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Using ^{137}Cs and $^{210}Pb_{ex}$ for quantifying soil organic carbon redistribution affected by intensive tillage on steep slopes

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Abstract

Studying on spatial and temporal variation in soil organic carbon (SOC) is of great importance because of global environmental concerns. Tillage-induced soil erosion is one of the major processes affecting the redistribution of SOC in fields. However, few direct measurements have been made to investigate the dynamic process of SOC under intensive tillage in the field. Our objective was to test the potential of ^{137}Cs and $^{210}Pb_{ex}$ for directly assessing SOC redistribution on sloping land as affected by tillage. Fifty plowing operations were conducted over a 5-day period using a donkey-drawn moldboard plow on a steep backslope of the Chinese Loess Plateau. Profile variations of SOC, ^{137}Cs and $^{210}Pb_{ex}$ concentrations were measured in the upper, middle and lower positions of the control plot and the plot plowed 50 times. ^{137}Cs concentration did not show variations in the upper 0–30 cm of soil whereas $^{210}Pb_{ex}$ showed a linear decrease ($P < 0.05$) with soil depth in the upper and middle positions, and an exponential decrease ($P < 0.01$) at the lower position of the control plot. The amounts of SOC, ^{137}Cs and $^{210}Pb_{ex}$ of sampling soil profiles increased in the following order: lower > middle > upper positions on the control plot. Intensive tillage resulted in a decrease of SOC amounts by 35% in the upper and by 44% in the middle positions for the soil layers of 0–45 cm, and an increase by 21% in the complete soil profile (0–100 cm) at the lower position as compared with control plot. Coefficients of variation (CVs) of SOC in soil profile decreased by 18.2% in the upper, 12.8% in the middle, and 30.9% in the lower slope positions whereas CVs of ^{137}Cs and $^{210}Pb_{ex}$ decreased more than 31% for all slope positions after 50 tillage events. ^{137}Cs and $^{210}Pb_{ex}$ in soil profile were significantly linearly correlated with SOC with R^2 of 0.81 and 0.86 ($P < 0.01$) on the control plot, and with R^2 of 0.90 and 0.86 ($P < 0.01$) on the treatment plot. Our results evidenced that ^{37}Cs and $^{210}Pb_{ex}$, and SOC moved on the sloping land by the same physical mechanism during tillage operations, indicating that fallout ^{137}Cs and $^{210}Pb_{ex}$ could be used directly for quantifying dynamic SOC redistribution as affected by tillage erosion.

Keywords: Soil organic carbon (SOC); ^{137}Cesium (^{137}Cs); Excess ^{210}Pb ($^{210}Pb_{ex}$); Tillage erosion

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1. Introduction

Accelerated soil erosion by intensive tillage on steep slopes is a major threat to sustainable agricultural production as well as environmental protection (Govers et al., 1994; Lindstrom et al., 1992; Frye, 1997). Soil erosion results in a loss of surface soil and a deterioration of soil quality (Reicosky, 1998; IPCC, 2000). Soil organic carbon (SOC), concentrated in soil surface horizons, is an important determinant of soil quality, agricultural productivity, water quality, and global climate (Lal et al., 1998; Post and Kwon, 2000; Reicosky, 2001; Smith et al., 2000). Depletion of SOC is usually followed by a deficiency of plant nutrients, a deterioration of soil structure, diminished soil workability, and a lower water-holding capacity (Frye, 1987; Batie et al., 1993; Richter, 1999; Gilly et al., 1997; Kimble et al., 2001; Dabney et al., 1999).

Depletion of SOC and erosion can be interrelated. Decrease in organic carbon increases the susceptibility of a soil to erosion, thereby increasing the rate of depletion of SOC (Veldkamp, 1994; Six, 1999). Soil organic carbon is preferentially removed by flowing water and tillage erosion. Little is known, however, about systematic assessment of the dynamic redistribution of SOC due to a lack of direct measurements to investigate this dynamic process occurring at the field level. Moreover, a historic reconstruction of long-term soil redistribution by tillage and water erosion on soil quality variations is urgently needed for establishing the cause–effect relationship (Pennock, 1998; Lal, 1999). The key question is how to link soil redistribution patterns on the slope to SOC patterns.

The use of environmental radionuclides, in particular ^{137}Cs, overcomes many of the limitations associated with the traditional approaches and has been shown as an effective way of studying erosion and deposition within the landscape (Ritchie et al., 1974; Ritchie and Mc Henry, 1975; Wallbrink and Murray, 1993; Zapata, 2003; Li and Lindstrom, 2001; Li et al., 2003). Li et al. (2002) reconstructed the changing sedimentation rates in the moraine agricultural landscape in NE-Germany using ^{137}Cs and ^{210}Pb$_{ex}$ dating techniques. Takenaka et al. (1998) suggested that the distribution of ^{137}Cs be related to the existence of SOC. Ritchie and McCarty (2003) proposed that both ^{137}Cs and SOC are moving along similar physical pathways but there is a lack of direct field evidence to support this proposal. The key benefit of using ^{137}Cs and ^{210}Pb$_{ex}$ techniques is that it can provide retrospective information on medium-term (45 year span) and long-term (150 year span) redistribution patterns of soils within the landscapes, without the need for long-term monitoring programs.

Against this background, the objectives of this study were: (i) to determine the profile variations of ^{137}Cs, ^{210}Pb$_{ex}$ and SOC concentrations before and after multiple tillage events and (ii) to quantify relationships of SOC with ^{137}Cs and ^{210}Pb$_{ex}$ on steep cultivated slopes. We hypothesized that ^{137}Cs, ^{210}Pb$_{ex}$ and SOC move on sloping land by the same physical mechanism during tillage operations. Through the following investigation, we provided a more direct assessment of the role of intensive tillage on redistribution of fallout radionuclides and SOC than in previous published investigations that were based on mixing effects by both water and tillage erosion processes.

2. Materials and methods

2.1. The study site

The trial was conducted on a steep backslope in the Yangjuangou watershed (36°42′N, 109°31′E), near Yan'an city, northern Shaanxi Province of China (Li et al., 2004). The distinctive characteristics of the landscape at the study site are narrow summits (averaging 30 m) and long linear backslopes (150–300 m). The long steep backslopes have been dissected and managed as several small fields by landowners since 1982. The site has a 40-year average of 550 mm rainfall with a 70% of the annual rainfall distribution between July and September. The soil in the study site was developed from Malan loess with uniform soil texture along the profile (16% clay, 50% silt, and 34% sand), and classified as Calciustepts in the U.S. taxonomic classification system (Soil Survey Staff, 1999). The soil contains 7.26 g kg^{-1} of organic matter and has a pH value of 7.8. Water erosion is a recurring problem due to deforestation on steep slopes and the extremely high erodibility of the loess soils (Li et al., 1990, 1991). Pearl millet [*Pennisetum glaucum* (L.) R. Br.] and soybean [*Glycine max* (L.) Merr.] are the major crops in rotation with potato (*Solanum tuberosum* L.) and corn (*Zea mays* L.) grown in the study area. The farmers in the region have been