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Soil organic carbon physical fractions and aggregate stability influenced by land use in humid region of northern Iran

Shamsollah Ayoubi, Zahra Mirbagheri, and Mohammad Reza Mosaddeghi*

Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan, 84156 83111, Iran

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A b s t r a c t. The present study was executed in order to examine the influences of land use change on aggregate stability and soil organic carbon fractions in the humid region of the north of Iran. The study area featured three land uses which included natural Hyrcanian forest, tea plantation and paddy rice cultivation. One hundred soil samples were taken from the 0-10 cm layer in a grid pattern to allow for variations in the study area as much as possible in summer 2016. The results revealed that land use change significantly altered the physical and chemical characteristics of the soil, as the highest values of soil organic carbon and complexed organic carbon, and the lowest values of pH, calcium carbonate equivalent and bulk density, were observed in the natural forest. The greatest percentage of macro-aggregates was found in the natural forest followed by the tea plantation. Particulate organic carbon and soil organic carbon associated with clay and silt particles as well as soil organic carbon associated with all aggregate fractions showed the following trend: natural forest > tea plantation > rice cultivation. Overall, our results confirmed the importance of forest soils in C sequestration and the vital role played by soil organic carbon in soils to improve soil quality indicators and aggregation.

K e y w o r d s: Hyrcanian forest, tea plantation, paddy rice, complexed organic carbon

INTRODUCTION

Soil is widely known as the supreme organic carbon store in the terrestrial environment (Guenet *et al.*, 2018; Stockmann *et al.*, 2013). Soils contain the largest C stock on Earth storing about 2500 Gt of total C in the first 25 cm depth, which is three times greater than that of the vegetation carbon pool and two times the carbon stored in the atmosphere (Lal, 2004; Li *et al.*, 2007), with a fundamental role in the global C cycle being the determining factor of the soil ecosystem which serves biological, physical and chemical functions (FAO, 2015). Therefore, even minimal effects on this large reserve can have substantial consequences for the biosphere, ranging from soil fertility to the concentration of greenhouse gases in the atmosphere (Minasny *et al.*, 2017). A minor change in soil carbon storage could lead to a huge variation in the CO_2 content of the atmosphere (Lal *et al.*, 2018). The soil organic carbon (SOC) pool can be significantly influenced by both biotic and abiotic factors and land use has been identified as the major affecting factor (Khormali *et al.*, 2009; Shahriari *et al.*, 2011; Karchegani *et al.*, 2012; Ayoubi *et al.*, 2012; Falahatkar *et al.*, 2014; Falahatkar *et al.*, 2016; Ajami *et al.*, 2016).

Physical fractionation methods including size portioning to primary particles and secondary particles and density portioning highlight the role of the physical proportions of the soil components in the stability and turnover of the SOC (Christensen, 1992; Six *et al.*, 2000). These approaches are considered to be less damaging than chemical portioning approaches, and the results are supposed to be more closely associated with the functions of SOC and soil structure (Christensen, 1992). Golchin *et al.* (1997) has stated that the dynamics of the formation of soil aggregates is very closely related to the SOC pool in soils. It is often

*Corresponding author e-mail: ayoubi@cc.iut.ac.ir

reported that native soils (*e.g.* natural forest or pastures) commonly have a higher SOC content, saturated hydraulic conductivity and aggregate stability with a lower bulk density when compared to their cultivated counterparts (Celik, 2005; Xiao *et al.*, 2018). Several studies in different environmental conditions have shown diminishing soil quality indices following the cultivation of native soils (Celik, 2005; Khormali *et al.*, 2009; Ayoubi *et al.*, 2011).

Land use change and erosion processes could considerably influence the soil organic carbon pool and its migration (Xiao *et al.*, 2018). Land use could significantly affect SOC build-up and pooling in soils that mediate the extent of the SOC pool and in addition significantly affect the quality and composition of soil organic matter (Helfrich *et al.*, 2006; Rodrigo-Comino *et al.*, 2016). Some studies have confirmed that land use could alter organic carbon distribution in various physical fractions (Karchengani *et al.*, 2012; Safadoust *et al.*, 2016). A degree of knowledge about the SOC in various physical fractions may provide valuable information concerning the influences of land use change on the storage of SOC and soil aggregation. Soil aggregates and SOC reciprocally preserve each other; also SOC is physically preserved by its bonds with the principal particles inside the aggregates; also this bonding may enhance the stability of the aggregates (Six *et al.*, 2002). When natural land use is altered, the macro-aggregates (> 250 μm) rapidly become disordered and trapped. SOC inside the aggregates are then exposed to decomposition processes (Cambardella and Elliott, 1993; Six *et al.*, 2002; Safadoust *et al.*, 2016). Following land use change, the quality and quantity of SOC pools are affected and subsequently the size distribution and stability of aggregates are influenced (Six *et al.*, 2002). While physically preserved organic matter stores are unprotected because of aggregate destruction after land use change, the stability of soil structure will be reduced thereby eventually accelerating soil erosion particularly in the hilly regions (Safadoust *et al.*, 2016; Rodrigo-Comino *et al.*, 2017).

Land use change, abandonment and the conversion of natural ecosystems to cultivated lands has an impact on the distribution of SOC in the various size fractions of aggregates, this has already been studied in various soils and diverse climatic conditions (Bronick and Lal, 2005; Helfrich *et al.*, 2006; Hoyos and Comerford, 2005, Cerdà *et al.*, 2018; Seeger *et al.*, 2019). However, few studies have been conducted concerning the effects of land use change on SOC pools and soil aggregate size fractions in the vulnerable ecosystem of Hyrcanian forest soils in north of Iran. In recent decades, the northern regions of Iran have suffered heavy flooding which is mainly related to land use change and improper soil management. Advancing our understanding of the variability in soil organic carbon pools and the effects of changes in land use on soil aggregation and SOC fractionation is crucial for the design of managerial practices and decision making concerning global warming and local threats in the Hyrcanian forest soils of Iran. Little attempt has been made to explore SOC in various aggregate size fractions in the humid regions of Iran. Hence, the major purposes of this research were to: i) evaluate the effect of land use change on some physical and chemical attributes of soil, ii) examine the influences of land use change on the stability of soil aggregates, and iii) evaluate land use impact on SOC pools in aggregate with different sizes and primary particles fractions in the humid region of the north of Iran.

MATERIALS AND METHODS

This study was conducted in an eastern part of Gilan province between 50° 18′ to 50° 26′ E longitude, and 37° 11′ to 37° 18′ N latitude, with an area of 2400 ha. The average elevation of the selected area is about 21 m a.s.l. The average annual temperature and rainfall in the study area are 15.8°C and 1500 mm, respectively (The Iran Metrological Organization). Soil temperature and moisture regimes of the studied area are Mesic and Udic respectively according to the Soil Survey Staff (2010). In the study area, three land uses were identified including: i) natural deciduous Hyrcanian forest, ii) tea plantation and iii) paddy rice cultivation. The prevailing tree species in the natural forest comprise Hornbeam, Persian and Maple. A significant portion of forest in the studied area has been cut cleared during recent decades and changed to produce agricultural crops such as tea, rice, kiwi, and some orchards have also been planted.

Those three major land uses were selected as the basis for soil collection to investigate the influences of land use change on the physical parameters of SOC. In total, 100 soil samples were collected to represent the selected land uses (33 for rice fields, 33 for tea garden, and 34 for natural forest) from the 0-10 cm layer in early August 2016. Based on a sampling pattern, three subsamples were collected from each location and then combined to achieve a composite sample in order to lessen variability on a micro-scale. Soil samples were transferred to the laboratory and air-dried for further analyses.

A portion of the soil samples were ground and allowed to pass through a two mm sieve for routine soil measurement. Soil pH was determined by a pH meter using a ratio of 1:2.5 soil:water (Page, 1982). The Bouyoucos hydrometer method was applied to determine soil texture (Gee and Bauder, 1979). Bernard's calcimetric approach was used to measure calcium carbonate equivalent (CCE) (Richard and Suarez, 1996). Bulk density (ρ_b) was measured by applying the core method using the cylinders collected from the 0-10 cm layer. The SOC concentration was measured using the method proposed by Walkly and Black (1934).

For aggregate stability measurements and aggregates fractionation, the soil was allowed to pass through 4.75 mm sieve. 50 g of the soil that was sieved was capillary-wetted and a wet-sieving method was applied to separate the water-stable aggregates into seven size groups including 2-4.75, 1-2, 0.5-1, 0.25-0.5, 0.1-0.25, 0.053-0.1 and <0.053 mm. The contents of gravel and sand were measured by passing the dispersed aggregates through their associated sieves. The percentage of water-stable aggregates (WSA%) was determined using the following equation (Kemper and Rosenau, 1986):

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

where: $W_{i(a+s)}$ is the dry mass of the aggregates on the ith sieve, $W_{i(s)}$ is the dry mass of gravel or sand on the ith sieve, W_t is the total dry mass of the soil (*i.e.* 50 g), and n is the number of fractions for the aggregates (*i.e.* 6). The last fraction (< 0.053 mm) was excluded in the calculation of WSA. The mean weight diameter (MWD, mm) of water-stable aggregates was computed by (Kemper and Rosenau, 1986):

$$MWD = \sum_{i=1}^{n} w_i \bar{X}_i, \quad (2)$$

where: $\bar{X}_i$ is the arithmetic average of aggregates size on the ith sieve, w_i – the fraction of water-stable aggregates on the ith sieve, computed using:

$$w_i = \frac{w_{i(a+s)} - w_{i(s)}}{\sum_{i=1}^{n} w_{i(a+s)} - \sum_{i=1}^{n} w_{i(s)}}. \quad (3)$$

Moreover, the following equation was applied to calculate the geometric mean diameter (GMD, mm):

$$GMD = \exp\left(\sum_{i=1}^{n} w_i \log \bar{X}_i\right). \quad (4)$$

For the purposes of simplification in the interpretation of the SOC results in various aggregate fractions, they were combined into three groups of 2-4.75, 0.25-2 and 0.053-0.25 mm, and SOC was determined for the fractions by applying the wet-oxidation method (Walkly and Black, 1934). For the determination of particulate organic carbon (POC), subsamples of bulk soil were dispersed in distilled water with high-energy sonication (12 000 J s^{-1}) for 15 min to achieve comprehensive aggregates disturbance and dispersion and then allowed to pass through a sieve with a size of 0.053 mm. The particles remaining on the sieve were dried at 70ºC and analysed for POC using the wet-oxidation method. The clay- and silt-sized fractions in the above-mentioned suspension were segregated by means of Stoke's law and the use of the siphon approach (Bronick and Lal, 2005) and the mineral-associated organic C was determined in the fine fraction (silt and clay) using the wet-oxidation method (Walkly and Black, 1934).

Descriptive statistics comprising the mean, maximum, minimum, coefficient of variation, standard deviation, kurtosis and Skewness were obtained using SPSS software (SPSS, version 21). The Kolmogorov-Smirnov test was applied to evaluate normality in the distribution of the studied variables. A completely random design was employed for the statistical analysis and the datasets were examined using analysis of variance (ANOVA) and SPSS software. The arrangement of the statistical design included three land uses as treatments (natural forest, tea plantation and rice paddy). A means comparison was completed using the LSD method at the $p < 0.05$ probability level. In addition, in our study the concept of non-complexed clay (NCC) and complexed clay (CC) was proposed by Dexter *et al.* (2008) and applied to explore the influences of land use on the clay fractions.

RESULTS AND DISCUSSION

Descriptive statistics of the studied soil chemical characteristics are given in Table 1. All of the studied variables within the study area were normally distributed regarding the Kolmogorov-Smirnov test. Values of Skewness ranging from –1 to +1 also confirmed this conclusion. The lowest variability (*i.e.* lowest CV) was observed for pH (presumably due to the logarithmic nature of pH) and this was followed by ρ_b. Similarly, other scholars obtained the lowest CV values for pH in the soils of western and central Iran (Norouzi *et al.*, 2010; Afshar *et al.*, 2010; Zolfaghari *et al.*, 2015). The highest CVs were obtained for CCE, primary

Table 1. Descriptive statistics of some physical and chemical properties of surface soils in all studied soils (N = 100)

Variable	Unit	Min	Max	Mean	SD	Skewness	Kurtosis	CV (%)	KS
pH	–	4.08	7.61	6.33	0.84	-0.75	0.13	13.3	0.11
Clay	kg 100 kg^{-1}	1.0	46.1	13.3	9.1	1.00	2.36	68.4	0.10
Silt	kg 100 kg^{-1}	6.5	87.4	49.3	23.2	0.21	-1.37	47.0	0.15
Sand	kg 100 kg^{-1}	4.9	87.2	37.4	23.8	0.21	-1.37	63.6	0.14
SOM	kg 100 kg^{-1}	0.35	9.83	3.49	1.76	0.76	1.05	50.4	0.12
TN	kg 100 kg^{-1}	0.02	0.90	0.26	0.14	1.00	3.17	53.8	0.10
ρ_b	Mg m^{-3}	0.89	1.46	0.96	0.22	0.03	-0.39	22.9	0.20
CCE	kg 100 kg^{-1}	1.5	17.5	8.6	7.5	0.48	-0.35	87.6	0.14

Min – minimum, Max – maximum, SD – standard deviation, CV – coefficient of variation, KS – Kolmogorov-Smirnoff criteria, TN – total nitrogen. SOM – soil organic matter, CCE – calcium carbonate equivalent, ρ_b – bulk density.

particles contents and soil organic matter (SOM). The high degree of variability in CCE and primary particles content may be attributed to soil distribution throughout the landscape by soil erosional processes (Karchegani *et al.*, 2011). In studying the variability of soil properties Jones *et al.* (2008) and Mokhtari Karchegani *et al.* (2011) stated that some properties are being affected by long-term soil detachment and deposition at different positions throughout the landscape.

The ANOVA results (data not shown) indicated that there were significant differences between the studied land uses for soil properties and aggregate stability indexes. Mean comparisons for the studied physical and chemical properties of the soil as well as aggregate stability indexes are presented in Table 2. The pH value was the lowest for the tea plantation (5.66), while the highest value was observed for rice cultivation (7.01). It seems that the long-term cultivation of tea plants in the study area led to a high rate of leaching and a lowering of the pH values. It is speculated that making farrows for tea farms induces better conditions for the deep percolation of soil water and increasing soil acidity through the translocation of basic materials to deeper soil levels. The CCE values followed the exact opposite trend to the pH values in the studied land uses (the lowest in the tea plantations and the highest in rice cultivation) which confirmed the above-mentioned statement. One of the well-known processes for soil acidification in tea plantations is the biogeochemical cycling of Al in tea litter (Ding and Huang, 1991; Khormali, *et al.*, 2007; Alekseeva *et al.*, 2011). Also, the application of chemical fertilizers such as NH_4^+-N fertilizers to increase the tea yield in the studied area could significantly accelerate the acidification of soils through NH_4^+ nitrification (Abe *et al.*, 2006; Ruan *et al.*, 2006; Oh *et al.*, 2006).

The SOM was significantly different between the studied land uses. The highest SOM values were related to natural forests (4.23 kg 100 kg^{-1}) and the lowest values were observed for rice cultivation (3.02 kg 100 kg^{-1}). The conversion of forest land to tea plantations led to a significant decrease ($p < 0.05$) in SOM values. These results are inconsistent with the findings of Abrishamkesh *et al.* (2011) in northern Iran and Solomon *et al.* (2002) in the sub-humid Ethiopian highlands who reported 23.9 and 51% reductions in the SOM values of surface soils after forest conversion to tea garden cultivation. Li *et al.* (2012) showed that the primary tropical forest had significantly more soil organic matter than the rubber and tea plantation fields ($p < 0.05$). Forest conversion to tea garden cultivation most likely influences the levels of soil organic C due to soil loss and the more rapid oxidation process of SOC linked to site disruption, and variations in the nature and quantity of crop residues which decomposes to form soil (Abrishamkesh *et al.*, 2011). In the forest ecosystem, there is to a considerable extent, an equilibrium between SOM decomposition and SOM recycling to soil (Tajik *et al.*, 2019a, 2019b), but in tea plantations this equilibrium is disturbed by picking tea leaves leading to a new equilibrium (Solomon *et al.*, 2002). Furthermore, excess stems are thrown away while lopping; this results in the turnover of SOM decreasing. The lowest content of SOM among the various land uses was observed for rice cultivation fields (3.02 kg 100 kg^{-1}).

Dexter and Czyż (2011) and Dexter *et al.* (2008) indicated that soil physical behaviour in mineral soils could be elucidated more precisely by applying the concept of non-complexed organic carbon (NCOC) and complexed organic carbon (COC). COC is a fraction of organic carbon that is associated with clay particles. By applying the concept of NCOC and COC, from the soil samples taken from three land uses, our results indicated that most of the selected soils in the forest were located above the saturation line (OC:clay ratio of 1:10) and the excess OC (*i.e.* the difference between the measured OC and 0.1 of clay content, OC-0.1 clay) in these soils was in the NCOC form (Fig. 1). Out of the 33 samples from the tea plantation, 12 soil samples originated from beneath the saturation line and the remaining ones originated from above the saturation line, whereas in paddy rice, the predominant proportion of the samples originated from underneath the saturation line with the result that in cultivated soils SOC is predominantly in the COC configuration. Soussana *et al.* (2004) reported that COC may be persistent for a more extended time period in pasture soils in the absence of any disturbance. Therefore, non-complexed/non-protected OC is vulnerable to decomposition and susceptible to soil management practices (Dexter *et al.* 2008). Our results are in accordance with

Table 2. Mean comparison of some soil physical and chemical properties and aggregate stability indexes between studied land uses

Variable / Land use	pH	Clay (kg 100 kg^{-1})	Silt (kg 100 kg^{-1})	Sand (kg 100 kg^{-1})	SOM (kg 100 kg^{-1})	CCE (kg 100 kg^{-1})	ρ_b (Mg m^{-3})	*MWD* (mm)	*GMD* (mm)	*WSA* (%)	POC (kg 100 kg^{-1})
Natural forest	6.31^b	9.5^b	36.7^c	53.6^a	4.23^a	7.95^b	0.87^b	1.19^a	0.82^a	77.2a	0.84^a
Tea plantation	5.66^c	17.6^a	41.5^b	40.7^b	3.11^b	5.93^c	0.98^{ab}	0.98^b	0.73^b	71.5^b	0.65^b
Paddy rice	7.01^a	12.7^b	68.9^a	18.2^c	3.02^b	11.71^a	1.20^a	0.74^b	0.68^b	65.9^c	0.27^c

CCE – Calcium carbonate equivalent, ρ_b – bulk density, *MWD* – mean weight diameter, *GMD* – geometric mean diameter, *WSA* – water stable aggregates, POC – particulate organic carbon. Different letters in each row indicate a significant difference (LSD, $p < 0.05$).

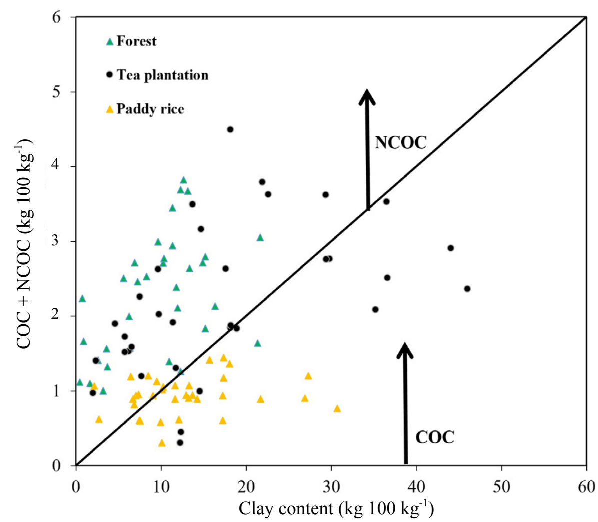


Fig. 1. Application of Dexter's COC-NCOC theory for the studied soils in three land uses. The diagonal line is the saturation line (1:10 line). The points below the line refer to the contents of complexed organic carbon (COC) and the heights above the line are the contents of non-complexed organic carbon (NCOC).

the findings of Zolfaghari *et al.* (2015) in western Iran and Havaee *et al.* (2015) and Baranian Kabir *et al.* (2017) in central Iran.

A comparison of means showed that there is a significant difference ($p < 0.05$) in ρ_b between selected land uses, somehow the greatest value (1.2 Mg m^{-3}) for paddy rice cultivation and the lowest for natural forest (0.87 Mg m^{-3}). It is frequently reported that native forests have a lower ρ_b value compared to their cultivated counterparts (*i.e.*, Khormali *et al.*, 2009; Ajami *et al.*, 2016). Kizilkaya and Dengiz (2010) and Lemenih (2004) reported that ρ_b increased due to soil compaction and a loss of SOC following soil ploughing and manipulation. Following soil ploughing, macro-aggregates are broken leading to lower porosity and higher ρ_b values. Clay, silt and sand contents also showed different values between the land uses. The lowest values of fine particles (clay and silt) were observed for rice fields, presumably due to the reception of more fine materials from upland areas through soil redistribution. Tea garden and forest soils are predominantly located in upland areas and they are affected by soil erosion processes and subsequently coarse materials are enriched in the surface levels. These observations are in accordance with the outcomes of other scholars (Jafari *et al.*, 2014; Zeraatpisheh *et al.*, 2019), who reported a higher content of fine materials in lowlands rather than uplands throughout the landscape.

Aggregate stability indexes (*e.g.*, *MWD*, *GMD* and *WSA*) may be applied as indexes of soil aggregation and could indicate the influence of soil management operations and land use (Six *et al.*, 2000). The results of means comparisons showed that forest soils had higher values of aggregate stability indexes (*MWD*, *GMD* and *WSA*), whereas tea plantation and rice cultivation soils had lower aggregation indexes. The reduction in the structural stability of cultivated soils may presumably be attributed to aggregate disruption and the exposure of the occluded SOC and physically preserved organic matter stores to rapid breakdown (Six *et al.*, 2000). Forest soil showed the greatest degree of aggregate stability, which may be due to the higher SOM content, and absence of practices which disturb the soil (Bronick and Lal, 2005). Gol (2009) and Ayoubi *et al.* (2012) found substantially higher total nitrogen, *WSA* and SOM contents in forest land as compared to cultivated land. A study by Khormali *et al.* (2009) concerning soil quality changes following deforestation in the north of Iran indicated that *MWD* was lower by about 40% in cultivated soils as compared to forest soils because of the significant loss of SOM and the destruction of aggregates.

It seems that due to cultivation operations in both tea garden and rice fields, SOC are being oxidized through a greater availability of SOM for microorganisms and this reduction led to lower aggregation. A significant and positive relationship between *MWD* and SOM content ($r = 0.87$, $p < 0.01$) in the whole soil samples confirmed the contribution of SOM to soil structural stability (Fig. 2). Aggregate stability demonstrates the interfaces between organic components and principal particles to organize stable aggregates that are influenced by several factors associated with management practices and soil environmental factors (Elustondo *et al.*, 1990; Celik, 2005).

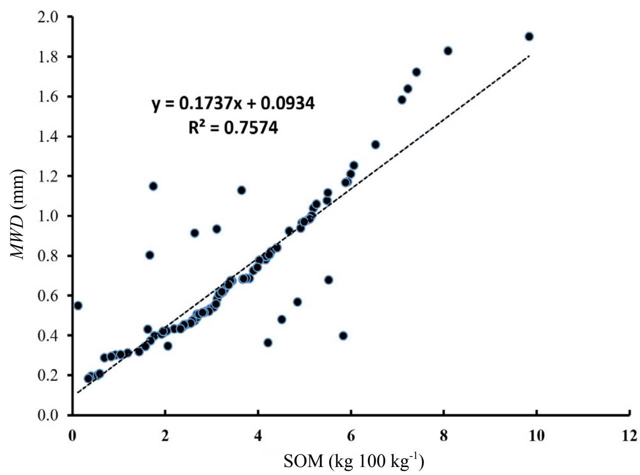


Fig. 2. Linear relationship between mean weight diameter (*MWD*) of water-stable aggregates and soil organic matter (SOM) for the whole soil samples in the studied area.

Figure 3 shows the distribution of aggregate-size categories as influenced by land use in the study area. There were significant differences in the scattering pattern of soil aggregates among the selected land uses. The greatest portions of coarse aggregate fractions (*i.e.*, 1-2 and 2-4.75 mm) were observed in forest soils, whereas the greatest portion of fine aggregates (< 0.053 mm) was observed in the rice paddy area, this was followed by the tea plantation.

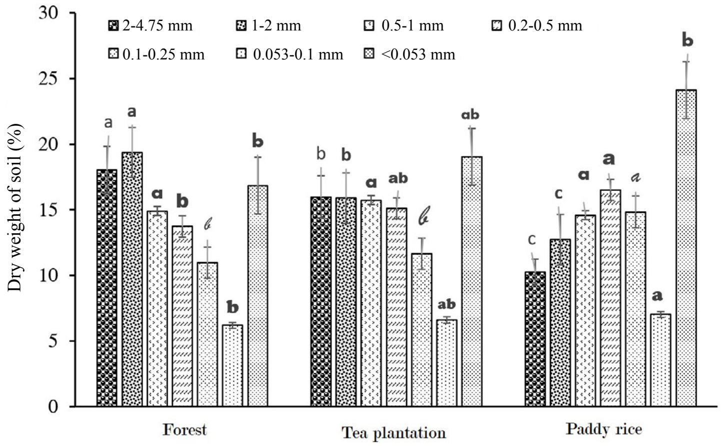


Fig. 3. Distribution of aggregate-size fractions as affected by land use. Means with at least one dissimilar letter indicate significant differences (LSD, $p < 0.05$) among the studied land uses.

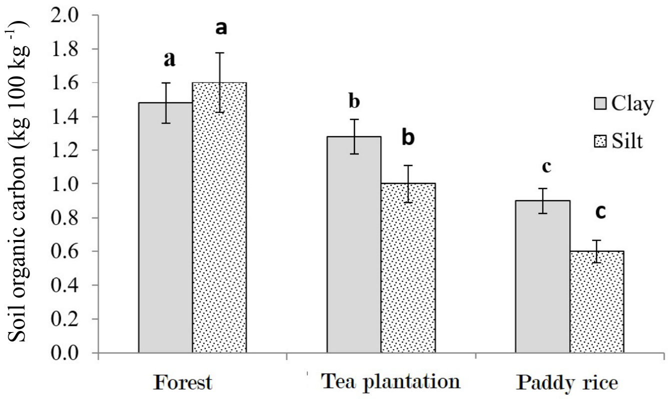
Tea plantation and rice-cultivated soils showed a near similar trend in the distribution of aggregates of various sizes (Fig. 3). Our results are in accordance with those of Besnard *et al.* (1996) and Ayoubi *et al.* (2012) who found a significantly higher portion of the macro-aggregates in forest soils as compared to cultivated soils. Micro-aggregates have been identified as an indicator of soil deterioration, and tillage practices in farmlands have resulted in the destruction of macro-aggregates into smaller ones (Bronick and Lal (2005).

The results of Celik (2005) similarly indicated the noteworthy differences between cultivated and forest soils regarding the size distribution of aggregates. A decrease in the concentration of aggregates in farmland may be ascribed to physical soil perturbation and the low stability of macro-aggregates. Grandy and Robertson (2006) examined the influences of ten years of ploughing on structural stability and found that ploughing substantially decreased the concentration of aggregates in the size range of 2 to 8 mm and increased the concentration of aggregates with a size of less than 0.25 mm in the surface soils.

Particulate organic carbon (POC) in forest land use (0.84 kg 100 kg^{-1}) was significantly ($p < 0.05$) higher than it was for the two other land uses (Table 2). The POC in the selected area was predominantly situated in the fraction with the size of sand. Furthermore, in the tea plantation (0.65 kg 100 kg^{-1}) a significantly higher POC was observed than in the soils cultivated for paddy rice (0.27 kg 100 kg^{-1}). The high contents of POC in forest land and tea plantations denote the high degree of insertion and larger nature of organic fragments of forest and tea plantation soils as opposed to the rice-cultivated soils. It seems that permanent vegetation such as the forest and evergreen vegetation such as the tea in our study area produce a high annual return of litter, and this accumulation leads to the highest proportion of SOM recovered as POC. In rice-cultivated soils, coarse organic fragments are impacted and oxidized due to aggregate devastation and the exposure of SOM that was physically preserved. Karchegani *et al.* (2012) in western Iran reported a higher POC in forest soils compared to the disturbed forest and cultivated soils.

Organo-mineral interactions play a protective role for SOC in contrast to biological disintegration. The size apportionment of mineral portions as well as mineralogy have an impact on SOC protection (Christensen, 1992; Schmidt and Kögel-Knabner, 2002). The SOC content associated with the primary particles was significantly affected by land use (Fig. 4a). A significant difference ($p < 0.01$) was observed between all of the studied land uses as the highest values in both fractions (clay and silt) were attributed to forest soils and the lowest ones were for rice-cultivated soils. In the forest soils, the silt-contributed OC was the highest among the principal particles which might be ascribed to the sizes of the organic matter particles in forest soil which is supplemented in the silt fraction. In addition, in the cultivated soils (tea and rice fields), clay-contributed OC was higher than that in the silt-sized fraction. Our results are in accordance with the outcome of Karchegani *et al.* (2012) who revealed the highest clay-associated SOC for cultivated soils and the highest silt-associated SOC for forest soils. Christensen (1992) stated that the SOC associated with the silt portion is too stable, whereas the SOC associated with the particles in the clay and sand fractions are frequently associated with newly-decomposed organic fragments and unstable microbial yields, respectively. Shi *et al.* (2009) in the China plateau indicated that SOC and POC in various land uses was the highest for native grassland and the lowest for land which had undergone fifty years of cultivation. In studying the influences of land use (pasture and cultivation) and slope position on SOM storage in central Iran, Safadoust *et al.* (2016) showed that the highest SOC content (*i.e.* 1.95 kg 100 kg^{-1}) was observed for pasture land use, in the clay fraction and from the footslope position, while the lowest was related to the sand portion in cultivated land at the backslope position.

a



b

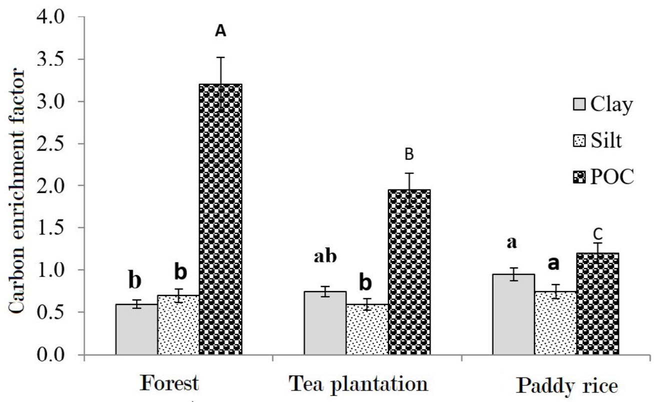


Fig. 4. Land use effects on the organic carbon (OC) content of fractions associated with the primary particles (a); enrichment factor for OC in different primary particle fractions and POC as affected by land use in the studied area (b). Different letters on the columns with a similar pattern stand for significant difference (LSD, $p < 0.05$).

The enrichment factor of SOC was calculated for all treatments. According to Christensen (1996) the contribution to SOC for each fraction is related to the SOC in the bulk soil. The enrichment factor (EF) was the highest for POC in all land uses (Fig. 4b). The following trend was observed for EF among all of the studied land uses: rice paddy > tea plantation > forest for both primary fractions of silt and clay. Larger SOC enrichment factors were calculated for the clay fraction in our study, which is consistent with the results of Six *et al.* (2002), Lorenz *et al.* (2008) and Karchegani *et al.* (2012). Bronick and Lal (2005) indicated that a combination of rotation and tillage practices had plausible impacts on the principal particle fractions and their contributed SOC. The results reveal that the clay size fraction was especially rich in SOC compared to the fraction I sizes of silt and sand.

The impacts of land use with various aggregate sizes on SOC are given in Table 3. The highest SOC was contributed by macro-aggregates (*i.e.* 2-4.75 mm) and was observed in the natural forest (33.19 kg 100 kg^{-1}), the soil presumably receives high amounts of inputs and fresh litter and experiences a lower decomposition rate. The SOC content in macro-aggregates was reduced significantly in the tea plantation and rice cultivation compared to the natural forest, for reasons that remain unclear the lowest value was obtained for paddy rice fields (12.43 kg 100 kg^{-1}). This trend was observed in all fractions and these differences were much greater for the larger aggregates. The existence of a higher amount of SOC in larger aggregates (Table 3), confirmed the perception of an aggregate hierarchy with regard to which aggregates in micro sizes unite and build up to aggregates in macro sizes with transitory coagulating agents like plant and microbial-derived products and coagulating agents like fungal hyphae and roots (Six *et al.*, 2000). Elliott (1986) investigated aggregate satiability and its contribution to SOC and revealed that the result of aggregate hierarchy was an enhancement in SOC content with the enlargement of soil aggregates due to the binding effects of SOC.

Table 3. Land use effects on soil organic carbon content (SOC, kg 100 kg^{-1}) in aggregate-size fractions of the surface layer (*i.e.* 0-10 cm)

Aggregate size (mm)	Land use		
	Forest	Tea planation	Paddy rice
2-4.75	33.19^{a} (±2.54)	20.08^{b} (±1.52)	12.43^{c} (±0.56)
0.25-2	25.08^{a} (±1.85)	17.04^{b} (±0.89)	11.03^{c} (±0.66)
0.053-0.25	16.77^{a} (±0.69)	15.85^{a} (±1.42)	10.93^{b} (±1.02)

Different letters in each row indicate significant difference (LSD, $p < 0.05$). The values in the parenthesis are standard deviations.

It has been revealed that long-term cultivation practices disturb aggregates and break down macro-aggregates into smaller ones (*e.g.*, Mikha and Rice, 2004; Ayoubi *et al.*, 2012; Safadoust *et al.*, 2016). Six *et al.* (2000) demonstrated an enhancement in SOC concentration in aggregates with a large size following no-tillage and an SOC decline in the smaller fractions following traditional tillage. Oades (1988) stated that SOC stock and its dynamic are for the most part meditated by the physical location of SOC in the soil architecture. Tillage practices destroy soil aggregates and subsequently expose physically protected SOC to oxidizing conditions. Macro-aggregates in the natural forest had a higher level of SOC as opposed to micro-aggregates which had levels that might be ascribed completely to fresh SOC storage, whereas the long-term SOC storage of the aggregates persisted with its efficiency unchanged.

Our results showed that the SOC associated with micro-aggregates was weakly influenced by paddy rice and tea cultivation. However, SOC in the macro-aggregates was substantially affected by land use and cultivation. Accordingly, John *et al.* (2005) and Bronick and Lal (2005) indicated that the SOC content in the macro-aggregates was greater than that of the meso-aggregates. A substantial portion of SOC in cultivated soils is usually stored in fine aggregates compared to forest soils. Our results are however not entirely consistent with the findings of Ayoubi *et al.* (2012) who reported that the majority of SOC stock is situated in the macro-aggregates in forest soils.

CONCLUSIONS

1. Soil quality indicators comprising soil organic carbon, bulk density, calcium carbonate equivalent as well as primary particle fractions differed significantly depending on the studied land uses. Tea plantations showed intermediate conditions compared to forest and rice fields.

2. Land use significantly influenced soil aggregation as the highest aggregate stability indexes were observed in forest soils and tea plantation soils, however rice cultivated soils showed lower aggregation levels due to anthropogenic practices that lead to the breakdown of macro-aggregates into micro-aggregates.

3. Among the various primary physical fractions, the highest enrichment factor was obtained for particulate organic carbon. The highest and lowest soil organic carbon values in the silt and clay fractions were observed in forest and paddy rice fields, respectively. Land use had definite effects on soil organic carbon content for different aggregate-size fractions. The highest soil organic carbon was associated with the macro-aggregates fraction and was obtained for forest soils that conformed to the conditions of a high rate of receiving fresh soil organic matter and a lower decomposition rate.

4. Our results indicate that indigenous forest may preserve large aggregates as opposed to disturbed soils, and could also improve the potential of soil for organic carbon sequestration compared to other damaged ecosystems.

Conflict of interest. The authors declare no conflict of interest.

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