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Geological controlling soil organic carbon and nitrogen density in a hillslope landscape, semiarid area of Golestan province, Iran

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Abstract

The effects of geological condition were assessed on density of Soil Organic Carbon (SOC) and Nitrogen (N) in a sequence of hillslope landscape, derived from different lithology i.e. loess deposit, reworked loess, marl with mixed siltstone and shale, reddish brown clay deposits and older loess in the semiarid area of northern Iran. However, other factors can influence SOC and N density such as land use, topography and climate with geology, pasture land use have been selected with a homogeneous climate to study their influence on density SOC and N of different lithology. Total of 108 soil samples were selected from two layers of 0-20 cm (surface) and 20-40 cm (subsurface). Results showed higher amount of SOC and N density, Cation Exchange Capacity (CEC) and silt were in surface layer of loess deposit that is related to vegetation density and root growth in this material than other conditions. On the contrary, the amounts of mentioned parameters were the lowest in marl. However, there was no significant difference between density of SOC and N in subsurface layer, but trend changes was similar with the surface. Overall, results show that there is a correlation between geological conditions and storing SOC and N. In conclusion, protection of surface and subsurface soil is important to increase density of SOC and N. Especially, overgrazing on steep slope of marl must be reduced or prohibited because rate of carbon loss to the atmosphere was significant and it is important in a changing environment from landscape to global scale.

Keywords: Lithosequence; Loess; Nitrogen density; Soil organic carbon density

1. Introduction

Knowledge of spatial variability as a natural phenomenon in soil properties is necessary for precision planning and managing agricultural lands. Density of Soil Organic Carbon (SOC) and Nitrogen (N) considered as one of the most important parameters to evaluate soil quality, ecosystem and the climate (Joneidi Jafari, 2013). On the other side, Naseri (2014) explained in the 21st century, one of the most important issues is the effect of SOC density and distribution on climate change in order to reduce greenhouse gases. Lal (2004) also revealed that reducing of SOC is one of the major causes of greenhouse gases and soil can store around 1500 Pg organic carbon (OC) in the upper 100 cm. SOC and N density are influenced by environmental factors such as climate, parent material, topography and landscape features, including landscape position and slope aspect (Khormali *et al*., 2009; Maleki *et al*., 2014; Nadeu et al., 2015).

Arid (including hyper arid) and semi-arid areas comprise about 36% of earth surface of the globe (Yang and Williams, 2015). More than 50% of Iran has also located in arid and semiarid areas that lead to low amount of SOC; due to lack of moisture and low speed

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evolutionary processes in these regions. Nevertheless, semiarid area comprises 16% of the global soil carbon pool (Joneidi Jafari, 2013). Therefore, lithology condition is an important factor in relation to SOC storage in these areas.

According to Jenny (1994), soil parent material has a main impact on the vegetation and soil formation and therefore greatly influences SOC and total nitrogen (TN) content (Barré *et al*., 2017). Also, Gruba and Socha (2016) expressed that parent material appeared to have a great importance for soil properties and SOC accumulation. Thus, their investigations show influence of SOC and parent material on the different plant species. The impact of parent material on density of SOC and N (Wiesmeier *et al*., 2013; Johnson *et al*., 2015; Barré *et al*., 2017) and soil formation (Lacoste *et al*., 2011; Tazikeh *et al*., 2017) is well documented. As mentioned above, various factors is influencing SOC and N density in some studies of climate or land-use (Wiesmeier *et al*., 2013), are usually used as co-variables with the parent material. Though, the result of these types of researches cannot obviously demonstrate the effect of geology condition on SOC and N density (Wiesmeier *et al*., 2013).

More studies on SOC and N density were commonly conducted in soil surface layer (0-30 cm). For example researches of Barré *et al*., (2017) showed importance of geological condition on SOC and N density in the top soil (0-30 cm) across in small landscape. This is in line with findings of Wiesmeier *et al*., (2013) and De Vos *et al*., (2015). But, to avoid underestimation of SOC density in ecosystems and also to reply too many questions about environmental problems such as global warming, simultaneous investigation of subsoil besides topsoil seems inevitable. Better land management is also needed to study the SOC density in both surface and subsurface soil layers (Ajami *et al*., 2016).

The studied area is part of the so-called Iranian loess plateau in the north facing slopes of the Alborz mountain that covered by extensive loess deposits (Khormali and Kehl, 2011). Hillslopes of these areas are mainly reserved as natural rangeland that overgrazing may be the main responsible factor for the changes in SOC and N density in this area. In addition, lithological changes in geological strata exposed at the surface in the loess plateau are still poorly documented. Besides readily perceivable differences between outcrops of marl, clay deposit, yellowish loess, loess-derived reworked and white limestone, more changes in soil properties must be expected. Thus, the main aim of this study was to investigate the effect of different lithology on SOC and N density both in surface (0-20 cm) and subsurface (20-40 cm) layers of hillslope landscape of semiarid part of Golestan province, northern Iran.

2. Materials and Methods

2.1. Description of the study area

The study area is located in part of the so-called Iranian loess plateau; the loess plateau covers an area of about 2250 km^2 in the Turkmen steppe of northern Iran. The selected region is approximately between 55°13′ 55°09′ E and 37°36′–37°41′ N in part of loess plateau (Figure 1). It covers an area of 47.3 km^2 (4729 ha) with different lithology of loess deposit, reworked loess, marl, marl with mixed siltstone and reddish brown clay deposits and older loess from south to north. This area is one of the most important pasture land of Golestan provinces. Also, wheat is the most important crop in the study area which is often grown in the valleys. The mean annual precipitation, temperature and evapotranspiration are 350 mm, 17 °C and 1750 mm, respectively. The soil moisture and temperature regimes of the study area according to Soil Survey Staff (2014) are dry Xeric and Thermic, respectively.

2.2. Sampling scheme

Using the Google Earth, field observation, geologic and topographic maps, 54 locations were selected for soil sampling that total of 108 samples were collected from two depths (0-20 cm and 20-40 cm) that are located on four different geological conditions, including: loess deposit, reworked loess, marl with mixed siltstone and shale and reddish brown clay deposits and older loess, Whereas the little information is available on lithology, 503 points (shown in Figure 1) picked by a portable Global Positioning System (GPS) for recognition of different lithology and land use in study area.

This loess have valuable archive of paleoclimate and regional landscape progress (Kehl *et al*., 2005; Frechen *et al*., 2009). Also, chronological and climatic studies of Wang *et al*., (2016) have been recorded age of clay deposits and older loess back to the early Pleistocene that can be evidenced from more humid climates in this condition.

The soils were mainly classified based on a taxonomic classification (Soil Survey Staff,

2014) and World Reference Base for Soil Resources (WRB, 2014) and as Calcic Haploxeralfs (Luvisol) just in reddish brown clay deposits and older loess, Typic Calcixerepts (Calcisols) only loess deposits, Typic Haploxerepts (Cambisols), Typic Xerortents and Lithic Xerortents (Regosols) in loess deposits and other geological conditions of four selected geological conditions.

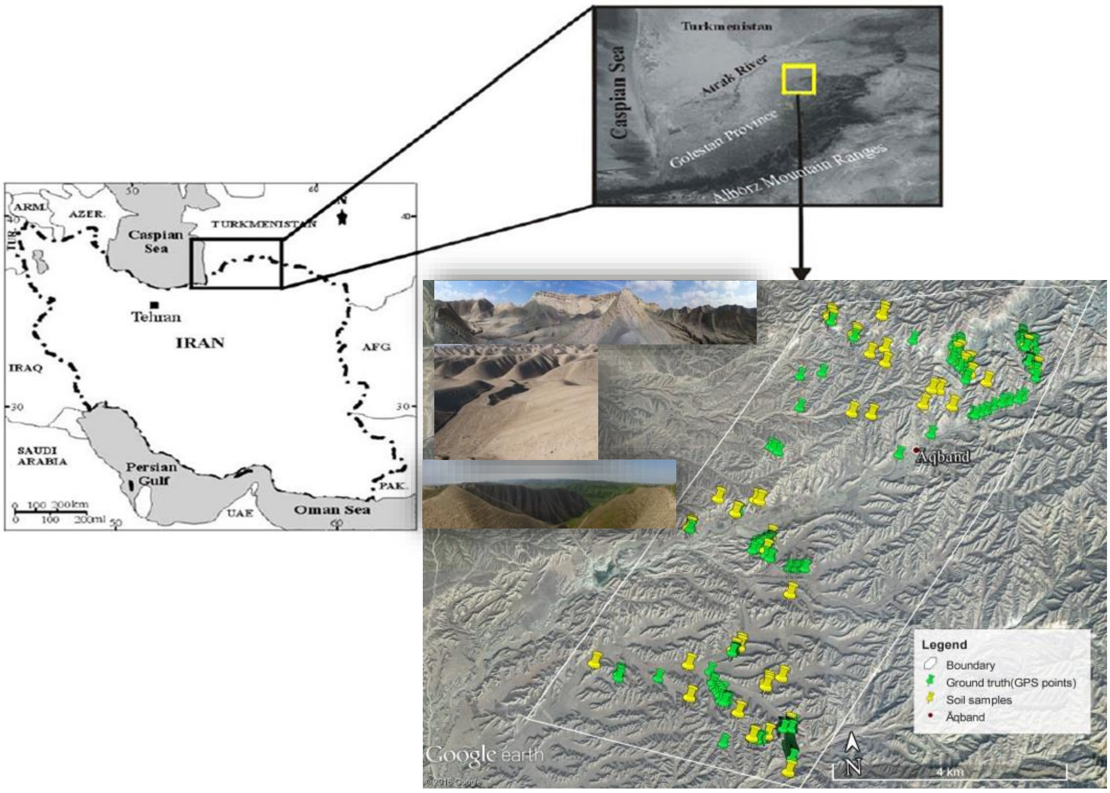


Fig. 1. Location of the study area in Northern Iran, Google Earth image showing different lithology occurrences and locations of soil sampling and GPS point of the studied area

2.3. Laboratory procedures

All samples after air-drying were homogenized and passed through a stainless steel sieve (<2 mm). Particle size distribution and bulk density were determined by the methods of Bouyoucos hydrometer (Gee and Bauder, 1986) and paraffin (Blake and Hartge 1986), respectively. SOC, TN and Cation Exchange Capacity (CEC) were measured using the Walkley-Black method (Nelson and Sommers 1982), Kjeldahl method (Bremner, 1996) and sodium acetate (NaOAc) at a pH 8.2 (Chapman, 1965), respectively. SOC and N density for a soil layer with a certain depth per unit area (kg m^{-2}) was calculated using the following equation:

$$\text{SOC density} = SOC \times BD \times D \times \left(\frac{1-G}{100}\right) \qquad (1)$$

$$\text{N density} = N \times BD \times D \times \left(\frac{1-G}{100}\right) \qquad (2)$$

Where SOC and N are the OC and N content (g kg^{-1}), BD is the soil bulk density (g cm^{-3}), D is the thickness of the soil layer (m) and G is the volumetric fraction (%) of rock fragments> 2mm (Lozano-García *et al.*, 2016).

2.4. Statistical analysis

One-way analysis of variance (ANOVA) was used with post hoc test (Duncan's test with significant differences of 0.05) using the SPSS software (version 16.0) in order to determine relationships among lithological condition, SOC and nitrogen density. Levene's test was also used for determining equality of variances.

3. Results and Discussion

3.1. Vertical distribution of soil properties

As shown in Table 1, in surface layer, SOC content and SOC density ranged from 0.10% to 2.00% and 0.20 (kg m^{-2}) to 5.40 (kg m^{-2}), respectively. The mean value of SOC and SOC density in surface layer (0-20 cm) are more than subsurface (20-40 cm). Results of N (content and density) are similar to SOC content and SOC density, which generally are consistent with Khormali *et al*., (2009); Joneidi Jafari, (2013); Ajami *et al*., (2016) and Lozano-García *et al*., (2016). This is due to this fact that, litter fall and root growths have higher accumulation in surface layer. Also, a change of CEC in two depths is in line with SOC and TN that will be discussed later in detail (section 3.2.2).

Table 1. Some statistical parameters of soil properties in two depths

Depth (cm)	Soil properties (unit)	Mean	Minimum	Maximum	SD	Skewness	Kurtosis
0-20	SOC content (%)	0.76	0.10	2.00	0.48	0.80	0.25
	TN content (%)	0.06	0.01	0.17	0.04	0.83	0.25
	SOC density (kg m^{-2})	2.07	0.20	5.40	1.31	0.80	0.18
	N density (kg m^{-2})	0.17	0.01	0.46	0.11	0.80	0.18
	BD (g cm^{-3})	1.36	1.08	1.57	0.10	-0.46	0.99
	CEC (Cmol kg^{-1})	19.93	12.10	31.10	5.48	0.36	-.082
	Clay (%)	22.62	6.40	47.50	9.04	1.13	1.13
	Silt (%)	50.38	21.70	74.30	10.98	-0.04	-0.05
	Sand (%)	27.60	12.80	60.00	9.76	0.83	1.04
20-40	SOC content (%)	0.49	0.10	1.00	0.20	0.71	-0.32
	TN content (%)	0.04	0.01	0.14	0.03	1.33	1.17
	SOC density (kg m^{-2})	1.35	0.27	3.01	0.73	0.46	-0.57
	N density (kg m^{-2})	0.12	0.02	0.34	0.08	1.15	0.70
	BD (g cm^{-3})	1.37	1.10	1.70	0.14	0.66	-.075
	CEC (Cmol kg^{-1})	17.60	10.4	32.50	5.21	1.16	0.72
	Clay (%)	22.91	9.20	55.00	9.91	1.77	3.99
	Silt (%)	48.20	19.20	71.10	11.77	-0.33	0.17
	Sand (%)	28.71	10.70	60.00	9.92	0.35	0.58

According to Table 1, mean, minimum and maximum values of BD in 20-40 cm are more than surface layer that shows increasing the porosity have led to decreasing in BD in the studied area. This clearly demonstrates the effect of higher accumulation of SOC on BD in the surface soil layer. Ajami *et al*., (2016) reported a negative correlation between BD and SOC.

Table 1 almost shows that the most frequent soil mineral particle is silt in the study area. Because a large part of the area is containing loess parent material in the studied soils, silt content is very high in loessial deposit (Ajami *et al*., 2016). Maniyunda *et al*., (2013) indicated influence of Lithosequence on the soil particles, too.

3.2. Soil properties and geological conditions

3.2.1. SOC, TN, SOC and N density

Results were identified significant differences of OC and SOC density for the four soil parent materials in surface layer. As shown in Figure 2a and Figure 2c, SOC content with significant differences ranged from 0.96% (loess deposits) to 0.31% (marl with mixed siltstone and shale) in surface soil. Results of Alijani and Sarmadian (2015) revealed low amount of SOC content in marl parent material. Mean value of SOC and SOC density had not significant differences with clay deposits and older loess that is almost conferred same loess deposit material in some part of area (Wang *et al*., 2016). Also, results of TN and N density (Figure 2b and Figure 2c) show a similar trend similar to SOC and SOC density that is in line with findings of Khormali *et al*., (2009) and Barré *et al*., (2017).

The contents of SOC and N, density of SOC and N in 20-40 cm had no significant differences in geologic conditions but Figure 2 shows that amount of the mentioned soil properties is higher in loess deposit than other materials. It means that the effect of geological conditions effect on topsoil layer is clear. According to Joneidi Jafari (2013) the principal of OC source is decomposing of animal, plant residue and root biomass. In arid and semiarid regions, plant cover is low or plants have short roots, so the roots cannot penetrate into subsoil depth, consequently OC, TN, SOC and N density in surface layer are more than subsurface. Joneidi Jafari (2013) also demonstrated the higher correlation of total root biomass with SOC in surface soil of 3 sites in semiarid and arid area of Iran that SOC content decreased at all 3 sites with depths. Meanwhile, our results support a geological control of SOC and N density in our landscape that the influence of soil parent material on SOC and N density has already been suggested across large areas (e.g. Wiesmeier *et al*., 2013; Vanguelova *et al*., 2013; De Vos *et al*., 2015).

Therefore, protection of surface and subsurface soil is important to increase density of SOC and N. Especially, overgrazing on steep slope of marl must be reduced or prohibited because rate of carbon loss to the atmosphere was significant and it is important in a changing environment from landscape to global scale.

3.2.2. CEC and BD

Geological conditions had no significant effect on BD in two soil layer except marl with mixed siltstone and shale had significant difference with others and no difference with reworked loess in depth of 20-40 cm (Figure 2e). As mentioned in section 3.1, increasing the porosity resulted in decreasing BD that in marl with mixed siltstone and shale and reworked loess conditions the amount of SOC was low than others (Figure 2a), therefore, BD has high amount. Also, there was a negative coefficient between BD and SOC in the study area ($r^2 = -0.22$, p= 0.05, n=108).

The mean value of CEC is high in the loess deposit and clay deposits and older loess (Figure 2f) than others. Also, Maniyunda *et al*., (2013) reported high amount of CEC in loess deposit in area of North - Western Nigeria. The results demonstrated that the highest and the lowest CEC are similar to changes of SOC in two depths (discussed in section 3.1). Except in 20-40 cm of clay deposits and older loess, amounts of CEC increased with depth. According Figure 2g, clay deposits and older loess condition has the highest clay contents of 32.84% and 34.31% in 0-20 cm and 20-40 cm, respectively. These results are in line with the findings of Khormali *et al*. (2009) stated that decrease and increase in CEC reflects the textural and SOC changes. Moreover, Figure 3a and 3b show the correlation coefficient between SOC content with CEC (r^2= 0.80, p = 0.01, in 0-20 cm and r^2= 0.60, p = 0.01, in 20-40 cm) is higher than clay content with CEC (r^2= 0.10, p = 0.01 (ns), in 0-20 cm and r^2= 0.38, p = 0.01) in this region that confirmed SOC is most effective in CEC, especially in surface. Results of Barré *et al*., (2017) introduced as same as this findings that reported weak relationship between SOC density and clay in different geology condition of cropland soils.

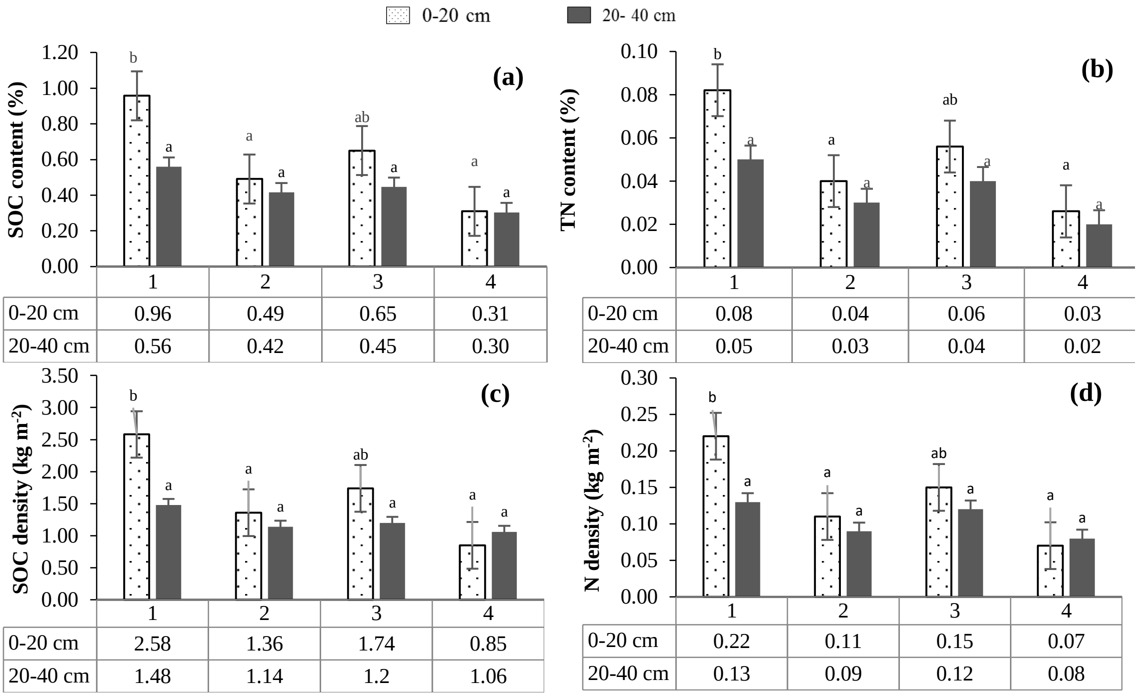
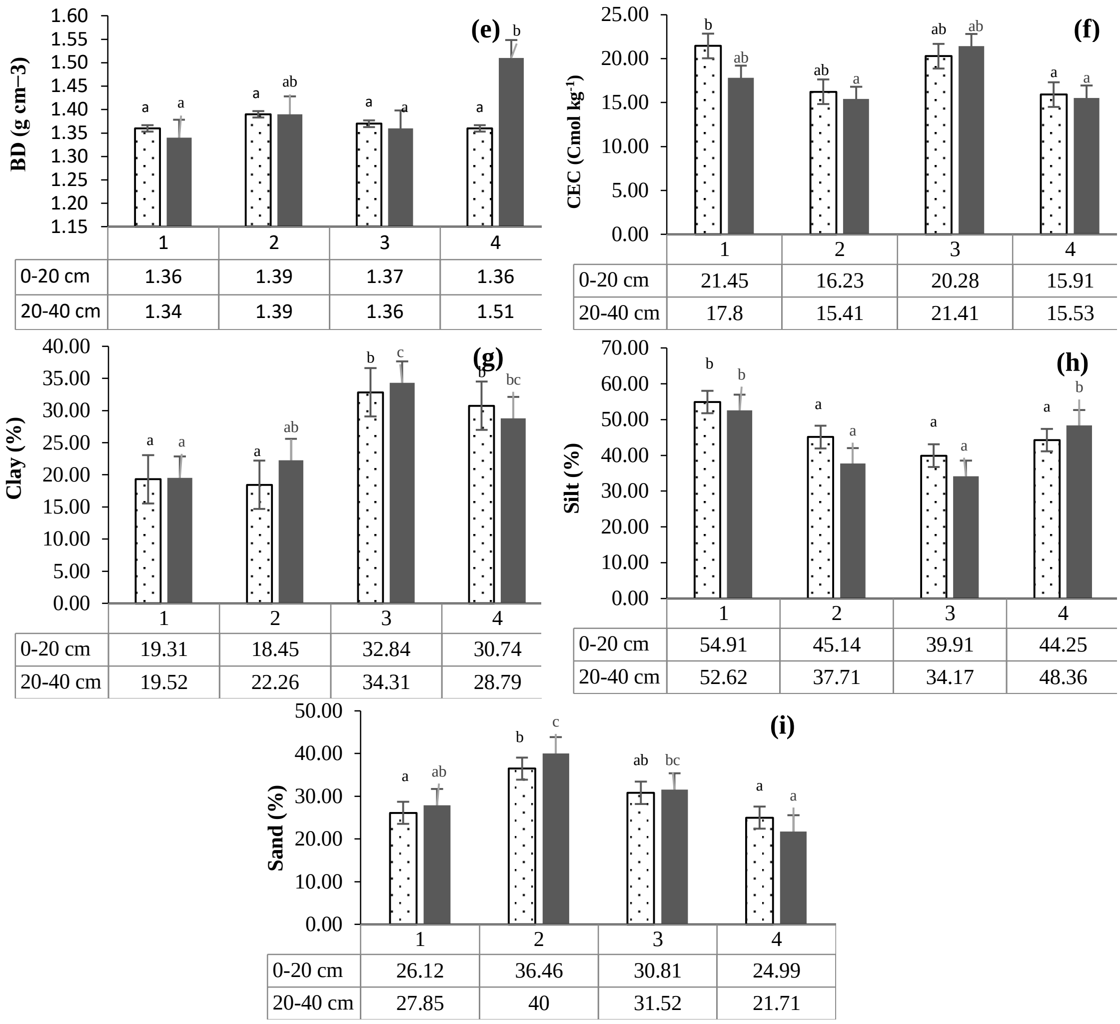


Fig. 2. SOC (a) TN (b) content, SOC (c) N (d) density, BD (e), CEC (f), clay (g), Silt (h) and Sand (i) in the two depths for the four geological conditions. 1: loess deposit, 2: reworked loess, 3: clay deposits and older loess 4: marl with mixed siltstone and shale. Error bars are standard errors. Also, columns with similar letters in each depth are not statistically significant (p <0.05)



	1	2	3	4
0-20 cm	1.36	1.39	1.37	1.36
20-40 cm	1.34	1.39	1.36	1.51

	1	2	3	4
0-20 cm	21.45	16.23	20.28	15.91
20-40 cm	17.8	15.41	21.41	15.53

	1	2	3	4
0-20 cm	19.31	18.45	32.84	30.74
20-40 cm	19.52	22.26	34.31	28.79

	1	2	3	4
0-20 cm	54.91	45.14	39.91	44.25
20-40 cm	52.62	37.71	34.17	48.36

	1	2	3	4
0-20 cm	26.12	36.46	30.81	24.99
20-40 cm	27.85	40	31.52	21.71

Fig. 2. SOC (a) TN (b) content, SOC (c) N (d) density, BD (e), CEC (f), clay (g), Silt (h) and Sand (i) in the two depths for the four geological conditions. 1: loess deposit, 2: reworked loess, 3: clay deposits and older loess 4: marl with mixed siltstone and shale. Error bars are standard errors. Also, columns with similar letters in each depth are not statistically significant ($p < 0.05$)

3.2.3. Particles size distribution

As seen in Figure 2h, silt is the most frequent soil mineral particle in the studied area that higher amounts of these particles with statistical difference were detected in loess deposit in two depths. But there is no statistical ifference with mixture marl and siltstone and shale condition in 20-40 cm. The results are in line with findings of Maniyunda *et al*. (2013)**.** In general, more significantly clay and sand particles were detected in clay deposits and older loess and reworked loess, respectively (Figures 2g and 2i) in two layers.

Our results are in line with the findings of Barré *et al*., (2017) stated that soil parent material affects soil properties such as texture or carbonate concentrations and they reported the highest clay concentrations was related to soils developed on clay deposits. Citable, marl with mixed siltstone and shale have not shown significant difference with clay deposit and older loess condition, because marl is a clayey parent materials that reveal clay properties are similar to clay deposit condition (Tazikeh *et al*., 2017).

Also, sand located in situation of reworked material that sand concentration in this condition was related to material have been developed by alluvium sediments that have come from another positions and deposited at depths over the time. This is due to transferred parent material from other surfaces (Alijani and Sarmadian, 2015) by deposition and accumulation processes in this area. Also, Cournane *et al*., (2011) have represented the effect of surrounding areas on sand and stone transition. The amount of sand is evidence of soil erosion, removal of finer particles and outcropping of high-sand content of loess parent material that take place in this situation (Khormali *et al*., 2009). The other reason for increasing sand percentage on this situation may be overgrazing that can be probably change soil texture (Jafari *et al*., 2014).

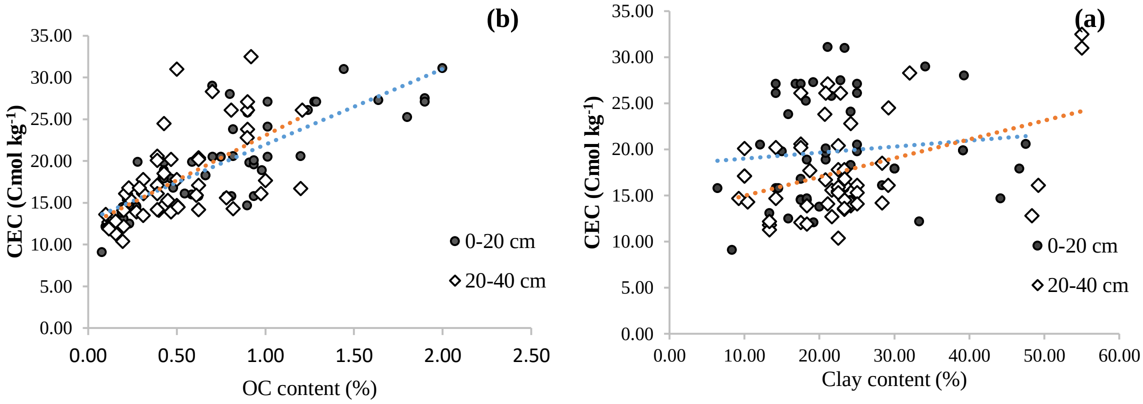


Fig. 3. The linear relationship between (a): SOC content with CEC (r^2= 0.80, p = 0.01, in 10-20 cm and r^2= 0.60, p = 0.01, in 20-40 cm) (b): clay content and CEC (r^2= 0.10, p = 0.01 (ns), in 10-20 cm and r^2= 0.38, p = 0.01, in 20-40 cm), n = 54 soil samples for every depth

It should be noted that the correlation between SOC content with silt, clay and sand is almost very low in this area and was not significant statistics. The correlation coefficient between SOC content with clay (r^2= 0.02, p = 0.01 (ns) in 0-20 cm and r^2= 0.008, p = 0.01 (ns), in 20-40 cm), SOC content with sand (r^2= 0.15, p = 0.01 (ns) in 0-20 cm and r^2= 0.10, p = 0.01 (ns) and SOC content with silt (r^2= 0.18, p = 0.01 (ns) in 0-20 cm and r^2= 0.08, p = 0.01 (ns) in this region that confirmed silt is most effective in SOC content, especially in surface. Results is in line with findings of Barré *et al*., (2017) that introduced weak relationship between SOC content and particle size distribution in different geology condition of some part of France soils.

4. Conclusion

The results of the present study on hillslope landscape provide insight into the impact of geological condition on SOC and N density in rangeland. However, the mechanism of soil forming and geological condition are complex but our study evidenced that good information of this factor on variation of SOC and N density in semiarid environments that accordingly these findings, geological condition and parent material should be included in SOC and N density models and predictions at small and landscape scales. Also, our results revealed studying the subsoil SOC and N density beside topsoil, provides better view to agricultural and natural resources issues, such as carbon sequestration, soil conservation and land management. Consequently, the potential of geological in C density should be considered for appropriate management in order to maximize CO_2 sequestering as well as to balance CO_2 emissions.

The study area is an important spring rangelands for local population and regions closer to Aghband rural area. Therefore with respect to soil quality a study should evaluate rangeland degradation with powerful tool by developing new plans and strategies for restoring degraded rangelands. Also, it is suggested steep loess lands are kept under vegetation via plantation that is compatible with climate in this region to help mutation of ecosystem and increasing SOC density from landscape to global scale and reducing global warming.

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