Exploring Soil Particle Size Fraction and Spatial Redistribution of $^{137}$Cs in Sloping Landscapes with Different Lynchet Heights of Terracing Hedgerows in the Remote Mountain Region of Southwestern China

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Abstract: Soil erosion is a global serious environmental problem related to anthropogenic activities which are influenced by natural factors. The sloping cultivated lands, with serious soil erosion, constitute a significant proportion of the landscape in the remote mountain regions of southwestern China. The traditional soil conservation strategy, involving a certain height of lynchets on the edge of the terracing hedgerows of the sloping lands, plays an effective part in soil and water conservation. A typical sloping landscape with a lynchet of terracing hedgerows was chosen in this study. The objective of this study was to explore soil particle size fraction and spatial redistribution of $^{137}$Cs in sloping landscapes with different lynchet heights of terracing hedgerows. The results showed that fine-grained sediments were deposited in front of the lynchet of terracing hedgerows, especially particle sizes grouped at <0.002 mm clay and 0.002–0.02 mm silt. The $^{137}$Cs concentration profiles of the lynchet from the upper to the lower sloping landscape showed first increasing and then decreasing trends when the soil depth increased. $^{137}$Cs inventory generally increased along with the whole sloping landscapes. Moreover, the results suggested that the mean $^{137}$Cs inventory and erosion rate could be represented by the average value of the middle slope position. The highest value of annual erosion modulus reached 4917.06 t km$^{-2}$ a$^{-1}$ on the upper site of the sloping lands. Moreover, the annual erosion modulus was synchronously reduced from the upper to the lower sloping landscape and the erosion rate had a similar trend. Meanwhile, the $K$ values of soil erodibility changed from 0.0338 t hm$^{-2}$ h (hm$^{-2}$ MJ$^{-1}$ mm$^{-1}$) to 0.0375 t hm$^{-2}$ h (hm$^{-2}$ MJ$^{-1}$ mm$^{-1}$) along the slope length. There was a logarithmic relationship between the $K$ value and the $^{137}$Cs inventory. Therefore, it is useful to study spatial patterns of soil erosion in different slope positions with different heights of lynchet of terracing hedgerows of the whole sloping landscape. Moreover, it is important to implement a soil conservation strategy in the remote mountain regions of China.

Keywords: soil particle fraction; $^{137}$Cs inventory; $K$ value of soil erodibility; different slope position; soil conservation strategy

1. Introduction

Soil erosion is a global serious environmental problem related to anthropogenic activities, such as deforestation, excess reclamation and tillage erosion. It is also influenced by natural factors such as precipitation and seasonal dryness [1,2]. Currently, soil degradation has reached 1966 million hectares worldwide, induced mainly by soil erosion effects [3]. Nearly one third of the lands have been impacted by soil and water loss in China [4], especially in the remote mountain regions [5] as a result of abundant precipitation, excess...
reclamation, broken topography and the complex geological background [6,7]. These impact factors have accelerated soil erosion on sloping lands [8,9]. Additionally, the proportion of average sloping lands per person is only 0.053 hm², which is only 56 percent of the average value in China. More than 15 degrees of the sloping cultivated lands have reached 35%. This has become a severe challenge for agricultural development in this region [10]. Additionally, soil erosion is the leading cause of soil loss and soil fertility decline, even potentially threatening the local safety of the environment. Meanwhile, a high proportion of the population in this region depends on agriculture for their livelihood; hence, it is imperative to preserve soil to sustain crop yields in this ecologically fragile region [3,11]. Consequently, many soil conservation strategies have been performed in the agricultural system for better soil and water conservation efficiency on the sloping cultivated lands [12]. Some of the soil conservation strategies have been advocated by policymakers and governments. Several agro-ecosystem measurements have received more attention in recent years, especially in resource-poor, low-input and smallholder farming ecosystem regions [13,14]. Meanwhile, purple soils cover an area of twenty million hectares in China, mainly in southwestern China. Due to their rapid weathering, the complexity of mineral composition and the richness of nutrients, purple soils are considered as valuable soil resources with high fertility and suitability for crops. However, frequent droughts severe soil erosion and serious land degradations are predominant in purple soils). The contour hedgerow was first introduced to sloping farmlands as an effective soil conservation strategy in this region. However, the contour hedgerow did not significantly reduce soil erosion, control non-point source pollution and increase economic effects [15]. Meanwhile, the local people stated that the existing lynchet of traditional terracing hedgerows played an essential part in soil and water conservation; also, the plants grew well on the hedgerow [16]. Why not adopt these traditional hedgerows with Lynchets to effectively control soil erosion?

The lynchet is built at the edge of the terrace. Moreover, the two adjacent levels of terrace are separated by the lynchet [16]. The width and height of lynchet depends on the original slope gradient and the micro-relief, which usually range from 0.3 to 2.0 m and from 3 to 10 m, respectively. This traditional soil conservation measurement has been extensively used and has also conserved soil and water effectively in the past decades. However, it is difficult to evaluate this traditional soil conservation strategy by using conventional methods such as the runoff plot monitoring technique or advanced modeling approaches. The main reason for this is the small patches of field, lynchet stability and complicated land use structure [17,18].

The 137Cs tracing technique has proved to be an effective tool for assessing soil redistribution resulting from soil erosion over the past 50 years in a wide range of environments [19–23]. 137Cs is an artificial radionuclide with a half-life of 30.12 years, which was introduced into the environment primarily by the high yield atmospheric testing of nuclear weapons in the 1950s and early 1960s. There are no natural sources of 137Cs in the environment [24]. 137Cs is strongly related to local precipitation patterns and rates and the number of surface nuclear weapon tests conducted each year [25–27]. The global fallout of 137Cs began in 1954, peaked from 1963 to 1964, and decreased steadily after the 1963 Test Ban Treaty [28]. In most environments, the atmospheric fallout of 37Cs reached the land surface rapidly and was strongly fixed by the surface soil. Its subsequent redistribution in the landscape was closely associated with erosion and associated soil redistribution processes [24,29,30]. 137Cs is by far the most widely used fallout radionuclide in soil erosion and sedimentation research. It is strongly and quickly adsorbed by the fine soil particles, showing the non-exchangeable ability in most environments and well-defined patterns of fallout input [22,31].

The objectives of this study were (1) to introduce the 137Cs fallout radionuclide technique to assess the effectiveness of the traditional soil and water conservation measurement called the lynchet of terracing hedgerows in the sloping landscape as an effective soil conservation measurement; (2) to illustrate the distribution characteristics of soil particle size fraction and spatial redistribution of 137Cs in sloping landscapes with different lynchet
heights of terracing hedgerows; (3) to evaluate the effects of soil and water conservation of the traditional terracing hedgerow.

2. Study Area and Methods

2.1. Description of Study Area

The experiments were conducted at the soil and water conservation station in Zhongxian county (30°24′53″ N, 108°10′25″ E), Chongqing city, located in the remote mountain region of the southwestern China (Figure 1), where the percentage of sloping lands accounts for 60% of the cultivated lands and around 20% of those sloping lands with more than 25 slope gradients in this region. The study area has a high population density, cropland shortage and high cropping intensity. The mean annual rainfall is 1150 mm, of which about 70% falls from April to October. Soils are mainly purple soils (Orthic Entisols in the Chinese Soil Taxonomic System, Regosols in FAO Taxonomy or Entisols in USDA Taxonomy) of fast weathering products of Jurassic rocks of the Shaximiao Group (J2s). With the rapid physical weathering, the complexity of mineral composition, richness of nutrients and loam soil texture, purple soils are considered a valuable soil resource with high fertility and suitability for various crops. Meanwhile, the poor capability of anti-scouring, severe soil erosion and serious land degradation are also predominant environmental problems in the purple soil regions. The wheat (*Triticum aestivum* L), corn (*Zea mays* L), sweet potato (*Ipomoea batatas* (L.) Lam), peanut (*Arachis hypogaea* L.) and rape (*Brassica napus* L.) are predominant crop rotations. The sloping land is bare without any residue coverage after the harvest in winter.

Most of the sloping lands have been divided into several slope segments by the lynchet of terracing hedgerows, and the slope segments with different slope gradients range from 4° to 25° in this mountain region. More and more people have kindly paid attention to the soil and water conservation function of the lynchet of the terracing hedgerows. Those lynchets work due to (1) the precipitation being intercepted, and the raindrop energy being reduced by the leaves and stems of the terracing hedgerow plants. Moreover, the soil scour capacity of the lynchets reduces as they exist aboveground of the hedgerow. (2) The roots of the terrace hedgerow plants enhance the lynchet’s stability and reinforce the lynchets. The anti-sourability of the soil is also enhanced by the existed lynchets of the terracing hedgerows (Baudry, et al., 2000). (3) The hedgerow plays an obvious part in reducing the soil loss and soil erosion modulus. (4) The lynchets also serve as walking channels for farmers.
Figure 1. Location of the study area and diagrammatic sketch of the different slope positions alongside the whole sloping landscape. Notes: TS—top slope; ULUS—upside lynchets of the upper slope position; LLUS—lowerside lynchets of the upper slope position; MS—middle slope position; ULMS—upside lynchets of the middle slope position; LLMS—lowerside lynchets of the middle slope position; LS—lower slope position; ULLS—upside lynchets of the lower slope position; LLLS—lowerside lynchets of the lower slope position; ST—slope toe (photo by P. Zhou).
2.2. Methods

To investigate the soil particles size fraction and redistribution of $^{137}\text{Cs}$ in the investigated sloping cultivated land, a typical purple soil sloping land with more than 100 years traditional cropping system was selected as the study site. The whole sloping landscape was divided into several slope positions (Figure 1). Samples of $^{137}\text{Cs}$ and soil texture were collected at intervals of 5 m along the transect of the toposequence of the whole slope. Soil samples of each control subfield were collected randomly in three replicates. All soil samples of different slope positions were collected from a soil depth of 0–30 cm using a 6.8 cm diameter hand-operated core sampler. Moreover, soil samples of the lynchets of terracing hedgerows were collected using a 6.8 cm diameter hand-operated core sampler to a depth of 0–35 cm. The soils were collected using a soil hand auger at 5 cm soil depth intervals. The soil samples were air-dried, gently ground with a mortar and pestle, homogenized and divided into two parts. A part of each soil sample was sieved to pass through a 2 mm mesh to analyze the $^{137}\text{Cs}$ inventory and soil particle size distribution. Measurements of the $^{137}\text{Cs}$ activities with a mass of 200 g were transferred into airtight plastic pots and undertaken simultaneously by gamma spectrometry, using a high resolution, low background, low energy, hyperpure n-type germanium γ-ray detector (Ortec LOAX HPGe, Oak Ridge, TN, USA). The samples were counted for $\geq 50,000$ s, providing a precision of approximately $\pm 5\%$ at the 95\% level of confidence for the measurements. The $^{137}\text{Cs}$ concentrations were measured at 662 keV. Meanwhile, the organic matter were removed with hydrogen peroxide and the MS2000 Laser particle size analyzer was used to measure the soil particle size gradation (Malvern Instruments, Marlwen, UK). The other part of the soil samples was sieved to pass through a 0.25 mm mesh for analysis of the chemical character of the soil.

2.3. Using the $^{137}\text{Cs}$ Technique to Assess Net Soil Loss Rates

The improved mass–balance model, which was advocated [32] was used to calculate the quantity of net soil loss rates.

$$A = A_0 \left(1 - R\right) \left(1 - \frac{h}{H}\right)^{y-1963}$$

where $A$ is the $^{137}\text{Cs}$ inventory (Bqm$^{-2}$), $A_0$ is the local $^{137}\text{Cs}$ reference inventory (Bqm$^{-2}$), $h$ is the annual soil loss depth (cm), $H$ is the plough depth (20 cm), $y$ is the sampling year and $R$ is the runoff efficiency.

When the values of the $^{137}\text{Cs}$ inventory were more than the $^{137}\text{Cs}$ reference inventory, the following function was used to calculate the $^{137}\text{Cs}$ accumulation velocity model by [33]:

$$S = 1000 \times \frac{C - Z}{W_d(N - 1954)}$$

where $S$ is the soil accumulation modulate (t km$^{-2}$ a$^{-1}$), $C$ is the $^{137}\text{Cs}$ inventory of the soil accumulation sites (Bqm$^{-2}$), $Z$ is the revised reference inventory of $^{137}\text{Cs}$ (Bqm$^{-2}$), $W_d$ is the $^{137}\text{Cs}$ concentration of the soil accumulation sites (Bqkg$^{-1}$) and $N$ is the sampling year.

2.4. The Value of the Soil Erodibility Factor ($K$)

The soil erodibility factor ($K$) is a potential erodibility index, which indicates the soil loss quantity of the standard plot, led by the unit rainfall erodibility [34]. The soil erodibility factor ($K$) is influenced by the soil texture and soil organic carbon. There is a relationship between the soil erodibility factor $K$, the soil texture and the soil organic carbon in the EPIC model [34]. Moreover, the value of the soil erodibility factor $K$ is calculated by the USLE model, which shows the relation between the soil erodibility factor $K$ and soil particle distribution, soil organic carbon, soil texture efficiency and soil infiltration. However, the value of soil erodibility factor $K$ might be minus when using the USLE model to calculate the soil erodibility factor $K$. The main reason for this relates to the higher value of the soil
carbon. So, the EPIC model was adopted when calculating the value of the soil erodibility factor $K$ in the study. The function of the soil erodibility factor $K$ was as follows.

$$K = \left\{ 0.2 + 0.3 \exp \left[ -0.0256S_a \left( 1 - \frac{S_n}{100} \right) \right] \right\} \times \left( \frac{S_i}{C_i + S_i} \right)^{0.3} \times \left( 1 - \frac{0.25C}{C + \exp(3.72 - 2.95C)} \right) \times \left[ 1 - \frac{0.7S_n}{S_n + \exp(-5.51 + 22.9S_n)} \right]$$

where $S_n = 1 - S_a/100$; $S_a$ is the sand content (0.05–2 mm), %; $S_i$ is the silt content (0.002–0.05 mm), %; $C_i$ is the clay content (<0.002 mm), %; and $C$ is the soil organic carbon content, %.

2.5. Statistical Analysis

Analysis of variance (ANOVA) was performed with SPSS 18.5 and Microsoft Excel software. The significance level was set as $p < 0.05$.

3. Results

3.1. The Distribution of Soil Particles in Downsloping Landscapes

The lengths of the upper sub-field, the middle sub-field and the lower sub-field were 5 m, 5 m and 7 m, respectively. Moreover, the slope degree was 15° of the whole sloping land. The three sub-fields were separated by the level lynchets of 15 cm in height. The results of the mass percentages of each soil particle size fraction are shown in Figure 2. The percentage of 0.002–0.02 soil particle size had the widest distribution compared to other particle size fractions, either compared with the lynchets of the terracing hedgerow of different slope positions or with the cultivated lands of different slope positions (Figure 2). The lynchet of the terracing hedgerow mostly intercepted the eroded soil material from the upper slope position. The movements of the eroded soil particles were influenced by the selectivity of detachment and the transport processes. The fine soil particles were easier to detach and transport along with the erosion soils, so the soils from the upper sloping lands were easier to erode. Moreover, the sloping landscape soils were easily eroded and the soil texture became coarser. The particle soil content of silt and fine sand was not significantly different between the different slope positions and the similar regular pattern among different sloping lynchets. There was a significant difference ($p < 0.05$) between clay and coarse sand contents among different sloping lynchets. The main reason was that it was easier to intercept and accumulate the runoff and soil erosion from the upper slope by the lynchets of the terracing hedgerow. As the erosion occurred, the fine soil particles accumulated in the front of the lynchets of the terracing hedgerows. If the precipitation was too heavy, the runoff soils’ erodibility over-topped the lynchets.

![Figure 2. The distribution characteristics of the soil particle fraction down sloping landscapes.](image-url)
3.2. 137Cs Reference Level

The value of the 137Cs reference level was the critical point of studying soil erosion using the 137Cs tracing technique. Through comparing the value of the 137Cs inventory with the 137Cs reference level, the study site was the erosion site and the accumulation site could be judged. Meanwhile, the quantity of erosion or the accumulation intensity was also evaluated. After investigating the whole watershed of the study sites, a natural Pinus massoniana woodland on the top of the sloping land was chosen to be considered the site of the 137Cs reference level. The natural Pinus massoniana woodland has existed for more than 50 years, and fewer human activities were carried out. So, one soil stratified sample and six soil whole depth samples were collected and analyzed. The 137Cs inventory changed from 1067.98 to 1504.97 Bq m\(^{-2}\) in the seven soil samples (Figure 3). Moreover, the average value of the 137Cs reference level was 1296.01 Bq m\(^{-2}\), which was considered the 137Cs reference inventory of this study site. Meanwhile, ref. [35] proposed that the runoff of the sloping land could bring part of 137Cs. Thus, the runoff efficiency was used to revise the regional 137Cs reference level. The function is:

\[
A = A_0 \times (1 - R) \times \left(1 - \frac{\Delta H}{H}\right)^{N-1963}
\]

where \(R\) is the runoff efficiency of the sloping land; \(A_0 \times (1 - R)\) is the revised 137Cs reference level.

When considering the runoff of the sloping land, the 137Cs reference inventory of the studied sites was 907.21 Bq m\(^{-2}\). Moreover, the values of the revised 137Cs reference inventory of this study area and in the nearby regions are shown in Figure 2 [36]. The revised reference inventory of 137Cs of this study was similar to the Yanting site. The main reason for this is that there is a similar soil type and climate condition in these two sites.

Figure 3. Revised reference inventory of 137Cs of this study and nearby regions.

3.3. Depth Distributions of 137Cs of the Lynchets in Different Slope Positions

137Cs is a useful tracer and it was used to evaluate the soil redistribution. 137Cs can be rapidly and strongly adsorbed by fine particles in soil surface when deposited in the atmosphere [24]. Therefore, the 137Cs spatial distribution on sloping lands usually reflects the net influence of soil redistribution in the soil profiles. So, the 137Cs nuclear tracing technique was used to estimate soil redistribution rates on a sloping field using traditional erosion control measures. The profiles of the 137Cs concentrations of the lynchets from the upper to the lower of the slope land showed first increasing then decreasing trends as the soil depth increased (Figure 4). Less 137Cs was detected below the soil depth of 30 cm. The highest values of the upper and middle slope position were between 10 and 15 cm, because the 0–5 cm and 5–10 cm depth soils of the lynchets of the terracing hedgerow were more accessible to erosion. The 137Cs concentration of the highest value of the lynchets of the lower slope position was in the 15–20 cm soil depth. The erosion soils were transported along the slope length then accumulated at the lower slope position. Meanwhile, the 137Cs inventory of the upper, middle and lower lynchets of the slope land were 640.86 Bq m\(^{-2}\),
830.15 Bqm$^{-2}$ and 1134.13 Bqm$^{-2}$, respectively, which reflected the downwards movement of $^{137}$Cs. The mean value of the $^{137}$Cs inventory of the terracing hedgerow from different slope positions was closely approximated with the lynchets of the middle slope position. Therefore, the mean inventory of the lynchets value from the middle slope position could be used to represent the lynchets’ inventory value of the whole slope length.

![Figure 4](image-url)  
**Figure 4.** $^{137}$Cs profile for the lynchets of different slope positions. Note: (a) the lynchet of the upper slope position; (b) the lynchet of the middle slope position; (c) the lynchet of the lower slope position.

3.4. Depth Distributions of $^{137}$Cs of Different Slope Positions along the Whole Sloping Landscape

The results of each slope position profile along the sloping lands are shown in Figure 4. The changes in the $^{137}$Cs concentration from each slope position profile may partly reflect the heterogeneity of the initial $^{137}$Cs fallout deposition and may also reflect the comprehensive effects of the erosion, transportation and deposition of the precipitation erosion and tillage erosion [37]. Meanwhile, in the lynchets of the terracing hedgerow, the eluviation–illuviation also played an important role along the whole sloping cultivated lands. The peak values of the $^{137}$Cs concentration in the 0–30 cm soil depth along the whole sloping land became more profound in the soil (Figure 5). On the top slope, the upside lynchets of upper slope position, the lowerside lynchets of the upper slope position and the middle slope position, the peak values of the $^{137}$Cs concentration were in the 5–10 cm soil depth, while on the upside lynchets of middle slope position, the lowerside lynchets of the middle slope position, the lower slope position and the upside lynchets of the lower slope position, the peak values of the $^{137}$Cs concentration were in the 10–15 cm soil depth. The peak value of the $^{137}$Cs concentration was in the 15–20 cm soil depth as for the study sites of downside lynchets of the lower slope position and slope toe. The main reason for this is that the erosion soil from the upper sloping land moved with the runoff and then accumulated at the lower slope position.
Figure 5. Cont.
Figure 5. $^{137}$Cs profile from the upper to the lower along the whole sloping landscape.
The results show the changes in the $^{137}\text{Cs}$ inventory from the different slope positions. The $^{137}\text{Cs}$ inventories ranged from 509.78 Bq m$^{-2}$ to 1237.43 Bq m$^{-2}$. (Figure 5). Moreover, the $^{137}\text{Cs}$ inventories increased from the upper slope position to the slope toe position, while at the lower slope position and upside lynches of lower slope position, the $^{137}\text{Cs}$ inventories partly decreased. The main reason was that the slope degree in these two slope positions was a little steeper than the other sites because the soil erosion in these two slope positions was more serious. So, the values of the $^{137}\text{Cs}$ inventories in these two slope positions were lower. Moreover, the results of ANOVA analysis showed that there was no significant difference between the middle slope position (MS), the upside lynches of the middle slope position (ULMS) and the lowerside lynches of the middle slope position (LLMS). There was an obvious significant difference among the the other slope positions ($p < 0.01$).

The downslope changes in the $^{137}\text{Cs}$ inventories in the sloping landscapes showed an increasing rolling trend (Figure 6). The values of the $^{137}\text{Cs}$ inventories were 836.63 Bq m$^{-2}$, 808.06 Bq m$^{-2}$ and 835.17 Bq m$^{-2}$, respectively, when compared to the upside lynches of the middle slope position (ULMS), the middle slope position (MS) and the lowerside lynches of the middle slope position (LLMS). The $^{137}\text{Cs}$ inventory of the upside lynches of the middle slope position was higher than that of the middle slope position (MS) because this site was close to the lynches of the middle slope where the water erosion occurred. Moreover, the farmers returned part of the deposited sediments back to the upside lynches of the middle slope position. Moreover, the highest value at the slope toe was caused by the sediment transported from the upper slope soil erosion both by rainfall and tillage measurements [35].

![Figure 6](image_url) **Figure 6.** The $^{137}\text{Cs}$ inventory along the whole sloping land. Note: (1) The meanings of the capital letters abbreviation are shown in Figure 1. (2) When compared the value of the $^{137}\text{Cs}$ inventory, the different lowercases mean there existed the significant difference between different slope positions.

The changes in the annual erosion modulus along the whole slope positions are shown in Figure 7. The highest annual erosion modulus reached 4917.06 t km$^{-2}$ a$^{-1}$ at the top slope site, while the soil erosion decreased as the slope length increased and the annual erosion modulus was synchronously reduced along the sloping landscape. These situations became more intricate with the spatial variation in the original micro topography because the steeper slope gradient of the lower slope position and upside lynches of the lower slope position led to a higher fluctuation. The results reflect that the changes in micro topography played a key role in the spatial soil redistribution of the sloping land. Meanwhile, the minus values indicated that the lowerside lynches of the lower slope position and slope toe were the deposited sites and the annual deposition positions. A negative relationship existed along the whole slope positions when compared to the annual erosion modulus and the $^{137}\text{Cs}$ inventory.
4. Discussion

4.1. Soil Conservation Function of the Lynchets of Terracing Hedgerows on Sloping Landscapes

In terms of long-term agricultural practice, farmers are aware that terracing can efficiently prevent soil and water losses in fields. Therefore, they developed a variety of terraces by dissecting long slopes into several short segments, such as a horizontal gully, contour hedgerows and reverse sloping terraces [38]. In the remote mountain areas of southwestern China, lynchets of terracing hedgerows on the sloping lands are the dominant soil and water conservation strategy in the farming system. Although the lynchets of the terracing hedgerow save the labor force and are cost-efficient, the original...
geomorphological shape is only slightly transformed with a small amount of construction engineering required [16]. Lynchets effectively intercept the soil particles and decrease soil erosion by water until a horizontal micro topography is created [12]. The segmented sloping lands, together with the lynchets of terracing hedgerows and the level surface, act to reduce erosion to a certain extent, except for intense tillage in combination with serious rainfall runoff. Maybe the compound measurements of soil and water conservation need to be carried out in that condition. According to the local inhabitants, runoff transports massive amounts of erosion sediment from the sloping lands to rivers or reservoirs whenever heavy rainfall occurs, which scour the soil nutrients along with the erosion soils, causing a loss of soil nutrients and non-point pollution [11]. So, the effective soil and water conservation measurements on the sloping lands are needed in the remote mountain regions of southwestern China [39].

4.2. Patterns of Soil Erosion or Sediment Deposition of the Sloping Landscape

The soils of the top slope and the upper slope position have been seriously lost or have become a thinner layer. Furthermore, higher clay contents are present in slope toe than in the upper slope positions [40]. Meanwhile, the removal of fine particles occurs at the slope scale due to water erosion, suggesting that the lower slope position and slope toe are much richer in fine particles [41]. The upper parts of the slope segments are characterized by a thin purple soil layer underlain by the rock stratum because the rate of erosion exceeds the rate of soil formation, whereas deep soil layers are found in the lower parts of the sloping lands [24]. Previous studies have shown a total $^{137}$Cs inventory less than the reference inventory indicates soil erosion and a total $^{137}$Cs inventory more than the reference inventory indicates sediment deposition [28]. Moreover, the depth distribution of the soil particle size fractions from the upper to the lower alongside the whole slope landscapes are shown in Figure 9. The soil fine particle fractions exhibited a gradual increase in the line of the toposequence in the entire sloping landscape, with a significant linear increase in the $<$0.002 mm clay fraction and 0.002 mm to 0.02 mm silt fraction. Also in this study, the lower lynchets of terracing hedgerow, the lowerside lynchets of lower slope position and the slope toe sites exhibited sediment deposition due to significantly large fine soil particle fractions, also with a relatively lower bulk density than other study sites [42,43]. As the interception function of the existing lynchets of terracing hedgerows, the fine particle soils were intercepted and accumulated in front of the sites closed to the lynchets of the terracing hedgerow. When compared to the upper lynchets and the lower lynchets of the terracing hedgerow, the percentage of fine particles less than 0.02 mm and 0.002 to 0.02 mm particle levels was more at the former than at the latter sites (Figure 7). Also in a certain time interval, the farmers return part of the deposited sediments to the upside sloping lands of the lynchets of terracing hedgerow. This farming activity could conserve the soil nutrients and reduce the non-point pollutions from the agricultural ecosystem [44]. This demonstrates that the lynchets of terracing hedgerows act to effectively limit the erosion of sloping lands to some extent. Moreover, soil redistribution by the existing embanks of the terracing hedgerows could result in severe modifications of landforms, surface/subsurface hydrology and geomorphic processes [45].
Figure 9. Cont.
4.3. Impact of the Micro Topography on the \( ^{137}\)Cs Concentration and Inventory

The lynchets of terracing hedgerows segmented the sloping land from top to the slope toe. As the existing lynchets on the terracing hedgerows on different slope positions, the fine soil particles were erode from the upper slope position and are transported along with the runoff and then are intercepted by the lynchets of the terracing hedgerows and accumulated in the front of the lynchets [16]. Meanwhile, with the combined water erosion and tillage, the soil erosion is more serious from the top to the lower slope position [30]. Moreover, the slope gradient of the micro topography impacts the soil particles’ redistribution and the \( ^{137}\)Cs inventory. As an example of the situations such as the lower slope position and the upside lynchet of the lower slope position, these two study sites became more intricate with spatial variation in the \( ^{137}\)Cs inventory. The steeper slope gradient of these two sites led to a higher fluctuation in relation to the \( ^{137}\)Cs inventory. \( ^{137}\)Cs inventories included in these two slope positions were all lower than the reference \( ^{137}\)Cs inventories’ value, indicating the occurrence of serious soil erosion. The result reflected that the changes in the micro topography played a crucial role in the spatial soil redistribution of the sloping field [46,47].

4.4. Relation between the K Value and \( ^{137}\)Cs Inventory

The \( K \) values of soil erodibility can effectively indicate the different levels of soil erosion capacity [48]. The soil with higher \( K \) values of soil erodibility is more accessible to
erosion. The content of soil organic carbon can influence the \( K \) value [49,50]. Meanwhile, the estimation of erosion rates from \( ^{137} \text{Cs} \) measurements was based on the degree of reduction or increase in the measured \( ^{137} \text{Cs} \) inventory relative to the local reference inventory in this study [17]. The \( ^{137} \text{Cs} \) inventory at any sampling point was lower than the reference value, which suggests a net \( ^{137} \text{Cs} \) loss. At the same time, the \( ^{137} \text{Cs} \) inventory at any sampling point was higher than the reference value, which suggests a net \( ^{137} \text{Cs} \) accumulation. Meanwhile, there also existed a logarithmic relation between the \( K \) value of soil erodibility and the \( ^{137} \text{Cs} \) inventory. The logarithmic function between the \( K \) value of soil erodibility and \( ^{137} \text{Cs} \) inventory was described as \( y = -6950 \ln(x) - 22284 \) (Figure 10). Moreover, the correlation coefficient was 0.7858. The higher \( K \) value of soil erodibility meant a lower \( ^{137} \text{Cs} \) inventory, a lower \( K \) value of soil erodibility meant a higher \( ^{137} \text{Cs} \) inventory. It indicated that when the \( K \) value of soil erodibility was higher, the soils of the sloping lands were easier to erode and the soil anti-erodibility capacity was also lower, and vice versa. Moreover, the \( K \) value and \( ^{137} \text{Cs} \) inventory could be influenced by climate change, local topography changes and the artificial activities [39,51], which are considered complex research fields. Further and intensive studies are critically needed in this region and similar mountain regions.

Figure 10. Correlation between the \( K \) value of soil erodibility and the \( ^{137} \text{Cs} \) inventory.

5. Conclusions

(1) Mainly, the fine particle size sediments ranging from \(<0.002 \text{ mm}\) to \(0.02 \text{ mm}\) were intercepted by the lynchets. Then they were intercepted and deposited in front of the lynchets of terracing hedgerows;

(2) The values of the \( ^{137} \text{Cs} \) levels increased from the upper to the lower edge of the slope toe;

(3) The \( K \) values decreased from the top slope to the slope toe. Meanwhile, the existing correlation between the \( K \) value of soil erodibility and the value of the \( ^{137} \text{Cs} \) level could be described as the logarithmic function. So, the indices of the \( K \) value and the \( ^{137} \text{Cs} \) level could better reflect the soil erosion of the sloping lands;

(4) The effects of lynchets are essential to reduce soil loss and are considered as an effective soil and water conservation measurement to control the soil erosion of the sloping lands. Moreover, they allow the sustainable cultivation of the purple soils in the remote mountain regions of southwestern China.

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References

1. Li, S.; Lobb, D.A.; Kachanoski, R.G.; McConkey, B.G. Comparing the use of the traditional and repeated-sampling-approach of the $^{137}$Cs technique in soil erosion estimation. Geoderma 2011, 160, 324–335. [CrossRef]


5. Rao, W.; Shen, Z.; Duan, X. Spatiotemporal patterns and drivers of soil erosion in Yunnan, Southwest China: RULSE assessments for recent 30 years and future predictions based on CMIP6. Catena 2023, 220, 106703. [CrossRef]


22. Porto, P.; Walling, D.E.; Capra, A. Using $^{137}$Cs and $^{210}$Pb measurements and conventional surveys to investigate the relative contributions of interrill/rill and gully erosion to soil loss from a small cultivated catchment in Sicily. Soil. Till. Res. 2014, 135, 18–27. [CrossRef]


50. An, Z.; Bernard, G.M.; Ma, Z.; Plante, A.F.; Michaelis, V.K.; Bork, E.W.; Carlyle, C.N.; Baah-Acheamfour, M.; Chang, S.X. Forest land-use increases soil organic carbon quality but not its structural or thermal stability in a hedgerow system. *Agric. Ecosyst. Environ.* 2021, 321, 107617. [CrossRef]


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