The Limitation of Using Cesium-137 for Investigating Soil Erosion in Devastated Hills in Southeastern China

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1 Introduction

The forest vegetation in the central part of Jiangxi Province, south China is subtropical coniferous forest. Most of the forest consists of *Pinus massoniana,* and are strongly devastated due to deforestation resulting from cutting and litter removal by the inhabitants for fuel use, and also from over-grazing. There are, therefore, many devastated hills where bare soil is exposed. Consequently, both the direct runoff percentage and the sediment yield are very high in the headwater catchments around this region. This very high erosion rate causes damage downstream impeding water traffic through obstruction due to the aggradation of the riverbed. These problems are commonly found in south China. In the devastated hills in south China, although evaluation of soil erosion rate is one of the most important factors for basin management, very few information have been obtained in south China.

The ^{137}Cs technique have used for estimating net (ca. 40 years) soil flux in many environments (e.g., Walling and Quine, 1990) and for determining spatial patterns of soil loss and sediment accumulation (Walling and Quine, 1991; Chappell, 1999). The technique has been used widely because the ^{137}Cs technique overcomes a number of the problems of monitoring soil erosion and deposition rate over the medium-term. In this respect, it can be thought that the ^{137}Cs technique offers the greatest potential for measuring net soil flux and for evaluation of spatial variability of soil erosion in devastated hills where information about soil erosion rate over the medium-term are limited. The studies in Loess Plateau have supported the potential of the ^{137}Cs technique (e.g., Zhang *et al.*, 1998). Recently, the ^{137}Cs technique have been used for estimating net soil flux in Chinese agricultural environments (e.g., Higgit *et al.*, 2000). However, the ^{137}Cs technique has not been used for the evaluation of soil erosion characteristics in devastated hills. Thus, to examine the applicability of the ^{137}Cs technique for the evaluation of soil flux from the devastated hill, we measured the spatial variability of ^{137}Cs activity, the sediment yield in terms of catchment scale and surface erosion depth, and carried out in-situ sprinkling experiments at Dahou experimental watershed, central part of Jiangxi Provience, China.

2 Dahou experimental basin

This study was conducted at the Dahou experimental watershed. The watershed is located in Dahou Village of Jiangxi Province in southern China (115°28′E, 26°30′N). The altitude of this watershed ranges from 340 m to 420 m above sea level. The dominant tree species is *Pinus massoniana*. The bedrock is weathered granite, and there is no significant organic soil generation. Annual precipitation is 1,870 mm and the mean annual temperature is 17.6 ℃. The stream channel depth ranges from 0.4 m to 2.0 m and width ranges from 0.2 m to 2.0 m (Figure 1).

The experimental hillslopes were classified into two based upon vegetation and topography (Figure 1). The lower part of the hillslope within laterally 10 m—20 m from the stream (Figure 1) is relatively gentle, ranging from 15 to 25 degrees. Vegetation on the lower part is denser than on the upper part. The mean height of Pine trees is 3.6 m and the mean density is 0.8 trees/m^2 at the lower part. Moreover the land surface is covered by a microbiotic crust (<1 mm) with sand and silt grains. Removal of microbiotic crust increased saturated hydraulic conductivities four times larger than before the removal (Uchida *et al.*, 2000).

In contrast, the gradient of the upper part of the hillslope is steeper, ranging from 25 to 40 degrees. The mean height of the Pine trees is 1.6 m and the mean density is 0.5 trees/m^2. There is no ground cover vegetation and weathered granite is exposed at the surface. Gullies develop parallel to each other on the hillslope. The gully runs almost perpendicular to the slope connecting the lower and upper parts of the hillslopes. The width and depth of the gullies are 2.0 m —5.0 m and 0.5 m—2.0 m, respectively.

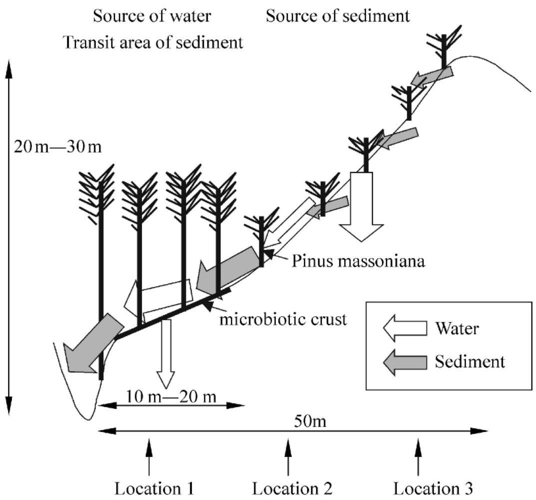

Fig. 1 Schematic illustration describing the mechanism of the sediment production and transport in Dahou Experimental watershed

3 The mechanism of the sediment production and transport in Dahou watershed

To understand the surface erosion processes in Dahou Experimental watershed, we measured sediment yield and surface erosion depth in terms of catchment scale, and carried out in-situ sprinkling experiments, focusing on the spatial variability of surface conditions and sediment sources (Kimoto *et al.*, 1998; Uchida *et al.*, 2000). The results of sediment yield measurements at the end of headwater catchment suggest that surface water is capable of transporting more material than is supplied by detachment. That is, the sediment discharge process is detachment-limited. In-situ sprinkling experiments indicate that in the lower part of the hillslope where the surface is covered by microbiotic crust, the ratio of surface runoff to rainfall is high, but sediment yield is small. In comparison, in the upper part of the hill slope where there is no microbiotic crust, the ratio of surface runoff to rainfall is low, but sediment yield is large. Measurements of surface erosion depths showed that the surface erosion depth is almost zero at the lower part of hillslope, indicating that microbiotic crusts provide a high degree of protection against soil erosion, even though the surface runoff ratio is large at the lower hillslope.

From all of these investigations, a conceptual model describing the mechanism of the sediment production and transport in this watershed is shown in Figure 1. On the upper part of the hillslope as weathered bedrock with no vegetation cover, a large quantity of unstable sediment is detached, although overland flow is relatively small compared to that on the lower part. While, on the lower part of the hillslope, the detachment of sediments is small because of the microbiotic crusts even though the surface runoff is much greater than that of the upper part. When overland flow occurs, detached sediments from the upper part are transported to the gully. Sediment and water concentrate in the gully, and the sediments are transported to the lower part along the gully. Since the ratio of surface runoff to rainfall is very large, even though the lower part of the hillslope is relatively gentle, the sediment transport capacity of the flow along the gully is not limited. Consequently, deposition does not occur on the lower part of the hillslope and the sediment is transported to the stream. The upper part of the hillslope with no vegetation is the source of the sediment, while the lower part of hillslope with microbiotic crust is the main source of surface runoff water and the transit zone of sediment (Figure 1).

4 Method

Soil samplings were conducted at three slope positions (Locations 1, 2 and 3: Figure 1). At each location, four 100 cm^3 soil samples were collected from shallow five depths (0 cm—2 cm, 2 cm—5 cm, 5 cm—10 cm, 10 cm—20 cm, 20 cm—30 cm) and two samples was collected from deeper soils using a core sampler. These samples were divided into fine soil (grains < 2 mm in diameter), gravel (> 2 mm), roots, and litter. The ^{137}Cs activity in fine soil was measured through direct gamma spectrometry using a high purity gamma detector and a multichannel analyzer..

To evaluate carbon content, soil samplings were collected from two sampling points per location. At each sampling point, a 400 cm^3 soil sample was collected from each of five depths (0 cm—5 cm, 5 cm—10cm, 10 cm—20 cm, 20 cm—30 cm, and 30 cm—50 cm) using a core sampler. These samples were divided into fine soil, gravel, roots, and litter. Fine soil was ground into powder and total carbon content was determined using an NC analyzer (NC-900, Shimadzu).

5 Results

The total ^{137}Cs activity in soil layer at the lower part of hillslope was lower than that at the upper part (Figure 2). There was significant difference in ^{137}Cs concentrations in the soil profile between the upper and lower part of hillslopes (Figure 3). The ^{137}Cs concentration at the lower part of the hillslope decreased with the increasing of thesampling depth and the ^{137}Cs concentrated predominantly in the top 10-cm of the soil profile. The ^{137}Cs activity in soil layer below 30 cm was not detected (Figure 3). In contrast, the ^{137}Cs activity in the upper part was not related to the sampling depth (Figure 3). The ^{137}Cs concentration in the top 10cm of the soil profile at the upper hillslope was lower than that at the lower hillslope (Figure 3a), while the ^{137}Cs concentration in soil layers from 20 cm to 100 cm depths at the upper hillslope was higher than that at the lower hillslope (Figures 3b and 3c).

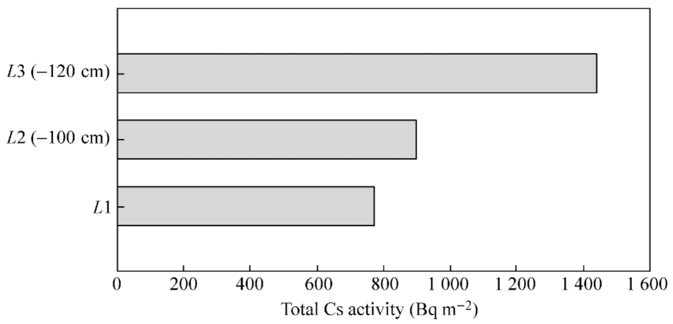

Fig. 2 Total ^{137}Cs activity in soil layer at Location 1 (*L*1), 2 (*L*2) and 3 (*L*3)

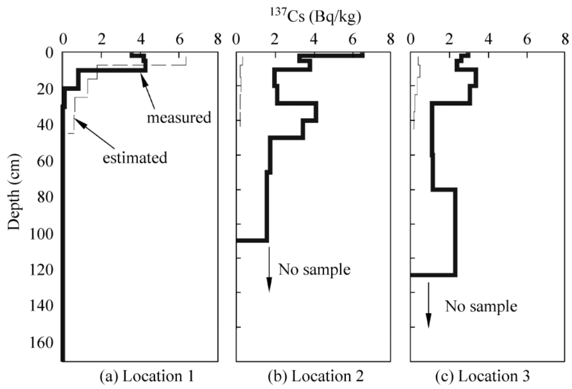

Fig. 3 The depth distribution of ^{137}Cs activity at Location 1 through 3. The fine lines show the estimated ^{137}Cs activity using Takenaka’s (1998) equation.

The carbon content in soil layer was very low, ranging from 0.1% to 1.3 % (Figure 4). The carbon content at the lower part of the hillslope exponentially decreased with increasing of the depth (Figure 4a). The carbon content in the top-20 cm soil was relatively high, compared to the deeper soil (Figures 4b and 4c). Anyway, the carbon content at the upper part of the hillslope was extremely low (< 0.3 %).

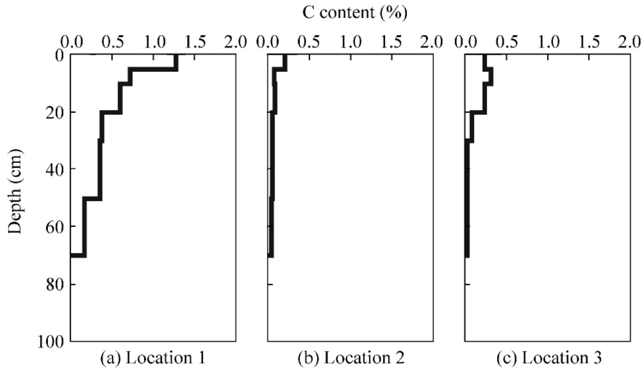

Fig. 4 The depth distribution of carbon content

6 Discussions

6.1 Total ^{137}Cs activity

Since we cannot find undisturbed sites near Dahou watershed, the baseline of the ^{137}Cs at Dahou has not been clarified. Higgit *et al.* (2,000) showed that the baselines of the ^{137}Cs at two sites in southeastern China (Shaxian, Fujian and Yujiang, Jiangxi) were about 4,000 Bq m^{-2}. The ^{137}Cs input was proportional to average annual precipitation (e.g., Lance *et al.*, 1986). The annual precipitations in Shaxian (1,643 mm) and Yujiang (1,733 mm) were similar to that of Dahou (1,870 mm), suggesting that the baseline of the ^{137}Cs at Dahou was similar to that of Shaxian and Yujiang. This indicates that 70 % of ^{137}Cs was removed from the lower part of the hillslope, suggesting that the net erosion rate over the medium-term at the lower part of hillslope was very high.

Moreover, comparison with the total ^{137}Cs activity on the upper part of the hillslope demonstrates that the net erosion rate over the medium-term at the lower part of hillslope was greater than that at the upper part. However, erosion depth measurements indicated that a current erosion rate at the lower part is almost zero (Uchida *et al.*, 2000). This confliction was probably caused by the spatial variability of the infiltration rate. A part of the fallout ^{137}Cs did not penetrate into the soil layer at the lower part of the hillslope, since the microbiotic crust promote surface runoff.

6.2 Profile of ^{137}Cs activity

The ^{137}Cs profile in the lower part of the hillslopes is similar to the characteristic exponential curve of undisturbed areas worldwide (e.g., Walling and Quine, 1991; Chappell, 1999). This concurs with the previous conceptual model in this watershed (Figure 1), indicating that the small activity of ^{137}Cs at the lower part of the hillslope may not indicate the great erosion rate over medium-term. While, the ^{137}Cs profile in the upper part of the hillslopes is similar to the characteristic of cultivated or depositional sites (Walling and Quine, 1991), although the soil erosion depth measurements indicate that the upper part of hillslope is a main source of discharged sediment.

Takenaka *et al.* (1998) reported that since most of cation exchangeable capacity has arisen from soil organic matter, the spatial distribution in ^{137}Cs activity could be characterized by the carbon content in an undistributed forest. In both parts, the pattern of ^{137}Cs profile was similar to that of the carbon content. Takenaka *et al.* (1998) also reported that the ^{137}Cs activity (*Cs*) in red pine forest soil can be described by $Cs=92.1\exp(-6.48\exp(-0.691C))$, where C is carbon content. Using Takenaka's equation and the observed carbon content, the estimate ^{137}Cs activity was shown in Figure 3. The estimated ^{137}Cs profile in the lower part of the hillslopes was 1.5 times greater than the observed ^{137}Cs profile, while estimated ^{137}Cs profile in the upper part was one order of magnitude smaller than that of observed. This result supports the previous suggestion that the rate of ^{137}Cs penetration into soil layer at the lower part of the hillslope was smaller than that of the upper part.

At the upper part of the hillslope, the penetrated ^{137}Cs was not fully absorbed by the topsoil, since the carbon content of the topsoil was extremely low. Thus, large amount of ^{137}Cs penetrated to the deeper soil. In contrast, the penetrated ^{137}Cs at the lower part of the hillslopes was readily adsorbed by the topsoil with relatively high carbon content.

7 Conclusions

At the lower part of the hillslope, the microbiotic crust did not allow considerable ^{137}Cs penetration, since the microbiotic crusts promote surface runoff (Figure 5). The penetrated ^{137}Cs was readily adsorbed by the topsoil with relatively high carbon content. Thus, the ^{137}Cs activity exponential decreased with the depth. Since the erosion rate was small, we can see the exponential decrease of ^{137}Cs activity. In contrast, at the upper part of the hillslope with no vegetation cover, the penetrated ^{137}Cs was greater than that of the lower part (Figure 5). The penetrated ^{137}Cs was not fully absorbed by the topsoil, since the carbon content of the topsoil was extremely low. Thus, large amount of ^{137}Cs moved to the deeper soil.

The results of this study indicated that the ^{137}Cs technique is difficult to use for the evaluation of soil flux from the devastated hillslopes where the carbon contents were extremely low and the infiltration capacity varied. Additional approaches (i.e., in-situ experiments and measurements of erosion depth) and/or information (i.e., spatial variability of infiltration capacity) are necessary for describing surface erosion process and quantifying soil flux on the devastated hills.

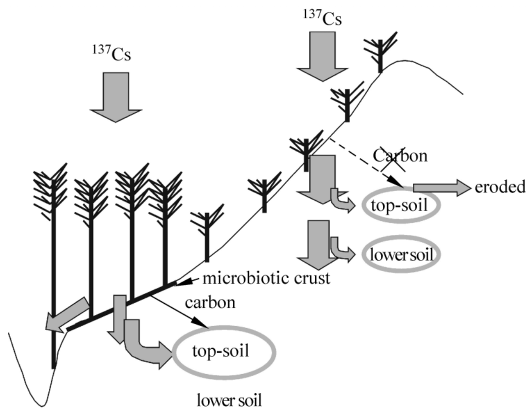

Fig. 5 Schematic illustration describing the dynamics of the fallout ^{137}Cs

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