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Soil carbon sequestration potential as affected by soil physical and climatic factors under different land uses in a semiarid region

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ABSTRACT

Carbon (C) sequestration in soil is recognized as a possible solution for climate change mitigation. Different land uses may alter carbon sequestration in soil. In the semiarid regions of central Iran, during the last decades, land use changes from native cover to farmlands have altered the C sink role of soil to a source of CO_2 emission to the atmosphere. This study was conducted to evaluate and compare changes and the potential of soil organic carbon (SOC) sequestration from 1988 to 2014, under different land uses, in western central Iran (Lordegan). The land uses included pasture, forest, rain-fed, and irrigated farmlands. Soil (450 samples) from 50 points across the study basin (390 km^2) was collected in three depth increments (0–5, 5–15 and 15–30 cm) during three sampling times (June and November 2014, and June 2015). Mean SOC concentrations in the pasture, forest, rain-fed and irrigated farmlands were 10.3, 20.2, 9.2 and 10.1 g kg^{-1}, respectively. The SOC concentration in the forest soil was significantly greater than the other land uses, and any reduction in forestland area would lead to the SOC stock decline. About 1390 Gg organic carbon was found to be stored in the top 0–30 cm depth of the study area. Comparing land use maps between 1988 and 2014 indicated an alteration in the relative contribution of each land use across the study area leading to SOC stock reduction by 100 Gg carbon during this period. The results showed that all studied soils comprised non-complexed clay, suggesting a considerable potential capacity for sequestering carbon. The results also indicated that the SOC controlling factors varied considerably among different land uses and soil depths. Mean weight diameter of aggregates (MWD), bulk density, clay and sand content, and altitude were identified as the important controlling variables by the stepwise multiple linear regression analysis.

1. Introduction

A growing concern over the increasing atmospheric greenhouse gases concentration and global warming has been reported in the recent decades (IPCC Climate Change, 2013). Climate change has become a crucial challenge for all nations, resulting in severe effects on the environmental components, such as temperature rise, these, in turn, have led to ecosystem degradation (Ko et al., 2017; Shen and Lukes, 2015).

Carbon sequestration in soil is a possible solution to mitigate climate change via converting atmospheric CO_2 into stable soil organic carbon; thus, it has the additional benefit of improving soil quality (Minasny et al., 2017). Soils are the main carbon sink/source and an important component of the global C cycle (Faggian et al., 2012), containing about 1206 Pg organic carbon (OC) in the upper 1 m depth (Hiederer and Köchy, 2011) which is significantly greater than the atmospheric carbon stock (800 Pg) (Zdruli et al., 2017). Therefore, a small increase in the soil carbon stocks plays an important role in reducing greenhouse gases of the atmosphere. According to this idea, the '4 per mille Soils for Food Security and Climate' was launched at the COP21 conference in Paris in December 2015. This program aims to compensate the global emissions of greenhouse gases through increasing soil organic carbon by 0.4% per year (Minasny et al., 2017).

The amount of OC in soil at any given time depends on the long-term balance between the carbon inputs and the losses rate. These rates are controlled by factors including soil attributes (e.g., soil lithology and texture), climatic variables (e.g., mean annual temperature and precipitation), biotic characteristics (e.g., microbial population and biomass production), and anthropogenic factors (such as land use and management) (Albaladejo et al., 2013; Zdruli et al., 2017). These factors affect SOC stock through influencing the SOC decomposition rate,

Abbreviations: SOC, soil organic carbon; SOCC, soil organic carbon concentration (g kg^{-1}); SOCD, soil organic carbon density (Mg ha^{-1}); SOCS, soil organic carbon stock (Mg); CC, complexed clay; NCC, non-complexed clay; COC, complexed organic carbon; NCOC, non-complexed organic carbon

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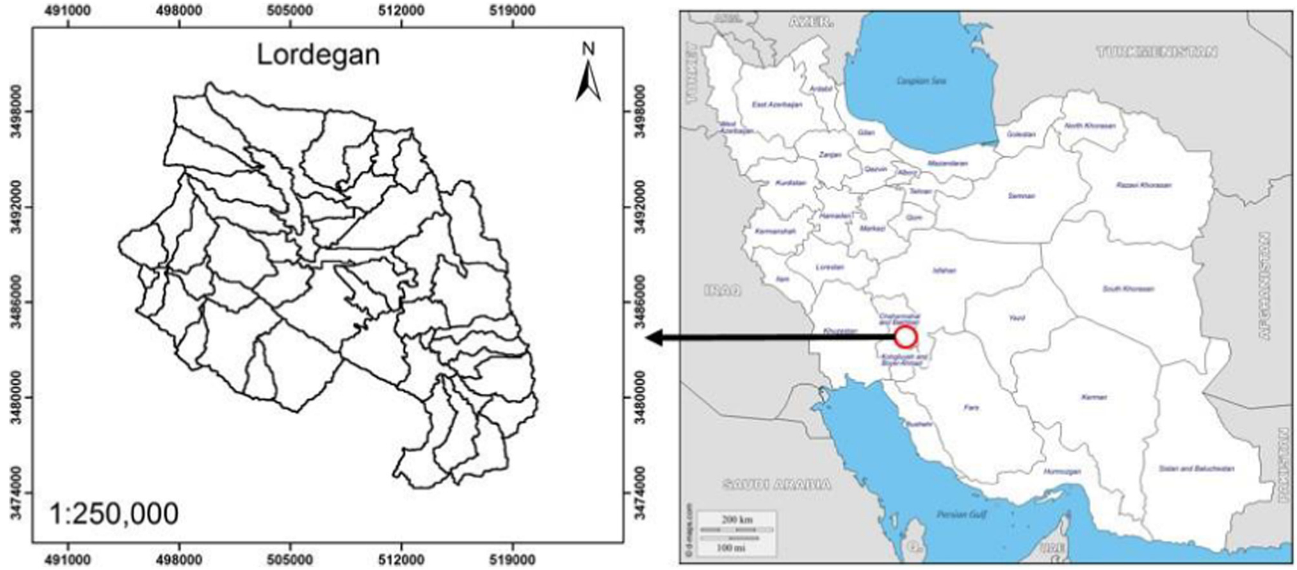

Fig. 1. Location of the study area (Lordegan, left) within the Iran's map.

SOC absorption, and stabilization, altering moisture regime and the vertical redistribution of SOC in the soil profile (Akpa et al., 2016; Dorji et al., 2014; Six et al., 2002b).

Some adverse consequences of negative carbon budget include soil biodiversity reduction, aggregate disruption, soil structure degradation, exacerbation of erosion hazards, green water supply reduction, increased drought risk, elemental cycling disruption, and soil fertility reduction (Zdruli et al., 2017). Positive carbon budget could be achieved through the restoration of low-biomass land use to their pristine ecosystems, or well-managed land uses (Akpa et al., 2016; Albaladejo et al., 2013; Fang et al., 2012; Poeplau and Don, 2013).

The organic carbon that is attached to soil clay becomes more stable, and the maximum amount of complexed or stable organic carbon can be calculated as C_{MAX} = clay / *n*, which is called "capacity factor" (Carter et al., 2003; Hassink, 1997). Therefore, the extra amount of the stable SOC that is stored in the soil can be computed by subtracting the capacity factor (the maximum possible amount) and the actual amount of the complexed organic carbon (COC). Dexter et al. (2008) proposed a simple algorithm to divide SOC into complexed and non-complexed organic carbon. The method could be used to estimate the maximum amount of complexed or stable organic carbon in carbon sequestration context.

Land use change affects SOC (Poeplau and Don, 2013) via the conversion of the natural land cover to agricultural ecosystems (Post and Kwon, 2000; Wilson et al., 2008). Generally, shifting from forests or virgin lands to cultivation leads to a reduction in SOC stocks by an average of almost 20–50% (Gregorich et al., 2005; Guo and Gifford, 2002). Forest soils with great amounts of organic matter represent a potential sink for sequestering atmospheric CO_2; thus they can be a source of greenhouse gases emission as a result of mismanagement and decomposition of the soil organic carbon (Lal, 2009; Zimmermann et al., 2007). The contribution of land use changes to CO_2 emission reaches 20% of atmospheric CO_2 due to the loss of SOM and biomass (Zdruli et al., 2017).

The agricultural sector has a considerable contribution to CO_2 emission through tillage, irrigation, cropping systems, fertilization and other operations which intensify global warming. Thus, there is a demand for SOC stocks spatial patterns information about agricultural activities and land use changes (Akpa et al., 2016; Lal, 2005).

Zagros forests are the vastest tree land (an area of about 5 million ha) in the semiarid region of central and western Iran. Although the contribution of these forestlands in wood industry is negligible, they play an important role in soil and water conservation and environmental functions in the region. A considerable part of these forests has been changed to farmlands in the last 40 years. The intensive deforestation and over grazing have declined soil quality and changed carbon balance between soil, biosphere, and atmosphere in the region (Mojiri et al., 2012).

In spite of many studies conducted on SOC stocks, there is a need to quantify the relationship between the SOC content and important influential factors (Lal, 2004). Establishing carbon stock inventories is required to determine a baseline and to estimate carbon stock changes (Leifeld et al., 2005). Lack of SOC distribution data, especially in the semiarid regions, is a main gap in the soil science (Hoffmann et al., 2012), thus leading to inappropriate management practices.

Therefore, the aims of this study were (1) evaluating the temporal changes of SOC, (2) determining soil carbon sequestration potential, and (3) outlining the main factors controlling variation in carbon sequestration under various land use types in Lordegan semiarid region (the central and western part of Iran). We hypothesized that the land use type could exert a significant influence on the SOC stock variation in this region.

2. Materials and methods

2.1. Study area

The study location was Lordegan (central, Iran), with the area of 390 km^2, between 31°23′ and 31°38′ N, 50°56′ and 51°13′ E (Fig. 1), with an altitude ranging between 1764 and 2856 m above the sea level. Soil texture in the region, which ranged from clay loam to silty clay loam, was developed on a calcareous parent material. The average yearly temperature and precipitation are 14.9 °C and 650 mm, respectively. The rainy season extended from October to May, with a maximum during November and February (Fig. 2). The land use distribution in the study area included forest (5%), pasture (47%), and the rest was used for irrigated and rain-fed farming.

The initial natural land cover used to be oak forests (*Quercus brantii* Lindl) which has been deforested continuously by the time. The deforested area was converted to agricultural lands with conventional tillage (both irrigated and rain-fed farming according to water availability). Wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) were found to be the dominant crops in the agricultural lands (Nourbakhsh, 2007).