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Monitoring of soil organic carbon and nitrogen stocks in different land use under surface water erosion in a semi-arid drainage basin of Iran

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ABSTRACT: Soil organic carbon (SOC) and soil nitrogen (SN) are the principal components in soil quality assessment, and in mitigation the global greenhouse effect. In Iran, little information exists on the stocks of SOC and SN. SOC and SN stocks are a function of the SOC and SN concentrations and the bulk density of the soil that are prone to changes under land use types and soil erosion. The objective of this study was to evaluate SOC and SN stock in different land use types under surface erosion at catchment scale. In view of this, bulk density, SOC and SN concentration were measured in 39 different sampling sites of three main groups of land use affected by surface erosion namely, rangeland, crop field, and forest land at Taleghani catchment, Khoramabad, Iran. The results showed that SOC and SN stock under all land use types was significantly different ($P < 0.01$). SOC and SN stocks were greatest in the forest land use. The SOC stock for the 30 cm soil layer in different land uses varied in order forest (66.9 Mg ha^{-1}) > rangeland (63.3 Mg ha^{-1}) > crop field (47.2 Mg ha^{-1}; $P < 0.01$). Also the SN stock had the same trend in all studied land uses. These results can be useful as a scientific basis for selecting the proper soil management as a simple and low-cost approach to mitigate the SOC and SN loss. ©JASEM

Soil erosion is a global environmental problem, which refers to the displacement of soil from the place of its formation by causative agents, including raindrops, runoff, wind and gravity (Lal, 2003). Water erosion as the principal component of total soil erosion is the removal of a thin layer of particulate matter across the land surface and truncating the A horizon, which can redistribute considerable amounts of soil, soil organic carbon (SOC) and soil nitrogen (SN). SOC and SN are important components of the terrestrial C and N pool and are important indicators of soil fertility and productivity. Soil erosion alters the fluxes of SOC and SN because removes and redistributes the C- and N-enriched sediment and accelerates the process of mineralization (e.g., C emissions). Each process of soil erosion including detachment, transport, distribution, and deposition affects C and N dynamics. The amount of C and N removed by erosion depends on the magnitude of sediment removal. Surface cover conditions, soil properties, and degree of soil organic matter decomposition are some of the factors that affect the magnitude of C removal (Blanco & Lal, 2008). Therefore, increase of SOC and SN loss by land use changes and soil erosion decrease SOM/SOC and consequently reduce the satisfactory level of SOC and TN that is necessary for sustainable agroecosystems. The net release of C to the atmosphere is in the range of 0.37 - 1 pg year^{-1} (Lal *et al.*, 2004) versus the sink is in the range of 0.56 - 1 pg year^{-1} (Smith *et al.*, 2005). The last estimations reported by Van Oost *et al.* (2007) point to an erosion-induced sink of atmospheric C equivalent to approximately 26% of the C transported by erosion. Therefore knowledge of soil organic carbon and nitrogen stocks are important to reduce CO_2 emission to the atmosphere.

In a review, Don *et al.* (2007) concluded that SOC stocks at the clay rich site with Vertisols were almost twice as high (86 t ha^{-1} in 0–60cm depth) as at the sandy site with Arenosols (48 t ha^{-1}). John et al. (2005) have shown that total SOC stocks down to a depth of 60 cm and including the humus layer were larger at the spruce site (10.3 kg m^{-2}) as compared with the grassland, wheat and maize (7 to 8 kg m^{-2}). However, SOC stocks in the mineral soil were smaller in the forest soil than in the agricultural soils. Grimm *et al.* (2008) estimate SOC stocks in the upper 30 cm on Barro Colorado Island ranged between 38 and 116 Mg ha^{-1}, with lowest stocks on midslope and highest on toeslope positions. Wang *et al.* (2010) found that SOC stock is as large as 2.67×10^3 t (0–30 cm) in Yangjuangou watershed, China. Leifeld *et al.* (2005) reported that about 16% of the SOC stock in Swiss land area has been lost historically due to peatland cultivation, urbanization, and deforestation.

Accelerated soil erosion is also a serious problem in Iran, leading to soil degradation and consequently decreasing SOC and SN stocks. SOC and SN stocks are a function of the SOC and SN concentration and the bulk density of the soil. All mentioned variables are prone to changes and are influenced by land use changes. Consequently, the types of land use are important factors controlling SOC and SN stocks. In Iran, also little information exists on the stocks of SOC and SN. Therefore, the objective of this study was to evaluate SOC and SN stock in different land use types under surface water erosion at catchment scale.

MATERIALS AND METHODS

Description of the catchment: The study was conducted in the Taleghani catchment (33°42' to 33

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44'N and 47°39' to 47°44' E) which is part of the Kashkan Drainage Basin, Karkheh Drainage Basin, in the 20 km Northern of Koohdasht, Lorestan Province, Iran (Fig. 1). The drainage area of the Taleghani catchment is 25 km^2. Taleghani catchment has a mountainous topography, with a minimum and maximum height 1240 m and 2320 m above the sea level.

The long-term (1975-2005) mean annual precipitation is 450 mm in the region that most rainfall occurs in late autumn and winter. Geological formations including Amiran, Taleh Zang and Quaternary Formations are exposed at the surface in the drainage basin.

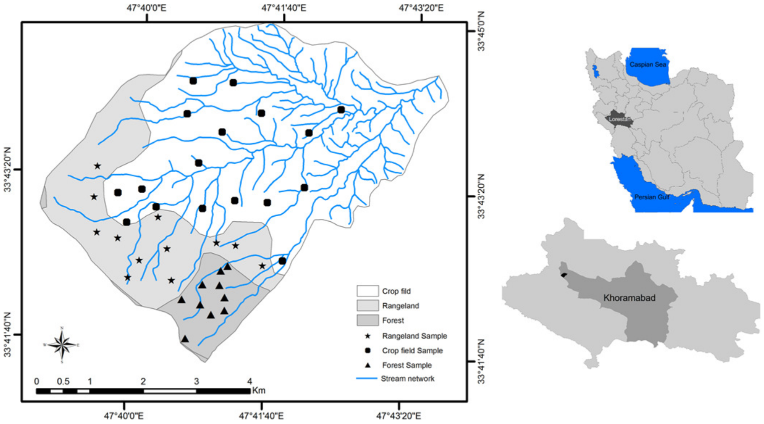

Fig. 1 Location map of the Taleghani catchment and sampling sites used in this analysis.

Sampling and data collection: Soil sampling sites were classified in three main land use types affected by surface water erosion; rangeland, forest and crop field and 12, 10 and 17 representative samples were collected from these sites at different locations within the Taleghani catchment, respectively (Fig. 1). Sampling sites were selected so that similar landform (slope, aspect and elevation) or uniform topographic positions were selected in all sites. The samples were collected by taking a representative sample of the top soil layer (0–30 cm) in 10 cm intervals. In each sampling site 5 sub-samples were collected over an area of approximately 100 m^2 which were mixed into a single composite sample.

Soil bulk density was measured on 6 cm long and 6 cm diameter stainless steel cores (Blake & Hartge, 1986). Samples were air-dried and sieved (<2 mm) for organic C and N concentrations measurement. The organic C content was measured by the Walkley-Black method (Skjemstad & Baldock, 2008). The nitrogen concentration was measured by the Kjeldahl method using Kjeldahl distillation unit FOSS Model 2100 (Rutherford et al, 2008). The SOC and SN stocks were calculated based on the following formula:

$$SOCS\,/\,SNS = \sum_{i=1}^{n} (1-\theta_i)\times \rho_i \times C_i \times T_i\,/10$$

where SOCS and SNS (Mg ha^{-1}) are soil organic carbon stock and soil nitrogen stock of a profile, respectively, θ_i is gravel (>2 mm) content in horizon i (%), ρ_i is soil bulk density in horizon i (Mg m^{-3}), C_i is concentration of organic carbon or nitrogen in horizon i (g kg^{-1}), T_i is the thickness of horizon i (cm), and n is the numbers of horizons involved.

Statistical analyses: Data were examined using the Kolmogorov-Smirnov test for normality and the Levene test for homogeneity of variance. These statistical analyses were followed by one-way ANOVAs (F-test) and unequal N Tukey HSD, post-hoc tests for the identification of significant differences among treatments. Statistical analyses were carried out using STATISTICA V.8.0 (StatSoft, 2008).

RESULTS AND DISCUSSION

The SOCS varied between 18.8 Mg ha^{-1} (i.e. crop field) and 88.7 Mg ha^{-1} (i.e. rangeland), mean 57.2 Mg ha^{-1} (Table 1). The range of SOCS in the study area roughly corresponds to that in other surveys, although some of the values we measured were relatively low (Table 1). For example Yu *et al.* (2007) reported SOCS ranged 29–167.5 Mg ha^{-1} in different ecosystems in china (i.e. in forestland 143.3 Mg ha^{-1}, in farmland 92.2 Mg ha^{-1} and in desert land 29 Mg ha^{-1}). Comparatively, the mean SOCS for forestland (66.8 Mg ha^{-1}) found in the present study differs greatly from those found in that study. The SOC stock was highest for forest land use sites for 0–30 cm soil layers ($P < 0.01$; Fig. 2), which showed the important contribution of soil organic towards enhancing SOC stock. Also a study in Laos showed that the highest organic carbon was stored in natural forests (Hett et al, 2011). The SOC stock was significantly different between three land use types

(Table 1, Fig. 2). The mean SOC stock for 0–30 cm soil layer under different land uses varied in order forest (66.9 Mg ha^{-1}) > rangeland (63.3 Mg ha^{-1}) > crop field (47.2 Mg ha^{-1}; $P < 0.01$) (Table 2 & Fig. 2). Also other studies have shown the reduction of soil organic carbon stock in agricultural land due to human activity. For example, Krogh *et al.* (2003) in a study in Denmark showed that the SOCS in agricultural land is lower than the wetland and forest. Liu *et al.* (2011) were expressed in a study in China that human activity affects the amount of SOCS.

Table 1. Descriptive statistics of SOCS & SNS in different land use types

Land use	No. of samples	SOCS (Mg ha^{-1}) Mean	S.D.	S.E.
Total	39	57.2	16.4	2.6
Crop field	17	47.1	14.3	3.5
Rangeland	12	63.3	17.2	5.0
Forest	10	66.8	7.8	2.5
Land use	**No. of samples**	**SNS (Mg ha^{-1}) Mean**	**S.D.**	**S.E.**
Total	39	9.3	3.44	0.55
Crop field	17	6.98	2.61	0.63
Rangeland	12	10.83	3.1	0.89
Forest	10	11.5	2.72	0.86

Table 2. One way ANOVA for the effects of land use types on SOCS and SNS

Effect	d.f.	SS	MS	F	p
SOCS					
Intercept	1	129848	129848	660	<0.0001
Land use	2	3098	1549	8	0.001
Error	36	7087	197		
Total	38	10185			
SNS					
Intercept	1	3547.66	3547.66	455	<0.0001
Land use	2	168.21	84.1	10.79	0.001
Error	36	280.67	7.8		
Total	38	448.88			

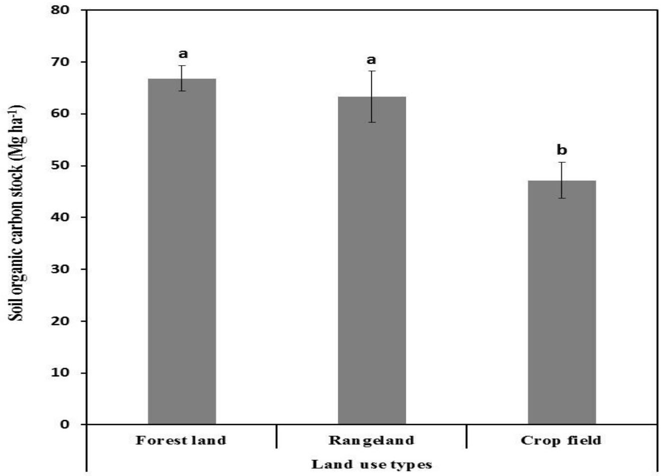

Fig. 2 Soil organic carbon (SOC) stock in different land unit under surface erosion. Different letters indicate that SOC stock is significantly different at 1% level based on Tukey HSD Post-hoc test.

Berhe *et al.* (2007) estimated that the annual erosion-induced C sink offset global fossil fuel emissions of CO_2 by up to 10% in 2005. Van Oost *et al.* (2007) point to an erosion-induced sink of atmospheric C equivalent to approximately 26% of the C transported by erosion. In semi-arid climates, Haregeweyn *et al.* (2008) underlined the potential of reservoirs to act as important stores of organic C in the global C balance. At a much larger scale and climatic conditions varying from semi-arid to humid in different sub-catchments, Smith *et al.* (2005) concluded that soil erosion results in a net sink of atmospheric CO_2. Results also differ concerning erosion mechanisms that lead to different amounts and types of mobilized soil organic C. About 75% of total terrestrial C is stored in the world's soils (Henderson, 1995), and forest soils hold about 40% of all belowground C (Dixon *et al.*, 1994). Therefore, even if surface soil erosion only slightly affects soil C stocks at catchment scale, it could have a significant effect on the global C budget.

The mean of SNS in the study area is 9.3 Mg ha-1. Our results indicated that land use had significantly impacted SNS ($p < 0.01$). As shown in Table 1 and Fig. 3, the mean SNS values for the three land-use-based groups were significantly different ($p < 0.01$), being highest for forest land (11.5 Mg ha−1), intermediate for rangeland (10.83 Mg ha−1) and lowest for crop field (9.98 Mg ha−1).

Fig. 4 shows the amount of organic carbon stock in the basin compared with other studies in other parts of the world. This comparison shows a lower SOCS in the study area compared to the other regions.

Top soil layer is affected by soil erosion process and land management practices, directly. Therefore, it will be sensitive to environment changes and land use. It seems unlikely that future changes in rangelands including land degradation could compensate for this SOC and TN loss in rangeland soils in the semi-arid area.

CONCLUSION

Organic carbon and nitrogen stocks are highly variable at a catchment scale. This study showed that at catchment scale forest land stored more carbon and nitrogen than rangeland and crop field. These differences can most probably be accounted for by vegetation percent cover. Our results can also help understand the major biogeochemical cycles that influence soil fertility and help devise management strategies that enhance the sustainability of these areas and thus slow further deforestation. Thus, slight reductions in SOC contents due to changes in land-use, soil management, or rates of soil erosion, could significantly raise the CO_2 concentration in the atmosphere. These results only present the current SOCS in different land use types affected by soil erosion across a semi-arid catchment in Iran. It is possible that appropriate management practices such as fertilization, soil erosion control and would enhance SOC sequestration in the study area.

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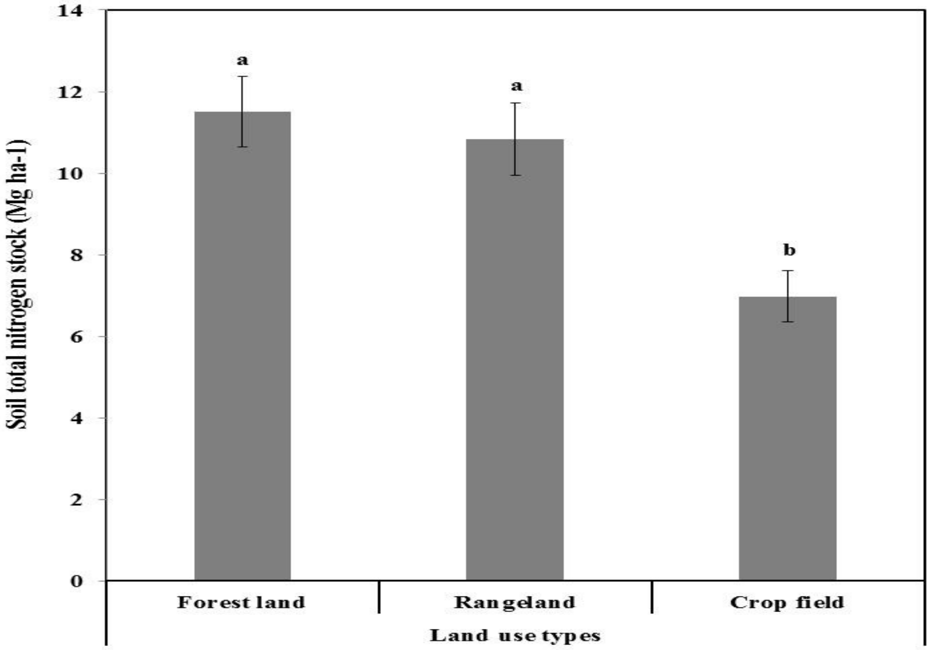

Fig. 3 Soil nitrogen (SN) stock in different land unit under surface erosion.
Different letters indicate that SN stock is significantly different at 1% level based on Tukey HSD Post-hoc test.

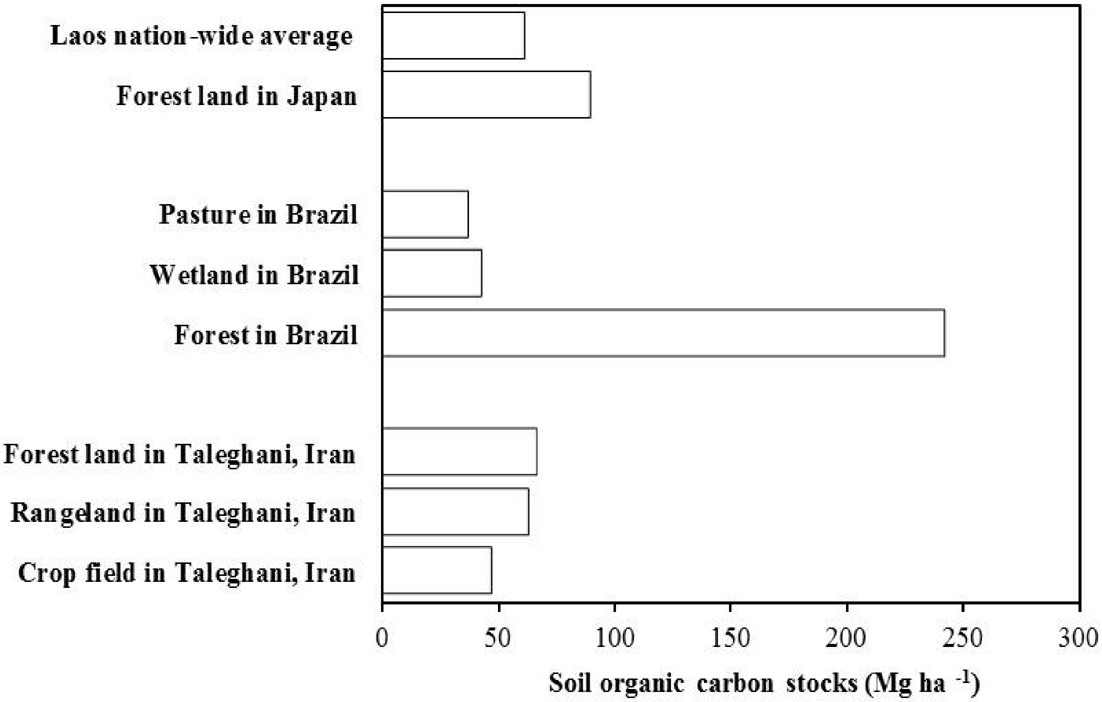

Fig. 4 Comparison of soil organic carbon in the study area in a depth of 30 cm with some studies of global and regional based on their data (Hett et al, 2011; Morisada et al, 2004; Wantzen et al, 2012).

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