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Soil Organic Carbon Pools in Particle-Size Fractions as Affected by Slope Gradient and Land Use Change in Hilly Regions, Western Iran

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Abstract: This study was conducted to explore the effects of topography and land use changes on particulate organic carbon (POC), particulate total nitrogen (PTN), organic carbon (OC) and total nitrogen (TN) associated with different size primary particle fractions in hilly regions of western Iran. Three popular land uses in the selected site including natural forest (NF), disturbed forest (DF) and cultivated land (CL) and three slope gradients (0-10 %, S_1, 10-30 %, S_2, and 30-50%, S_3) were employed as the basis of soil sampling. A total of 99 soil samples were taken from the 0-10 cm surface layer in the whole studied hilly region studied. The results showed that the POC in the forest land use in all slope gradients was considerably more than the deforested and cultivated lands and the highest value was observed at NF-S_1 treatment with 9.13%. The values of PTN were significantly higher in the forest land use and in the down slopes (0.5%) than in the deforested and cultivated counterparts and steep slopes (0.09%) except for the CL land use. The C:N ratios in POC fraction were around 17–18 in the forest land and around 23 in the cultivated land. In forest land, the silt-associated OC was highest among the primary particles. The enrichment factor of SOC, E_C,was the highest for POC. For the primary particles, E_C of both primary fractions of silt and clay showed following trend for selected land uses and slope gradients: CL> DF> NF and S_3 > S_2> S_1. Slope gradient of landscape significantly affected the OC and TN contents associated with the silt and clay particles, whereas higher OC and TN contents were observed in lower positions and the lowest value was measured in the steep slopes. Overall, the results showed that native forest land improves soil organic carbon storage and can reduce the carbon emission and soil erosion especially in the mountainous regions with high rainfall in west of Iran.

Keywords: Land use change; Soil organic carbon; Slope gradient; Physical fractionation; Particulate organic carbon

Introduction

Soil organic carbon (SOC) is an important source of nutrients for crop yield in natural ecosystems, which is influenced by land use, soil type, climate and vegetation (Loveland and Webb 2003). It is also one of the important factors affecting soil quality, sustainability of agriculture, soil aggregate stability and plant production (Freixo et al. 2002; Loveland and Webb 2003). The intensity of global warming in the future is attributed to the SOC cycle.

The SOC pool is strongly affected by land use changes and management strategies and is derived from the surface input of plants as well as roots and associated turnover of mycorrhizal hyphae (Lal

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2004; Lorenz et al. 2008). The SOC content is strongly influenced by land use change and therefore, has been widely used as an indicator of soil quality (Lal 2004; Celik 2005; Khormali and Shamsi 2009; Ayoubi et al. 2011). The SOC pool may increase by conversion of forest to pasture, whereas conversion of forest to cultivated land presumably results in reduction of the SOC pool (Lorenz et al. 2008).

Changes in land use such as clear or partial cutting of forest often influence both quantity and quality of the soil organic matter (SOM). It is frequently reported that the soils in natural ecosystems such as forest and pastures have lower bulk density (BD), higher SOM content, aggregate stability and saturated hydraulic conductivity as compared to the cultivated counterpart fields (Scott et al. 1986; Saviozzi et al. 2001; Puget and Lal 2005).

The SOC concentrations in mineral soils, however, may be recovered in centuries after a land use change (Leifeld and Kögel-Knabner 2005). Therefore, at early stages of anthropogenic agitations, assessment of changes in sensitive SOC fractions may be practical and valuable in predicting route in the SOC pool. Evaluation of the total SOC pool provides little information concerning the biochemical stability and duration of C stored in soils (Puget et al. 2005; Lorenz et al. 2008), hence, quantification of SOC in different fractions provide more valuable information on functionality of the SOC pool.

Organo-mineral interactions protect the SOC against biological decompositions. The mineralogy and size distribution of the mineral fractions affect the SOC protection (Baldock and Skjemstad 2000; Schmidt and Kögel-Knabner 2002). Generally, clay and silt contents are correlated positively with SOM concentrations, and their amount in soil is directly contributed to the accumulation of silt- and clay-protected SOC (Six et al. 2002; Zinn et al. 2005). Therefore, studying the dynamics and functional characteristics of SOC and physical fractionation of primary organo-mineral complexes (i.e., clay-, silt-, and sand-sized separates) are useful approaches (Christensen 1992).

Puget et al. (2005) in a study on meadow and no-till corn showed that the SOC pools associated with the clay-size fraction (<0.002 mm) in the surface horizons were only slightly affected by cultivation, compared to forest land use. They also showed that cultivation mostly affected the SOC pool in the silt-size fraction (i.e. 0.002–0.020 mm) with a higher fraction of particulate organic matter (POC, >0.25 mm). Lorenz et al. (2008) compared three different management systems (meadow; no-till corn, NT; no-till corn with manure, NTm) in terms of SOC pools. They observed that NTm stored the largest pool of mineral-associated OC in 0-30 cm depth. The silt-associated and mineral-bound SOC pool in NTm was greater than NT due to increased SOM input.

The natural Querqus forest in hilly and mountainous region of western Iran has been disturbed since approximately fifty years ago and comprehensively has been cleared in some parts and subsequently cultivated for a long time afterward (Abbaszadeh Afshar et al. 2010). In this study, three land uses including natural forest; disturbed forest and cultivated land were studied. The objectives of our investigation were to: (i) determine impacts of land use changes on selected soil properties, (ii) quantify differences among selected land uses over time in stabilizing SOC by physical fractionation, and (iii) determine whether the slope gradient in the hilly regions affects the particle-size fractions and their associated SOCs.

1 Materials and Methods

1.1 Description of the study area and soil sampling

This study was conducted in hilly regions of the Lordegan upland watershed located in western Iran (Figure 1). The study area is located within 50° 12' to 50° 37' E longitude and 31° 58' to 32° 03' N latitude. The mean elevation of the area is approximately 1860 m a.s.l. The mean annual temperature and precipitation at the site are 15 °C and 600 mm, respectively. The hill slopes of the study area have been developed by extensive dissection of sedimentary Quaternary deposits. The soils of the study area are dominantly classified as Fine loamy, mixed, thermic, Typic Haploxerolls and Fine mixed, thermic, Typic Calcixerepts (Soil Survey Staff 2006).

The study area naturally forested by Querqus, but since 50 years ago because of the anthropogenic pressures and land disturbances, a variety of land uses have been observed: (i) natural forest land (NF), (ii) disturbed forest land (DF),

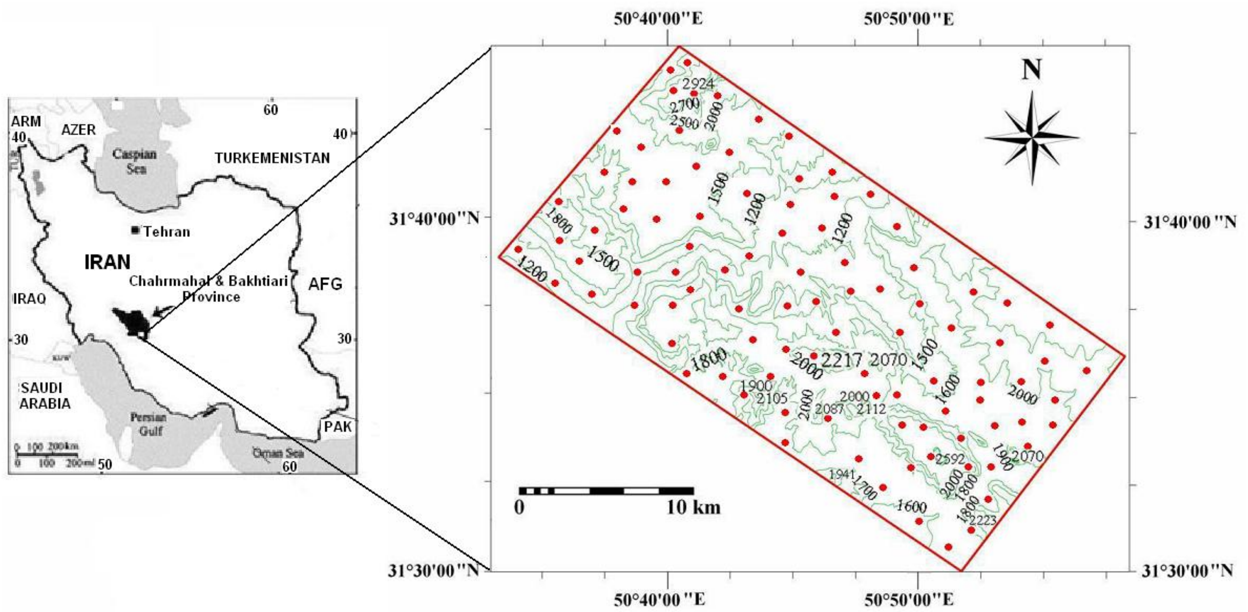

Figure 1 Location of the studied site in Lordegan district, Charmahal & Bakhtiari province, western Iran (a), and spatial distribution of soil sampling sites (b).

and (iii) cultivated land (CL) under intensive cultivation after clear forest cutting. Therefore, the described land uses were considered as the basis for selection of soil samples to predict land use effect on physical fractions of SOC. In each land use approximately 33 soil samples were collected in three slope gradient including 0-10 % in lowland position (S_1), 10-30 % (S_2) and 30-50% (S_3) and, therefore, totally 99 soil samples were collected in the entire hilly region studied. The sampling pattern is shown in Figure 1. Soil samples were collected from 0-10 cm depth using an auger, three sub-samples per 1 m^2 area in each site, and then composed to reduce micro-variability. The transaction of the studied hillslope in the studied area is illustrated in Figure 2.

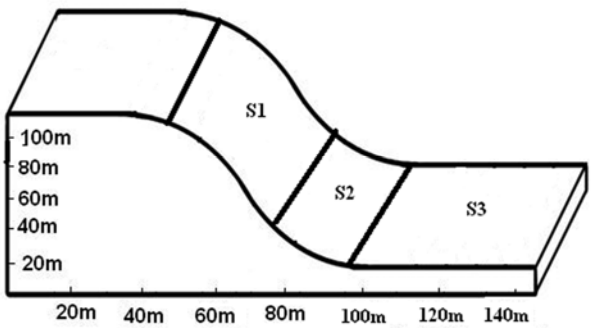

Figure 2 Transaction form a hillslope and schematic illustration of selected slope gradients at the site of west of Iran

1.2 Laboratory analysis

Percentages of clay and silt were measured using hydrometer method (Gee and Bauder, 1986) and sand fraction was measured by sieving. Calcium carbonate equivalent (CCE) was measured by the Bernard's calcimetric method (Black et al. 1965).

To determine particulate organic carbon (POC) and particulate organic nitrogen (PTN), sub-samples of whole soil (2 mm) were dispersed in distilled water with particulate organic carbon (POC) removal at high-energy sonication (12500 J) for 13 min to complete aggregate breakdown and dispersion (Edwards and Bremner 1967). The dispersed sample was passed through a 0.053 mm sieve. The material left on the sieve (>0.053 mm) was dried at 50 °C in a ventilated oven and gently ground to pass a 0.053 mm sieve for POC and PTN analyses.

The POC was expressed on an oven-dried soil basis. The PTN was also calculated in a similar manner (Chan 2001). The silt- and clay-sized organo-mineral particles in suspension were separated considering the Stocks' law and using sedimentation and siphoning method (Bronick and Lal 2005) and the mineral-associated organic C and N were measured in the clay and silt fractions. The SOC content was measured using the wetoxidation method (Walkly and Black 1934) and the total nitrogen (TN) was measured using the Kjeldahl method (Institute of Soil Science, Academia Sinica 1978) in bulk soil and various fractions.

1.3 Statistical analysis

Factorial arrangement in a completely randomized block design was used for the statistical analysis. The overall statistical design was: three land use treatments (NF, DF and CL) and three slope gradients (S_1, S_2 and S_3). The data were analyzed using analysis of variance (ANOVA) in the SAS statistical program (SAS Institute 1995). Comparison of means was done using the Duncan's multiple range method. Statistical significant was accessed at the $P < 0.05$ probability levels.

2 Results and Discussions

2.1 Physical and chemical properties of the soils

Table 1 presents the major characteristics of the soil studied. There is a significant difference for the soil particle distribution following 50 years of cultivation and land use change from natural forest to cultivation. The parent material of the site is approximately uniform in terms of particle size distribution; therefore the textural alterations are attributed to the land use changes and slope gradient effects. The highest values of fine materials, 55.5% clay content and 38.5% silt content, were found in cultivated land at downslope (CL-S1), whereas the highest value of sand content was observed in the steep slopes of cultivated land (NF-S3), likely because of accelerated detachment of finer particles during the soil erosion in the bare and disturbed areas.

It is well known that conversion of forest to cropland results in soil physical degradation and makes the land more susceptible to erosion. This is because macro-aggregates are fragmented into primary particles which are susceptible to detachment by runoff (Celik 2000). High slope gradient and the unstable soil structure in the CL-S3 treatment are the main responsible factors for the soil erosion and the loss of upper horizons following deforestation. This conclusion is supported by Dengiz et al. (2007), who studied the effects of different topographic positions on some soil properties such as soil texture in Cankiri-Acicay in Turkey.

The intermediate changes were found for disturbed forest land use (DF). These results are in agreement with finding of Celik (2005), Wang et al. (2006) and Khormali et al. (2009). Unlike two other slope gradients, the surface soil (0–10 cm) in downslope position of the CL had finer texture with significantly higher clay content than the other slope gradients. This is related to the deposition of the clay-sized particles which were transported from the upper positions. Wilding et al. (1982) and Khormali et al. (2009) stated that soils of toeslopes had finer soil texture than the other landscape positions.

Table 1 Land Use (LU) and Slope Gradient (SG) effects on selected soil physical and chemical properties in the 0-10 cm layer

SG	LU	Clay %	Silt %	Sand %	BD (Mg m^{-3})	SOC %	CCE %
S_1	NF	55.46^{abc}	32.79^{ab}	11.74^{bc}	1.39^{d}	3.58^{a}	14.30^{d}
	DF	59.69^{a}	24.75^{cde}	15.54^{b}	1.60^{c}	1.09^{c}	31.46^{bcd}
	CL	58.38^{ab}	38.51^{a}	3.10^{c}	1.65^{b}	0.98^{c}	38.26^{bc}
S_2	NF	53.27^{abc}	$28.13b^{cd}$	18.59^{b}	1.40^{d}	2.51^{b}	21.71^{de}
	DF	53.83^{abc}	31.67^{b}	14.49^{b}	1.64^{b}	1.12^{c}	40.65^{bc}
	CL	52.8^{abc}	26.05^{bcd}	21.14^{ab}	1.65^{b}	0.84^{c}	55.60^{a}
S_3	NF	51.67^{bc}	30.16^{bc}	18.16^{b}	1.38^{d}	2.48^{b}	29.50^{cd}
	DF	51.88^{bc}	27.69^{bcd}	21.41^{ab}	1.65^{b}	1.05^{c}	44.84^{ab}
	CL	49.26^{c}	18.69^{e}	32.03^{a}	1.75^{a}	0.98^{c}	56.51^{a}

S_1: Slope 0–10%; S_2: Slope 10–30%; S_3: Slope 30–50%;

NF: Natural forest; DF: Disturbed forest; CL: Cultivated land; BD: Bulk density; SOC: Soil organic carbon; CCE: Calcium carbonate equivalent.

* Figures with at least one similar letter within a column are statistically similar ($P < 0.05$).

Bulk density (BD) showed significant differences between the NF and CL land uses. The BD increased significantly (P ≤ 0.05) from 1.39 Mg m^{-3} in the NF to 1.65 Mg m^{-3} in the CL at downslope position (Table 1). This difference was more noticeable in the steep slopes (i.e. 1.38 Mg m^{-3} in the NF vs. 1.75 Mg m^{-3} in the CL). Gol & Dengiz (2008) and Kizilkaya & Dengiz (2010) showed that bulk density increased because of losses of SOC and soil compaction following soil ploughing.

The BD increase was also observed in the DF land use. Degradation of forest land by deforestation and traffic of goats and sheeps under intensive grazing has led to soil quality decline and consequently increased the BD in the DF land use. No significant difference for the BD was found between the DF and CL. The increased BD was related to the loss of SOM and soil compaction, due to tillage practices in the CL (Dang et al. 2002). The highest BD values in CL and DF land uses on the downslope (S1) are mainly caused by heavy machinery practices and intensive grazing traffic in this slope position.

The effects of land use change and slope on calcium carbonate equivalent (CCE) variability was also considered. The parent material of selected hillslopes derived from sedimentary rocks of Zagros zone in western Iran, contain high amount of lime. Land use change has resulted in the significant change in CCE (Table 1). The CCE content in the upper 10 cm soil is significantly lower in the NF land use at low land (NF-S1) (14.3%) which received high amount of water from the upper positions. The higher moisture availability together with CO_2 released from microbial respiration helped the downward leaching of carbonates. Khormali et al. (2006) indicated different complex processes accounting for the CCE dynamics in soil. In the positions with high available soil moisture and partial pressure of CO_2 (PCO_2), lithogenic carbonate is dissolved and migrates downward. The high value of CCE (56.5%) in downslope position of CL indicates the accumulation of carbonate which originated from carbonate movement of upper slopes to downslope through soil erosion processes. The increasing trend of CCE content in the surface horizon in steep slopes (S3>S2>S1) might be due to the loss of topsoil during the last decades and subsequent outcrop of the carbonate-enriched subsurface horizons. Similar results were reported by Khormali et al. (2009).

2.2 Organic matter of bulk soil and particulate organic matter

The SOM has been reported as a very powerful indicator for assessing soil potential productivity in different regions/climates under various land uses and managements (Shukla et al. 2006; Ajami et al. 2006). Kizilkaya and Dengiz (2010) in a study according to land use changes in natural forest of Cankiri-Uludere in Turkey, indicated that deforestation and subsequent tillage practices resulted in significant decrease in organic matter and total nitrogen.

About 60-70% of SOC has significantly reduced following deforestation (P < 0.01). These results are in agreement with Nardi et al. (1996) who suggested that the rupture of the larger aggregates into the smaller ones following deforestation aggravates the loss of SOM. Physically-protected organic materials are exposed to microbial decomposition upon aggregates breakdown. Increasing soil temperature after deforestation, due to the less shading and low vegetation cover, as well as tillage practices presumably lead to higher susceptibility of soils to erosion (Carter et al. 1998).

The mean comparison test indicated that there was significant (P < 0.01) difference in SOC among the three land uses on the three slopes, with the main difference between the natural forest in downslope (3.58%) and the cultivated land in upper slope (0.84%) (Table 1). Evrendilek et al. (2004) showed that deforestation and subsequent cultivation decreased SOM by 48.8%. Significant differences in SOC content were also reported between cultivated soils and mature woodland (e.g. Chidumayo and Kwibisa 2003; Evrendilek et al. 2004; Ajami et al. 2006; Khormali et al. 2006). Several studies on variation of the organic carbon due to slope gradient showed that the downslope positions are mostly high in SOC compared to the upper positions. Wilding et al. (1982) explained that the higher SOC of the lower slope positions (with finer soil texture) are mainly due to greater soil water storage that promote vegetative growth and low anaerobic decomposition of organic matter. Another reason for the higher SOC content of the lower slope positions is the bulk (massive) transport of the surface soil materials from the upper positions.

Particulate organic carbon (POC) in forest land use (NFS_1, NFS_2 and NFS_3) was considerably more than deforested and cultivated lands (see Table 2).

Table 2 Effects of land use and Slope Gradients (SG) on the POC (a), PTN (b) and C:N ratio of particulate OM

SG	Land use	POC %	PTN %	C:N ratio
	NF	9.13a	0.50a	18.275b
S_1	DF	6.83ab	0.39a	17.35c
	CL	7.79a	0.45a	17.31c
	NF	1.20c	0.05b	21.11ab
S_2	DF	1.56bc	0.07b	22.10ab
	CL	0.68c	0.03b	22.05ab
	NF	2.13bc	0.09b	23.71a
S_3	DF	2.12bc	0.10b	21.29a
	CL	2.11bc	0.09b	23.44a

S_1: Slope 0–10%; S_2: Slope 10–30%; S_3: Slope 30–50%; NF: Natural forest; DF: Disturbed forest; CL: Cultivated land; POC: Particulate organic carbon; PTN: Particulate total nitrogen
* Figures with at least one similar letter within a column are statistically similar ($P < 0.05$).

POC in the studied site was mainly in the sand-size fraction. The high amount of POC in the forest land implies the high input and coarser nature of organic debris under forest compared to the cultivated land. Generally, soils under permanent vegetation with large annual return of litter (forest and grassland) indicate the highest proportion of SOM recovered as POC (Mendham et al. 2004). In disturbed forest and cultivated lands, coarse organic residues are being disintegrated and oxidized due to aggregate destruction and deliberating/exposing the physically-protected SOM.

Particulate total nitrogen (PTN) values are presented in Table 2. The values of PTN were significantly higher in the forest land use and in the down slopes than in deforested and cultivated counterparts and steep slopes except for the CL land use. This trend may be attributed to movement of litter of cereals with relatively high C:N ratio. The C:N ratios of POC under three land uses showed significant differences at 95% probability level. The C:N ratios in POC fraction were around 17–18 in the forest land and around 23 in the cultivated land. The higher C:N ratio of POC fraction in the cultivated soils compared to the forest soil indicated a greater loss of N pool than C pool. This result is also in agreement with findings of Shi et al. (2010). It presumably shows that decomposition and/or turnover processes of C and N are not totally coincided. Cambardella and Elliott (1993) also reported 18% of total soil carbon and 25% of total soil nitrogen in no-tilled soil was associated with fine-silt size particles in macroaggregates. The organic nitrogen decreased as the intensity of tillage increased, but organic carbon contents remained unchanged, suggesting that the processes controlling the organic carbon and nitrogen cycles are not coupled. They assumed that organic carbon turnover is controlled by physical protection mechanisms while organic nitrogen turnover is controlled by chemical processes. This may be attributable to differences in quality of POC in selected land uses. These results are similar to the report by Mendham et al. (2004) which reported C: N ratio around 19 for afforested land under *Eucalyptus globulus* compared to pasture soils with C:N ratio of 17.

2.3 Mineral-associated soil organic matter

The OC content associated with the primary particles was significantly ($P < 0.01$) influenced by the land use and slope gradient (Figure 3). In forest land the silt-associated OC was highest among the primary particles. It may be attributed to the nature and sizes of SOC in forest land use which is enriched in silt fraction. But, in deforested and cultivated lands the SOC in the clay-sized fraction was higher than that of silt-sized fraction. It has been frequently reported that organic matter associated with silt-sized fraction is very stable since the sand-sized and clay-sized fractions are usually linked with newly-decomposed residue materials and with microbial (unstable) products, respectively (Christensen 1992).

The enrichment factor of SOC, E_C (mass of OC per mass fraction/mass of OC per mass of soil; Christensen 1996) was the highest for POC (Figure 4). For the primary particles, E_C showed following

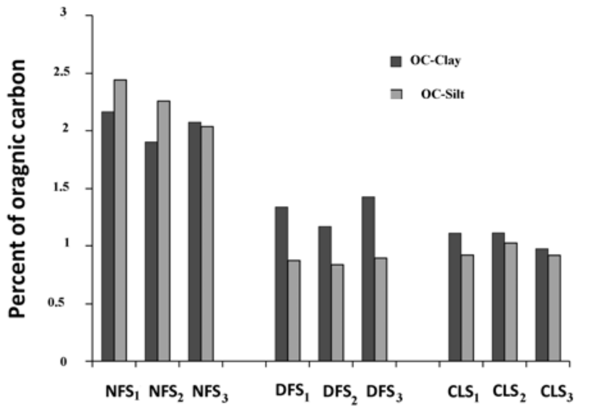

Figure 3 Land use and slope gradient effects on the OC content of fractions associated with the primary particles (i.e. clay and silt)

trend for selected land uses and slope gradients: CL>DF>NF and $S_3>S_2>S_1$ for both primary fractions of silt and clay. Natural forest land in all slope gradients showed higher mineral-associated OC than the disturbed forest and cultivated lands. In general, silt-associated OC was significantly influenced by land use and decreased as following: NF (21.01 g kg^{-1})> DF (11.34 g kg^{-1}≥CL (7.53 g kg^{-1}). Also N concentration in silt-associated OM was markedly affected by land use and was in the order: CL (0.60 g kg^{-1}N) < DF (1.04 g kg^{-1}) < NF (1.51 g kg^{-1}). Clay-associated OC was significantly affected by land use change. The trend of OC changes followed the order: NF (20.31 g kg^{-1})> DF (12.51 g kg^{-1})≥ CL (12.30 g kg^{-1}) and N concentration was as follows: NF(2.72 g kg^{-1}) > DF(1.56 g kg^{-1}) ≥ CL(1.53 g kg^{-1}). In the Qinghai-Tibetan of China plateau, Shi et al. (2009) showed that OC and ON contents, free and occluded POCSs, and mineral-associated OM in different land uses were increased in the following order: native grassland > 12 years cultivation > 50 years cultivation.

In cultivated and deforested lands the OC content in clay fraction is higher than in silt fraction indicating the stability of clay-sized associated OM in disturbed ecosystems. Observation of relatively higher OC enrichment factors for the clay fraction is consistent with findings by Christensen (1996), Six et al. (2002) and Lorenz et al. (2008). It is interesting to note the role of clay in carbon sequestration by protecting it from decomposition. Three reasons are considered here: 1) low aeration in micropores formed by the clay particles, 2) greater specific area of fine particles enhances a high carbon adsorption, and 3) clay particles are also able to absorb the microbial enzymes and make them inactive (Balabane and Plante 2004). Bronick and Lal (2005) reported that tillage and rotation combination had influences on the primary particle percentages and their associated-OC contents. They concluded that the clay-sized particles were highly rich in OC compared with the silt- and sand-sized particles. In agreement with our findings, they also found that the primary particle associated OC content was higher in no-tilled soils than in cultivated soils.

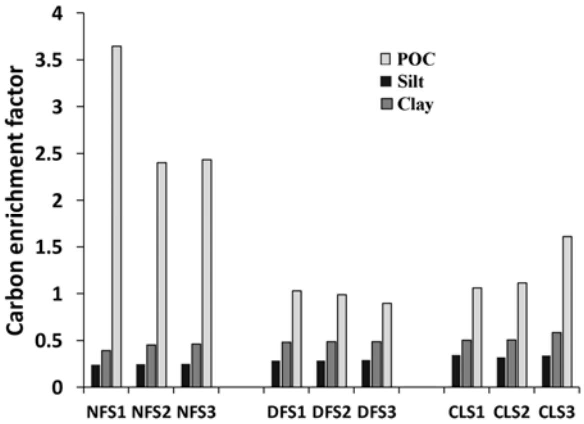

Figure 4 Enrichment factor for OC in different primary particle fractions and POC as affected by land use and slope gradient

Slope gradient of landscape significantly affected the OC and TN contents associated with the silt and clay particles. Higher OC and TN contents were observed in lower positions and the lowest value was measured in steep slopes. The OC associated with fine particles was higher in lower slopes presumably due to preferential soil erosion from the upper slopes and more water in this part of landscape for SOM maintenance. These results are in line with results by Doaei (2008) in Broujen district, south-west Iran. They reported that footslope position had the highest SOC and STN contents when compared with other slope positions.

3 Conclusions

The impacts of long-term land use and slope gradient on particulate organic carbon (POC) and mineral-associated soil organic carbon (SOC) were explored. The effect of land use on OC in the POC, and silt- and clay-associated fractions were highly significant in the upper slopes (slope > 50%) and downslope positions (slope < 10%), the most and least stable landscape positions. The POC and PTN, and OC and TN in the primary particles were all reduced substantially after deforestation and intensive cultivation. The practices in cultivated land resulted in exposure of physically-protected POC to microbial attack and rapid oxidation. There was evidence that POC and mineral-associated OC are valuable as indicators of soil degradation due to land use change. Overall, the results showed that native forest land holds soil organic carbon and reduces the carbon emission and soil erosion especially in the mountain regions with high rainfall in west of Iran. However, a more accurate comparison are required on the SOC sequestration capacity and release of the land uses mineralogical and molecular-level analyses on a large set of fractions from the entire soil profiles.

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