Aggregation, carbohydrate, total and particulate organic carbon changes by cultivation of an arid soil in Central Iran

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Abstract
The objectives of this paper were to determine the response of soil quality indicators and organic carbon (OC) distributions within different aggregate classes to changes in land use from desert soils to cropland occurring in the Abarkooh plain, Central Iran. Composite soil samples of the desert soil, wheat and alfalfa fields were taken from three different depths and soil quality indicators, including aggregate stability (MWD), OC, carbohydrate, particulate organic carbon existent in macro (POC_{mac}) and microaggregates (POC_{mic}) in these soils were determined. Conversion of desert soils to croplands resulted in a significant decrease in electrical conductivity (EC), but an increase in MWD, OC, carbohydrate, POC_{mac} and POC_{mic} contents. OC content increased with increased aggregate size and the aggregate; OC ratio in cultivated and desert soils was highest in the 1-2 and <0.05 mm aggregates, respectively. The improvement soil quality in cropland is due to the long-term use of irrigation water and soil fertilization and also the poor SOM in desert soils. The results of this study further indicate the POC_{mac}, POC_{mic} and POC_{mac}/POC_{mic} ratio are sensitive parameters that reflect differences of soil aggregation, SOM quality and tillage intensity in soils of this region. These parameters are more reliable indicators of soil quality than OC in reclaimed desert soils.

Key Words
Soil quality, desert soils, cultivation, irrigation, soil aggregate, particulate organic carbon (POC).

Introduction
The desert soils in arid regions of Central Iran are characterized by low rainfall, low fertility, high evaporation and salinity. Also, soil water and salinity are crucial factors influencing crop production in these regions. Numerous field trials have demonstrated the effectiveness of leaching for salt removal. For example, Fullen *et al*. (1995) reported that use of irrigation water resulted in distinct and rapid improvements in the physical and chemical properties of reclaimed desert soils. Soil aggregate structure and stability are important factors that contribute to sustainable soil quality (Shepherd *et al.* 2002). Numerous studies have shown that conversion of native ecosystems to agriculture, especially in tropical and temperate regions have led to a negative impact on soil quality (Islam and Weil 2000). Nonetheless, information about the soil quality of desert soils and marginal cropland is scarce. Thus, the main objectives of this study were: (1) to analyze the effects of changes in land use from desert soils to croplands on soil quality indicators (2) to determine aggregate organic carbon (OC) ratio (OC in aggregate/OC in total aggregates) and also the distribution of OC in the aggregates of soils under desert and cropland.

Methods
Study area
The study area was located in Abarkooh plain at an elevation of around 1500 m above sea level, nearly 140 km southwest of Yazd, Iran (31° 18′ N, 53° 17′ E). The climate of the region is arid with a mean annual rainfall of 60 mm, potential evapotranspiration of 2800 mm and the temperatures ranging from 40 °C in summer down to -13 °C in winter. In the southeast Abarkooh plain, groundwater is mainly saline (1700–2500 µmho cm^{-1}), but could be exploited to meet crop water requirement. A flood-irrigation system was developed during 1979–1981 to reduce salinity levels in the root zone and increase water availability. Therefore, this research was conducted to understand the changes of soil quality and aggregation resulting only from cultivation of desert soils. For this purpose, three different land uses were chosen in the study area including virgin desert, alfalfa (*Medicago sativa* L.) in rotation with wheat, and wheat (*Triticum aestivum* L.) in rotation with fallow and barley. At the time of sampling, the vegetation of the desert soils was dominated by *Tamarix hispida*. In the cropland, mineral N (urea) and P (di-ammonium phosphate) fertilizers are usually applied for improving soil productivity.

Soil sampling and analysis
In June 2008, three blocks (each 60×60 m) were randomly selected from each of the two treatments (wheat and alfalfa fields) for soil sampling to produce nine pseudo replications. At each block, nine sub-samples at each depth of 0–10, 10–20 and 20–30 cm were taken and mixed as three composite samples. Adjacent to sampling areas of the two treatments, three uncultivated (desert soils) blocks were randomly selected and sampled in the same way. Overall, 81 composite soil samples were collected, comprising three land uses, three depths and nine replicates. 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 electrical conductivity (EC) was measured in saturated extracts and OC with the Walkley & Black method, were determined. The content of dilute acid-hydrolysable carbohydrate (CH_{da}) in whole soils was determined by the phenol-sulphuric acid method of Dubois *et al.* (1956).

Fractionation of water stable aggregates and separation of POC_{mac} and POC_{mic}
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). Also, the material passing the 0.05 mm sieve (<0.05 mm) was collected. 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). Soils from the bulked macroaggregate and microaggregate fractions were dried (50˚C) in the oven overnight and cooled in a decicator to room temperature. Then, 10 g of each aggregate fraction was dispersed in 30 ml sodium hexametaphosphate (5%) for 16 h on a reciprocating shaker at 120 reciprications per minute. After dispersion, the suspensions were sieved through 0.05 mm sieve to separate sand particles and POM. The separation of POM by Loss on Ignition (LOI) was done following the procedure of Cambardella *et al.* (2001). 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.

Statistical analysis
The physical and chemical properties in the whole soils and aggregate fractions were repeated nine and three times, respectively. In each depth, one-way ANOVA was conducted to detect significant differences between land uses and, among the different aggregate size classes. Significant treatment means were separated using Duncan test at $p < 0.05$. Statistical procedures were carried out using the software package SPSS 15.0 for Windows.

Results and discussion
The electrical conductivity (EC)
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 fields than in the desert soils. Desert soils contained the highest EC at all depths (Figure 1).

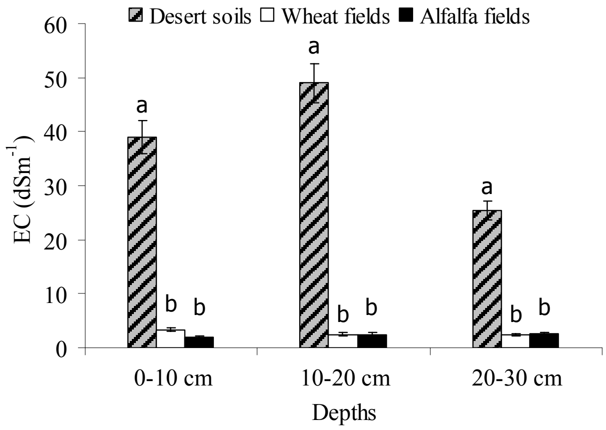

Figure 1. Electrical conductivity (EC) of soils under different land uses at the three depths. In a depth, similar letters indicate no significant difference among the land uses at *p* <0.05. Each value represents means ± S.E. (n=9).

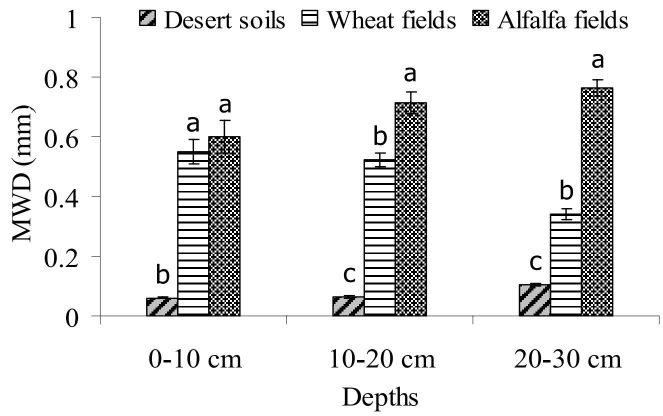

Figure 2. Mean aggregate stability (MWD) of soils under different land uses at the three depths. In a depth, similar letters indicate no significant difference among the land uses at *p* <0.05. Each value represents means ± S.E. (n=3).

The Water-stable aggregates distribution and stability

The most frequent aggregate fractions were the aggregates <0.05 mm for the desert soils, the microaggregates for wheat and the aggregates 1–2 mm for alfalfa at all depths (data not shown). 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. Hence reclamation and cultivation of desert soils considerably increased the value of aggregate stability (Figure 2). The long-term use of irrigation water led to substantial leaching of soluble salts from topsoil and caused an improvement in the soil structure.

The OC and CH_{da} contents

The OC and CH_{da} contents were highest in the soil samples of alfalfa fields, intermediate in wheat fields and lowest under desert soils at all depths (Table 1). The lower OC and CH_{da} contents in desert soils may partly be attributed to reduced plant residues input to the soil because of limitation to plant growth in the harsh environment (low moisture and fertility and high salinity of soil). Salinity-induced degradation in arid soils is characterized by low soil OC values and indeed, the most saline soils had the lowest OC content (Yuan *et al.* 2007). Therefore the increases in OC and CH_{da} contents in cultivated fields were mainly related to higher carbon inputs from crop residues incorporated in the surface soil during improvement of soil property with irrigation. In agreement with our results, Fullen *et al*. (1995) found that the irrigation caused an increase in SOM content of reclaimed desert soils. On the other hand, soil fertilization with nitrogen fertilizer (urea) in cropland could increase the level of crop residue returned to the soil, leading to enhanced OC content. Similar findings were reported by Alvarez, (2005) who found that the effect of nitrogen fertilizer on SOM storage was very probably a consequence of the increase in residues returned to the soil where fertilizer nitrogen was used. Our results are in contrast with the findings of studies in tropical and temper regions that shows conversion of the virgin lands into continuous cultivation resulted in significant decrease in the content of SOM (Islam and Weil 2000). Indeed, these researches show that the most virgin lands (pasture or forest) in tropical or temperate regions had the high SOM content and cultivation resulted in significant reduction in inputs of plant residues. Nonetheless, our results revealed that in arid regions, virgin soils because of existing water limitation and high salinity had low productivity and generally are very poor in SOM. The irrigation and soil fertilization in cropland increases the level of crop residue returned to the soil.

Table 1. OC and CH_{da} contents of soils under different land use systems at the three depths.

Depths (cm)	OC (g/kg soil)			CH_{da} (g/kg soil)		
	Desert soils	Wheat fields	Alfalfa fields	Desert soils	Wheat fields	Alfalfa fields
0-10	0.56 C (0.03)	2.88 B (0.26)	3.80 A (0.30)	0.03 C (0.01)	0.78 B (0.07)	1.0 A (0.09)
10-20	0.72 C (0.06)	2.18 B (0.21)	3.30 A (0.27)	0.11 B (0.01)	0.60 A (0.06)	0.72 A (0.05)
20-30	0.26 C (0.02)	1.76 B (0.18)	3.01 A (0.27)	0.08 B (0.02)	0.47 A (0.06)	0.57 A (0.05)

OC; organic carbon, CH_{da}; dilute acid-hydrolysable carbohydrate, Means and S.E. (n= 9). In a row, similar letters indicate no significant difference between the land uses p <0.05.

The POC_{mac} and POC_{mic} contents

In desert soils, because the proportion of the macroaggregates for separation of POM was scant, the POC_{mac} in these soils was not determined. Also, the POC_{mic} contents in these soils were very low. Data on POC_{mac} and POC_{mic} contents (g/kg soil <4 mm) indicated that whereas the POC_{mac} contents were significantly higher in the alfalfa than in the wheat, POC_{mic} contents for alfalfa and wheat fields were not statistically different mainly due to large proportion of soil in microaggregate of soils under wheat (Table 2). In most of the cases, the POC_{mac} content was consistently higher than the POC_{mic}. These results are in agreement with the observation of John *et al.* (2005) who found that in cultivated soils, the organic matter content of macroaggregates is considerably greater than that of microaggregates. Since soil quality is dependent upon organic matter content, our results showed that land use changes from desert soils to cropland have resulted in positive influences on SOM components and these demonstrate that cultivation of desert soils that are very poor in SOM, could improve soil quality. At all depths, the alfalfa fields showed a higher POC_{mac}/POC_{mic} ratio compared to the wheat fields. This could be attributed to different annual organic matter input and the decomposing of crop residuals and SOM, due to annual tillage in wheat fields. The annual ploughing and disturbing the soil in wheat fields versus soil ploughing every 6-7 years in alfalfa fields may have led to the transfer of SOM from the macroaggregates to microaggregates. John *et al.* (2005) found that OC in macroaggregates is younger than OC in microaggregates; consequently POC_{mac} is younger and more labile than POC_{mic}. This suggested that the SOM in alfalfa fields is more labile than organic matter in wheat fields. It was concluded that POC_{mac}, POM_{mic} and POC_{mac}/POM_{mic} ratio are sensitive parameters that reflect differences of soil aggregation, organic matter quality and tillage intensity in soils of this region. These results showed that POC_{mac}, POC_{mic} and POC_{mac}/POM_{mic} ratio are more reliable indicators of soil quality than OC in reclaimed desert soils.

Table 2. POC_{mac} and POC_{mic} contents in cultivated soils at the three depths.

Depths (cm)	POC (g/kg soil <4 mm)			
	Alfalfa fields		Wheat fields	
	POC_{mac}	POC_{mic}	POC_{mac}	POC_{mic}
0-10	2.35±0.24a	0.36±0.03	0.57±0.06	
10-20	1.25±0.15a	0.26±0.02	0.65±0.05	0.27±0.03c
20-30	0.84±0.07a	0.25±0.03	0.4	

POC_{mac}; particulate organic carbon in macroaggregate, POC_{mic}; particulate organic carbon in microaggregate. Means ± S.E. (n=3). Similar letters in rows indicate no significant difference at p <0.05.

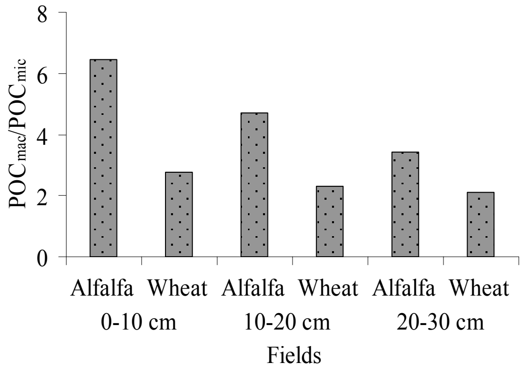

Figure 3. POC_{mac}/POM_{mic} ratios of cultivated soils at the three depths.

The OC content and aggregate OC ratio in aggregates

In the desert soils, OC content and the aggregate OC ratio (ratio of OC in aggregate to OC within total aggregates) were highest in the fraction <0.05 mm (data not shown). Conversely, in both cultivated soils, OC content was highest in aggregates 2-4 and 1-2 mm and the 1-2 mm aggregates had the highest aggregate OC ratio for the two cultivated soils. This indicated the importance of 1-2 mm aggregates, which stored more than 30-48% and 20-26% of the OC in soils under alfalfa and wheat fields, respectively. The general trend showed that OC content, in the cultivated soils, increases as aggregate size increased from 0.05 to 4 mm diameter (data not shown).

Conclusion

This study concluded that water deficit and soil salinity have larger roles in reducing soil quality than agricultural practices such as tillage. The results of the present study show the positive influences that land use conversion from desert soils to cropland might have on indicators of soil quality. The results of this study further indicate the POC_{mac}, POM_{mic} and POC_{mac}/POM_{mic} ratio are sensitive parameters that reflect differences of soil aggregation, SOM quality and tillage intensity in soils of this region. These parameters are more reliable indicators of soil quality than OC in reclaimed desert soils. In arid ecosystems, cultivation of desert soils that are very poor in SOM could improve soil quality.

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