The long-term use of irrigation water led to significant leaching of soluble salts from topsoil, therefore, soil EC was substantially lower in the alfalfa and wheat than in desert soils. Soil's plant-available P content was significantly ($p < 0·001$) greater in wheat and alfalfa compared with the desert soils (Table I). Higher values of available P in cultivated soils could be attributed to nutrient fertilization (i.e. N and P). Unlike available P, the available K content was significantly lower in the cultivated soils than in desert soils (Table I) because harvest regularly removed K from the system. Moreover, farmers in this area usually do not apply mineral K fertilizers in the wheat and alfalfa fields.

Table I. Soil physical and chemical characteristics measured in desert and croplands at different soil depths

Sampling depth and site	Sand	Silt (per cent)	Clay	Texture (–)	pH (–)	$CaCO_3$ (per cent)	EC ($dS\,m^{-1}$)	Pa	K ($mg\,kg^{-1}$)
0–10 cm									
Desert	31	34	35	Clay-loam	7·9	34	39·0 b	5·0 d	370 a
Wheat	28	35	37	Clay-loam	7·7	33	3·4 d	16·8 b	162 cd
Alfalfa	28	35	37	Clay-loam	7·8	33	1·9 d	22·8 a	219 bc
10–20 cm									
Desert	29	34	37	Clay-loam	8·1	33	48·5 a	5·7 d	405 a
Wheat	27	34	39	Clay-loam	7·8	32	2·6 d	15·5 bc	134 d
Alfalfa	30	32	38	Clay-loam	7·8	32	2·5 d	17·5 b	117 d
20–30 cm									
Desert	28	34	38	Clay-loam	8·0	33	25·1 c	5·0 d	346 a
Wheat	29	34	37	Clay-loam	7·7	32	2·4 d	12·2 c	226 b
Alfalfa	26	35	39	Clay-loam	7·9	32	2·6 d	15·4 bc	116 d
Summary of ANOVA[a]									
Site	NS	NS	NS	—	NS	NS	(5·8)***	***	***
Depth	NS	NS	NS	—	NS	NS	***	**	NS
Site × depth	NS	NS	NS	—	NS	NS	***	(3·6)*	(64)***

[a]Statistical significance: NS: not significant,
*$p < 0·05$,
**$p < 0·01$,
***$p < 0·001$.
EC: electrical conductivity; Pa: available P. Means ($n = 9$) within a column followed by the same letter are not significantly different at $p < 0·05$. The numbers in parentheses stand for values of least significance differences (LSD) at 0·05 level.

The OC, TN and CH_{da} Contents of Entire Soil

The OC and TN contents were highest in soil samples of alfalfa, intermediate in wheat and lowest in the desert soils at all depths (Table II). The CH_{da} content was also significantly ($p < 0{\cdot}001$) greater in the cropland than in the desert soils. At 0–30 cm depth, the contents of OC, TN and CH_{da} in wheat fields were about 3–7, 2–3 and 6–26-times higher than those of desert soils, respectively. These values for alfalfa were 5–12, 3–4 and 7–35 times, respectively (Table II). The lower OC, TN and CH_{da} contents in desert soils may partly be attributed to reduced plant residues input to the soil because of limitations on plant growth in this harsh environment (high salinity and especially low soil moisture). Soil salinity prevents plant growth, with substantial reductions in above and below ground biomass (Rameeh *et al.,* 2004). In arid soils, salinity-induced degradation is characterized by low soil organic carbon (SOC) content, and indeed the most saline soils had the lowest OC content (Yuan *et al*., 2007). Therefore, the increases in SOM content by cultivation were mainly related to higher carbon inputs from crop residues incorporated in the surface soil with improvement of soil property through leaching by irrigation water. Martens *et al.* (2005) reported that irrigated crop and pasture land in Idaho (in the northwestern USA) had a SOC content of 10–40 Mg C ha^{-1} greater than in native grassland and dryland. Fullen *et al*. (1995) also found that irrigation caused an increase in SOM contents of reclaimed desert soils in Ningxia, China. Rixon (1966) reported that a large amount of carbon was accumulated in response to irrigating in a low fertility and low carbon content soil in NSW, Australia. On-the-other-hand, soil fertilization with nitrogen fertilizer (urea) in cropland could increase the content of crop residue returned to the soil, leading to enhanced SOM levels. Similar findings were reported by Paustian *et al.* (1997) and Alvarez (2005). Alvarez (2005) reported that the increasing effect of N fertilizer on SOC stocks is due to a higher crop residue returned to the soil. In semiarid ecosystems, Cochran *et al.* (2007) observed that cultivation of native shrub-steppe resulted in greater OC and nitrogen contents in cultivated fields. Raiesi (2007) showed that land use changes from pastures to alfalfa fields have resulted in positive influences on soil quality indicators (SOC and TN). Also in cultivated sites, crop residues (wheat straw) during land preparation were not burned. Burning of crop residues significantly reduces SOC in the upper few centimeters of soil (Vågen *et al.,* 2005).

Table II. Organic carbon, total nitrogen and carbohydrate contents ($g\,kg^{-1}$ soil) of desert and croplands at different soil depths

Sampling depth and site	OC	TN ($g\,kg^{-1}$ soil)	CH_{da}
0–10 cm			
Desert	0·56 d	0·07 d	0·03 e
Wheat	2·88 b	0·18 bc	0·78 b
Alfalfa	3·80 a	0·30 a	1·04 a
10–20 cm			
Desert	0·72 d	0·08 d	0·11 e
Wheat	2·18 c	0·16 c	0·60 cd
Alfalfa	3·30 ab	0·27 a	0·72 bc
20–30 cm			
Desert	0·26 d	0·05 d	0·08 e
Wheat	1·76 c	0·14 c	0·47 d
Alfalfa	3·01 b	0·22 b	0·57 cd
Summary of ANOVA[a]			
Site	***	***	(0·16)***
Depth	(0·58)***	(0·04)**	***
Site × depth	NS	NS	***

[a]Statistical significance: NS: not significant,
**$p < 0{\cdot}01$,
***$p < 0{\cdot}001$.
OC: organic carbon; TN: total nitrogen; CH_{da}: dilute acid-hydrolysable carbohydrate. Means ($n = 9$) within a column followed by the same letter are not significantly different at $p < 0{\cdot}05$. The numbers in parentheses stand for values of least significance differences (LSD) at 0·05 level.

Unlike Chan (2001) and John *et al.* (2005) which concluded the adverse effects of cultivation on SOM, the results revealed that the virgin soils in this arid region because of existing water limitation and high salinity had low productivity and generally very poor in SOM. Thus the long-term irrigation resulted in a significant decrease in soil salinity, and also the irrigation along with the fertilization in cropland increased the level of crop residue returned to the soil and consequently increasing of SOM.

The amount of OC, TN and CH_{da} were significantly higher in alfalfa compared to the wheat fields (Table II). This could be due to a greater return of plant residues (especially root residues) and less soil disturbance in alfalfa which led to a greater rate of SOM in alfalfa fields. Wu *et al.* (2003) reported that conversion from fallow-wheat to alfalfa as perennial forage for 10 yr resulted in greater SOC in alfalfa fields in Canada. Alfalfa has an extensive network of roots which upon senescence, leads to higher SOC and carbon sequestration (Zhang *et al.,* 2009).

The POC_{mac} and POC_{mic} Contents

Data on POC contents ($g\,kg^{-1}$ soil <4 mm) of the soil macro- and microaggregates are reported in Table III. The POC_{mac} in desert soils was not determined because the proportion of the macroaggregates for separation of POM was scant. Also, the POC_{mic} contents in these soils were very low (near zero). The POC_{mac} in 0–30 cm layer was increased by 92–312 per cent under alfalfa, compared to the wheat fields. However, the content of POC_{mic} in 0–10 cm depth was increased by 71 per cent under alfalfa relative to the wheat fields (Table III). These results are agreed with the findings of Su (2007) who showed that POM-C in perennial forages was significantly greater than that in annual crops. Greater inputs of young residues from alfalfa could be accounted for

Table III. POC_{mac} and POC_{mic} contents and ratio of POC_{mac}/POC_{mic} in croplands at different soil depths

Sampling depth and site	POC_{mac}	POC_{mic}	POC_{mac}/POC_{mic} ratio
	($g\,kg^{-1}$ soil <4 mm)		–
0–10 cm			
Wheat	0·57 cd	0·21 b	2·7 d
Alfalfa	2·35 a	0·36 a	6·5 a
10–20 cm			
Wheat	0·65 cd	0·27 ab	2·4 e
Alfalfa	1·25 b	0·26 b	4·7 b
20–30 cm			
Wheat	0·41 d	0·19 b	2·2 e
Alfalfa	0·84 c	0·25 b	3·4 c
Summary of ANOVA[a]			
Site	***	(0·09)*	(0·4) ***
Depth	***	NS	***
Site × depth	(0·38)***	*	***

[a]Statistical significance: NS: not significant,
*$p < 0{\cdot}05$,
***$p < 0{\cdot}001$.
POC_{mac}: particulate organic carbon in macroaggregate; POC_{mic}: particulate organic carbon in microaggregate. Means ($n = 3$) within a column followed by the same letter are not significantly different at $p < 0{\cdot}05$. The numbers in parentheses stand for values of least significance differences (LSD) at 0·05 level.

the higher POC in alfalfa relative to wheat fields. The POM is the first product of SOM stock in the decomposition process of plant residues and also consists of relatively young plant debris primarily from plant roots (Gale and Cambardella, 2000). The smaller differences in POC_{mic} contents between the soils from the wheat and alfalfa fields were mainly due to larger proportion of microaggregate fractions in soils of wheat (Table IV). Unlike wheat fields, in the soils from alfalfa fields, the POC_{mac} and POC_{mic} contents were higher at 0–10 cm depth than at 10–20 and 20–30 cm depths. This was probably because plant residual (e.g. stem remainders, dead roots and leaves) were annually transferred to the deep soil by ploughing in the wheat fields. In contrast, no ploughing was conducted in the alfalfa fields and the plant residuals were mainly added to the soil surface.

The POC_{mac}/POC_{mic} ratios at the three depths of cultivated soils are shown in Table III. In all soils, the POC_{mac}/POC_{mic} ratios were >2 indicating that more OC was associated with macroaggregates compared to micro-aggregates. These results are in agreement with the observation of John *et al.* (2005) who found that in cultivated soils, the SOC concentration was greater for macroaggregates than microaggregates. At all depths, the alfalfa showed a higher POC_{mac}/POC_{mic} ratio compared to the wheat fields. The annual ploughing of soil in wheat fields may have led to the transfer of SOM from the macro-aggregates to microaggregates (Christensen, 1992). The POC can serve as a useful component of a general soil quality index (Gregorich *et al.,* 1994; Chan 2001). This study showed that the POC available in aggregates (POC_{mac} and POC_{mic}) and POC_{mac}/POC_{mic} ratio can also serve as a sensitive indicator of changes in SOM because of its responsiveness to management (tillage intensity) and soil aggregation.

The results showed that in the cultivated desert soils, irrigation largely increased soil moisture and plant biomass input to the soil and led to positive influences on SOM components. The increase in SOC pool caused an increase in soil quality (Lal, 2002, 2006). The results of this study further showed that cultivation of irrigated desert soils that are very poor in SOC could improve soil quality. Thus irrigation might be the main factor of improvement in soil quality of the cultivated desert soils, and avoiding or reduction in irrigation, probably reduces the soil quality.

The Water-Stable Aggregates Distribution and Stability

The proportion of the large aggregate size classes (2–4 and 1–2 mm) was increased by irrigation and cultivation. Furthermore, continuous cultivation of desert soils significantly reduced the proportion of <0·05 mm aggregate size class (Table IV). Although, John *et al.* (2005) and Raiesi (2007) observed a greater aggregate stability in the virgin compared to the cultivated soils, cultivation of desert soils increased water-stable aggregates to a larger diameter. This was also reflected in the aggregate stability index used (MWD), which shows consistently higher values in the cultivated soils at all depths (Figure 1). At 0–10 cm depth, the values of MWD for desert, wheat and alfalfa fields were 0·06, 0·55 and 0·6 mm, respectively. At 10–20 and 20–30 cm depths, the MWD values were 0·06 and 0·1 mm for desert soils, 0·52 and 0·34 mm for soils in wheat and 0·71 and 0·76 mm for soils in alfalfa, respectively (Figure 1).

Weak structural stability of desert soils is basically due to high EC and low SOM. Tejada and Gonzalez (2005) also reported that an increase in EC has adverse effects on soil structural stability. Because of high soil EC in the desert soils, larger aggregates (>1 mm) are unstable and the formation of stable aggregates is very poor in these soils. In fact, soil aggregation was much less pronounced in the desert soils. Fullen *et al.* (1995) found that irrigation caused an improvement in the structure of reclaimed desert soils. In this study, the continuous cultivation (long-term use of irrigation water) led to substantial leaching of soluble salts from topsoil, and probably improved soil conditions for aggregation (e.g. increase in activity of roots, micro- and macro-organisms). Formation of aggregates may be caused by the activities of roots, microorganisms and fungi, which bind microaggregates to form macroaggregates (Tisdall and Oades, 1982). Higher values of MWD in the soils of wheat and alfalfa fields might be attributed to cropping via

Table IV. Distribution (per cent) and organic carbon contents ($g\,kg^{-1}$ aggregate) of aggregate size classes in desert and croplands at different soil depths

Sampling depth and site	Aggregate size class											
	2–4 mm		1–2 mm		0.5–1 mm		0.25–0.5 mm		0.05–0.25 mm		< 0.05 mm	
	Distribution per cent	OC ($g\,kg^{-1}$ aggregate)	Distribution per cent	OC ($g\,kg^{-1}$ aggregate)	Distribution per cent	OC ($g\,kg^{-1}$ aggregate)	Distribution per cent	OC ($g\,kg^{-1}$ aggregate)	Distribution per cent	OC ($g\,kg^{-1}$ aggregate)	Distribution per cent	OC ($g\,kg^{-1}$ aggregate)
0–10 cm												
Desert	0.0 d	0.0 d	0.0 e	0.0 d	1.2 e	1.2 d	3.7 c	0.1 e	16.3 cd	0.5 de	43.0 a	0.8 e
Wheat	10.3 b	4.6 bc	8.6 d	4.2 c	4.3 cd	3.6 bc	12.9 ab	2.4 d	19.4 abc	1.4 c	13.9 d	1.8 d
Alfalfa	5.9 c	14.3 a	20.3 a	13.6 a	6.3 ab	7.6 a	13.4 a	6.0 a	12.6 de	4.2 a	8.1 de	3.7 a
10–20 cm												
Desert	0.0 d	0.0 d	0.0 e	0.0 d	0.0 e	0.0 d	5.1 c	0.2 e	24.4 a	0.5 de	36.3 b	1.1 e
Wheat	6.5 c	5.8 b	13.3 c	3.9 c	6.8 a	3.2 c	13.3 ab	2.8 cd	18.6 bc	1.7 c	12.1 de	2.3 cd
Alfalfa	10.6 b	5.8 b	20.0 a	6.4 b	5.2 abc	4.7 b	11.1 ab	3.8 b	9.7 e	3.2 b	9.4 de	3.4 ab
20–30 cm												
Desert	0.0 d	0.0 d	0.0 e	0.0 d	3.4 d	0.3 d	10.2 b	0.0 e	22.8 ab	0.0 e	27.6 c	0.85 e
Wheat	3.9 c	6.0 b	6.7 d	5.0 bc	5.1 abc	3.9 bc	13.0 ab	2.0 d	22.1 ab	1.0 cd	6.0 e	2.0 d
Alfalfa	13.8 a	4.0 c	16.9 b	4.4 c	5.0 bcd	3.3 bc	10.8 ab	3.3 bc	11.4 de	2.5 b	10.2 de	2.8 bc
Summary of ANOVA[a]												
Site	(2.67) ***	(1.58) ***	***	(1.93) ***	***	***	***	***	***	***	***	(0.67) ***
Depth	NS	***	**	***	NS	(1.50)**	NS	(0.92)**	NS	(0.77)**	**	NS
Site × depth	***	***	(2.85)*	***	(1.68)**	**	(3.15)**	**	(5.03)*	NS	(6.25)*	NS

[a]Statistical significance: NS: not significant,
*$p < 0.05$,
**$p < 0.01$,
***$p < 0.001$.
OC: organic carbon. Means ($n = 3$) within a column followed by the same letter are not significantly different at $p < 0.05$. The numbers in parentheses stand for values of least significance differences (LSD) at 0.05 level.

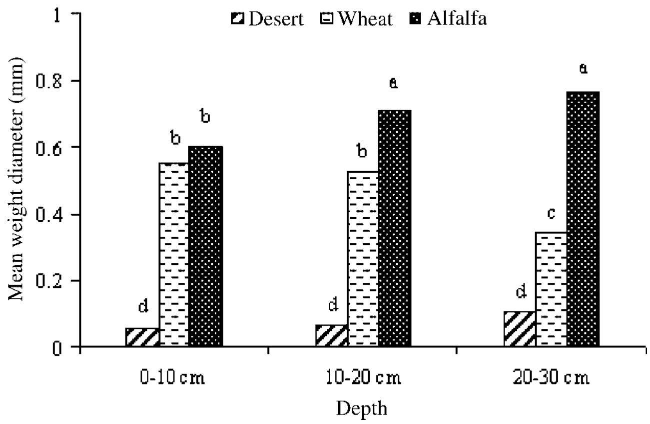

Figure 1. Mean weight diameter of soil in desert and cropland sites. Means ($n = 3$) followed by the same letters are not significantly different at $p < 0{\cdot}05$, (LSD = 0·08).

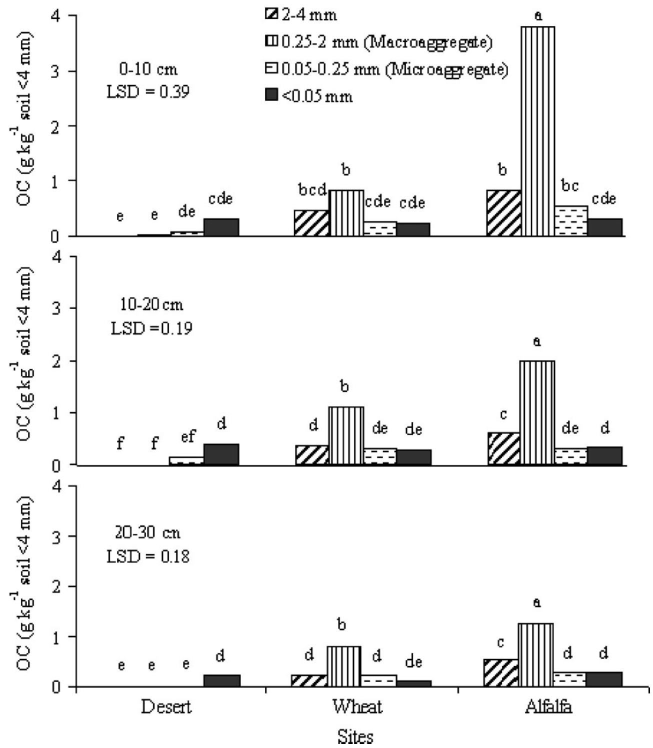

Figure 2. Organic C contents (g kg^{-1} soil <4 mm) of different fractions in desert and cropland sites. Means ($n = 3$) followed by the same letters are not significantly different at $p < 0{\cdot}05$.

increased inputs of organic matter, and probably the increased contents of POC and CH_{da}. Jastrow and Miller (1997) emphasizing on the role of POC and Haynes and Beare (1996) proposed the positive effects of carbohydrate on improving soil aggregation. In most depths, the wheat showed a lower soil aggregate stability compared to the alfalfa fields (Figure 1). The extensive root system of alfalfa and high level of SOM in these fields probably contributed the increase of soil aggregate stability. Reclamation and cultivation of desert soils resulted in the significant increase in aggregate stability. This result indicates that there was an improvement in soil structure and consequently in soil quality during the cultivation of desert soils.

The OC Contents in Aggregates and Fractions

Data on the OC contents (g kg^{-1} aggregate) of the different aggregate size classes are reported in Table IV. Irrigation and fertilization of desert soils resulted in significant increases in OC associated with aggregates which were corresponded to the changes (increase) in the whole SOC. In most cases, the OC contents in the soil aggregate size classes of the alfalfa were significantly higher than those in the wheat fields (Table IV). There was a significant site × aggregate fractions interaction on the OC contents (g kg^{-1} soil <4 mm) of fractions indicating that the effect of cultivation was much more evident in the 2–4 mm and macroaggregates fractions than microaggregates and <0·05 mm fractions (Figure 2). With the exception of OC in the microaggregates and <0·05 mm fractions, the contents of OC in the different fractions of the cultivated soils were significantly higher than those in the desert soils (Figure 2). At all depths, a large portion of the total soil organic carbon was stored in the fractions <0·05 mm for desert and macroaggregates (0·25–2 mm) for cultivated soils (Figure 2). These results indicated that in the cultivated sites, large portion of SOC was stored in stable aggregates, and the silt plus clay particles contained small fraction of SOC (Figure 2). This is in agreement with the finding reported by John *et al.* (2005). As with the findings of Cambardella and Elliot (1993) and John *et al.* (2005), the data indicated that the OC contents in the microaggregates were lower than those in the macroaggregates fractions in the cultivated soils at all depths. Overall (0–30 cm depth) results show that in terms of soil quality indicators like MWD, OC, TN, CH_{da}, POC_{mac}, and POC_{mic} alfalfa has respectively 1·6, 1·5, 1·6, 1·2, 2·7 and 1·3 higher values than wheat. But, the volume of applied water is approximately twice in alfalfa than wheat fields, thus in terms of water resources management in central Iran, wheat cropping may be more efficient than alfalfa.

CONCLUSIONS

Positive influences of irrigation, cultivation and fertilization of desert soils were acquired on soil quality indicators measured in this study. Since a vast area of central Iran is desert with low precipitation, high amount of salt and a structure-less soil with very low organic matter, any activity improving these characteristics could help increasing soil quality in this region. In most cases, the SOM components and soil aggregate stability were greater in alfalfa than in the wheat fields, reflecting a better soil quality and thus higher potential for increasing SOC sequestration in the alfalfa fields. Nonetheless, the volume of applied water was far greater in alfalfa compared to wheat fields. Therefore, one should decide between a higher soil quality and more SOC sequestration in alfalfa or lower use of water in wheat fields.

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