Response of changes in soil nutrients to soil erosion on a purple soil of cultivated sloping land

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Abstract: Severe soil erosion of cultivated sloping land in hilly areas of Sichuan, China, has resulted in deterioration of soil quality, and therefore has an adverse impact on crop production. A hillslope of 110 m in length was selected with a slope steepness of 10.12% where the soils were classified as Regosols. Soil samples for determining ¹³⁷Cs, soil organic matter (SOM), total N, P, K, available N, P, K and particle size fraction were collected at 10 m intervals along a transect of the hillslope. Loss of soil nutrients owing to soil erosion was studied by using ¹³⁷Cs technique, and the relationships between ¹³⁷Cs-derived soil redistribution rates and soil nutrients were established over the cultivated sloping land in hilly areas of Sichuan, China (30°26′N, 104°28′E). The values of SOM, total N, available N, P, K and the soil particle fractions of size <0.002 mm were smaller at upper and middle slope positions where ¹³⁷Cs inventories were lower (i.e., soil erosion rates were higher) than at downslope positions where ¹³⁷Cs inventories were higher (i.e., soil erosion rates were lower). The lowest ¹³⁷Cs inventories were found at the hilltop, showing that besides erosion owing to water flow, tillage also contributed to soil losses, and intensive tillage was mostly responsible for severe erosion at upper slope positions. There were significant differences in SOM, total N, available N, P, K and the soil particle fractions of size<0.002 mm between different slope segments, and these properties were significantly correlated with slope length. These soil properties were also significantly correlated with ¹³⁷Cs inventories, indicating that both ¹³⁷Cs and nutrient concentrations varied with topographical changes. The variation in soil properties was strongly influenced by erosion-induced soil redistribution, and therefore ¹³⁷Cs inventories mirroring soil redistribution rates would be considered as an integrated indicator of soil quality.

Key Words: ¹³⁷Cs technique; soil erosion; soil nutrient; purple soil; cultivated sloping land

1 Introduction

Effects of spatial variation in soil nutrients on crop yields would be evident on cultivated sloping land. Nevertheless, little is known of the mechanism of spatial variation in soil nutrients. Soil intrinsic properties and agricultural practices are responsible for the spatial variation in soil nutrients. If the mechanism of the spatial variation in soil nutrients is well known, it is possible to overcome its adverse effects on agricultural production by changing on-field management practices. Hilly areas of the Sichuan Basin are considered as one of the most severely eroded regions in the Upper Yangtze River Basin. Sloping farmland that accounts for more than 60% of the total farmland is intensively cultivated owing to dense population and limited availability of land. As a result, severe erosion of soil and loss of water have occurred on cultivated sloping land in this region with soil erosion rates of 3000–5000 t km⁻² a⁻¹ and soil erosion amounts of 60%–80% of the total erosion on sloping farmland. Soil degradation caused by soil erosion has been widely accepted and the impacts of soil redistribution on spatial variation in soil quality on sloping farmland are being paid more attention all over the world. Although studies show that soil loses from convexities and soil quality decline, soil quality does not improve much better in concavities where soil is accumulated [1–3]. Studies in Loess region of China also show that soil erosion affects soil properties of sloping farmland [4–6]. Since 1980s, experiments carried out in the Upper Yangtze River Basin has indicated that soil erosion is extremely severe [7–9]. Meanwhile, the spatial variation in soil properties was observed in hilly areas of the Sichuan Basin [10,11], yet little was reported on how soil erosion affects soil quality. Thus, the objectives of this study...
were 1) to quantify effects of soil erosion on SOM, N, P, K by using $^{137}$Cs tracer technique on cultivated sloping land, and 2) to identify the relationship between soil redistribution and the spatial variation in soil quality.

2 Materials and methods

2.1 Study area

The study area was located in Jianyang County, Sichuan Province, southwestern China (30°26′N, 104°35′E). The elevation ranges from 454 to 489 masl. It belongs to the subtropical climate with an average annual temperature of 17°C and an annual precipitation of 872.2 mm. The soils in the study area, derived from purple mudstone and sandstone of the Jurassic Age, are classified as Orthic Entisols in accordance with the Chinese soil taxonomy\textsuperscript{[12]}, i.e., regosols as per the FAO soil taxonomy.

Soil texture was classified as silty loam in the upper- and mid-slope portions, but as silty clay loam in the downslope portions as the soil particles are selectively moved by runoff. Farmers are accustomed to tilling from the bottom of the field and gradually moving up the slope in this area. The top of hillslopes are characterized by thin soil layers (~20 cm), whereas deep soil layers up to a depth of 40–50 cm are founded at the downslope positions. Dominant crops are wheat (\textit{Triticum aestivum} L), corn (\textit{Zea mays} L) and sweet potato (\textit{Ipomoea batatas} Lam).

2.2 Soil sampling and laboratory analysis

A toposequence with a gradient of 10.12% and a slope length of 110 m was selected from the study area. The slope is steep in the upper- and mid-slope portions, whereas there is gentle slope in the downslope portions, the end of which is in the proximity of a pond. The coordinates of each sampling point as well as elevation were measured using a DGPS with a horizontal accuracy of a few centimeters. Soil sampling for $^{137}$Cs determination was carried out using a hand-operated core sampler with a diameter of 6.8 cm and at 10 m intervals along the hillside. From each sampling point, two cores were collected and then mixed together to make a composite sample. There were 12 composite samples, i.e., 12 sampling points along the transect.

Soil samples were air-dried, crushed and passed through a 2 mm-mesh sieve to remove coarse material. Samples composed of soil particle fractions of size $< 2$ mm with a mass of 350 g were packed and put into a plastic beaker, and $^{137}$Cs activity was measured using a hyperpure lithium-drifted germanium detector (CANBERRA, USA) coupled with a Nuclear Data 6700 multichannel gamma-ray spectrophotometer with a counting time of 50000 s. The relative errors of test results were lower than 5%.

Soil physical and chemical properties were determined as per the regular analysis methods\textsuperscript{[13]}. Soil particle-size fractions were determined by the pipette method following H$_2$O$_2$ treatment to destroy organic matter and subsequent dispersion of soil suspensions by Na-hexametaphosphate. Soil bulk densities were determined using oven-dried weight and sample volume. Soil organic matter (SOM) was determined using wet oxidation with K$_2$Cr$_2$O$_7$. Total nitrogen analysis followed the standard water erosion pattern (Fig.1). This is attributed to the translocation of soil and tillage erosion that has occurred in the upper-slope positions\textsuperscript{[16–18]}. As a result, tillage erosion also contributed to soil losses besides water erosion. From Fig. 1, $^{137}$Cs inventories of all the samples were lower than the local
3.2 Relationship of soil erosion to soil chemical properties

3.2.1 Variation in SOM and soil nutrients down the slope

SOM, total N and available N, P, K were significantly correlated with slope length ($R^2 = 0.50, 0.72, 0.77, 0.45, 0.71; P < 0.01$), while total P, K were not significantly correlated with slope length ($R^2 = 0.07, 0.01; P > 0.1$). Contents of SOM, total N and available nutrients increased from the summit to the lower slope portions, suggesting that SOM, total N and available nutrients along the slope was dependent on topographical changes (Figs.2, 3). Differences in total N and available N, P, K were highly significant ($P \leq 0.01$); SOM and total K were significant ($P < 0.05$), whereas total P was not significant ($P > 0.05$) between the upper-slope (0–10 m, 2 sampling points), mid-slope (20–90 m, 8 sampling points) and toe-slope (100–110 m, 2 sampling points) portions (Table 1).

3.2.2 $^{137}$Cs inventory and soil chemical properties

Umost intensive soil erosion occurred at the upper-slope positions where there was minimum SOM content of 1.16% (Figs.1, 2). SOM contents increased with elevation decreasing from the summit to the toe-slope with the highest value of 1.65%, indicating that SOM content at the toe-slope position was 42.13% higher than that at the summit position and that soil erosion was one of the most important reasons for the change in SOM contents in the slope. SOM content showed a significantly positive correlation with $^{137}$Cs inventories ($R^2 = 0.62, \, P = 0.0024$; see Fig.4), which agrees with the study results on the eroded slope of a pasture $^{20}$. Likewise, total N contents at the upper-slope position were less than those at the mid-slope and toe-slope positions, and there was a significant correlation between total N contents and $^{137}$Cs inventories ($R^2 = 0.75, \, P = 0.0003$; see Fig. 5). Similar to the distribution of SOM and total N over the slope, contents of available N, P, K increased from top-slope to toe-slope portions (Fig.3) and were significantly correlated with $^{137}$Cs inventories ($R^2 = 0.91, 0.53, 0.79, \, P < 0.01$; see Figs.6–8). As a result, the variation in soil chemical properties induced by soil erosion on the slope was affected by slope gradient, slope curvature and soil redistribution.

Changes in total P, K were not significant over the whole slope. This is mostly attributed to the characteristics of those
elements. Phosphorus is difficult to move with overland water flow, while total K of eroded areas still remained at a higher level as a result of a great deal of potassium derived from soil parent materials.

Besides runoff caused by precipitation, tillage is another dynamic factor causing soil erosion. Studies on tillage erosion in this study area by Zhang et al. showed that tillage erosion is one of the important contributors to total soil erosion [16-18]. Local farmers are accustomed to tilling with hoe from the bottom of the field and gradually moving up slope for saving energy and for convenient farming operations. As tillage occurs, the tilled soil is always pulled downslope, resulting in soil loss and shallow soil layers at the upper slope positions and soil accumulation and deep soil layers at toe-slope positions [17]. Subsequently, SOM and nutrient loss occurred at the upper-slope positions and their accumulation was observed at toe-slope positions.

3.2.3 Relationship of soil particles and 137Cs inventories and soil nutrients

Fine soil materials, i.e. silt (0.002–0.02 mm) and clay (<0.002 mm) were present in less amounts at the upper-slope positions, and increased in the downslope direction and finally accumulated at toe-slope positions. Significant correlations were found between 137Cs inventories and soil particle fractions of size <0.02 mm and <0.002 mm (R² = 0.77 and 0.72, respectively; P < 0.01). From previous studies it was notable that fine soil materials (i.e. soil particle fractions of size <0.02 mm) were selectively transported by runoff from upslope to downslope, and they would accumulate at the downslope position. Owing to easy movement of the fine materials through runoff, some chemical elements captured by fine particles exhibited a similar spatial distribution pattern. Results of analysis showed that soil particle fractions of size <0.02 mm and <0.002 mm were highly significantly correlated with total N, available N, P, K and SOM except for the correlation between soil particle fractions of size <0.002 mm and available P (Table 2). This result suggested that available P in soil was easily absorbed in bigger soil particles instead of clay particles.

4 Conclusions

Severe soil erosion occurred over the cultivated sloping

### Table 2: Correlations between soil particle-size fraction and soil properties

<table>
<thead>
<tr>
<th>Item</th>
<th>&lt;0.02mm</th>
<th>&lt;0.002mm</th>
<th>0.002–0.02mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOM</td>
<td>0.642</td>
<td>0.679</td>
<td>-0.313</td>
</tr>
<tr>
<td>Total N</td>
<td>0.837**</td>
<td>0.789*</td>
<td>-0.258</td>
</tr>
<tr>
<td>Total P</td>
<td>0.394</td>
<td>0.116</td>
<td>0.278</td>
</tr>
<tr>
<td>Total K</td>
<td>0.205</td>
<td>-0.320</td>
<td>0.739**</td>
</tr>
<tr>
<td>Available N</td>
<td>0.858**</td>
<td>0.854*</td>
<td>-0.335</td>
</tr>
<tr>
<td>Available P</td>
<td>0.785**</td>
<td>0.478</td>
<td>0.168</td>
</tr>
<tr>
<td>Available K</td>
<td>0.719**</td>
<td>0.839*</td>
<td>-0.474</td>
</tr>
</tbody>
</table>

*P<0.05; **P<0.01
land in hilly areas of Sichuan, China. At the upper slope positions, $^{137}$Cs inventories were the lowest and there were subsequently higher soil erosion rates. From middle- to toe-slope positions, soil erosion gradually became weak. Besides water erosion, tillage erosion also contributed to soil losses, and intensive tillage was mostly responsible for severe erosion at upper slope positions. Soil erosion exerted a crucial impact on the spatial variation in soil properties. Loss of fine soil material occurred at the upper-slope positions and accumulation was observed at the toe-slope positions. $^{137}$Cs inventories showed significantly positive correlations with the soil particle fractions of size $<$0.02 mm and $<$0.002 mm. Combination of both water and tillage erosion caused lack of soil nutrients at the upper-slope positions, and in the downslope direction soil erosion intensity decreased, and SOM and nutrients were relatively accumulated at downslope positions. There were significant differences in SOM, total N, available N, P, K and soil particle fractions of size $<$0.002 mm between different slope segments, and these properties were significantly correlated with slope length. The variation in soil properties was strongly influenced by erosion-induced soil redistribution, and therefore $^{137}$Cs inventories mirroring soil redistribution rates would be considered as an integrated indicator of soil quality.

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**References**


