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Effects of wind erosion on soil organic carbon dynamics and other soil properties: Dejgah catchment, Farashband County, Shiraz Province, Iran

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Wind erosion effecting on soil carbon losses, should be considered from the standpoints of sustaining farmland productivity and producing accurate national carbon accounts.The worldwide spread of arid and semiarid areas with extensive damage to these areas gives them potential for carbon sequestration. Considering that a large portion of soil carbon is concentrated in 0 to 20 cm soil depth, carbon sequestration increases soil fertility, prevents erosion and improves the hydrological system. This paper introduces a case study in Dejgah catchment, Farashband County, Shiraz Province, Iran, which used to be a typical area with wind erosion and desertification in south western Iran. A field experiment was conducted in this region to investigate changes in soil carbon in relation to wind erosion. Samples were taken randomly from areas of up to 0.25 ha from each of the different wind erosion categories in June 2011. In each site 20 samples from surface layer (0 to 10 cm) and 20 samples from subsurface layer (10 to 20 cm) were collected, then samples from each layer were combined. Finally, two composite sample from each site and 24 composite soil samples were collected from surface layer (0 to 10 cm) and subsurface layer (10 to 20 cm) in 4 different wind erosion categories (light, moderate, high and severe). In the laboratory, each soil sample was thoroughly sieved to 2 mm to remove roots and incorporated litter and air-dried to determine soil physicochemical properties including pH, electrical conductivity, soil texture, bulk density, total nitrogen, and organic carbon content. Analysis results showed some soil properties largely influenced by the severity of wind erosion. In addition the results showed the impact of wind erosion on loss of carbon and nitrogen so that the organic C and N contents decreased significantly with wind erosion development. In addition changes in organic C content had a significant positive correlation with the soil fine particle content (clay) (Pb 0.01) and a significant negative correlation with sand content (Pb 0.01).

Key words: Wind erosion, loss of soil organic carbon, carbon sequestration, global change.

INTRODUCTION

Wind is a natural force that detaches and transports soil particles. Wind erosion is a natural hazard in the dry climatic regions of the world where vegetative cover tends to be sparse due to a lack of rainfall and recurring drought (Singh, 1994). Many arid and semi-arid regions of Iran are influenced by wind erosion. The effects of wind erosion and associated deposition include damage to soils through loss of chemical fertility (Birch, 1981), the loss of soil depth, damage to crops and pastures through sandblasting and burial, damage to infrastructure by drift sand (Gorddard et al., 1982) and dispersion of weeds and diseases. The consideration of wind erosion induced

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carbon loss, both from the standpoint of sustaining farmland productivity and also in producing accurate national carbon accounts, at both the project and national scales, requires resolution.

Soil organic carbon (SOC) content is the result of the long-term net balance between loss and accumulation of organic carbon in the soil (Wan et al., 2010). Positive effects on the quality of soil organic carbon through soil conservation have been emphasized by McCarty and Ritchie (2000) and Feiza et al. (2008). The soil organic matter (SOM) comprises about 58% of SOC and is a key determinant of soil quality, biomass productivity and environment moderating capacity. The beneficial impacts of SOC on soil quality are attributed to: (1) stabilization of soil structure through formation of organo-mineral complexes and development of stable aggregates; (2) improvement in available water-holding capacity of the soil through an increase in soil moisture retention at field capacity (0.3 bar suction); (3) improvement in soil biodiversity, especially activity of soil fauna (e.g., earthworms); (4) biodegradation of contaminants; (5) buffering soil against sudden changes in pH and elemental concentrations; (6) minimizing leaching losses of fertilizer through chelation and absorption; (7) filtering and purification of water by sorption and degradation of pollutants; (8) strengthening mechanisms of elemental cycling; (9) improving soil quality and productivity; and (10) sequestering C and mitigating climate change (Roose et al., 2006).

Although, the depletion of soil C is accentuated by soil degradation (Lal, 2004), changes in soil carbon due to erosion are rarely measured (Roose et al., 2006; Sinoga et al., 2011). SOC also plays a significant role in the global carbon cycle, affecting climate change in both in its causes and remediations (Roose et al., 2006). It has been recognized that global warming and climate change are due to the increased amount of carbon dioxide and other greenhouse gases in the atmosphere (IPCC, 2001). Soil organic carbon accumulate in the surface layer (0 to 20 cm depth) of soils (Roose et al., 2006; Shaoshan et al., 2010). Loss of carbon from agricultural soils is due to increased organic matter decomposition rate of carbon loss upon cultivation and soil erosion (Freibauer et al., 2004). On the other hand, the increase in atmospheric concentration of CO_2 by 31% since 1750 from fossil fuel combustion and land use change necessitates identification of strategies for mitigating the threat of the attendant global warming (Lal, 2004). Since the industrial revolution, global emissions of carbon (C) are estimated at 270±30 Pg (Pg=petagram=10^{15} g=1 billion ton) due to fossil fuel combustion and 136±55 Pg due to land use change and soil cultivation (Lal, 2004). The global carbon cycle shows that the world soils contain 1500 to 2000 Gigatonnes (Gt) of carbon depending on the soil depth. In contrast, vegetation, mainly perennials, contains 600 to 700 Gt C. Vegetation and soil can be either sources or sinks for atmospheric carbon (Roose et al., 2006). So they can be managed with a restoration or change in their ability to significantly increase carbon storage.

Global climate change is the most serious environmental problem of the twenty-first century (IPCC, 2001). IPCC (2001) reported an increase in temperature of +0.6°C during the twentieth century and the projected increase in surface temperature, based on a large range of scenarios, ranges between 1.4 to 5.8°C (and even higher increase for the northern latitudes). If natural causes have played a great role in explaining the precedent historical variations (for example what is called in Europe "the short ice period"), the recent increase in temperature is now well correlated with anthropic causes and especially with the increase in concentration of different greenhouse gases: CO_2, CH_4, N_2O (Roose et al., 2006). There is increased awareness of the environmental impacts of soil carbon (C) and nitrogen (N) losses through wind erosion, especially in areas heavily affected by dust storm erosion (Wang et al., 2006). Since one of the effevtive factors on soil organic carbon is erosion, the purpose of this study is comparison of different wind erosion categories (sever, high, moderate and light) with different soil characteristics, especially soil organic carbon content in a typical area with arid and semi arid climate and significant desertification in south westernIran where wind erosion is dominant.

MATERIALS AND METHODS

Study area

The study area is located in Dejgah catchment, Farashband County, Shiraz Province, (52° 14′–23′ 55″ N, 28° 08′–11′ 28″) which used to be a typical area with significant desertification in south western Iran (Figure 1). Annual mean precipitation is 190 mm, annual mean potential evaporation is 1927.35 mm, and annual mean temperature is 25.45°C. The average annual wind speed is 4.07_5.18 m s^{-1} and mean wind speed in the wind erosion season (summer) is 5.11 m s^{-1}. Farmland accounts for about 40% of the total area in Dejgah catchment, where wheat (triticum spp.) is the dominant crop. Most farmland has incurred some degree of desertification due to soil erosion by wind. The natural grassland is used mainly for grazing by sheep. Dominant plant species include Salsola sp, Stipa capensis, Prosopis juliflora Atriplex canescens and Haloxylon sp. Native grasslands have also become desertified due to overgrazing and wind erosion.

Data collection and analysis

Wind erosion status was investigated using the IRIFR2 method (Ekhtesasi and Ahmadi, 1995) and the study site was classified according to four different wind erosion categories, severe, high, moderate and light (Figure 2). Samples were selected randomly in June 2011 from areas of up to 0.25 ha from each of the different wind erosion categories (Figure 3). In each site 20 samples from surface layer (0 to 10 cm) and 20 samples from subsurface layer (10 to 20 cm) were collected, then samples from each layer were combined. Finally, two composite sample from each site and 24 composite soil samples were collected from surface layer (0 to 10 cm) and subsurface layer (10 to 20 cm) in 4 different wind erosion categories (light, moderate, high and severe). Soil samples were

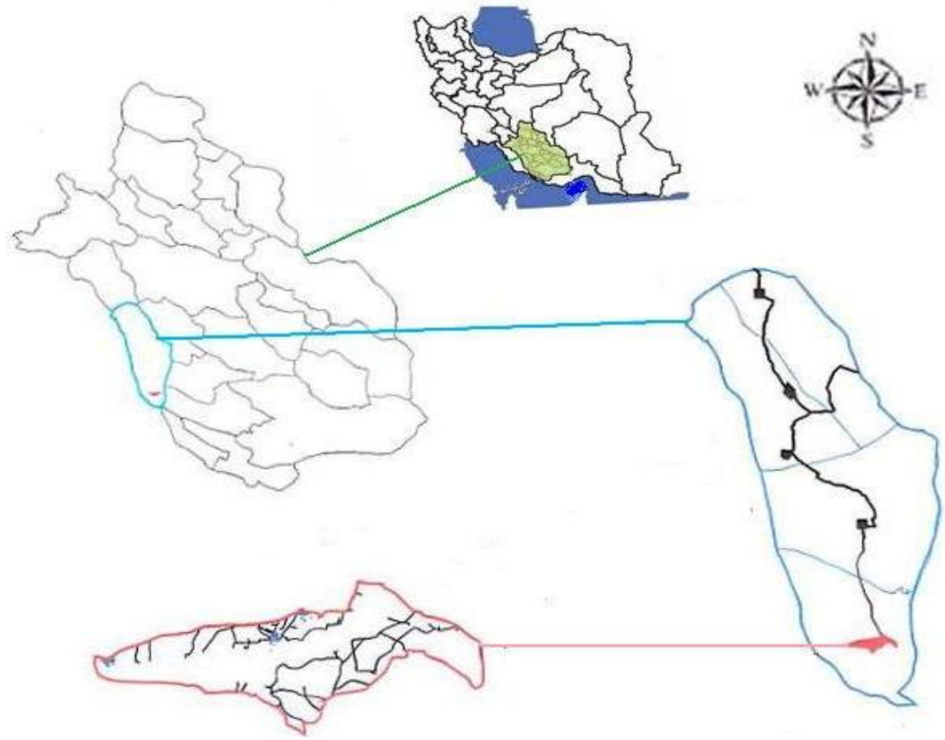

Figure 1. Study Area. Dejgah catchment, Farashband County, Shiraz Province, (52° 14′–23′ 55″ N, 28° 08′–11′ 28″).

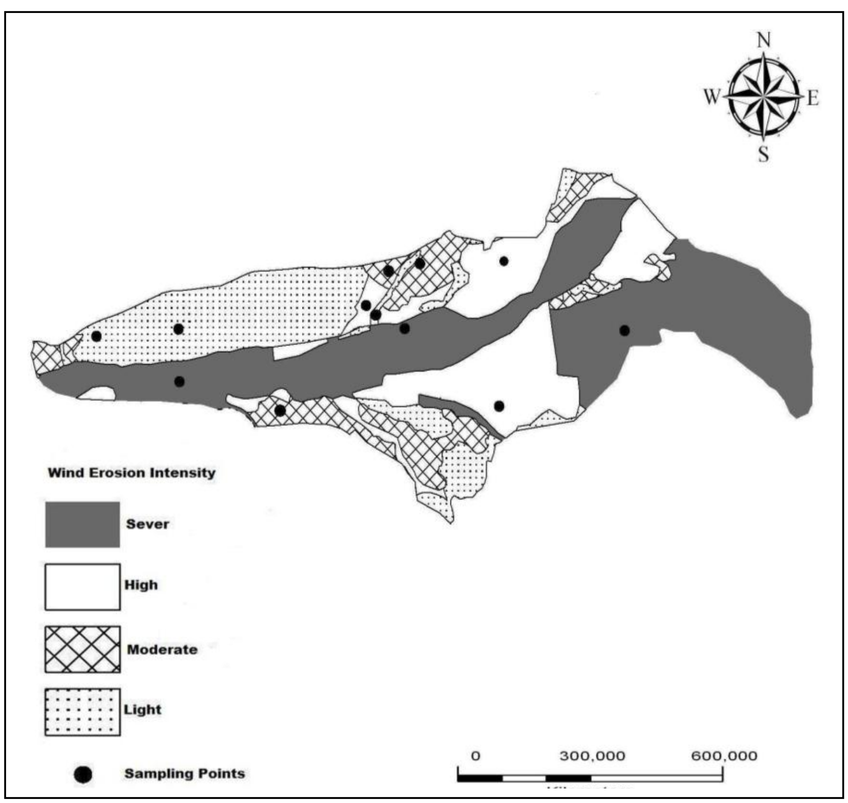

Figure 2. Sampling sites.

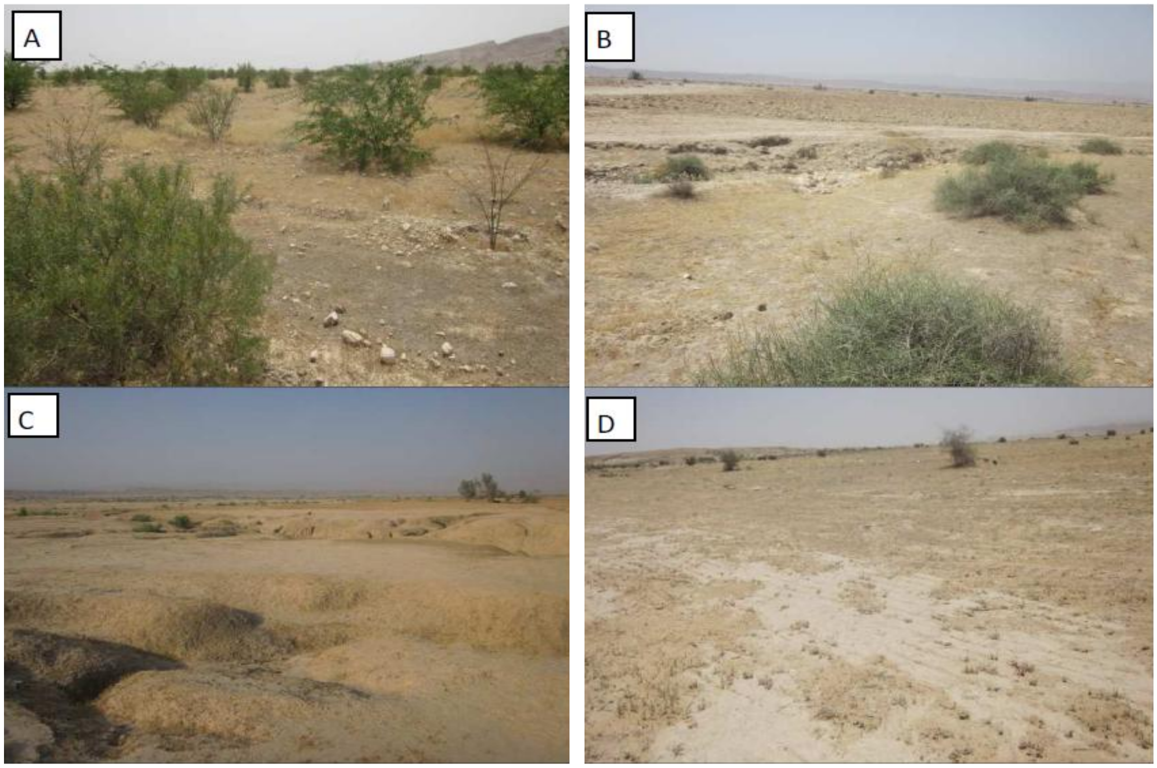

Figure 3. Typical photographs of study area showing wind erosion intensity; (A) light, (B) moderate, (C) high, and (D) severe.

placed in sealed plastic bags and taken to the laboratory. Soil organic carbon and soil texture were determined at each site at two depths in three replicates.

In the laboratory, each soil sample was sieved to 2 mm to remove roots and incorporated litter, then air-dried prior to determining particle size distribution (sand, fine and course silt, and clay), and organic carbon. Soil particle size distribution was determined by the hydrometer method according USDA classification of soil separaetes (Gee and Bauder, 1986). Soil organic carbon was measured by the $K_2Cr_2O_7$–H_2SO_4 oxidation method of Walkey and Black (Nelson and Sommers, 1982). The amount of carbon sequestration (tons per hectare) was calculated for the different wind erosion categories by means of the following equation (Zarinkafsh, 1993):

$$\%OC=10000\times OC\times Bd\times E$$

Where: OC=organic carbon (kg/ha), %OC=% organic carbon, Bd=bulk density (gr/cm^3), E=depth of sampling (cm).

Soil bulk density and total nitrogen were determined by the method Clog and kjeldahl respectively (Jafari, 2003).

All data were analyzed using SPSS software (16.0), with multiple comparisons and analysis of variance (ANOVA) and Duncan's multiple range test used to determine the differences among the treatments. Pearson correlation coefficients were used to evaluate relationships between the corresponding variables (Su et al., 2004).

RESULTS

Soil pH ranged between 7.1 to 8.1 in the study area and 70% of the soil region was alkaline. At 5% level, there was no significant effect of pH on the intensity of erosion. However, there was a significant effect of salinity on erosion intensity. The average salinity in each of the wind erosion categories was 1.1, 19.4, 17.4, and 1.06 dsm^{-1} for light, moderate, high, and severe erosion categories, respectively.

Results showed decreasing levels of both organic carbon and total nitrogen content from light, through moderate to high and, ultimately, severe wind erosion categories, respectively. The results reflect the impact of wind erosion on loss of carbon and nitrogen, so that the values of carbon and nitrogen decreased with increasing intensity of wind erosion. Further, the magnitude of change was greater from the light to the severe stage compared to other stages. Also, carbon sequestration tend to increase with wind erosion development (Table 1).

Clay and silt content tends to decrease the same as organic carbon and sand content tends to increase with wind erosion development (Table 2). Soil bulk density tends to increase with wind erosion development. Results of analysis of soil bulk density for different wind erosion intensities showed the highest bulk density in severe (1.77 gr/cm^3), followed by high (1.54 gr/cm^3), moderate (1.53 gr/cm^3) and light (1.44 gr/cm^3) wind erosion categories, respectively (Pb 0.01) (Figure 4).

Table 1. Soil properties in wind erosion categories.

Variable	Light	Moderate	High	Severe
Organic Carbon (%)	1.19±0.23[a]	0.82±0.11[b]	0.8±0.07[b]	0.47±0.12[c]
Total Nitrogen (%)	0.04±0.012[a]	0.035±0.014[ab]	0.021±0.012[b]	0.006±0.011[c]
Carbon sequestration	147.2±64.83[a]	125.74±18.91[ab]	120.83±9.85[ab]	83.19±21.37[b]

Table 2. Soil properties in ''different wind erosion categories''.

Wind erosion intensity	% Sand	% Silt	% Clay
Light	6.97±6.44[c]	45.3±9.17[a]	47.7±2.7[a]
Moderate	20.96±3.57[bc]	36.74±5.16[ab]	42.3±9.8[b]
High	25.51±13.8[b]	36.34±12.17[a]	38.2±12.5[bc]
Severe	56.94±15.3[a]	22.75±14.45[b]	20.3±1.03[c]

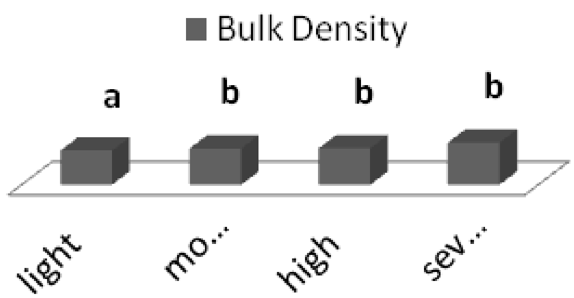

Figure 4. Bulk density in wind erosion categories.

DISCUSSION

Salinity, toxicity and extremes in soil pH (acid or alkaline) result in poor biomass production and, thus in reduced additions of organic matter to the soil. For example, pH affects humus formation in two ways: decomposition, and biomass production. In strongly acid or highly alkaline soils, the growing conditions for micro-organisms are poor, resulting in low levels of biological oxidation of organic matter (Bot and Benites, 2005). Generally, arid and semi-arid areas have more alkaline soils which was also observed in the study site in Farashband County. Highest pH was observed in areas that were affected by severe erosion.

The depletion of soil carbon and total nitrogen is accentuated by wind erosion development. The proportion of organic C and total N decreased significantly (Pb 0.01) with wind erosion development, while soil organic carbon was concentrated in the surface layer (0 to 20 cm depth) (Roose et al., 2006; Shaoshan, et al., 2010; Guang-Lu and Xiao-Ming, 2010). Woomer et al. (2004) reported that about 60% of soil organic carbon is stored at a depth of 20 cm from the soil surface. Results of mean soil property comparisons between different erosion categories showed that areas with light erosion had the highest organic carbon content (1.19%), followed by moderate (0.82%), high (0.80%) and in sever (0.47%) wind erosion intensity, respectively. Given the low levels of organic carbon and the hot dry climate, sparse vegetation is expected. Climate is an essential factor in controlling the amount of soil organic matter because it determines the type of plant species, the amount of plant material and the rate of microbial activity.

When the climate becomes drier, the processes of soil deterioration are seen, especially in Mediterranean semi-arid areas where soil erosion is one of the main causes of soil decline. In addition, less rainfall provides less soil moisture, thus reducing growth and survival of vegetation; less vegetation causes less storage of soil organic matter and increased loss of nutrients (Sinoga, 2011). Inappropriate distribution of vegetation on land and the wide range of land without vegetation is a very effective factor in intensifying the phenomenon of desertification in this region (Haseb karaji co, 2007). Another reason for low levels of organic carbon is because of erosion, particularly wind erosion in this region. Monsoons and high wind conditions over open desert landsprovide optimum conditions for the wind erosion processesin the area, leading to sandy wind erosion sediments.

Visser et al. (2005) have also reported that wind erosion is responsible for loss of nutrients and fine particles in the Sahel region in West Africa. It is also estimated that the annual loss of soil carbon to erosion in northern China dust storms is between 53 and 1044 kg ha (Wang et al., 2006). Harper et al. (2009) also estimated that the total loss of soil carbon in study area from 1980 to 1981, using the classification of soil series, was 3.6 tons of carbon per hectare of eroded soil. As the results in Table 1 show there is a significant difference (Duncan's multiple range test) between different wind erosion intensity and the percentage of total nitrogen (pb 0.05) in the soil. Most nitrogen was found in areas with light erosion intensity (0.039%) and a minimum amount of nitrogen in areas with severe erosion (0.006%) was observed. Soil nitrogen levels is variable between 0.006% in the sandy areas with severe erosion up to 0.039% in the light erosion areas of the region. Type and density of vegetation cover plays an important role in amount of soil nitrogen.

Soil with more vegetation and roots typically have more organic matter and nitrogen (Javadi, 2004). So, nitrogen content in areas with low erosion intensity was more than other areas due to high concentration of vegetation rooted in the soil.

The total amount of nitrogen is variable between 0.001% in sandy lands to 0.052% in the groves. The total amount of nitrogen in soils of arid and semiarid areas was low. Nitrogen in desert soils is less than 0.1% (Jafari, 2003). Since organic matter is the main source of nitrogen storage, arid and semi-arid soils are typically deficient in this nutrient.

Other factors contributing to low soil nitrogen include low rainfall, lack of proper crop rotation, high temperatures, low humidity, little vegetation and low consumption of animal and green manure as fertilizer (Malakoti and Homaie, 2004).

Area includes a variety of soil texture like clay, silty clay, loam, sandy loam, sandy clay loam and silty clay loam. There is a significant difference at 5% level between the severity of erosion in the clay, silt and sand (Table 2).

Average values of soil particle size in different wind erosion intensity categories is given in the Table 2. With wind erosion development, the clay and silt decreased and the sands increased significantly (Pb 0.05).

Compared to light wind erosion intensity, in severely wind erosion intensity, the clay contents decreased by (27.4%) and sand contents decreased by (49.9%) and the magnitude of change was greater from the light to the severe desertification stage compared to other stages. Also, correlation between organic carbon and clay (%) in this study were 0.72 (pb 0.01).

Soil organic matter tends to increase as the clay content increases. This increase depends on two mechanisms. First, bonds between the surface of clay particles and organic matter retard the decomposition process.

Second, soils with higher clay content increase the potential for aggregate formation. Macroaggregates physically protect organic matter molecules from further mineralization caused by microbial attack (Rice, 2000; Bot and Benites, 2005).

One reason for the high bulk density in areas with severe erosion is because about 66% of the erosion affected areas include sandy lands, and bulk density of sandy soil is much higher than other soils. Soil bulk density and sand content increases and the amount of clay decreases with wind erosion development. The bulk density in surface soil horizons of sandy soil is more than other horizons (Han et al., 2010). In sandy lands of the study area, the bulk density in surface soil horizons (1.81 gr/cm^3) is bigger than in the lower layer (1.37 gr/cm^3).

Results of Singh et al. (2003) in India also showed that the amount of soil organic matter and consequently the amount of carbon sequestration per unit area of soil depends on several factors such as soil bulk density. Also, correlation between organic carbon and soil bulk density in this study were -0.67 (pb 0.01). The soil bulk density could be affected by wind erosion intensity. For different wind erosion intensities, the soil bulk density varied as follows: severe>high>moderate>light. On the contrary, the SOC content in sandy soil was higher than that of the clay soil. The relationship between the soil bulk density and the carbon content in the catchment could be expressed as (Figure 5):

$$Y=-2.213 \log(x)-1.81,\ R^2=0.68\ (pb\ 0.05)$$

Conclusions

The results obtained showed that in Dezhgah catchment, Farashband County, measured soil properties are under the influence of the intensity of wind erosion. Analysis of variance showed that the physical and chemical soil organic carbon such as organic matter, organic carbon, total nitrogen and carbon-to-nitrogen ratio, bulk density, clay, silt, and sand content are all under influence of wind erosion wind erosion intensity. The survey results reflect the impact of wind erosion on loss of carbon and nitrogen, so that the values of carbon and nitrogen decreased with increasing intensity of wind erosion, and the magnitude of change was greater from the light to the severe stage compared to other stages. Thus, carbon and nitrogen loss through wind erosion processes can be intensified. Carbon and nitrogen loss are exacerbating the factors of global climate change by releasing greenhouse gases.

Also, results show that wind erosion is a cause of reduced soil particles (clay) in the study area. Compared with light wind erosion intensity, in severely wind eroded areas, the clay contents decreased by (27.4%) and sand contents decreased by (49.9%). The thermal and moisture regime of soils derived from the specific climatic conditions of the study area also makes it very difficult for the growth of plant species. These restrictions exacerbate the desertification process. In addition, human interference in ecosystems, such as pastures degradation, increasedcrowding of livestock in the winter season, and land use changes over 50 years exacerbate the degradation. World-wide spread of arid and semiarid areas with extensive damage to these areas gives them potential for carbon sequestration. Considering that a large portion of soil carbon is concentrated in the depth of

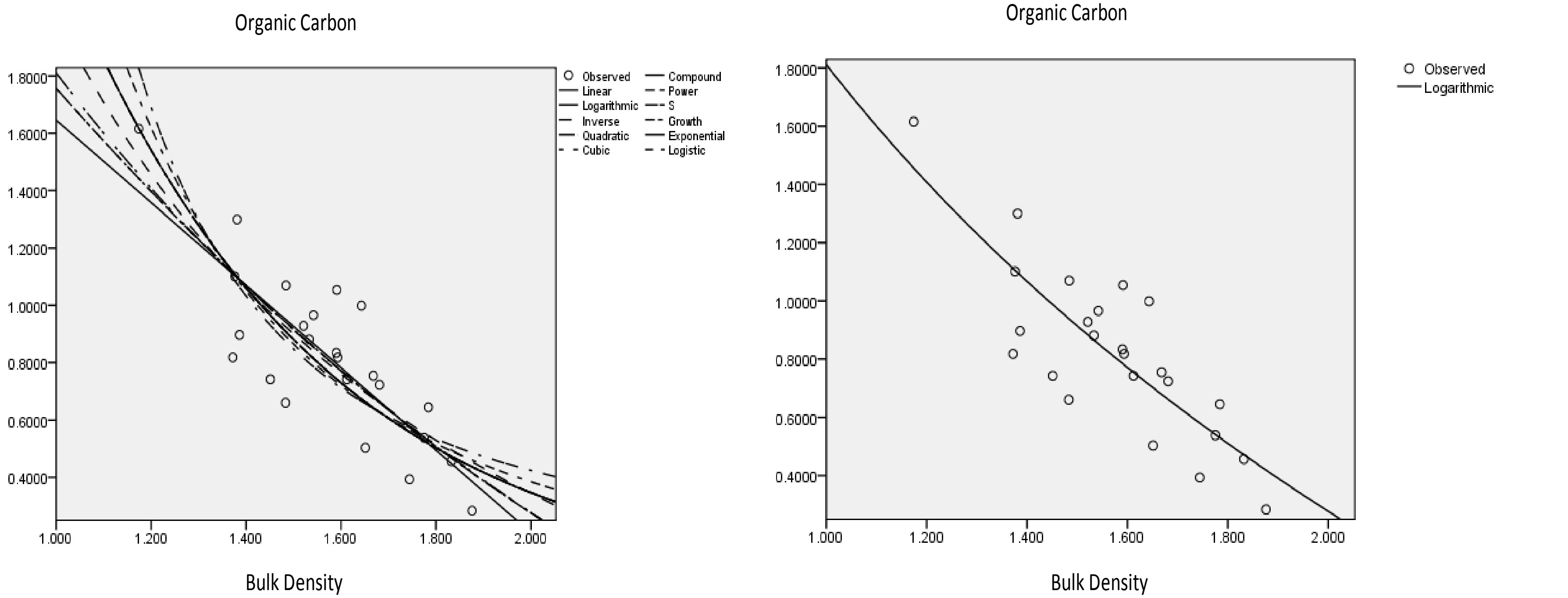

Figure 5. The scatter plot of bulk density and soil organic carbon content.

0 to 20 cm, carbon sequestration increases soil fertility, prevents erosion and improves the hydrological system.

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