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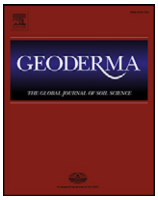

Environmental factors controlling soil organic carbon storage in loess soils of a subhumid region, northern Iran

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ABSTRACT

Soil organic carbon (SOC) storage is a basic measure used to study soil productivity, hydrology and the balance among greenhouse gases. Variation of SOC is controlled by environmental factors such as land use and topography. Toshan watershed located in northern Iran was selected to study the effects of different land uses i.e. forest (FO), cropland (CP), orchard (OR) and abandoned land (AB) on different slope gradients and aspects on SOC both in surface (0–30 cm) and subsurface (30–100 cm) layers. A total of 364 soil samples plus 1638 undisturbed ones were collected from two soil layers in 182 sampling sites. Results showed that the surface 30 cm soil layer was solely responsible for 54.8% of SOC density. On average, FO with 22.84 kg m^{-2} had the highest SOC density in 0–100 cm layer. Deforestation and agricultural activities have resulted in a significant 48.2% decrease of SOC density in 0–30 cm soil layer. North facing slope (N) aspect and also flat area of all land uses had the higher SOC density compared to east (E) and west facing slope (W) aspects in this subhumid region in 0–100 cm layer. Generally, in the upper 100 cm soil layer of deforested lands, gentle and moderate slopes had higher SOC density than steeper slopes. There was a positive significant correlation between SOC density and clay content. The largest amount of SOC storage was observed in the surface 30 cm layer accounting for 74,907.94 Mg (54.4% of total SOC storage), indicating the important key role of topsoil in conserving SOC. FO with one-third proportion of the total area stored the largest amount of SOC (39,325.55 Mg; 52.5%) in surface layer. In conclusion, protection of forest lands is higher important to increase SOC storage. Agricultural activities on steep E and W aspects in deforested lands must be reduced or prohibited. The subsoil has almost the same contribution to SOC storage and therefore should be carefully considered for management measures. Generally, interaction between environmental factors on storing SOC and also rate of carbon loss to the atmosphere was significant.

1. Introduction

Soils are the largest and, undoubtedly, the most important carbon reservoir in terrestrial carbon cycle (Watson et al., 2000). SOC originates from litter fall, roots and soil biomass decomposition, root exudates and microbial fixation (Feller and Beare, 1997). SOC storage is the balance between the input of dead plant material (leaf and root litter) and losses from decomposition and mineralization processes (heterotrophic respiration) (FAO, 2004). SOC distribution and storage are the basic measures used to study soil productivity, hydrology and the balance among greenhouse gases (Kern, 1994).

Globally, about 1500 Pg organic carbon is stored in the upper 100 cm of the soil (Lal, 2004). SOC storage is about three times more than carbon stored in vegetation (Schlesinger, 1990) and twice as much as that present in the atmosphere (Lal, 2004). According to FAO (2010) soil organic matter (SOM) stored in forest lands is a particularly important part of the global carbon cycle as these soils are characterized by high SOC storage. Many authors have reported large amount of SOC storage in forest compared to agricultural land (e.g. Khormali et al., 2009; Yang et al., 2009; Saha et al., 2011).

According to numerous studies such as Khormali et al. (2009), Liu et al. (2011), Fernández-Romero et al. (2014), Sun et al. (2015) and Wiesmeier et al. (2015) the variation of SOC is controlled by environmental factors such as climate, topography, soil parent material, land use and anthropogenic management. Yu et al. (2007) believe that SOC is sensitive to land use change, human interfere and soil management.

There is a strong interest in stabilizing the atmospheric abundance of carbon dioxide to mitigate the risks of global warming. Increasing this greenhouse gas in the atmosphere accelerates the rate of global

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Abbreviations: SOC, soil organic carbon; SOM, soil organic matter; BD, bulk density; FO, forest; CP, cropland; OR, orchard; AB, abandoned land; N, north facing slope; S, south facing slope; E, east facing slope; W, west facing slope.

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warming. Small changes in the soil carbon pool will greatly impact the concentration of atmospheric CO_2 and affect global change (Li et al., 2013). The matched balance between carbon gain and carbon losses, under steady state conditions is greatly affected by deforestation (Korkanc et al., 2008). Forest clearance and conversion to intensive agricultural uses could drastically release SOC into the atmosphere (Dorji et al., 2014) in the form of CO_2. Zheng et al. (1997) believe that 22–37% of SOM lost from the upper 20 cm of the soil in the first year after forest clear cutting. Cultivation and tillage practices lead to lower SOC stocks (Li et al., 2009). Khormali et al. (2009) by studying the effects of land use change on loess soils reported that deforestation caused a remarkable loss of SOC in a cultivated toposequence compared to adjacent natural forest. They estimated the average SOC storage of the upper 60 cm depth of the forest and deforested cultivated lands as 184.8 and 58.8 ton ha^{-1}, respectively.

Topography has a significant influence on soil properties and it is the key factor forming the soil in climatically and geologically homogenous areas (Gerrard, 1981). Tsui et al. (2004) found that the slope gradient and aspect can control the movement of water and result in variations of soil properties. Wang et al. (2001), studying a hillslope in semi-arid small catchment of the loess plateau of China, reported that topography influences soil properties variation due to its effects on runoff, drainage, microclimate and soil erosion. Slope aspect determines the length of exposure to sunlight, solar energy and soil hydrological regimes may lead to distribution patterns of vegetation and SOM decomposition (Yimer et al., 2006; Sidari et al., 2008).

Most of the studies on SOC storage were commonly restricted to the upper 30 cm of soils (Wiesmeier et al., 2012). To avoid underestimation of SOC storage 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 storage in both surface and subsurface soil layers. Wiesmeier et al. (2015) believe that future studies on SOC should consider also the subsoil and detect SOC changes induced by land use changes.

Large areas of the north facing slopes of the Alborz mountain range in northern Iran are covered by extensive loess deposits (Khormali and Kehl, 2011). Loess often contain little clay results in a loss of SOC under cultivation (Catt, 2001). Hillslopes of these areas are mainly reserved as natural forests, but recently forest clearance and land use change have been dramatically increased and is the main responsible factor for the changes in SOC storage. Deforestation and cultivation on the loess hillslopes in northern Iran have resulted in a deterioration of soil quality, particularly significant reduction in SOC (Khormali et al., 2009). Khormali and Ajami (2011) and Ajami et al. (2014) concluded that disappearance of the mollic epipedon in deforested area could point to the severe soil erosion that occurred after land use change.

Loess lands of Golestan province in northern Iran is densely being cultivated following deforestation. As indicated by Maleki et al. (2014) and Bameri et al. (2015) topographic attributes are important with regard to SOC variations in surface soil of cultivated lands in this area. Moreover, role of slope gradient and aspect on SOC storage, especially in 0–100 cm soil layer, was not studied in Iran. Thus, the main objective of this research was to investigate the variation of SOC density as affected by different land uses in contribution to slope gradient and aspect both in surface and subsurface soil layers of loess lands in a subhumid region of northern Iran. Further, SOC storage in the entire study area was estimated.

2. Materials and methods

2.1. Description of the study area

The study area is Toshan watershed, located in south-west of the city of Gorgan (Golestan province) in northern Iran, between 54°24′ to 54°26′ E longitudes and 36°46′ to 36°49′ N latitudes (150 to 600 m above sea level) (Fig. 1a). Total area of the watershed is 843 ha.

The study area is located in subhumid climatic zone. The average annual temperature and precipitation are 16 °C and 620 mm, respectively. The soil moisture regime is xeric and the temperature regime is thermic (Soil and Water Research Institute of Iran, 2000). The watershed is occupied by hills and plains with high variety of slope gradients and aspects. The slope gradient reaches >35°. The soil parent material is mainly composed of loess deposits. Based on the reports of Iranian Organization of Forest, Rangeland and Watershed Management, the history of deforestation in the study area goes back to more than fifty years ago (Fig. 1b). Interpretation of air photos taken in the year 1966 showed that 585.2 ha (69.3%) of the studied watershed had been covered by natural forest. Current satellite images, however, indicated that the forest coverage has decreased to 281.5 ha (33.4%) in 2014 (Fig. 2). In other words, during less than half of a century, nearly 52% of forests have been destroyed and converted to agricultural lands and urbanization.

Four dominant land use types in the studied area are forest (FO), cropland (CP), orchard (OR) and abandoned land (AB) (Fig. 3). When urban fabric is not considered, CP is the largest land use followed by FO, OR and AB (Table 1). The main species of the FO are oak (*Quercus* sp.), hornbeam (*Carpinus* sp.), ironwood (*Parratia* sp.) and also planted coniferous vegetation. The CP is mainly under wheat, canola and soybean cultivation. OR is mostly under olive plantation and AB is commonly covered by raspberries. AB was previously deforested and mostly cultivated.

2.2. Soil sampling design and field work

Using ArcGIS software (ESRI, 2011), a fishnet sampling design including 193 grids was created (Fig. 3). The grid interval was 200 × 200 m. During soil sampling, a portable Global Positioning System (GPS) was used to precisely locate the sampling sites. 11 sites of 193 grids were urbanized (mostly limited by fence) and were not sampled. Therefore, total of 182 sampling sites were selected.

In each grid, a 100 cm depth pit was dug. Pits were divided into two main layers, surface and subsurface, 0–30 cm and 30–100 cm. In each site, a soil sample was separately taken from surface 0–30 cm layer. Subsurface layer was subdivided into two layers, 30–60 cm and 60–100 cm. Using a spade and hammer, two samples from 30 to 60 and 60–100 cm were collected and homogenized by hand mixing in the field, to form one representative sample for the 30–100 cm subsurface layer. In a similar procedure, another set of undisturbed samples with three replications were taken from considered layers for bulk density (BD) determination. Distribution of sampling depths covers the whole thickness of each layer. A total of 364 soil samples were collected from two soil layers in 182 sampling sites (182 sites × 2 layers = 364 samples). Additionally, 1638 undisturbed samples were taken (9 undisturbed samples from each pit).

2.3. Laboratory procedures

After air-drying, the soil samples were crushed and passed through a 2 mm sieve for chemical and physical analysis. Sieved samples and undisturbed ones were dried in oven for moisture content determination. For laboratory analyses replication of each soil samples was considered. BD was determined by calculating original volume of undisturbed samples and measuring the dry mass after oven-drying. Soil texture was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986). SOC was measured using the Walkley-Black method (Nelson and Sommers, 1982). The mean extraction efficiency of SOC by the Walkley-Black method is 76% (Walkley and Black, 1934). In this research, the SOC data were adjusted with a correction factor of 1.32 to estimate 100% SOC recovery (Meersmans et al., 2009). Thus for simplicity, SOC in the whole text is referred as the total SOC.