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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 practicing animal-drawn contour tillage for over 1000 years.

2.2. Experiment procedure

To evaluate the role of intensive tillage on soil C movement, we established a control plot (reference) and an adjacent experimental treatment plot to evaluate the role of intensive tillage on translocation of radionuclides and SOC. The intensive tillage treatment was defined as multiple tillage events in a short time interval.

The tillage was conducted in the lower boundary of a sloping field (20 m × 20 m) with average slope of 27° (range 19–36°) in August 2001 (Li et al., 2004). The plot area was tilled along the contour to a depth of 15 cm with a 20 cm wide moldboard plow. No rain occurred during tillage operation. For each tillage operation, tillage (plow) started at the lower boundary and worked upslope, turning the soil downslope. Both the control and tilled plots were plowed once a year before the study. We conducted 50 plowing operations over a 5-day period to simulate 50 years of tillage as farmers normally till their land once a year. While we recognize 50 tillage events in 5 days may not allow SOC loss and decomposition to accurately simulate 50 years of one tillage per year due to other climate effects on temporal decomposition, the primary emphasis of the work was on the physical movement of SOC and radionuclides as a result of repeated tillage.

To determine the profile variations of ^{137}Cs, $^{210}Pb_{ex}$ and SOC concentration as affected by tillage, soil samples were collected at three positions (upper, middle, and lower) on the treatment plot plowed 50 times. To ensure complete ^{137}Cs and $^{210}Pb_{ex}$ inventories of the soil profile were measured, soil sampling depths at upper and middle positions in the plot were 0–15, 15–30 and 30–45 cm, and soil sampling depths at the lower portion in the slope were 0–15, 15–30, 30–45, 45–60, 60–80 and 80–100 cm, respectively. Soil bulk density samples were obtained using the core method (Blake and Hartge, 1986) with a metal cylinder of 5 cm (diameter) by 5 cm (length). Similar sampling was also conducted on a control plot, adjacent to the treatment plot plowed 50 times. Both the control plot and the treatment plot had the same land use history.

2.3. Analyses

Soil samples were air-dried, weighed, and divided into two parts, one for measurement of SOC concentration, and the other for measurements of ^{137}Cs and $^{210}Pb_{ex}$ concentrations. Lead-210 is a naturally occurring radionuclide from the ^{238}U decay series. It is derived from the decay of gaseous ^{222}Rn. Some ^{222}Rn in soil diffuses into the atmosphere and decays to

Table 1
Depth distribution of SOC, ^{137}Cs, and $^{210}Pb_{ex}$ activity between the control plot and the treatment plot

Location	Depth (cm)	Control plot			Treatment plot		
		SOC (g kg^{-1})	^{137}Cs (Bq kg^{-1})	$^{210}Pb_{ex}$ (Bq kg^{-1})	SOC (g kg^{-1})	^{137}Cs (Bq kg^{-1})	$^{210}Pb_{ex}$ (Bq kg^{-1})
Upper	0–15	6.17 a[a]	2.17 a	42.29 a	3.64 a	0.36 a	4.36 b
	15–30	6.72 a	2.26 a	30.71 a	3.59 a	0.27 a	7.65 a
	30–45	4.51 b	0.00	10.13 b	3.52 a	0.24 a	6.45 a
Middle	0–15	8.55 a	3.37 a	50.94 a	4.07 a	0.30 a	1.50 a
	15–30	7.05 a	4.21 a	32.23 a	3.81 a	0.30 a	1.60 a
	30–45	4.52 b	0.00	23.20 b	2.87 b	0.38 a	1.60 a
Lower	0–15	9.62 a	4.77 a	55.93 a	6.17 b	2.54 b	11.01 c
	15–30	6.98 b	4.11 a	29.50 b	6.59 b	1.98 b	16.74 b
	30–45	5.63 b	0.00	22.12 b	6.46 b	2.11 b	16.33 b
	45–60	4.78 c	0.00	21.01 b	7.10 a	2.66 b	19.10 a
	60–80	3.92 c	0.00	12.32 c	7.51 a	3.50 a	25.75 a
	80–100	3.76 c	0.00	12.30 c	7.26 a	4.04 a	27.46 a

[a] Figures followed by the same letters within a column at the same slope location are not significantly different at $P = 0.05$ based on least significant difference test.

^{210}Pb and subsequent fallout of ^{210}Pb to the landscape surface provides an input that is not equilibrium (excess) with its parent ^{226}Ra (Robbins, 1978; Zapata, 2003). Fallout ^{210}Pb is commonly termed unsupported or excess ^{210}Pb (^{210}Pb$_{ex}$) when incorporated into soils or sediments in order to distinguish it from the ^{210}Pb produced in situ by the decay of ^{226}Ra. ^{137}Cs and ^{210}Pb concentrations were measured using a hyperpure coaxial Ge detector coupled to a multi-channel analyzer (Li et al., 2003). Soil samples passing through a 2 mm sieve were stored for 28 days to ensure equilibrium between ^{226}Ra and its daughter ^{222}Rn (half-life 3.8 days), an inert gas. Excess ^{210}Pb concentrations of the samples were calculated by subtracting ^{226}Ra-supported ^{210}Pb concentration from the total ^{210}Pb concentrations. ^{137}Cs concentration of samples was detected at 662 keV peak while total ^{210}Pb concentration was determined at 46.5 keV and the ^{226}Ra was obtained at 609.3 keV using counting time over 80,000 s, which provided an analytical precision of ±6% for ^{137}Cs, ±10% for ^{210}Pb. Soil organic carbon concentration was measured by the wet combustion method (Nelson and Sommers, 1982).

One-way analysis of variance (ANOVA) was conducted to test the significance in the variability of SOC, ^{137}Cs and ^{210}Pb$_{ex}$ at the individual positions of the treatment plot and control plot. Regression modeling techniques were used to develop relationship between SOC with ^{137}Cs and ^{210}Pb$_{ex}$ on the control plot and the treatment plot. All statistical analyses were performed using statistical analysis system (SAS) general linear model procedures (SAS Institute, 1990).

3. Results

3.1. Depth distribution of ^{137}Cs, ^{210}Pb$_{ex}$ and SOC on the control plot and treatment plot

As expected, ^{137}Cs concentration was uniformly distributed within the surface layer of 0–30 cm of soil on the control plot (Table 1). Excess lead-210, however, showed a linear decrease ($P < 0.05$) at upper and middle portions, and an exponential decrease ($P < 0.01$) with soil depth at the lower position of the control plot with a long-term farming history. All sample locations of the control plot contained higher SOC within 0–30 cm layers than below 30 cm, and had a similar decrease tendency to the profile distribution of ^{210}Pb$_{ex}$ with soil depth on the control plot. For the treatment plot, uniform profile distributions of ^{137}Cs, SOC and ^{210}Pb$_{ex}$ with soil depth were observed in the upper and middle positions as compared with their substantial increase in the lower position (Table 1).

3.2. Redistribution of ^{137}Cs, ^{210}Pb$_{ex}$ and SOC down slope by intensive tillage

The amounts of ^{137}Cs, ^{210}Pb$_{ex}$, and SOC were calculated from Table 1 and soil bulk density (Fig. 1).

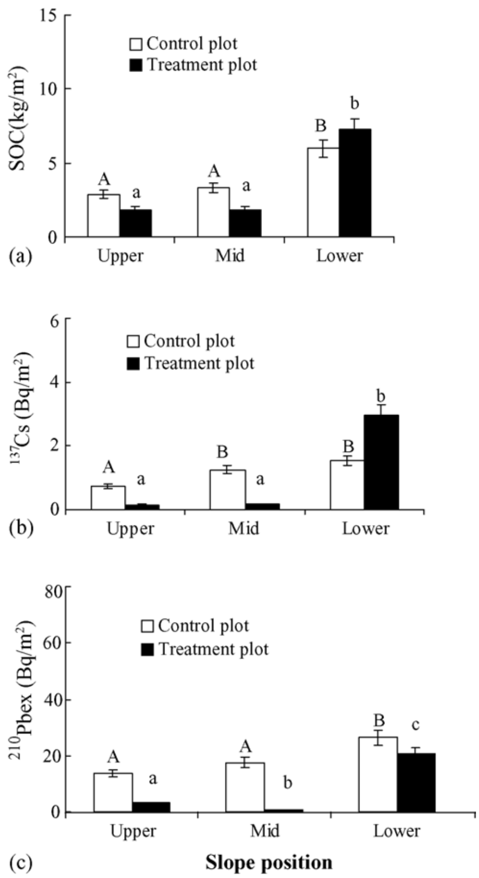

Fig. 1. Comparison of (a) SOC, (b) ^{137}Cs and (c) ^{210}Pb$_{ex}$ amounts on the different slope positions between the control plot and the treatment plot. Figures followed by the same letters are not significantly different at $P = 0.05$ based on least significant difference test.

Table 2
Comparison of profile variability of SOC, ^{137}Cs, and $^{210}Pb_{ex}$ between the control plot and treatment plot

Location	Soil depth (cm)	Variability	Control plot			Treatment plot		
			SOC (g kg^{-1})	^{137}Cs (Bq kg^{-1})	$^{210}Pb_{ex}$ (Bq kg^{-1})	SOC (g kg^{-1})	^{137}Cs (Bq kg^{-1})	$^{210}Pb_{ex}$ (Bq kg^{-1})
Upper	0–45	Mean ± S.D.	5.8 ± 1.15	1.5 ± 1.28	27.7 ± 16.29	3.6 ± 0.06	0.3 ± 0.06	6.2 ± 1.66
		CV (%)	19.8	86.7	58.8	1.7	21.5	27.1
Middle	0–45	Mean ± S.D.	6.7 ± 2.04	2.5 ± 2.23	35.5 ± 14.15	3.6 ± 0.63	0.3 ± 0.05	1.6 ± 0.06
		CV (%)	30.4	88.2	39.9	17.6	14.1	3.7
Lower	0–100	Mean ± S.D.	5.8 ± 2.22	1.5 ± 2.30	25.5 ± 16.26	6.9 ± 0.52	2.8 ± 0.81	19.4 ± 6.2
		CV (%)	38.5	155.6	63.7	7.6	28.8	32

The results indicated that effects of intensive tillage on redistribution of ^{137}Cs, $^{210}Pb_{ex}$ and SOC varied, depending on slope locations. The amounts of SOC, ^{137}Cs and $^{210}Pb_{ex}$ of sampling soil profiles increased in the following order: lower > middle > upper on the control plot. The lower slope position of the treatment plot contained much higher amounts of SOC, ^{137}Cs and $^{210}Pb_{ex}$ than the upper and middle slope positions (Fig. 1a–c). As compared with the control plot, intensive tillage resulted in a significant decrease of SOC amounts by 35% and by 44% for the soil layers of 0–45 cm at upper position and middle portion, respectively. However, amount of SOC in the complete soil profile (0–100 cm) at the lower position was increased by 21% after 50-plowing operations. Similar trends to SOC, ^{137}Cs inventory decreased by 79% and 86% at upper and middle position, but increased by 94% at the lower position after intensive tillage. In contrast to SOC and ^{137}Cs, $^{210}Pb_{ex}$ inventory to tended to sdecrease for all plot positions.

3.3. *Profile variability of ^{137}Cs, $^{210}Pb_{ex}$ and SOC as affected by intensive tillage*

To quantify variability of ^{137}Cs, $^{210}Pb_{ex}$ and SOC in soil profile as affected by intensive tillage, we calculated the coefficients of variations (CVs) of SOC, ^{137}Cs and $^{210}Pb_{ex}$ on the control plot and the treatment plot (Table 2).

For the complete soil profile on the control plot, the CVs for SOC, ^{137}Cs and $^{210}Pb_{ex}$ fall into high variable class of Wilding and Drees (1983) (CVs > 35%) except that SOC on the upper portion belonged to moderately variable class (CV = 19.8%) (Table 2).

Intensive tillage operations resulted in a decrease of profile variability for SOC, ^{137}Cs and $^{210}Pb_{ex}$ for the entire plot, and all CVs belonged to the least and moderate category (CV: 1.7–32%) (Table 2). As compared with the control plot, CVs of SOC after 50-plowing operations decreased by 18.2%, 12.8%, and 30.9% in the upper, middle and lower slope positions, respectively. Similar to the trend of SOC, CVs of ^{137}Cs and $^{210}Pb_{ex}$ decreased more than 31% (65.1–126.8% and 31.7–36.2%) for all slope positions.

3.4. *Relationships of SOC with ^{137}Cs and $^{210}Pb_{ex}$ on the two study plots*

Regression analyses indicated positive correlations between ^{137}Cs and SOC, $^{210}Pb_{ex}$ and SOC on both control and treatment plots (Fig. 2). Concentrations of ^{137}Cs and $^{210}Pb_{ex}$ in soil profile were significantly linearly correlated with SOC concentrations with R^2 values of 0.81 and 0.86 on the control plot (Fig. 2a and b), and R^2 values of 0.90 and 0.86 on the treatment plot (Fig. 2c and d) at $P < 0.01$, respectively. Intercept of the regression equation was remarkably smaller between SOC and $^{210}Pb_{ex}$ than between SOC and ^{137}Cs concentration on the control plot, while intercepts of two regression equations were nearly the same on the treatment plot. The difference between two intercepts was due to the different depth distribution of ^{210}Pb and ^{137}Cs in soil profile on the control plot.

4. Discussion

Our results provided direct field evidence that fallout ^{137}Cs, $^{210}Pb_{ex}$ and SOC are moving on sloping land by the same physical mechanism and the same pathway during tillage due to four reasons. First, ^{37}Cs,

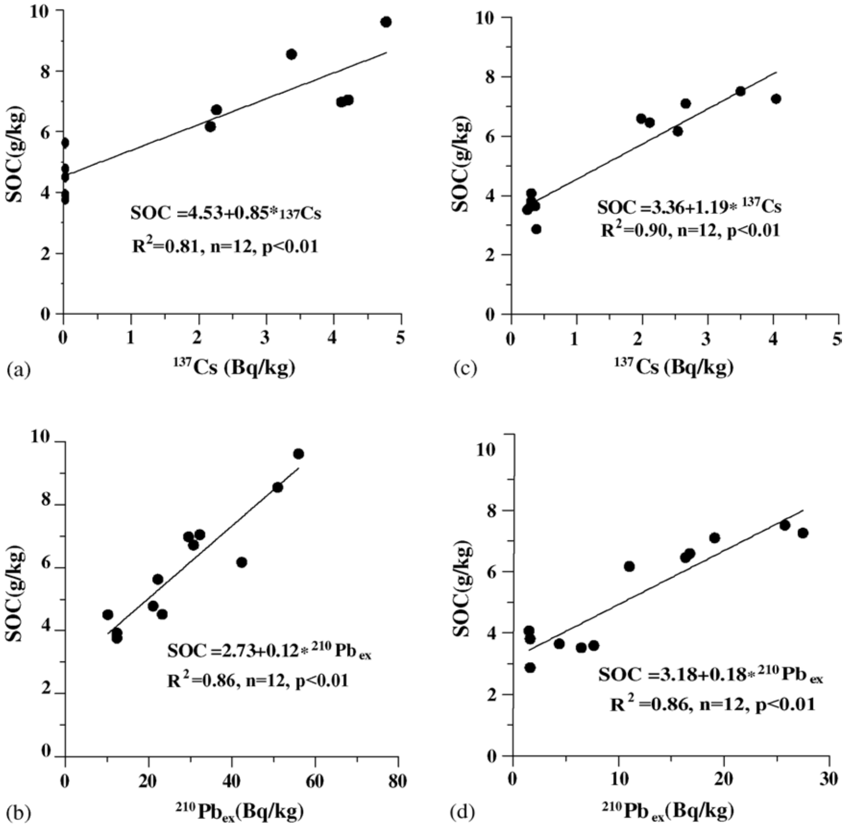

Fig. 2. Relationships between SOC with ^{137}Cs and ^{210}Pb$_{ex}$ on the control plot (a and b) and on the treatment plot (c and d).

^{210}Pb$_{ex}$ and SOC had the similar depth distribution on the treatment plot after intensive tillage (Table 1). Second, the amounts of SOC, ^{137}Cs and ^{210}Pb$_{ex}$ increased along the down slope transect on the control plot and had a similar changing pattern for different sample locations of the treatment plot (Fig. 1). Third, CVs of SOC, ^{137}Cs and ^{210}Pb$_{ex}$ for the complete soil profile fall into the similar variable range, and the similar decreasing trends of profile variability for SOC, ^{137}Cs and ^{210}Pb$_{ex}$ of the entire plot were observed after 50 plowing operations (Table 2). Finally, ^{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. The variation in SOC could be explained by 81% and 90% of ^{137}Cs on the control plot and on the treatment plot; the variation in SOC could be explained by 86% of ^{210}Pb$_{ex}$ on both the control plot and treatment plot, respectively. The profile distributions of SOC and ^{137}Cs on the control plot are in agreement with the findings of Ritchie and McCarty (2003) who studied the profile distribution of SOC and ^{137}Cs in four management systems (conventional farming, precision farming, and two levels of animal waste treatments) in a small agricultural watershed, located on the Northern Coastal Plain physiographic region of the U.S. Ritchie and McCarty's results showed that ^{137}Cs concentration is strongly correlated ($R^2 = 0.66$) to soil carbon (%) concentration in an upland agricultural system. They found that ^{137}Cs had similar patterns of distribution to SOC concentrations, and both ^{137}Cs and SOC concentrations were uniformly distributed in the top 0–20 cm in upland soils. The distribution of ^{137}Cs (0–30 cm) on the control plot in our work was deeper than those in the upland at Beltsville (0–20 cm), which was due to the difference in tillage intensity, landuse history, soil types, and soil landscapes. Both SOC and $^{210}Pb_{ex}$ in the tilled layer decreased linearly with soil depth at the upper and middle position, and decreased exponentially with soil depth on the lower position of the control plot, implying that $^{210}Pb_{ex}$ has the potential capacity to quantify the dynamic distribution of SOC concentration. Excess lead-210 would be as an effective tracer independently or as a potential complement to assess the SOC distribution where little or no ^{137}Cs is detected before and after intensive tillage, especially at location with severe erosion.

The decrease in the amount of SOC in the upper position and the increase in the lower position with 50 plowing operations further confirmed the direct role of tillage in the movement of SOC in the upper position and temporary improvement or carbon storage in the lower position (Schumacher et al., 1999; Thapa et al., 2001; Li et al., 2004). The downslope movement of SOC in the plot was attributed to soil translocation by tillage. Our previous study (Li et al., 2004) showed that soil redistribution after 50-tillage operation resulted in a maximum soil surface level (SSL) decrease of 1.25 m in the upper slope position and an increase of 1.33 m at the bottom position of the slope. Several authors have observed substantial losses of SOC due to intensive tillage of agricultural soils. Data of Meints and Peterson (1977) indicated decreases in SOC content ranging from 30.6% to 55.5% by cultivation through a comparison between virgin and cultivated Ustoll soil profiles, and showed that the effects of cultivation could be extended to depths of more than 127 cm. Mitchell et al. (1991) discussed the long-term impacts of agronomic practices on SOC in United States. They summarized that SOM declined rapidly during the first 35 years, maintained a lower rate of decline for the next 52 years, and then stabilized. Mikhailova et al. (2000) also reported that a significant decline in soil organic matter beyond the plow depth with long-term continuous cultivation with and without cropping. They observed a significant loss in SOC extending to 60 cm in a continuously cropped field. West and Post (2002) reported, on average, that a change from conventional tillage using a moldboard plow to no-till could sequester 57 ± 14 g C m^{-2} yr^{-1}. Gilly et al. (1997) observed that conversion of undisturbed land under Conservation Reserve Program (CRP) to tilled cropland resulted in drastic reductions in SOC pool by 20 Mg ha^{-1} in the top 30 cm layer. Our results supported these findings. Based on the calculations of differences in SOC concentrations between the control plot and the treatment plots (Table 1), intensive tillage operations resulted in a decrease of SOC concentration (g kg^{-1}) for layers of 0–45 cm by 38% and by 47% at upper and middle positions respectively, and an increase of SOC concentration (g kg^{-1}) by 23% for the complete soil profile of 0–100 cm at the lower position. Redistribution depth of SOC extending to 100 cm by intensive tillage suggested that the complete soil profile should be considered to assess the impacts of tillage on SOC movement in agricultural landscape. For the entire study, intensive tillage resulted in a total SOC loss of 18 Mg ha^{-1} averaging 36 g C m^{-2} yr^{-1}, assuming that the 50 operations were equivalent to 50 yr of tillage in our research (Fig. 1). A little lower C loss rate in our study than that reported by West and Post (2002) and Gilly et al. (1997) may be explained by the difference in overland flow, slope gradients, tillage tool, and land management practices, etc.

The finding of $^{210}Pb_{ex}$ depth distribution different from that of ^{137}Cs is of great importance for using $^{210}Pb_{ex}$ to estimate soil redistribution in cultivated landscapes. The model to date for derivation of quantitative estimates of erosion and deposition rates by using $^{210}Pb_{ex}$ was based on the assumption that both fallout $^{210}Pb_{ex}$ and ^{137}Cs have the similar behavior in soil, i.e. uniformly distributed in plow layers (Walling and He, 1999; Zhang et al., 2003). From the results of present investigation, ^{137}Cs concentration was uniformly mixed in the upper 0–30 cm of soil whereas $^{210}Pb_{ex}$ concentration showed a linear decrease at upper and middle position, and an exponential decrease with soil depth in the lower position of the control plot on the Chinese Loess Plateau. Excess lead-210 was distributed below 15 cm layers (15–30 cm, even 30–45 cm) on the control plot (Table 1). Difference between $^{210}Pb_{ex}$ and ^{137}Cs distribution profile was possibly due to that $^{210}Pb_{ex}$ fallout input is constant and supply to the soil surface is being continuously replenished. Farming activity, landscape dynamics, rainfall change and loess soil variation might result in differences in the depth distribution and the total inventories of the $^{210}Pb_{ex}$ and ^{137}Cs in soil profile on the cultivated slopes of the

Chinese Loess Plateau. Therefore, normal tillage operation once a year does not mix fallout $^{210}Pb_{ex}$ uniform in soil profile, and further studies are required on how to apply $^{210}Pb_{ex}$ for estimating soil redistribution rates in cultivated landscapes.

5. Conclusions

Intensive tillage resulted in a significant decrease of SOC amounts and ^{137}Cs inventory for the soil layers of 0–45 cm at upper position and middle position, and an increase in the complete soil profile (0–100 cm) at the lower position. The profile variability of SOC, ^{137}Cs, $^{210}Pb_{ex}$ were significantly decreased in treatment plot due to intensive tillage. ^{137}Cs and $^{210}Pb_{ex}$ in soil profile were positively correlated with SOC on the control and treatment plots. Our results demonstrate that fallout ^{137}Cs and $^{210}Pb_{ex}$ could be used directly for quantifying dynamics of SOC–soil redistribution relationship as affected by tillage erosion. Our finding of $^{210}Pb_{ex}$ depth distribution different from that of ^{137}Cs in cultivated landscapes further indicates that the present model to derive quantitatively soil redistribution rates on cultivated land by using $^{210}Pb_{ex}$ should consider some revision. However, the results presented above should be viewed as preliminary and suggest. Further work is required to explore more fully the potential for using ^{137}Cs and $^{210}Pb_{ex}$ in assessment of SOC redistribution.

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