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Changes in soil organic carbon in the upper Heihe river basin, China

Cambios en el carbón orgánico del suelo en la cuenca superior del río Heihe, China

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Abstract. The Heihe River Basin is a globally significant carbon pool, but its soil organic carbon dynamics is poorly understood. Soil samples taken between 2500 m and 4100 m revealed that the majority (>75%) of soil organic carbon was from 0-40 cm. It showed a negative relationship with pH and soil bulk density, and a positive relationship with altitude and soil water content, respectively. From 2005 to 2011, soil carbon content in the upper catchment decreased from 93 g/kg to 53 g/kg. These results suggest that policies should aim to reduce carbon loss by transferring it from the top- to the sub-soil.

Keywords: Meadow; Soil properties; Soil carbon content; Soil carbon storage; Qilian Mountains.

Resumen. La cuenca del río Heihe representa globalmente una cantidad de carbono significativa, pero su dinámica de carbono en el suelo no está entendida con claridad. Las muestras de suelo obtenidas entre 2500 m y 4000 m revelaron que la mayoría (>75%) del carbono orgánico del suelo provino desde los 0-40 cm desde la superficie del suelo. Este mostró una relación negativa con el pH y la densidad del suelo, y una relación positiva con la altitud y el contenido de agua del suelo, respectivamente. Desde 2005 a 2011, el contenido de carbono del suelo en el desagüe superior se redujo de 93 g/kg a 53 g/kg. Estos resultados sugieren que las decisiones políticas se deberían enfocar en reducir la pérdida de carbono transfiriéndolo desde la parte superior del suelo al subsuelo.

Palabras clave: Pradera; Propiedades del suelo; Contenido de carbono del suelo; Almacenaje de carbono del suelo; Montañas Qilian.

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INTRODUCTION

The soil is important in sequestering atmospheric CO_2, and soil organic carbon (SOC) is estimated to be 684-724 Pg of C in the upper 30 cm (Batjes, 1996). Thus the quantity of SOC in the 0-30 cm layer is about twice the amount of C in the atmospheric carbon dioxide (CO_2), and three times that in the global above-ground vegetation (Powlson et al., 2011). Transfer of carbon to the atmosphere as a result of human disturbances of natural vegetation was estimated from 1 to 2×10^{15} g C/yr in the early 1980's, with about 17% derived from organic matter (Houghton, 1991). Releasing of CO_2 to the atmosphere, however, can further enhance the warming trend (Batjes, 1996). Between 2000 and 2013, about 18200 papers addressed this issue (Web of Science, 2013). In general, global warming will be most pronounced at high latitudes (Serreze, 2000); thus, major carbon pools must be understood.

The potential of soils to sequester carbon is determined by abiotic (physical and chemical) properties (Lal, 2003; De Deyn et al., 2008). Soil organic carbon (SOC) is used to indicate system sustainability or vulnerability to land degradation (Jiao et al., 2011). The concept of soil quality (Doran & Parkin, 1994) can be used to define combinations of soil properties that might either reflect or not sustainable land use for food production and carbon storage (Sharma et al., 2012). Reduction in storage can be due to physical processes (e.g., erosion: King, 2011) or disruption leading to increased oxidation. Understanding the processes that regulate the soil carbon pool is critical for identifying soil vulnerability and protection policies (Powlson et al., 2011).

The Heihe river basin is one of the largest inland river basins in the arid regions of northwest China. Its source is the Qilian Mountains, and it flows from the Hexi Corridor of Gansu Province to the western part of the Inner Mongolian Plateau, providing water for irrigated agriculture. It is an important carbon pool (Kang et al., 2007), but there is little understanding of its carbon dynamics. The objectives of this work were (1) to examine the relationships between SOC and altitude and those with soil properties that exert a strong influence on SOC, and (2) to identify how SOC has changed through time by comparison with older studies. We hope our findings are interpreted in the light of policy supports needed to protect the SOC stocks in the Heihe basin.

MATERIALS AND METHODS

The Heihe river is 821 km long, and it crosses the intersection between the Westerly and East Asian summer monsoons. This results in maximum summer temperatures of 40 °C with 250 mm/year rainfall in the downstream plains (altitude around 2000 m.a.s.l.), and winter minimum of about -40 °C with 500 mm/year rainfall in the high mountain areas (up to around 5500 m.a.s.l.). The vegetation ranges from brushes, meadows and mountain grasses (e.g., *Polygonum viviparum, Carex atrata, Stipa, Reaumuria soongorica, Sympegma regelu, Ceratoides lateens* and *Achnatherum splendens*) and forests (mainly *Picea crassifolia*) in the high mountains to desert grasses in the north. The soil has a distinct zonation with gray-brown alpine forest soils, subalpine shrub meadow soils, alpine meadow soils, and alpine chestnut soils upstream. Downstream, gray desert, saline meadow and aeolian sandy soils are dominant. The Qilian Mountains have been a national natural protection zone since 1988.

The grasslands in the catchment were studied at 29 sampling points between 2500 m and 4100 m (just below the snow line) in 2011. Forest has been studied previously (Chang et al., 2008). All soil samples were collected from shrub (16 locations) and alpine meadows (13 locations). In the shrub meadow, one 10×10 m plot was randomly selected, and within it three 1×1 m grassland quadrats were analysed. In the alpine meadow, three 1×1 m grassland quadrats were randomly selected. In each plot, cover was first estimated, and the harvested aboveground biomass was dried at 80 °C to constant weight during 48 hours and weighed. Also, three soil samples were collected using an auger at 0-10 cm, 10-20 cm, 20-40 cm and 40-60 cm soil depth.

Soil organic carbon was determined by wet dichromate oxidation using an homogenized subsample of 0.2 g soil, and titrated by $FeSO_4$ (Nelson & Sommers, 1982). pH was determined using a 2.5:1 water to soil ratio, and a standard pH meter (Chapman & Pratt, 1961). Soil bulk density was determined by the soil core method (Grossman & Reinsch, 2002). Soil water content was determined using the same ring samples after oven drying at 105 °C overnight (Topp & Ferre, 2002). All data were analyzed using SPSS 16.0, with a critical threshold of $P<0.05$.

RESULTS

SOC was significantly related to altitude (Fig. 1). Over the Heihe river basin, >75% of SOC was found in the top 40 cm of soil. The SOC of the shrub meadow (78.04 ± 46.20 g/kg) was not significantly different (P=0.24) from that in the alpine meadow (59.14 ± 35.72 g/kg). Thereafter a composite soil sample was made between both meadows (Table 1).

There was a significant decrease in SOC content with increasing soil depth (Table 1). Soil bulk density (SBD) was lower at shallower than deeper soil depths (Table 1). pH did not differ among soil depths. Soil water content (SWC) decreased significantly with increasing soil depths (Table 1). SOC was negatively correlated with pH and SBD at each study soil layer (Fig. 2). SOC was positively related to SWC in all study soil depths (Fig. 3). In our study, SWC was significantly related to aboveground biomass (r=0.65, $P<0.05$).

Table 1. Soil properties and SOC by soil depth.
Tabla 1. Propiedades del suelo y SOC en cada profundidad del suelo estudiada.

		0-10 cm	10-20 cm	20-40 cm
pH	This study	7.43 (±0.75) a	7.52 (±0.81) a	7.80 (±0.79) a
	Cao (2010)	7.63 (±0.07)	8.10 (±0.03)	8.37 (±0.06)*
SBD (g/cm3)	This study	1.09 (±0.25) a	1.20 (±0.33) b	1.31 (±0.26) c
	Cao (2010)	0.44 (±0.04)	0.65 (±0.03)	0.67 (±0.01)*
SWC (%)	This study	19.80 (±9.23) a	15.21 (±10.22) b	14.42 (±8.06) b
	Cao (2010)	43.3 (±0.8)	36.4 (±0.2)	34.5 (±0.5) *
SOC (g/kg)	This study	75.14 (±39.73) a	55.36 (±28.49) b	38.91 (±28.14) c

Note: "*" means that in Cao (2010) study, SBD and SWC refer to the depth of 20-30 cm. The numbers in brackets are SD.
Nota: "*" significa que en el estudio de Cao (2010), SBD y SWC se refieren a una profundidad de 20-30 cm. Los números entre paréntesis se refieren a la D.S.

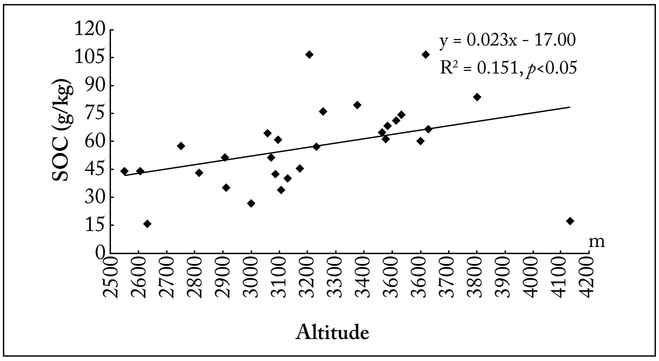

Fig. 1. SOC at different altitudes.
Fig. 1. SOC a diferentes altitudes.

DISCUSSION

Soil properties and organic carbon content. Like in previous studies (Smith et al., 2002), SOC was significantly, positively related to altitude (Fig. 1). This is due to the fact that low soil temperatures delay litter decomposition (Zhang et al., 2012). There was a significant difference in SOC content with depth, decreasing from 75.14 g/kg at 0-10 cm to 38.91 g/kg at 20-40 cm, which is consistent with Ussiri & Lal (2013). While soil bulk density (SBD) showed an inverse trend, increasing from 1.09 g/cm^3 at 0-10 cm to 1.31 g/cm^3 at 20-40 cm, pH did not differ among depths. These results are consistent with those of Cao (2010). Soil water content (SWC) decreased significantly with depth (Table 1); these results are similar to those of Cao (2010). Other studies found, however, that SWC increased when soil depth also increased (Kutiel & Lavee, 1999). As SWC is site specific this difference is expected because there is no common relationship between SWC and depth. SOC was negatively correlated with pH and SBD at each of the study soil layers (Fig. 2). The negative relationship with pH perhaps reflected an accelerated mineralization at high pH leading to greater microbial substrate availability (Whittinghill & Hobbie, 2012). The negative relationship of SOC with SBD suggested that a greater biological activity in the upper soil layers were most likely linked to root development, greater SOC input, more microbial activity and aeration and water content. These biological processed and physical soil properties enhance aggregation and biological activity (Ussiri & Lal, 2013). SOC was positively related to SWC (Fig. 3) as reported by Zhang et al. (2010). This is because high SWC cause aboveground biomass increases, and thus lead to an increase in the source of organic C input to the soil (Grosse et al., 2011). In our study, SWC was significantly related to aboveground biomass (r=0.65, P<0.05).

SOC in Heihe river basin. In 2005, the average SOC from 0-35 cm was about 93 (±23) g/kg (Wu et al., 2008), and about 78 g/kg from 0-60 cm (Chang et al., 2008) in the study area. In 2011, the average SOC was 57 (±18) g/kg from 0-40 cm. The SOC from 40-60 cm was 25 (± 4) g/kg. Thus the average SOC content from 0-60 cm was 49.10 (± 21.74) g/kg, i.e. about half the 2005 value. A similar trend was also found by Cao (2010). SOC in the upstream Heihe River basin decreased from 2005 to 2011. The most likely reasons might be: (1) over exploitation of natural resources including deforestation (not studied here) and over-grazing (Kang et al., 2007), leading to changes in plant species composition (Lauber et al., 2008); (2) decrease in soil plant cover of 69.2 (± 35.5)% vs a grassland ideal of 100%, and a dry biomass of 125 (± 85) g/m^2 *vs* a grassland norm of 295 g/m^2) [the former data from this study, and the later data from Cao (2010)]; (3) conversion of land from permanent grassland to farmland (in 1980s) because of abandonment of adequate policies (Cao, 2010); (4) temperature increased acceleration of C loss from soil (Trumbore et al., 1996); and (5) change in soil properties, especially SBD, caused by land use changes (overgrazing and abandonment). Crusting and compaction, both linked to increased SBD resulted in a decreased infiltration; thereafter, SBD changes are very important for SOC stocks (Sharma et al., 2012). There was insufficient evidence of changes in SBD

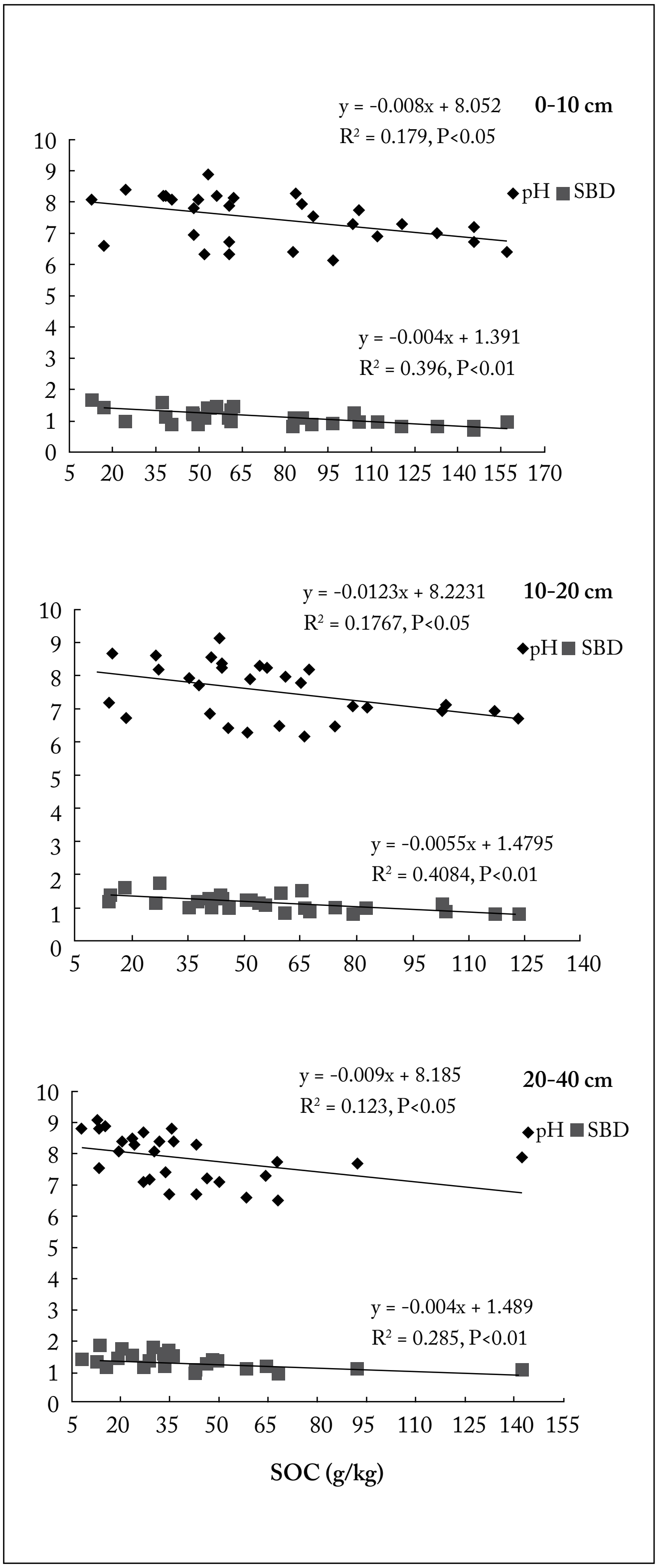

Fig. 2. Relationships between SOC versus pH and SBD at the study soil depths.

Fig. 2. Relaciones entre SOC versus pH y SBD en las profundidades de suelo estudiadas.

to identify whether this is a controlling variable in the Heihe river basin (Table 1). Using multivariate regression linear analysis with the stepwise method, we found that the optimum imitative straight line equation was: SOC=80+148.29 SWC-39.91 SBD, suggesting that SOC was mainly related to SWC and SBD in the upstream of the Heihe river basin.

Policy implications of change in SOC in Heihe river basin. China's grasslands represent 6–8% of world grasslands and have 9–16% of world carbon, thus making a massive contribution to global carbon storage. Changes are likely to have significant effects on the global carbon cycles. The alpine meadow had the greatest soil carbon storage, which is estimated to be about 56% of the carbon storage in China's grassland soils (Ni, 2002). Based on Table 1, carbon storage by soil depth was 76 (± 32) Mg/ha at 0-10 cm, 71 (± 48) Mg/ha at 10-20 cm, 94 (± 55) Mg/ha at 20-40 cm and 65 (± 46) Mg/ha at 40-60 cm, with a total carbon storage of 306 Mg/ha at a soil depth of 60 cm. Zeng et al. (2004) found that soil carbon storage of the alpine meadow of the Yellow River was about 218 Mg/ha, a value much lower than that in the upstream of the Heihe River. This suggests that the Heihe River basin is an important carbon pool for China's carbon budget and the global biogeochemical cycles.

Powlson et al. (2011) noted that if environmental factors or management practices cause increases in the SOC storage over time, then that storage could be described as a sink because SOC is moving into it. The results of our work indicate a loss of SOC in this region, suggesting that here it might rather be regarded as a SOC source due to the current land management practices and policies. Therefore, ongoing anthropogenic disturbances such as overgrazing should be reversed, perhaps by compensation (Cao et al., 2012) to improve vegetation cover, increase water infiltration, and decrease erosion (Jiao et al., 2011; Powlson et al., 2011). It might also be possible to enhance carbonate deposition (King 2011). The high altitude areas need more attention because they have a strong ability to sequester carbon if land use is managed more appropriately.

As there is evidence that the SOC is more sensitive to land use changes and perturbations in the topsoil than in the subsoil (Powlson et al., 2011; Ussiri & Lal, 2013), a better understanding of techniques that help place organic matter at depth (e.g., encouraging deep rooting plants) might be beneficial (Powlson et al., 2011; Sharma et al., 2012). Whether such management is possible in these environments remains unknown.

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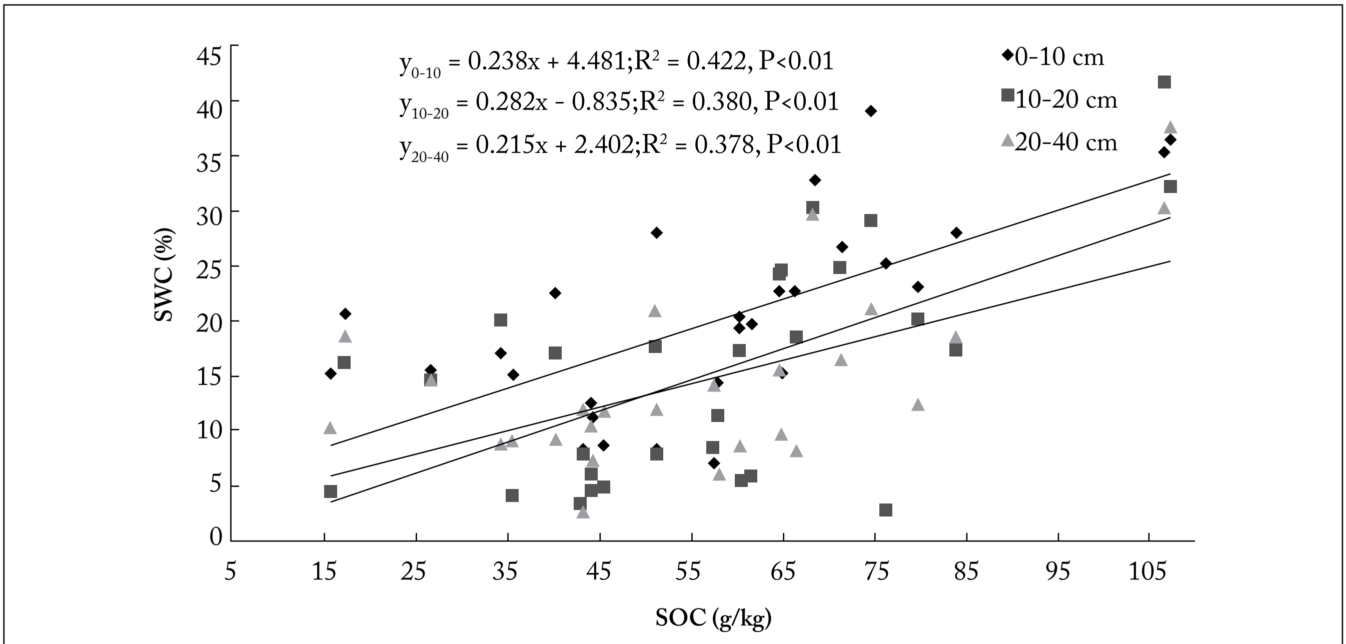

Fig. 3. Relationships between SOC and SWC at each of the study soil depths.
Fig. 3. Relaciones entre SOC y SWC en cada una de las profundidades estudiadas.

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