Arid Land Research and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uasr20

# Long-term Cultivation and Landscape Position Effects on Aggregate Size and Organic Carbon Fractionation on Surface Soil Properties in Semi-arid Region of Iran

A. Safadoust[a], N. Doaei[a], A. A. Mahboubi[a], M. R. Mosaddeghi[b], B. Gharabaghi[c], P. Voroney[d] & B. Ahrens[e]

[a] Department of Soil Science, College of Agriculture, Bu-Ali Sina University, Hamadan, Iran

[b] Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, Iran

[c] School of Engineering, University of Guelph, Guelph, ON, Canada

[d] School of Environmental Sciences, University of Guelph, Guelph, ON, Canada

[e] Department of Geography, University of Guelph, Guelph, ON, Canada

To cite this article: A. Safadoust, N. Doaei, A. A. Mahboubi, M. R. Mosaddeghi, B. Gharabaghi, P. Voroney & B. Ahrens (2015): Long-term Cultivation and Landscape Position Effects on Aggregate Size and Organic Carbon Fractionation on Surface Soil Properties in Semi-arid Region of Iran, Arid Land Research and Management, DOI: 10.1080/15324982.2015.1016244

To link to this article: http://dx.doi.org/10.1080/15324982.2015.1016244

Arid Land Research and Management, 0:1–18, 2015
Copyright © Taylor & Francis Group, LLC
ISSN: 1532-4982 print/1532-4990 online
DOI: 10.1080/15324982.2015.1016244

# Long-term Cultivation and Landscape Position Effects on Aggregate Size and Organic Carbon Fractionation on Surface Soil Properties in Semi-arid Region of Iran

A. Safadoust[1], N. Doaei[1], A. A. Mahboubi[1],
M. R. Mosaddeghi[2], B. Gharabaghi[3], P. Voroney[4], and B. Ahrens[5]

[1]Department of Soil Science, College of Agriculture, Bu-Ali Sina University, Hamadan, Iran
[2]Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, Iran
[3]School of Engineering, University of Guelph, Guelph, ON, Canada
[4]School of Environmental Sciences, University of Guelph, Guelph, ON, Canada
[5]Department of Geography, University of Guelph, Guelph, ON, Canada

*This study was carried out to investigate the effects of long-term cultivation and landscape position on organic carbon content and soil aggregation. Sampling sites were determined based upon land use at the end of 50 years soil use and management, cultivated/annual wheat cropping and grazed pasture, and landscape position in Chaharmahal-va-Bakhtiary province, southwest Iran. Soil samples were collected from the 0–5 cm and 5–15 cm depths in two adjacent fields that have the same slope and aspect. The soil was silty clay at the summit and footslope positions, and was a silty clay loam at the backslope. Wet-sieving analysis and aggregate-size fractionation methods were used to separate the samples into three aggregate fractions (i.e., 2–4.75, 0.25–2, and 0.053–0.25 mm). The treatments were arranged in a factorial design. Land use significantly affected the water-stable aggregate fractions, so that the wet soil stability of the macroaggregates (i.e., 2–4.75 mm) was higher in the pasture, whereas it was greater for the meso-aggregates (i.e., 0.25–2 mm) in the cultivated soils. Cultivation decreased both the wet-aggregate stability and percent of macroaggregates whereas long-term pasture enhanced aggregation. Soil organic carbon (SOC) content within aggregates and primary particles was also significantly influenced by landscape position, land use, and the depth of sampling. The SOC content was higher in clay than those in silt and sand contents. The SOC content decreased as depth increased in all fractions. In general, the highest and lowest wet-stable aggregates were observed on the footslope and backslope positions, respectively.*

**Keywords** aggregates, cultivation, land use, soil stability, soil use and management

Received 26 May 2013; accepted 3 February 2015.

Address correspondence to A. Safadoust, Department of Soil Science, College of Agriculture, Bu-Ali Sina University, Azadegan Street, Hamadan 65174, Iran. E-mail: safadoust@basu.ac.ir

## Introduction

Soil organic matter (SOM), was significantly affected by land use in both quality and quantity (Ayoubi and Karchegani, 2012). Changes in land use, such as the cultivation of pasture soils for field crops, reduces SOM content, causes soil bulk density (BD) to increase, and causes aggregate stability and saturated hydraulic conductivity to decrease (Skidmore, Carstenson, and Banbury, 1975; Scott, Rutledge, and Miley, 1983; Puget and Lal, 2005). Several parameters including soil structure, texture, and soil management are important determinates in soils associated with rate and quality of C sequestration (Hao et al., 2002; Mishra, Ussiri, and Lal, 2010). Bauer and Black (1981) reported a rapid decrease of SOM and total nitrogen content during the initial ten years of cultivation and cropping of a pasture land, where a decline of SOM continued approaching a steady state level after a long-term of cultivation. Tillage impacts soil structure by reducing SOM and altering the distribution and aggregates' stability (Angers, Pesant, and Vigneux, 1992; Six et al., 1998). The beneficial effect of no-tillage management on soil aggregation and aggregate stability, due to minimum soil mixing and disturbance that results in SOM accumulation, was reported by several studies (Blevins and Frye, 1993; Mahboubi, Lal, and Faussey, 1993; Six, Elliott, and Paustion, 1999).

Land use change and different management practices partition SOM into different aggregate-size fractions and into different primary particle-associated fractions (Bronick and Lal, 2005; Hoyos and Comerford, 2005). When a soil is subjected to agricultural practices the macroaggregates are broken down, resulting in the SOM being more vulnerable to mineralization (Cambardella and Elliott, 1993; Six, Elliott, and Paustion, 2000). The soil organic carbon (SOC) and aggregates reciprocally conserve each other in the sense that SOC is protected from degradation by its association with soil primary particles and/or by being contained within aggregates, whereas aggregate stabilization is enhanced by the SOC that is physically-protected (Six, Elliott, and Paustion, 1999; Six et al., 2002). The soils in the foothills of the Zagros mountains of western Iran are consistently under risk of degradation due to the severe slope and the high frequency of heavy rains. Livestock overgrazing and changes in the natural forests and grasslands to dryland farms (with unsuitable management systems), has resulted in destruction of the soils' structure, which has led to erosion in these regions.

Unfortunately, information on the effects of cropping in terms of landscape position and the effect of this system to SOC storage is lacking. The objective of this study is to determine: (1) how wet-aggregate stability and distribution of aggregate-size fractions are altered by long-term changes in land use; (2) how land use and landscape position impact the particle size fractions and the associated SOC content; and (3) how cultivation affects the partitioning of SOC content in different aggregate fractions. The hypothesis is that changes in land use and landscape position will affect the soils' physical quality, which is demonstrated by soil organic carbon content and aggregate stability. Changes in the soil properties that are associated with these factors can be useful the development of sustainable land management practices and to determine the potential of these hilly regions for carbon sequestration.

## Material and Methods

### *Site Description and Soil Sampling*

This study was conducted on the dry land farming region located 45 km south of Borojen, Charmahal-va-Bakhtiari Province, Iran (32°31′ N, 51°1′ E), at an elevation of 2240 m. The region is characterized as having a semi-arid climate, with long-term average annual precipitation of 450 mm. Mean monthly temperatures range from 30°C in July to −26°C in January, as reported by Charmahal-va-Bakhtiari Meteorological Administration. The soil was fine mixed, mesic, typic calsixerepts (Soil Survey Staff, 2006). Soil pH was approximately 8.5 and EC was about 0.16 dS/m in 0–5 cm and about 0.13 dS/m in 5–15 cm layer. The EC value of rain water was about 0.021 dS/m. The percentage of $CaCO_3$ in pasture soils was 35.7 whereas cultivated soils were 31.1 (except in footslope where cultivated soil was higher than pasture). Also, the percentage of $CaCO_3$ was lower with depth. The experimental field included two adjacent plots having the same slope and aspect (about 5–10 degree slope at the summit, 30–35-degree slope at the backslope and 3–6-degree slope at the footslope). Treatments consisted of land use (wheat cropping and pasture), landscape positions (summit, backslope, and footslope) and soil sampling depths. The free-grazing pasture (the pasture without grazing management) that had not received any external fertilizer had been covered with leguminous species (*Astragalus cyclophyllus*) and gramineous species (*Agropyron* spp. and *Aegilops* spp.) since about 100 years ago, as reported by Agricultural and Natural Resources Research Center of Charmahal-va-Bakhtiari. The average pasture dry matter yields were approximately 571 kg $ha^{-1}$. The rainfed wheat (*Triticum aestvum* L.) cultivation with average crop yield of 1.48 t $ha^{-1}$ was farmed using conventional tillage (moldboard plowing) in a depth of 10 cm without a special rotation program since approximately 50 years ago. The mineral fertilizer of 92.1 kg $ha^{-1}$ of N, 32 kg $ha^{-1}$ of P and 79 kg $ha^{-1}$ of K was applied to the soil according to soil analysis recommended by Agricultural and Natural Resources Research Center of Charmahal-va-Bakhtiari.

Three composite sub-samples (a, b, c in Figure 1) were taken from 0–5 and 5–15 cm soil depths of the adjacent pasture and cultivated with minimal destruction of aggregates. The systematic sampling was used to collect the soil samples (Figure 1). Soils were taken at regularly spaced intervals in all directions. The samples of each position and plot (about 20 ha from summit to footslope) were mixed and four replicates were used for experiments. The 24 samples were used for wet-aggregate stability measurements and the determination of SOC content within aggregate-size fractions and/or associated with primary particles.

Core samples were (5 cm diameter and 5 cm height) taken from each plot, landscape position, and soil depth, with four replicates for bulk density (BD) measurements.

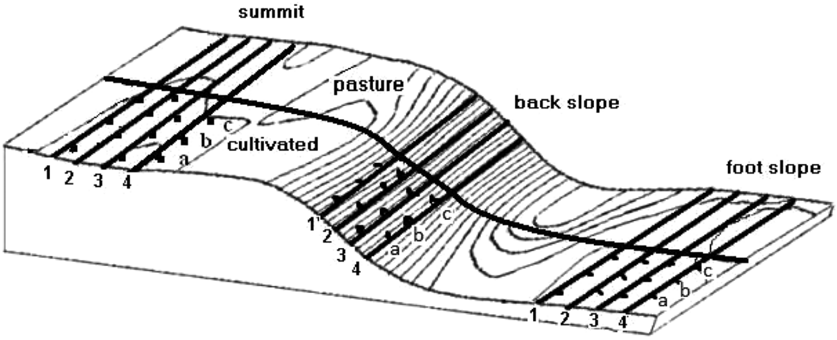

**Figure 1.** Schematic diagram of sampling site. a, b, and c are three composite subsamples.

### Aggregate Size Fractionation

A 100 g soil sample, containing intact aggregates that had passed through a 4.75 mm sieve was capillary-wetted to a matric suction of 30 kPa. This approach was used to minimize the breaking of aggregates that result from entrapped air and rough swelling. The wet-sieving analysis with three sieves of 2, 0.25 and 0.053 mm were done on the wetted samples (Cambardella and Elliott, 1994). The aggregates were separated into three sizes (i.e., 4.75–2, 2–0.25, and 0.25–0.053 mm). The aggregates were wet-sieved in a container of tap water for 30 min with a vertical stroke of 1.3 cm and speed of 30 strokes per min.

Aggregate fractions were recovered after each wet-sieving treatment, oven-dried (at 105°C) and weighed. Corresponding sieves were used to determine the percentage of sand and gravel. The percent of water-stable aggregates (%WSA), (Hoyos and Comerford, 2005), mean weight diameter (MWD), Van Bavel (1950), and geometric mean diameter (GMD), Mazurak (1950) of aggregates were calculated as follows:

$$\%\mathrm{WSA} = \left( \sum_{i=1}^{n} \frac{W_{i(a+s)} - W_{i(s)}}{W_t - \sum_{i=1}^{n} W_{i(s)}} \right) \times 100, \tag{1}$$

in which $W_{i(a+s)}$ is the weight of particles on sieve $i$, $W_{i(s)}$ is the weight of sand or gravel on sieve $i$ (determined by dispersing the particles on sieve $i$, washing the material through sieve $i$, oven-dry the sand or gravels left on sieve $i$ and weight), $W_t$ is the weight of soil (i.e., 100 g), and $n$ is the aggregate fractions (i.e., 3). It is notable that the <0.053 mm fraction was not taken into account because the focus was on the meso- and macroaggregate stability.

$$\mathrm{MWD} = \sum_{i=1}^{n} w_i . \bar{X}_i, \tag{2}$$

where $\bar{X}_i$ is arithmetic mean of aggregates size on sieve $i$, and $w_i$ is the fraction of stable aggregates on sieve $i$, determined as follows:

$$w_i = \frac{W_{i(a+s)} - W_{i(s)}}{\sum_{i=1}^{n} W_{i(a+s)} - \sum_{i=1}^{n} W_{i(s)}}, \tag{3}$$

$$\mathrm{GMD} = \exp\left[ \frac{\sum_{i=1}^{n} w_i \log \bar{X}_i}{\sum_{i=1}^{n} w_i} \right]. \tag{4}$$

### Fraction of Particle Size

A 50 g of air-dried sample from fine earth (<2 mm) was transferred into a flask containing 125 ml of de-ionized water plus 50 shots (5 mm iron beads) and was subjected to dispersion in a reciprocal shaker (250 strokes per min, for 8 hr) (Puget, Chenu, and Balesdent, 1995). The complete dispersion of aggregates <0.053 mm was carried out by ultrasonic treatment (1500 J/g) for 15 min. The sand fraction and particulate organic matter (POM) fraction were recovered by passing the sonified suspension using a 0.053 mm sieve.

The weight of sand fraction was determined after overnight oven-drying (50°C). The silt- and clay-sized organo-mineral particles were separated using the method of Bronick and Lal (2005).

### *Organic Carbon Measurement*

The SOC content was measured by wet-oxidation (Walkley and Black, 1934) in the clay, silt, and sand-sized particles (which were dispersed using ultrasound) and in the aggregate fractions.

### *Statistical Analysis*

Completely randomized block design was used for the statistical analysis. The fractional arrangement was: two treatments of land use and three landscape position and two depths. The data were analyzed using ANOVA in the SAS statistical program (SAS Institute Inc., 1995). Mean comparison was performed by using the Duncan's multiple range method.

## Result and Discussion

The analyses of variance for measured properties are shown in Tables 1 and 2. All treatments had significant effects on measured properties with the exception of land use on silt and depth on the aggregate size of 0.25–2 mm. Neither of the variables were significantly affected by interaction between three treatments and some of them were affected by interaction of two treatments (Tables 1 and 2).

The effects of landscape position and land use on the bulk density (BD) and organic carbon of the two soil layers (i.e., 0–5 and 5–15 centimeters) are shown in Table 3. Soil bulk density was increased by cultivation and annual cropping. This effect may be due to the disturbance of soil structure and aggregate disruption causing porosity reduction. Khormali et al. (2009) showed that forested land included highly porous crumb microstructure unlike the soil in deforested and cultivated soils. Soil BD increased with depth (Table 3), showing the compaction of sub-surface soil due to cultivation and machinery traffic. Lower BD was observed in the 0–5 cm layer

**Table 1.** The *F* ratio of analysis of variance for soil organic carbon (SOC) content, bulk density (BD), sand, silt, and clay under slope position (S), land use (LU), depth (D), and their interactions

| Source of variance | df | SOC | BD | Sand | Silt | Clay |
|---|---|---|---|---|---|---|
| S | 2 | 5.17* | 727.26** | 190.84** | 204.45** | 84.56** |
| LU | 1 | 19.93** | 1507.21** | 105.79** | 0.55 | 68.1** |
| D | 1 | 4.65* | 247.83** | 114.63** | 259.37** | 74.59** |
| S × D | 2 | 0.34 | 65.52** | 22.94** | 0.10 | 1.30 |
| S × LU | 2 | 1.05 | 215.19** | 1.24 | 19.48** | 3.36* |
| LU × D | 1 | 0.76 | 6.86* | 3.73* | 43.24** | 17.61** |
| S × D × LU | 2 | 0.63 | 121.32 | 2.90 | 3.33 | 0.12 |

* and ** mean significant effects at 0.05 and 0.01 levels for probability, respectively.

**Table 2.** The *F* ratio of analysis of variance for water stable aggregate (WSA), mean weight diameter (MWD), geometric mean diameter (GMD), and aggregate size (2–4.74, 0.25–2, and 0.052–0.25 millimeters) under slope position (S), land use (LU), depth (D), and their interactions

| Source of variance | df | WSA | MWD | GMD | 2–4.74 | 0.25–2 | 0.052–0.25 |
|---|---|---|---|---|---|---|---|
| S | 2 | 11.30** | 56.08** | 66.30** | 52.06** | 9.75** | 76.4** |
| LU | 1 | 8.32** | 607.12** | 765.46** | 884.38** | 131.05** | 653.25** |
| D | 1 | 3.46 | 32.77** | 41.04** | 42.64** | 1.99 | 21.87** |
| S × D | 2 | 0.12 | 1.67 | 2.96 | 2.34 | 0.13 | 5.92** |
| S × LU | 2 | 0.26 | 0.48 | 0.65* | 3.17* | 24.69** | 14.18** |
| LU × D | 1 | 0.87 | 10.47* | 13.68** | 25.84** | 33.01** | 4.3 |
| S × D × LU | 2 | 0.23 | 0.17 | 0.35 | 0.12 | 0.3 | 2.73 |

* and ** mean significant effects at 0.05 and 0.01 levels for probability, respectively.

of pasture land compared to the cultivated land. In agreement with Six et al. (1998) higher values of BD were found for the sub-surface layer. Landscape positions had fewer differences in BD, in that the lower and higher BD values were observed in the footslope and backslope respectively, for both land uses and soil layers. Greater clay and organic matter contents and consequently enhanced aggregation might be the cause of this difference. Extensive rooting was observed in this position, which might also increase the soil pore space and decrease the BD. These results are in agreement with those reported by Grandy and Robertson (2006).

The percentages of clay, silt, and sand were significantly affected by the long-term cultivation and landscape position, so that in the backslope and footslope positions of the cultivated soil the soil texture was changed (Table 4).

Long-term soil erosion and sever sediment transport processes on the surface of backslope following tillage may have caused the formation of coarser textures of cultivated soil in the 0–5 cm layer. Consequently, erosional deposition of the finer material at the footslope position may have caused the formation of finer soil texture (i.e., clay) in the 5–15 cm layer.

### *Aggregate Stability*

Aggregate stability indexes (e.g., water stable aggregate, mean weight diameter and geometric mean diameter) can be employed as indicators of soil structural quality and can exhibit the impact of soil management practices (Six, Elliott, and Paustion, 2000). The soil under cultivation (continuous mono-cropping of wheat) resulted in significantly lower WSA, MWD, and GMD in all of the landscape positions (Table 5). The lower structural stability of the cultivated soil may be attributable to cultivation effects on SOC content rapid decomposition (Six, Elliott, and Paustion, 2000). The pasture soils showed higher aggregate stability, which may be due to the extensive rooting of grasses, higher SOC content, permanent plant coverage, higher soil conservation, and soil nondisturbance (Bronick and Lal, 2005). Balabane and Plante (2004) reported that the greater MWD and stable macro-aggregates in the pasture soils may be due to the higher amount of microbial

**Table 3.** Land use and landscape positions effects on bulk density (BD) and soil organic carbon (SOC) in the 0–5 and 5–15 centimeters layers

| | | Landscape position | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Summit | | Backslope | | Footslope | | |
| Soil Properties | Depth | cultivated | pasture | cultivated | pasture | cultivated | pasture | Mean |
| BD (Mg $m^{-3}$) | 0–5 | 1.17a (0.14) | 1.11ab (0.06) | 1.25a (0.06) | 1.15ab (0.06) | 1.19a (0.02) | 1.00b (0.07) | 1.14*B* (0.10) |
| | 5–15 | 1.22ab (0.02) | 1.16bc (0.05) | 1.27a (0.05) | 1.18bc (0.03) | 1.20ab (0.02) | 1.12c (0.03) | 1.19*A* (0.06) |
| Mean | | 1.19ab (0.09) | 1.13bc (0.06) | 1.26a (0.05) | 1.17b (0.04) | 1.20ab (0.02) | 1.06c (0.08) | |
| SOC(%) | 0–5 | 1.22d (0.07) | 1.18d (0.04) | 1.02e (0.07) | 1.72b (0.06) | 1.37c (0.03) | 2.84a (0.01) | 1.56*A* (0.63) |
| | 5–15 | 0.92 h (0.06) | 1.49d (0.03) | 0.74i (0.05) | 1.25f (0.06) | 1.27f (0.04) | 2.06b (0.03) | 1.30*B* (0.44) |
| Mean | | 1.07d (0.17) | 1.33c (0.18) | 0.88e (0.16) | 1.48b (0.26) | 1.32c (0.06) | 2.45a (0.43) | |

*Note:* Values associated with the same small letter within a row and italic capital letters within a column are statistically similar ($P < 0.05$) using Duncan's multiple range test. Values in the parenthesis are standard deviations.

**Table 4.** Land use and landscape position effects on the primary particle size fractions

| | | Landscape position | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Summit | | Backslope | | Footslope | | |
| Primary particles | Depth | cultivated | pasture | cultivated | pasture | cultivated | pasture | Mean |
| Sand | 0–5 | 4.37c (0.57) | 3.54de (0.21) | 6.68a (0.38) | 5.27b (0.22) | 3.88cd (0.40) | 3.12e (0.27) | 4.48*A* (1.26) |
| | 5–15 | 3.76b (0.15) | 2.95d (0.24) | 4.63a (0.15) | 4.02b (0.26) | 3.44c (0.07) | 2.81d (0.16) | 3.60*B* (0.66) |
| Mean | | 4.07c (0.51) | 3.25de (0.38) | 5.65a (1.13) | 4.65b (0.70) | 3.66cd (0.36) | 2.96e (0.26) | |
| Silt | 0–5 | 52.45b (1.07) | 48.91c (0.48) | 59.43a 2.14) | 53.87b (1.75) | 45.50d (2.27) | 47.50cd (1.51) | 51.28*A* (4.94) |
| | 5–15 | 41.85c (0.20) | 46.15b (0.30) | 50.08a (0.24) | 49.96a (0.26) | 37.86d (0.89) | 42.58c (2.11) | 44.75*B* (4.61) |
| Mean | | 47.15c (5.71) | 47.53c (1.52) | 54.75a (5.19) | 51.92b (2.39) | 41.68e (4.38) | 45.04d (3.13) | |
| Clay | 0–5 | 43.18c (2.00) | 47.55b (2.00) | 33.89d (3.20) | 40.86c (3.39) | 50.62ab (2.26) | 52.53a (1.87) | 44.77*B* (6.81) |
| | 5–15 | 54.32ab (1.98) | 50.90b (4.06) | 45.29c (3.32) | 46.02c (2.60) | 58.70a (2.48) | 54.61ab (2.51) | 51.64*A* (5.53) |
| Mean | | 48.75b (6.23) | 49.23b (3.46) | 39.59d (6.80) | 43.44c (3.92) | 54.66a (4.84) | 53.57a (2.33) | |
| Soil Texture$^+$ | 0–5 | SiC | SiC | SiCL | SiC | SiC | SiC | |
| | 5–15 | SiC | SiC | SiC | SiC | C | SiC | |

*Note:* Values associated with the same small letter within a row and italic capital letters within a column are statistically similar ($P < 0.05$) using Duncan's multiple range test. Values in the parenthesis are standard deviations.

$^+$C, clay; SiC, silty clay; SiCL, silty clay loam.

**Table 5.** Land use and landscape positions effects on the aggregate stability indices in the two soil layers

| | | Landscape position | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Summit | | Backslope | | Footslope | | |
| Aggregate stability indices | Depth | cultivated | pasture | cultivated | pasture | cultivated | pasture | Mean |
| WSA (%) | 0–5 | 89.85ab (4.25) | 92.10ab (3.50) | 86.35b (6.66) | 88.37b (3.19) | 92.72ab (3.62) | 95.80a (3.40) | 90.*86A* (4.92) |
| | 5–15 | 88.17b (3.86) | 90.6ab (5.09) | 81.12c (3.20) | 87.50b (3.92) | 89.12a (6.88) | 94.67a (3.18) | 88.53*A* (5.77) |
| Mean | | 89.01b (3.86) | 91.34ab (4.11) | 83.74c (5.58) | 87.94bc (3.34) | 90.92ab (5.45) | 95.24a (3.11) | |
| MWD (mm) | 0–5 | 1.20c (0.14) | 2.15a (0.15) | 0.81d (0.08) | 1.80b (0.09) | 1.33c (0.11) | 2.33a (0.12) | 1.60*A* (0.56) |
| | 5–15 | 1.09d (0.14) | 1.81b (0.09) | 0.84e (0.09) | 1.55c (0/09) | 1.15d (0.09) | 1.98a (0.16) | 1.40*B* (0.43) |
| Mean | | 1.14d (0.14) | 1.98b (0.23) | 0.83e (0.08) | 1.68c (0.16) | 1.24d (0.13) | 2.15a (0.23) | |
| GMD (mm) | 0–5 | 0.87c (0.04) | 1.21a (0.06) | 0.72d (0.01) | 1.10b (0.02) | 0.93c (0.04) | 1.27a (0.02) | 1.02*A* (0.20) |
| | 5–15 | 0.83c (0.03) | 1.09a (0.01) | 0.74d (0.03) | 1.02b (0.02) | 0.86c (0.02) | 1.14a (0.08) | 0.95*B* (0.15) |
| Mean | | 0.85e (0.04) | 1.15b (0.08) | 0.73f (0.02) | 1.06c (0.05) | 0.89d (0.04) | 1.20a (0.09) | |

*Note:* Values associated with the same small letter within a row and italic capital letters within a column are statistically similar ($P < 0.05$) using Duncan's multiple range test. Values in the parenthesis are standard deviations.

GMD, geometric mean diameter; MWD, mean weight diameter; WSA, water-stable aggregate.

biomass, plants residue, plants root, polysaccharides, and humic materials in the macroaggregates of these soils. Gol (2009) reported significantly larger water stable aggregates, SOC content, and total nitrogen in forest and pasture soils than in cultivated soils. Lal, Mahboubi, and Fausey (1994) observed that reduced and no-tillage systems had higher soil aggregate stability when compared to conventional tillage practices on two Ohio soils.

Aggregate stability decreased with soil depth. This reduction was not significant in all of the landscape positions of cultivated soils, which are linked to the mixing the soil by tillage practices (Table 5). Our finding is in agreement with those of Ayoubi et al. (2012). Only in the backslope position of cultivated soils was the aggregate stability in 0–5 cm layer less than 5–15 cm layer, which may be the result of low amounts of clay and SOC, and the higher impact of erosional processes in surface soils. The backslope shows qualitative field erosion symptoms (nonuniform vegetation cover and surface crusting due to greater erosion potential in the slope, as a result of formation of a soil crust, decreased infiltration, and increased velocity of water causing a greater degree of carrying capacity), a decrease in aggregate stability, and higher amounts of clay. In general, the highest and lowest values of aggregate stability in both treatments and soil layers are observed in the footslope and backslope, respectively.

Aggregate stability differences between the summit and footslope were not significant (Table 5). This could be attributed to the similar degree of slope gradient. However, Hoyos and Comerford (2005) reported the higher and lower aggregate stability in the summit and footslope, respectively. They also showed a significant impact of land use (pasture vs. coffee cultivation) on the aggregate stability in these two positions. De Gryze et al. (2004) reported that the MWD in the 0–7 cm layer of a cultivated soil was almost one-third of that in a natural ecosystem.

### *Primary Particle Size Fractions and Associated Soil Organic Carbon*

The pasture soils had higher clay content than the cultivated soils, while the percentage of sand in the cultivated soils was greater than the pasture soils (Table 4). Cultivation affected the soil structure by destroying soil aggregates, leading to greater dispersible clay content (Pulleman et al., 2003; Bronick and Lal, 2005).

The amount of clay tended to increase with soil depth, although it was not significant in the cultivated soil due to soil mixing by tillage practices. The high root density and permanent plant coverage resulted in the higher aggregation and lower clay removal in the pasture soil. Naturally, vegetation and residue cover can slow the movement of water while increase water infiltration by covering the soil and improving soil structure, which tends to decrease the soils' erodibility (Tang et al., 2010; Quintero and Comerford, 2013).

The silt percentage in the 0–5 cm layer was higher in the cultivated treatment; however, there was no significant difference in the 5–15 cm layer between the two land uses. Primary particles were significantly influenced by the landscape position, especially in the 0–5 cm layer. The clay percentages of both sampling layers were highest and lowest in the footslope and backslope, respectively. Therefore, the backslope was the most erosive location and the clay removal was the highest there in the cultivated soil. Generally, tillage and cropping practices resulted in poor soil structure, decreases in soil organic matter, and compaction of the soil, which all contribute to increases in soil erodibility (Rezaei, Roozitalab, and Ramezanpour, 2012).

The SOC content associated with the primary particles was significantly ($P < 0.01$) influenced by the land use, landscape position, and the soil depth. The SOC associated with the clay content was higher than those with the sand and silt (Figure 2). The role of clay in sequestering carbon by protecting it from decomposition is an interesting phenomenon. Low aeration in micropores formed by the clay particles may be important in this process (Balabane and Plante, 2004) and may be important to the greater specific area of this fraction by promoting higher organic carbon adsorption. The adsorption of microbial enzymes (which renders them inactive) by clay particles may be another cause of this protection (Balabane and Plante, 2004). It is interesting (as shown in Figure 2) that although the sequestration of SOC content was greater in the clay fraction than in sand and silt, the following cultivation of SOC content in clay fraction has decreased more than sand and silt fractions. However, despite SOC content diminution in the clay fraction due to cultivation, the content of SOC was greater in clay in both treatments. Similar results were reported by Bronick and Lal (2005).

Landscape position significantly affected the SOC content associated with the clay, silt and sand particles. The differences between the SOC content associated with the primary particles at the backslope and the two positions was very high, whereas little difference was found between the summit and footslope. Gregorich et al. (1998) and Guzman and Al-Kaisi (2011) also reported the greatest SOC contents in the toe-slope that was followed by summits and midslopes. They attributed their finding to distribution of SOC content and losses due to soil erosion and deposition effects by slope position. Tsui, Chen, and Hsieh (2004) reported the higher amount of SOC content, available N and K, extractable Fe and exchangeable Na in the summit than in the backslope and footslope.

The SOC contents of the 0–5 cm layer were consistently higher than those of the 5–15 cm layer in all of the land use and landscape combinations, while the effect of depth on the SOC content associated with the primary particles of the backslope were not significant. Tillage affected the SOC content in all of the particles fractions

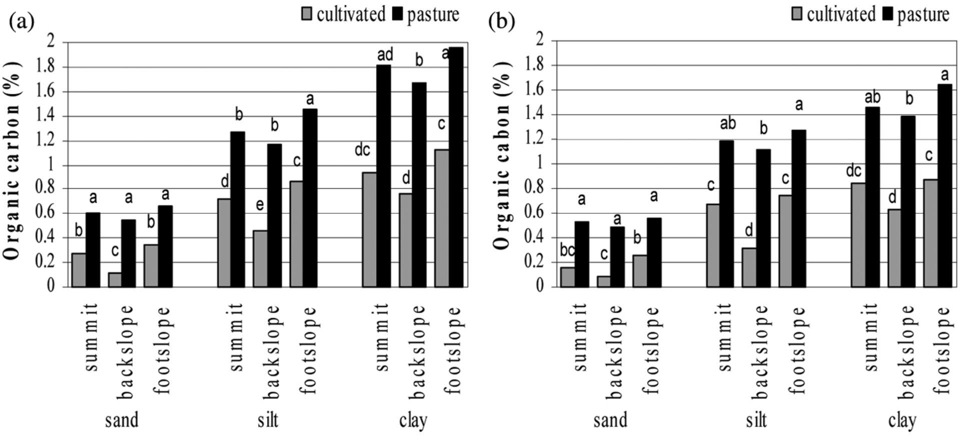

**Figure 2.** Land use and landscape effects on the soil organic carbon (SOC) content associated with the primary particles (sand, silt, and clay) in 0–5 cm (a) and 5–15 cm (b) layers. Values associated with the same letter within each particle size fractions are statistically similar ($P < 0.05$).

considerably. Tillage and rotation combination influence on SOC content was studied by Bronick and Lal (2005). They reported that the primary particle percentages and the clay-sized particles were highly enriched in SOC content when compared to the silt and sand-sized particles. In agreement with our findings, they also found that the SOC content associated with all fractions of primary particles (sand, silt, and clay) was higher in no-tilled soils than in cultivated soils. Lorenz, Lal, and Shiptalo (2008) also reported a decreasing amount of SOC pool by conversion of forest to cultivated land.

In general, the highest SOC content (i.e., 1.95%) was associated with the clay fraction of pasture soil in the 0–5 cm layer of the footslope while the lowest (i.e., 0.08%) was related to the sand fraction of cultivated soil in the 5–15 cm layer at the backslope position. These results are consistent with results by Karchegani et al. (2012) in the hilly region western Iran, which reported higher SOC content in clay fraction than silt fraction in cultivated soils in respect to forest soils indicating the potential of clay-sized minerals to sequestrate organic carbon in disturbed ecosystems.

### *Aggregate Size Fractions and Associated Soil Organic Carbon*

Aggregate sizes and associated SOC contents were reduced considerably more in the cultivated soil than in the pasture soil. It has been reported that many long-term cropping systems result in reduction of aggregation and stability of macroaggregates (e.g., Gupta and Germida, 1988; Jastrow, Miller, and Boutton, 1996; Grandy, Porter, and Erich, 2002; Mikha and Rice, 2004).

The highest percentages of the two larger groups of aggregates (i.e., 2.00–4.75 and 0.25–2.00 mm) were found in the footslope and summit positions (Table 6). In general, the impact of landscape position on the aggregates size of pasture soils was much less than that of cultivated soils (Table 6). The highest percentages of macroaggregates (i.e., 2.00–4.75 mm) were observed in the 0–5 cm layer of pasture soil at the footslope position (i.e., 61.5%), while the lowest was noted in the same layer of cultivated soil (12%), at the backslope position. Cultivation accelerated erosion factors, resulting in destruction of macroaggregates, especially at the backslope position and at the soil surface.

The highest percentage of macroaggregates (i.e., 2.00–4.75 mm) that was calculated for the pasture soil and that of meso-aggregates (i.e., 0.25–2.00 mm) was observed in the cultivated soil. Ayoubi et al. (2012) studying the effect of land use changes on aggregate size distribution in different slope gradients western Iran, found that the highest percent of two groups of large aggregates (i.e., 2.00–4.75 and 0.25–2.00 mm) were in the lower slope and natural forest soil and the highest percent of microaggregates (0.053–0.25 mm) were in the cultivated and disturbed forest soils. The results of Mikha and Rice (2004) showed that the aggregates larger than 2.00 mm and those of 0.25–2.00 mm were higher in the no-tillage system than in the conventional tillage system. However, the smaller aggregates (i.e., 0.053–0.25 and 0.02–0.053 mm) had the highest percentages in the conventional tillage.

As soil depth increased, the percentages of large aggregates (i.e., 2.00–4.75 and 0.25–2.00 mm) were reduced. At the backslope, the microaggregate fraction (i.e., 0.053–0.25 mm) was more frequent than the two other positions in both treatments and soil layers. Reduction of large aggregates in the cultivated soil may be attributed

**Table 6.** Land use and landscape effects on the aggregate size distribution (percent) in the 0–5 and 5–15 centimeters layers

| | | Landscape position | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Summit | | Backslope | | Footslope | | |
| Aggregate size (mm) | Depth | cultivated | pasture | cultivated | pasture | cultivated | pasture | Mean |
| 4.75–2.00 | 0–5 | 21.6d (3.8) | 56.1b (3.8) | 12.0e (1.2) | 44.4c (2.9) | 24.1d (2.7) | 61.5a (3.7) | 36.6*A* (19.0) |
| | 5–15 | 19.1cd (4.6) | 43.8a (5.0) | 14.2d (2.1) | 35.1b (2.4) | 20.1c (2.7) | 48.3a (4.6) | 30.*1B* (13.7) |
| Mean | | 20.4d (4.1) | 49.9b (7.7) | 13.1e (1.9) | 39.7c (5.5) | 22.1d (3.3) | 54.9a (8.1) | |
| 2.00–0.25 | 0–5 | 37.7a (3.5) | 20.6c (3.5) | 30.5b (3.9) | 24.6c (2.7) | 42.3a (2.4) | 21.3c (2.5) | 29.5*A* (8.8) |
| | 5–15 | 34.9a (2.4) | 26.5b (2.5) | 26.6b (2.4) | 29.7b (1.6) | 37.9a (3.1) | 28.6b (3.3) | 30.7*A* (4.9) |
| Mean | | 36.3b (3.1) | 23.5e (4.2) | 28.6c (3.6) | 27.2cd (3.4) | 40.1a (3.5) | 24.9ed (4.7) | |
| 0.25–0.053 | 0–5 | 30.5b (2.4) | 15.4e (1.4) | 43.7a (2.2) | 19.3d (2.1) | 26.3c (3.0) | 13.0e (0.5) | 24.7*B* (10.8) |
| | 5–15 | 34.1b (2.3) | 20.2cd (1.6) | 40.2a (2.8) | 22.6c (1.6) | 31.1b (3.4) | 17.8d (1.9) | 27.7*A* (8.5) |
| Mean | | 32.3b (2.9) | 17.8e (2.9) | 42.0a (3.0) | 21.0d (2.5) | 28.7c (3.9) | 15.4e (2.9) | |

*Note:* Values associated with the same small letter within a row and italic capital letters within a column are statistically similar ($P < 0.05$) using Duncan's multiple range test. Values in the parenthesis are standard deviations.

to the physical soil disturbance and lower stability of the macroaggregates. The binding agents stabilizing large aggregates are temporary and unstable, including fungal hyphae and plant roots. Wright and Hons (2005) showed that in the no-tillage crop production, the percent of aggregates >2 mm and of those 0.25–2.00 mm were greater than in the conventional tillage in the 0–5 cm and 5–15 cm layers, respectively. The impact of a ten year tillage management on soil aggregation was studied by Grandy and Robertson (2006); they reported that tillage significantly reduced the large aggregates (i.e., 2–8 mm) and increased small aggregates (i.e., <0.25 mm) in the 0–7 cm layer.

The effects of land use and landscape position on the SOC contents of aggregate fractions are illustrated in Figure 3. Aggregate-associated SOC content was significantly affected by the land use, landscape position, and soil layer. The percentage of aggregate SOC content in the pasture soil was higher than that in the cultivated soil. These results are in agreement with Golchin et al. (1994). High SOC content would result in the stability of macroaggregates of pasture soil compared to the cultivated soil. According to Dick and Durkalski (1998), cultivation reduces SOC content resulting in instability of aggregates. Rodionov et al. (2000) concluded that tillage enhances decomposition of SOC content by mixing and disrupting soil aggregates and exposing physically-protected organic material to the microorganisms.

Kong et al. (2005) observed an increase in SOC content with addition of manure and consequently the formation of water-stable macroaggregates. They concluded that the carbon pools were occluded within the small aggregates, and that these small aggregates were encapsulated within the large aggregates. Six, Elliott, and Paustion (2000) reported an increase of SOC content in the large aggregate-size fractions with no-tillage and decrease of that in small-size fractions under conventional tillage. Much more SOC content located inside aggregates was reported in virgin soils compared to a cultivated soil (Bronick and Lal, 2005).

In this study we found that with increasing soil depth, the SOC content of the aggregates decreased. This was most pronounced in the pasture soil, since tillage

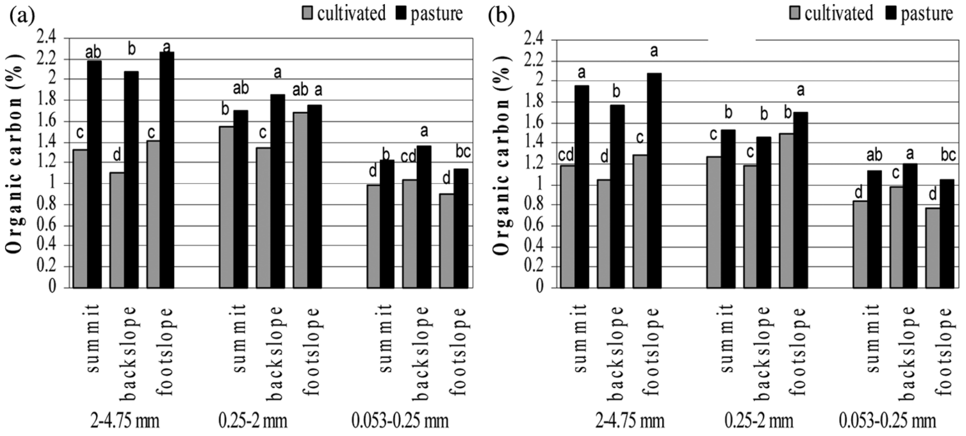

**Figure 3.** Land use and landscape effects on the soil organic carbon (SOC) content of the aggregates (2–4.75, 0.25–2, and 0.053–0.25 mm) in the 0–5 cm (a) and 5–15 cm (b) layers. Values associated with the same letter within each particle size fractions are statistically similar ($P < 0.05$).

and cultivation practices in the cultivated soil turn over the soil, thereby distributing aggregates to deeper depths. In the 0–5 cm of layer, the differences among SOC contents of the aggregates at landscape positions were higher than in the 5–15 cm layer (see Figure 3). Higher SOC content was observed in the pasture because of frequent large aggregates, while in the cultivated soil most of SOC content accumulated in the aggregates of 0.25–2.00 mm. This finding indicates that high soil aggregation and stability of macroaggregates (in which SOC content accumulated and were protected) are observed in the pasture soil. Although large aggregates stored greater SOC content, following cultivation they lost more SOC content when compared with microaggregate fraction (Figure 3). This can be attributed to the nature of the organic matter acting as a binding agent in aggregates; young and relatively unstable organic matter was in large aggregates whereas old and more stable organic matter was in small aggregates. This finding is in agreement with the results reported by Bronick and Lal (2005) and Wright and Hons (2005).

The SOC contents of the aggregates were significantly lower in the backslope when compared to those in the two other positions for both land use treatments and soil layers, with the exception of 0.053–0.25 mm aggregates. This result suggests that soil erosion processes and tillage may have reduced the organic matter and inhibited the formation of large and stable aggregate fractions, especially in soils at the backslope position. The highest SOC content (i.e., 2.26%) was observed for aggregates of 2.00−4.75 mm in the 0–5 cm layer at the footslope of the pasture land, while its lowest value (i.e., 0.78%) was found for the aggregates of 0.053 – 0.25 mm in the 5–15 cm layer, at the footslope position of the cultivated soil. The SOC content of aggregates in the summit was lower than those in the backslope and footslope (Figure 3).

## Conclusions

One of the main components of agricultural soils is soil organic matter, which affects soil physical, chemical, and biological properties and also plant growth. The potential effects of long-term land use and landscape position on soil aggregate stability, aggregate size fractions, and soil organic carbon (SOC) content were investigated. Pasture management may have incorporated more SOC content into the aggregates than cultivation as the SOC content inside the macroaggregates may have been better preserved in the pasture soil. The high water-stable aggregates and aggregate-associated SOC content in the pasture soil, showed the central role of land management on the carbon sequestration. It was observed that over 30% of SOC content was maintained under the pasture management. This demonstrated the pronounced SOC content sequestration potential and environmental sustainability of this type of land use. Overall, the results suggest that no-tilled pasture land improves soil aggregation, structural stability, and soil carbon storage, and reduces the carbon emission to the atmosphere, especially in the mountainous regions with similar climate as in southwest Iran. However a combination of land use and landscape position on soil physical quality indicators is a complex process that correlated to climate, soil type, and landscape morphology.

## Funding

This research was supported by Bu-Ali Sina University's foundation grants.

## References

Angers, D. A., A. Pesant, and J. Vigneux. 1992. Early cropping induced changes in soil aggregation, organic matter, and microbial biomass. *Soil Science Society of American Journal* 56: 115–119.

Ayoubi, S., and P. M. Karchegani. 2012. Determination the factors explaining variability of physical soil organic carbon fractions using artificial neural network. *International Journal of Soil Science* 7(1): 1–14.

Ayoubi, S., P. M. Karchegani, M. R. Mosaddeghi, and N. Honarjoo. 2012. Soil aggregation and organic carbon as affected by topography and land use change in western Iran. *Soil and Tillage Research* 121: 18–26.

Balabane, M., and A. F. Plante. 2004. Aggregation and carbon storage in silty soil using physical fractionation techniques. *European Journal of Soil Science* 55: 415–427.

Bauer, A., and A. L. Black. 1981. Soil carbon, nitrogen and bulk density comparison in two cropland tillage systems after 25 years and in virgin grassland. *Soil Science Society of American Journal* 45: 1166–1170.

Blevins, R. L., and W. W. Frye. 1993. Conservation tillage: an ecological approach to soil management. *Advances in Agronomy* 51: 33–78.

Bronick, G. J., and R. Lal. 2005. Manuring and rotation effect on soil organic carbon concentration for different aggregate size fractions on two soils northeastern Ohio, USA. *Soil and Tillage Research* 81: 239–252.

Cambardella, C. A., and E. T. Elliott. 1993. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. *Soil Science Society of American Journal* 57: 1071–1076.

Cambardella, C. A., and E. T. Elliott. 1994. Carbon and nitrogen dynamics of soil organic matter fractions from cultivated grassland soils. *Soil Science Society of American Journal* 58: 123–130.

De Gryze, S., J. Six, K. Paustian, S. J. Morris, E. A. Paul, and R. Merckx. 2004. Soil organic carbon pool changes following land-use conversions. *Global Change Biology* 10: 1120–1132.

Dick, W. A., and J. T. Durkalski. 1998. No-tillage production agriculture and carbon sequestration in a Typic Fragiudalf soil of northeastern Ohio. In *Management of carbon sequestration in soil*, eds. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, 59–71. Boca Ration, FL: CRC Press.

Gol, C. 2009. The effects of land use change on soil properties and organic carbon at Dagdami river catchment in Turkey. *Journal of Environmental Biology* 30(5): 825–830.

Golchin, A., J. M. Oades, J. O. Skjemstad, and P. Clarke. 1994. Soil structure and carbon cycling. *Australian Journal of Soil Research* 32: 1043–1068.

Grandy, A. S., G. A. Porter, and M. S. Erich. 2002. Organic amendment and rotation crop effects on the recovery of soil organic matter and aggregation in potato cropping systems. *Soil Science Society of American Journal* 66: 1311–1319.

Grandy, A. S., and G. P. Robertson. 2006. Aggregation and organic matter protection following tillage of a previously uncultivated soil. *Soil Science Society of American Journal* 70: 1398–1406.

Gregorich, E. G., K. J. Greer, D. W. Anderson, and B. C. Liang. 1998. Carbon distribution and losses: erosion and deposition effects. *Soil and Tillage Research* 47: 291–302.

Gupta, V. V. S. R., and J. J. Germida. 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. *Soil Biology & Biochemistry* 20: 777–786.

Guzman, J. G., and M. M. Al-Kaisi. 2011. Landscape position effect on selected soil physical properties of reconstructed prairies in southcentral Iowa. *Journal of Soil and Water Conservation* 66(3): 183–191.

Hao, Y., R. Lal, L. B. Owens, R. C. Izaurralde, W. M. Post, and D. L. Hothem. 2002. Effect of cropland management and slope position on soil organic carbon pool at the north appalachian experimental watersheds. *Soil and Tillage Research* 68: 133–142.

Hoyos, N., and N. B. Comerford. 2005. Land use and landscape effects on aggregate stability and total carbon of Andisols from the Colombian Andes. *Geoderma* 129: 268–278.

Jastrow, J. D., R. M. Miller, and T. W. Boutton. 1996. Carbon dynamics of aggregate-associated organic matter estimated by carbon-13 natural abundance. *Soil Science Society of American Journal* 60: 801–807.

Karchegani, P. M., S. Ayoubi, M. R. Mosaddeghi, and N. Honarjoo. 2012. Soil organic carbon pools in particle-size fractions as affected by slope gradient and land use change in hilly regions, western Iran. *Journal of Mountain Science* 9: 87–95.

Khormali, F., M. Ajami, S. Ayoubi, Ch. Srinivasarao, and S. P. Wani. 2009. Role of deforestation and hillslope position on soil quality attributes of loess-derived soils in Golestan province, Iran. *Agriculture, Ecosystems & Environment* 134: 178–189.

Kong, A. Y. Y., J. Six, D. C. Bryant, R. F. Denison, and C. van Kessel. 2005. The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. *Soil Science Society of American Journal* 69: 1078–1085.

Lal, R., A. A. Mahboubi, and N. R. Fausey. 1994. Long-term tillage and rotation effect on properties of a central Ohio soil. *Soil Science Society of American Journal* 58: 517–522.

Lorenz, K., R. Lal, and M. J. Shiptalo. 2008. Chemical stabilization of organic carbon pools in particle size fractions in no-till and meadow soils. *Biology and Fertility of Soils* 44: 1043–1051.

Mahboubi, A. A., R. Lal, and N. R. Faussey. 1993. Twenty-eight years of tillage effects on two soils in Ohio. *Soil Science Society of American Journal* 57: 506–512.

Mazurak, A. P. 1950. Effect of gaseous phase on water-stable synthetic aggregates. *Soil Science* 69: 135–148.

Mikha, M. M., and C. W. Rice. 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. *Soil Science Society of American Journal* 68: 809–816.

Mishra, U., D. A. N. Ussiri, and R. Lal. 2010. Tillage effects on soil organic carbon storage and dynamics in Corn Belt of Ohio USA. *Soil and Tillage Research* 107: 88–96.

Puget, P., C. Chenu, and J. Balesdent. 1995. Total and young organic matter distributions in aggregates of silty cultivated soils. *European Journal of Soil Science* 46: 449–459.

Puget, P., and R. Lal. 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil and Tillage Research* 80: 201–213.

Pulleman, M., A. Jongmans, J. Marinissen, and J. Bouma. 2003. Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in a marine loam in the Netherlands. *Soil Use and Management* 19: 157–165.

Quintero, M., and N. B. Comerford. 2013. Effects of conservation tillage on total and aggregated soil organic carbon in the Andes. *Open Journal of Soil Science* 3: 361–373.

Rezaei, N., M. H. Roozitalab, and H. Ramezanpour. 2012. Effect of land use change on soil properties and clay mineralogy of forest soils developed in the Caspian Sea region of Iran. *Journal of Agricultural Science and Technology* 14: 1617–1624.

Rodionov, A., W. Amelung, I. Urusevskaja, and W. Zech. 2000. Carbon and nitrogen in the enriched labile fraction along a climosequence of zonal steppe soils in Russia. *Soil Science Society of American Journal* 64: 1467–1473.

SAS Institute Inc. 1995. *SAS/STAT1 user's guide, version 6*, 4th ed., Vol. 1. Cary, NC: SAS Institute, Inc.

Scott, H. D., E. M. Rutledge, and W. M. Miley. 1983. Effect of tillage on soil physical properties. *Arkansas Farm Research* 32(6): 5.

Six, J., R. T. Conant, E. A. Paul, and K. Paustian. 2002. Stabilization mechanisms of soil organic matter: implications for C- saturation of soils. *Plant and Soil* 241: 155–176.

Six, J., E. T. Elliott, and K. Paustion. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of American Journal* 63: 1350–1358.

Six, J., E. T. Elliott, and K. Paustian. 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry* 32: 2099–2103.

Six, J., E. T. Elliott, K. Paustian, and J. W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of American Journal* 62: 1367–1377.

Skidmore, E. L., W. A. Carstenson, and E. E. Banbury. 1975. Soil changes resulting from cropping. *Soil Science Society of American Journal* 39: 964–967.

Soil Survey Staff. 2006. *Keys to soil taxonomy*, 10th ed. Washington, DC, USA: US Department of Agriculture, North Resource Conservation Service.

Tang, X., S. Liu, J. Liu, and G. Zhou. 2010. Effects of vegetation restoration and slope positions on soil aggregation and soil carbon accumulation on heavily eroded tropical land of southern China. *Journal of Soils and Sediments* 10: 505–513.

Tsui, C. C., Z. S. Chen, and C. F. Hsieh. 2004. Relationships between soil properties and slope position in a lowland rain forest of southern Taiwan. *Geoderma* 123: 131–142.

Van Bavel, C. H. M. 1950. Mean weight-diameter of soil aggregates as a statistical index of aggregation. *Soil Science Society of American Journal* 14: 20–23.

Walkley, A., and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29–38.

Wright, A. L., and F. M. Hons. 2005. Tillage impact on soil aggregation and carbon and nitrogen sequestration under wheat cropping sequences. *Soil and Tillage Research* 84: 67–75.