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Suitability of using ^{137}Cs and ^{210}Pb for Quantifying Soil Organic Carbon Redistribution Affected by Intensive Tillage on the Slope Land

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ABSTRACT : Spatial and temporal variation in soil organic carbon is of great importance because of global environmental concerns. Tillage intensive erosion adversely affects soil organic carbon profile pattern. However, few direct measurements have conducted to investigate the dynamic process of soil organic carbon (SOC) as affected by intensive tillage at the field level. Our objective is to test the potential of ^{137}Cs and $^{210}Pbex$ for directly assessing SOC contents redistribution on the slope land as affected by tillage operation. 50 plowing operations were conducted over a 5-days period using a donkey-drawn moldbord-plow on steep backslope of the Chinese Loess Plateau. Profile variations of SOC contents, ^{137}Cs and ^{210}Pb were measured at upper, mid and lower portion of the slope after 50 plowing operations. ^{137}Cs concentration was uniformly mixed in the upper 0-30 cm of soil whereas $^{210}Pbex$ showed a linear decrease at upper and mid portion, and an exponential decrease with soil depth on the lower portion of the control slope. SOC contents of 0-30 cm layers were much higher than the soil layers below 30 cm on the control slope, and showed a similar decrease pattern to $^{210}Pbex$ on the mid and lower portion of the control slope. 50-plowing operations resulted in a decrease of SOC content (g/kg) by 38% and by 47% for the soil layers of 0-45 cm at upper portion and mid portion respectively. However, SOC content in the soil layers of 0-100 cm at the lower position increased by 18% after 50 plowing operations. Weighed mean values of ^{137}Cs concentrations decreased from 1.48 Bq/kg to 0.29 Bq/kg at upper position, from 2.53 Bq.kg to 0.33 Bq/kg at mid position, and increased from 1.48 Bq/kg to 2.81 Bq/kg at lower position. Weighed mean values of $^{210}Pbex$ concentrations

decreased from 27.71 Bq/kg to 6.15 Bq/kg at upper position, from 35.46 Bq/kg to 1.57 Bq/kg at mid position, and from 25.53 Bq/kg to 19.40 Bq/kg at lower position. Profile concentration of ^{137}Cs and ^{210}Pbex are significantly correlated with SOC contents with R^2 of 0.81 and 0.86 for the control slope, 0.91 and 0.86 for experimental slope The results suggested that fallout ^{137}Cs and ^{210}Pbex could be used directly for quantifying dynamic soil organic carbon redistribution as affected by tillage erosion.

Key words: Soil organic carbon, ^{137}Cesium (^{137}Cs), Unsupported ^{210}Pb(^{210}Pbex), Profile variation, Tillage erosion

INTRODUCTION

Accelerated soil erosion by intensive tillage on steep slopes is the major threat for the sustainable agricultural production as well as environment in the western China. This accelerated soil erosion results in severe lose of surface soils and militate against the quality of soil on-site. Soil organic carbon (SOC), mainly concentrated in soil surface horizon, is an important determinant of the soil quality, agricultural productivity, water quality, and the global climate. Depletion of soil organic carbon is followed by depletion of plant nutrients, deterioration of soil structure, diminished soil workability (Frye, 1987; S. S. Batie, J. W. Gilliam, ect, 1993), and lower water-holding capacity of the soil.

Depletion of soil organic carbon and erosion are interrelated, since a decrease in organic carbon increases the susceptibility of a soil to erosion, thereby increasing the rate of depletion of soil organic carbon. SOC is susceptible to change by soil erosion, and preferably removed by flowing water and tillage erosion. Little is known, however, about systematic assessment of the dynamic redistribution of soil organic carbon due to few direct measurements to investigate this dynamic process occurred 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. The environmental radionuclides, in particular ^{137} Cs has been demonstrated the effective way for studying erosion and deposition within the landscape (Felipe Zapata, 2003; Li, 2003; Wallbrink, 1993). The key problem is how to link the soil redistribution pattern on the slope to soil organic carbon patterns. Ritchie and McCarty suggested that both ^{137}Cs and soil organic carbon are moving along similar physical pathways (Ritchie and McCarty, 2003), however, there is lack of direct field evidence to support this proposal.

Against this background, we conducted the following two investigations. We assumed that fallout radionuclides could be used directly for assessing soil organic carbon redistribution as affected by the intensive tillage if ^{137}Cs, ^{210}Pbex and SOC move on the slope land by the same physical mechanism during tillage operations. To confirm this hypothesis, we measured the profile variations of ^{137}Cs, $^{210}Pbex$ and SOC contents along downslope before and after tillage series.

MATERIALS AND METHODS

EX\RIMENT PROCEDURE

We conducted 50 plowing operations over a 5-days period using a donkey-drawn moldbord-plow on steep backslope of the Chinese Loess Plateau, in August 2001 (Li et al., 2004). We assumed that the 50 operations could be equivalent to 50 yr of tillage as farmers normally till their land once a year. The tillage experiment plot was demarcated from the lower boundary of a sloping field (20 by 20 m) of 27° (19°-36°). The plot area was tilled along contour to a depth of 15cm with a 20-cm wide moldboard.

To determine the profile variations of ^{137}Cs, $^{210}Pbex$ and SOC content as affected by the intensive tillage, soil samples were collected at upper, mid, and lower portion in the slope land in February 2002, 6 months later after 50-plowing operations. Three sampling points at every portion in the slope land were taken. To ensure that all ^{137}Cs and $^{210}Pbex$ inventory of the soil profile were measured, soil sampling depths at upper and mid potion in the slope are 0-15, 15-30 and 30-45, and soil sampling depths at the lower portion in the slope are 0-15, 15-30, 30-45, 45-60, 60-80 and 80-100 respectively.

DATA ANALYSES

Intensive tillage effects on ^{137}Cs, $^{210}Pbex$ and SOC contents were determined from a control slope adjacent to experimental slope. Soil samples were air-dried, weighed, and was divided into two parts, one of which for measurement of SOC content, while another one for measurements of ^{137}Cs and $^{210}Pbex$ concentration. Soil organic carbon content was measured by the wet combustion method (Nelson and Sommers, 1982; Li, 2004). Measurements of ^{137}Cs and $^{210}Pbex$ concentration were undertaken at the institute for Application of Atomic Energy, Beijing, using a hyperpure coaxial Ge detector coupled to a multi-channel analyzer. $^{210}Pbex$ concentrations of the samples were calculated by subtracting ^{226}Ra-supported ^{210}Pb concentration from the total ^{210}Pb concentrations. Soil samples were passed through a 2 mm sieve and were stored 28 days to ensure equilibrium between ^{226}Ra and its daughter ^{222}Rn (half-life 3.8 days), an inert gas. ^{137}Cs content of samples was detected at 662 keV peak while total ^{210}Pb concentration was determined at 42.52 keV and the ^{226}Ra was obtained at 351.9 keV and using counting time over 80,000s, which provided an analytical precision of ±6% for ^{137}Cs and ±10% for ^{210}Pb.

RESULTS

The results indicated that ^{137}Cs concentration was uniformly distributed in the top 0-30 cm of soil whereas $^{210}Pbex$ showed a linear decrease at upper and mid portion, and an exponential decrease with depth on the lower portion of the control slope (Table 1, Fig.1).

TABLE 1 PROFILE VARIATION OF SOC CONTENT (MEAN ± SD), 137CS, AND 210PBEX ACTIVITY BETWEEN 50 PLOWING SLOPE AND CONTROL SLOPE

Location	Depth (cm)	Control slope			50-plowing slope		
		SOC (g/kg)	^{137}Cs (Bq/kg)	$^{210}Pbex$ (Bq/kg)	SOC (g/kg)	^{137}Cs (Bq/kg)	$^{210}Pbex$ (Bq/kg)
Upper	0-15	6.17±0.63	2.17	42.29	3.64±0.13	0.36	4.36
	15-30	6.72±0.38	2.26	30.71	3.59±0.03	0.27	7.65
	30-45	4.51±0.11	0.00	10.13	3.52±0.07	0.24	6.45
Mid	0-15	8.55±0.44	3.37	50.94	4.07±0.41	0.30	1.50
	15-30	7.05±0.39	4.21	32.23	3.81±0.57	0.30	1.60
	30-45	4.52±0.21	0.00	23.20	2.87±0.47	0.38	1.60
Lower	0-15	9.62±0.23	4.77	55.93	6.17±0.31	2.54	11.01
	15-30	6.98±0.01	4.11	29.50	6.59±0.38	1.98	16.74
	30-45	5.63±0.22	0.00	22.12	6.46±0.31	2.11	16.33
	45-60	4.78±0.20	0.00	21.01	7.10±0.29	2.66	19.10
	60-80	3.92±0.25	0.00	12.32	7.51±0.44	3.50	25.75
	80-100	3.76±0.03	0.00	12.30	7.26±0.20	4.04	27.46

Soil organic contents of 0-30 cm layers were much higher than those of the soil layers below 30 cm on the control slope, and showed a similar decrease pattern to profile pattern of $^{210}Pbex$ with soil depth on the mid and lower portion of the control slope. Mean values of SOC contents, ^{137}Cs, and $^{210}Pbex$ of sampling soil profiles are spatially increased in the following order: lower > mid > upper for both the control slope and the 50-plowing slope (Table 1).

SOC concentration increase at the lower boundary of the 50-plowing slope indicated that the soil organic carbon in the soil is significantly affected by tillage intension, although climate, drainage, soil type and landform also influence the level of soil carbon. Monitoring levels of soil organic carbon provides a good measure of the impact of land management on soil health. Exploitative, environmentally damaging land management practices tend to reduce soil carbon levels.

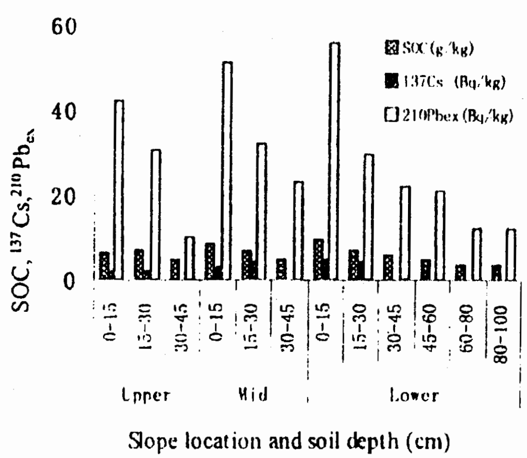


Fig 1. Profile distribution of SOC, ^{137}Cs and ^{210}Pb on the control slope

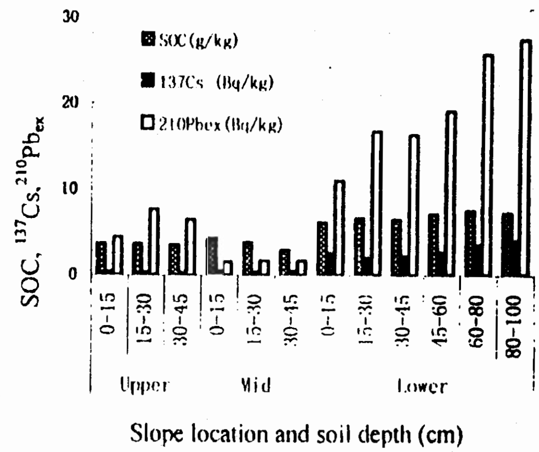
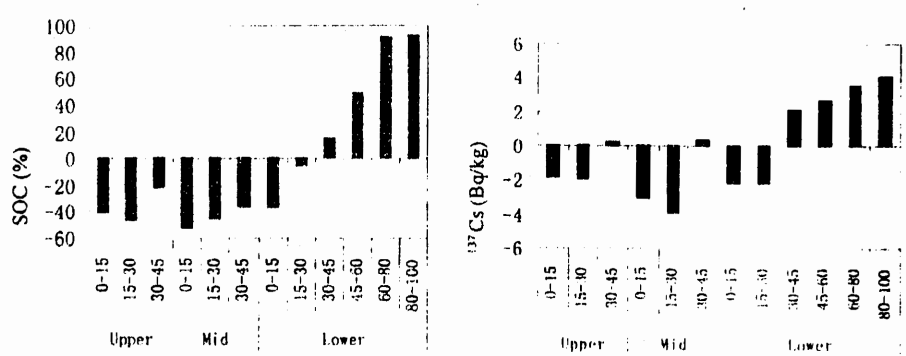


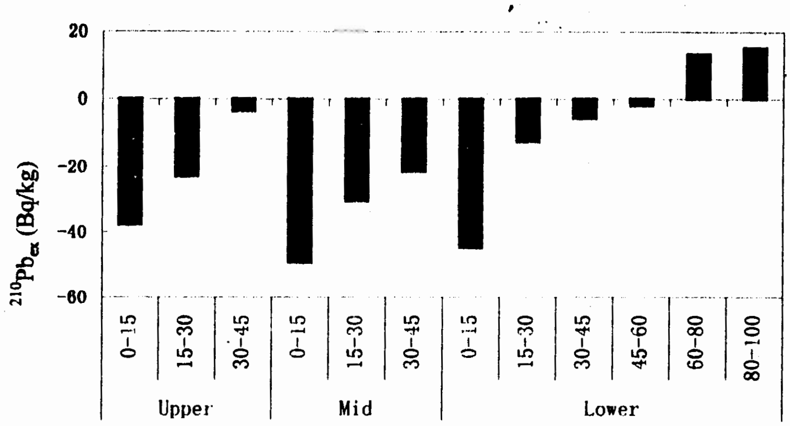
Fig 2. Profile distribution of SOC, ^{137}Cs and ^{210}Pb on the 50-plowing slope

On the basis of the calculations of changes in ^{137}Cs, ^{210}Pb$_{ex}$ and SOC contents between the control slope and the 50-plowing slope, intensive tillage operations resulted in a decrease of SOC content (g kg^{-1}) by 37% and by 45% for the soil layers of 0-45 cm at upper portion and mid portion, respectively (Table 2, Fig 3a, 3b, 3c).



a. Slope location and soil depth

b. Slope location and soil depth(cm)



c. **Slope location and soil depth**

FIG3. CHANGE IN SOC, 137CS AND 210PB BETWEEN 50 – PLOWING SLOPE AND CONTROL SLOPE

(Change in SOC, %=(SOC on 50 - plowing slope - SOC on control slope)/ SOC on control slope *100; Change in ^{137}Cs (^{210}Pbex), Bq/kg=^{137}Cs (^{210}Pbex) on 50-plowing slope - ^{137}Cs (^{210}Pbex) on control slope)

However, the lower position showed an increase of SOC content by 34% in the soil layers of 0-100 cm after 50 plowing operations. Weighed mean values of ^{137}Cs concentrations decreased from 2.2 to 0.32 Bq kg^{-1} at upper position, from 3.79 to 0.33 Bq kg^{-1}at mid position, and increased from 1.48 to 2.63 Bq kg^{-1} at lower position. Weighed mean values of $^{210}Pb_{ex}$ concentrations decreased from 27.71 to 6.45 Bq kg^{-1} at upper position, from 35.46 to 1.57 Bq kg^{-1}at mid position, and from 25.53 to 19.40 Bq kg^{-1} at lower position (Fig.3a, 3b, 3c).

The results (Table 2) supported the conclusion proposed by other researchers that tillage operation tends to reduce the profile variations of soil properties. After 50-plowing operations, the profile coefficients of variations (CV) in SOC decreased from 19.87 to 1.77% at upper, from 30.42 to 17.64% at middle, from 38.45 to 7.61% at lower position. CV of ^{137}Cs and ^{210}Pbex decreased from 86.66, 58.78 to 21.53 and 27.06% at upper position, from 88.18, 39.90 to 14.14 and 3.69% at middle, and from 155.56, 63.68 to 28.80 and 31.97% at lower position, respectively.

TABLE 2 SUMMARY STATISTICS OF SOC, 137CS, AND 210PBEX OF SAMPLING PROFILES

Table 2 Summary statistics of SOC, ^{137}Cs, and ^{210}Pbex of sampling profiles

Location		Control slope			50-plowing slope		
		SOC (g/kg)	^{137}Cs (Bq/kg)	^{210}Pbex (Bq/kg)	SOC (g/kg)	^{137}Cs (Bq/kg)	^{210}Pbex (Bq/kg)
Upper	Mean	5.80	1.48	27.71	3.58	0.29	6.15
	SD	1.15	1.28	16.29	0.06	0.06	1.66
	CV	19.87	86.66	58.78	1.77	21.53	27.06
Mid	Mean	6.71	2.53	35.46	3.58	0.33	1.57
	SD	2.04	2.23	14.15	0.63	0.05	0.06
	CV	30.42	88.18	39.90	17.64	14.14	3.69
Lower	Mean	5.78	1.48	25.53	6.85	2.81	19.40
	SD	2.22	2.30	16.26	0.52	0.81	6.20
	CV	38.45	155.56	63.68	7.61	28.80	31.97

Profile concentrations of ^{137}Cs and ^{210}Pbex are significantly correlated with SOC contents with R^2 values of 0.81, 0.86 on the control slope (Fig.4a, 4b), and R^2 values of 0.91 and 0.86 respectively on the 50-plowing slope (Fig.4c, 4d). That is to say, 81% and 91% of the variation in SOC could be explained by variation in ^{137}Cs profile concentrations on the control slope and on the 50-plowing slope; 86% of the variation in SOC could be explained by variation in ^{210}Pbex profile concentrations both on the control

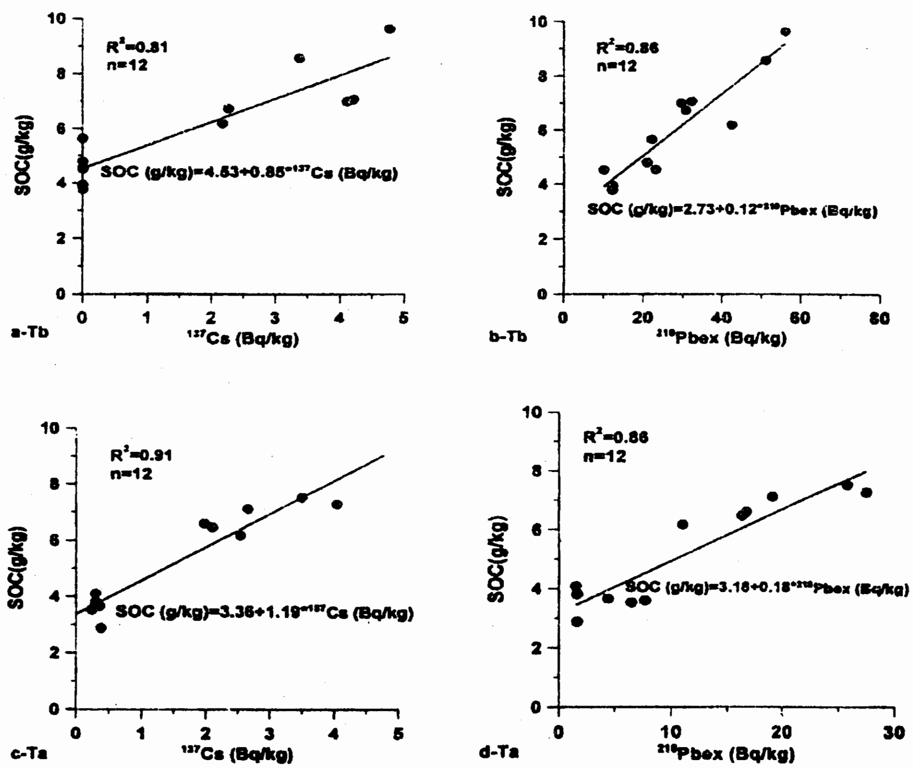


Fig. 4. SOC vs ^{137}Cs and ^{210}Pbex on the control slope and on the 50-plowing slope

(Tb- Before the intensive tillage; Ta- After the intensive tillage.)

These results provided the new evidence that fallout ^{137}Cs, $^{210}Pbex$ and SOC are moving on the slope land by the same physical mechanism and the same pathway during tillage operations. Therefore, fallout ^{137}Cs and $^{210}Pbex$ could be used directly for quantifying dynamic soil organic carbon-soil redistribution relationship as affected by tillage erosion.

Discussion

The rapid decline in soil organic carbon in the upper position is attributable to the loss of surface soil with tillage. The intensive tillage resulted in deterioration in soil quality within the tilled layer in the upper slope and temporary improvement in the lower slope. Schumacher et al.

The same profile variations and significant correlation of SOC contents and ^{137}Cs implicated that fallout ^{137}Cs could be used directly for quantifying dynamic soil organic carbon redistribution as affected by tillage erosion. Ritchie and McCarty (2003) studied the profile distribution of SOC and ^{137}Cs in a small agricultural watershed, located on the Northern Coastal Plain physiographic province at the USDA-ARS, Beltsville Agricultural Research center of USA. Ritchie and McCarty found that ^{137}Cs had the similar patter distribution to SOC contents, and both ^{137}Cs and SOC contents were uniformly distributed in the top 0-20 cm in the upland soils. Using only the soils data from the upland agricultural system, their results showed that ^{137}Cs concentration per gram is strongly correlated (R^2=0.66) to soil carbon (%) concentration. The result from this study supported the conclusion given by Ritchie and McCarty. As for the landscape on Chinese Loess Plateau, profile distribution depths of ^{137}Cs (0-30cm) on the control slope were deeper than those on the upland in Beltsville (0-20cm), which was due to the tillage intension, landuse history, soil types, and soil landscape ect.

The result also implicated that $^{210}Pbex$ has the potential capacity to quantify the dynamic distribution of soil organic content. SOC contents in the tilled layer had the similar decrease pattern to the profile pattern of $^{210}Pbex$, linearly decreased with soil depth at upper and mid portion, and exponentially decreased with soil depth on the lower portion of the control slope. Although SOC contents below 30 cm is lower than that of 0-30 cm layers, it still could not be negligible. ^{137}Cs was uniformly distributed only in the top 0-30 cm whereas $^{210}Pbex$ was uniformly distributed much deeper than 30 cm, therefore, $^{210}Pbex$ would be as an effective tracer to assess the soil organic content distribution where no or little ^{137}Cs is detectable before and after intensive tillage operation, especially at some severe erosion place.

CONCLUSION

Based on the results, SOC contents decreased linearly with soil depth at the upper and mid position, and decreased exponentially with soil depth on the lower portion of the control slope. 50-plowing operations resulted in a decrease of SOC content for the soil layers of 0-45 cm at upper and mid portion, and a temporal increase of SOC content in the soil layers of 0-100 cm at the lower position. The rapid decline in soil organic carbon in the upper position is attributed to the loss of surface soil with tillage. ^{137}Cs concentration was uniformly mixed in the upper 0-30 cm of soil whereas ^{210}Pbex showed a linear decrease at upper and mid portion, and an exponential decrease with soil depth on the lower portion of the control slope. Profile concentrations of ^{137}Cs and ^{210}Pbex showed nearly the same variations to SOC contents after the intensive tillage.

The same profile variations and significant correlation of SOC contents with ^{137}Cs and ^{210}Pbex implicated that ^{37}Cs and ^{210}Pbex, and SOC are moving on the slope land by the same physical mechanism and the same pathway during tillage operations. Therefore, fallout ^{137}Cs and ^{210}Pbex could be used directly for quantifying dynamic soil organic carbon-soil redistribution relationship as affected by tillage erosion.

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