Exploring soil particle size fraction and spatial redistribution of ^{137}Cs in sloping landscapes with different lynchet height of terracing hedgerows in the remote mountain region, southwestern China

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Abstract

Soil erosion is a global environmental problem related to anthropogenic activities, as well as being influenced by natural factors. The sloping cultivated lands, which have serious soil erosion, constitute a major proportion of landscape in the remote mountain region. The traditional soil conservation strategy, referred as 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 lynchets of terracing hedgerows was chosen in this study. The results showed that fine-grained sediment was deposited in front of the lynchets of terracing hedgerows, especially particle size grouped at $< 0.002\text{mm}$ and $0.002\text{--}0.02\text{mm}$. The profiles ^{137}Cs concentration of the lynchets from the upper to the lower sloping landscape showed first increased then decreased trends as the soil depth increased. ^{137}Cs inventory generally increased along the whole sloping landscapes. And 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 to $4917.06\text{ tkm}^{-2}\text{a}^{-1}$ on the upper site of the sloping lands. While the annual erosion modulus were synchronous reduced from the upper to the lower of the slope landscape, the erosion rate had the similar trends. Meanwhile, K values of soil erodibility changed from $0.0338\text{ thm}^2\text{h}(\text{hm}^{-2}\text{MJ}^{-1}\text{mm}^{-1})$ to $0.0375\text{ thm}^2\text{h}(\text{hm}^{-2}\text{MJ}^{-1}\text{mm}^{-1})$ along the slope length. There existed the logarithmic relationship between K value and ^{137}Cs inventory in the correspondent slope position. Therefore, it is useful to study spatial patterns of soil erosion in different slope positions with the different height of lynchets of terracing hedgerows of the whole sloping landscape. Also it is important for implementing soil conservation strategy in the remote mountain region, China.

1. Introduction

Soil erosion is a global serious environmental problem related to anthropogenic activities such as deforestation, excess reclamation and tillage erosion. Which is also influenced by natural factors such as precipitation and seasonal dry (Li et al., 2011). Currently, soil degradation induced by erosion affects 1966 million hectares worldwide (Lal, 1998). Nearly one third of the lands were impacted by soil and water loss in China (Li et al., 2008), especially in the remote mountain region. As a result of abundant precipitation, excess reclamation, broken topography and complex geological background (Olson et al., 2002; Zhang et al., 2017). These impact factors have accelerated soil erosion on sloping lands (Wiederholt and Post, 2011). Additionally, the proportion of average sloping lands per person was only 0.053 hm^2 , which only constitute 56 percent of average value in China. More than 15 degree of the sloping cultivated lands reached to 35%. It becomes a serious challenge for agricultural development in this region (Sun et al., 1999). Additionally, soil erosion is the main cause of the nutritious soil loss and soil fertility declination, even potentially threatening the safety of the local environment. Meanwhile, high density of population in this region depends on agriculture for their livelihood, hence it is imperative to preserve soil to sustain crop yields in this fragile ecological region (Geng et al., 2010). Consequently lots of soil conservation strategies have been performed in agricultural system for better efficiency of soil and water conservation on the sloping cultivated lands (Li et al., 2000; Brogaard and Zhao, 2002). Some of the soil conservation strategies have been advocated by policy-makers and governments and several agro-ecosystem managements have been received more attention in recent years, especially in resource-poor, low-input and smallholder farming ecosystem regions (Osbaahr and Allan, 2003; Malley et al., 2004). Meanwhile, purple soils cover an area about twenty million hectares in China, mainly in southwestern China. Due to their rapid weathering, complexity of mineral composition and richness of nutrients, purple soils are considered as the valuable soil resource with high fertility and suitability to crops. However, frequent drought, severe soil erosion and serious land degradations are also predominant in purple soils (He et al., 2003; Ni and Zhang, 2007). So the agro-forestry complex strategy such as the contour hedgerow was first introduced to sloping farmlands as an effective soil-conservation strategy in this region. However, it didn't play a significant role in reducing soil erosion, controlling non-point source pollution and increasing economic effects (Sun et al, 2008). Meanwhile, the local people stated that the existed lynchets of traditional terracing played important part in soil and water conservation, also the plants grew well on the hedgerow (Zhou et al, 2017). Why not adopt this traditional hedgerows with lynchets to control soil erosion?

The primary features of the terracing hedgerow with lynchets are described as the local farmers always constructed the sloping lands with certain height lynchets and planted the terrace hedgerow plants on the lynchets. The two adjacent levels of terrace separated only by the lynchet (Zhou et al., 2017). The width and height of lynchets depends on the original slope gradient and the micro-relief, usually ranged from 0.3 to 2.0 m and from 3 to 10 m, respectively. This traditional soil conservation strategy has been extensively used, 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 due to small patches of field, lynchet stability and complicated land use structure (Walling and Quine, 1990).

The ^{137}Cs 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 (Zhang et al., 2003, 2008; Li et al., 2010; Gaspar et al., 2013; Porto et al., 2014). ^{137}Cs is an artificial radionuclide, with the 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, since there are no natural sources of ^{137}Cs in the environment (Ritchie and McHenry, 1990). ^{137}Cs was strongly related to local precipitation patterns and rates and the number of surface nuclear weapon tests conducted each year (Collins et al., 2001; Yang et al., 2006; Golosov, 2003). Global fallout of ^{137}Cs began in 1954, peaked in 1963 to 1964 and has decreased steadily from this peak after the 1963 Test Ban Treaty (Walling and Quine, 1990). In most environments, ^{137}Cs fallout reaching the land surface was rapidly and strongly fixed by the surface soil and its subsequent redistribution in the landscape was closely associated with erosion and associated soil redistribution processes (Walling, 1988; Ritchie and McHenry, 1990; Lobb et al., 1999). ^{137}Cs is by far the most widely used fallout radionuclide in soil erosion and sedimentation research by virtue of its strong and quick adsorption to fine soil particles, essentially non-exchangeable in most environments and well defined patterns of fallout input (Walling, 1988; Porto and Walling, 2012).

The objectives of this study were (1) to introduce the ^{137}Cs fallout radionuclide technique to assess the effectiveness of the traditional cultivation measurement called lynchets of terracing hedgerow in the sloping landscape as an effective soil conservation measurement; (2) to illuminate the characterizer of soil particle redistribution; (3) to value the effects of soil and water conservation in the remote mountain region of southwestern China.

2. Material And Methods

2.1. Study areas

Experiments were conducted at the soil and water conservation station in Zhongxian county (30°24'53"N, 108°10'25"E), Chongqing city, which was located in the remote mountain region of the southwestern China (Fig. 1), where the percentage of sloping lands accounts for 60% of the cultivated lands and around 20% of those sloping lands were more than 25 degree in this region. This region has high population density, cropland shortage and high cropping intensity. And the mean annual rainfall is 1150 mm, 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 the Jurassic rocks of the Shaximiao Group (J2s) in this regions (He et al., 2009). As the rapid physical weathering, complexity of mineral composition, richness of nutrients and loam in texture, the purple soils are considered as the valuable soil resource with high fertility and suitability to various crops. Meanwhile, the poor capability of anti-scouring, severe soil erosion and serious land degradations are also predominant in the purple soil region (He 2003). The crop rotations were the popular cropping system in this region, including wheat (*Triticum aestivum* L), corn (*Zea mays* L), sweet potato (*Ipomoea batatas* (L.) Lam), peanut (*Arachis hypogaea* L.) and rape (*Brassica napus* L.). The sloping land is bare without any residue coverage after the harvest in winter.

Most of the sloping lands have been divided into slope segments by the lynchets of terracing hedgerows, and the slope segments with different slope gradients ranging from 4° to 25° in this mountain region. More and more people paid attention

to the soil and water conservation function of the lynchets of the terracing hedgerows. Those lynchets are served as (1) the precipitation was intercepted and the energy of rain drops were reduced by the leaves and stems of the terracing hedgerow plants. Also the soil scour capacity of the lynchets reduced as the existed of the aboveground of the hedgerow. (2) The roots of the terrace hedgerow plants enhance the stability of the lynchet and reinforced the lynchets. The anti-sourability of the soil was also enhanced as the existed lynchets of the terracing hedgerows (Baudry, et al, 2000). (3) Hedgerow played an obviously part in reducing the soil loss and soil erosion modulus. (4) The lynchets also serviced as walking channels for farmers.

2.2 methods

To document the soil particles fraction and redistribution of ^{137}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 slope. The whole sloping landscape was divided into several different slope positions (Fig. 1). Samples of ^{137}Cs and soil texture were collected at an interval of 5m along the transect of the toposequence of the whole slope length. Soil samples of each control sub field were collected randomly in three replicates. All soil samples of different slope positions were collected to a depth of 0-30cm using a 6.8-cm diameter hand-operated core sampler. And soil samples of three lynchets of terracing hedgerows were collected to a depth of 0-35cm using a 6.8-cm diameter hand-operated core sampler. The bulk density of the sample soils were measured in situ. The soils were collected using soil hand auger at 5 cm soil depth intervals. The soil samples were air-dried, gently grounded with a mortar and pestle, homogenized, and divided into two parts. One part of the soil samples were sieved to pass through a 2 mm mesh to analyze ^{137}Cs inventory and soil particle size distribution. Measurements of ^{137}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 coaxial γ -ray detector (Ortec LOAX HPGe). 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}Cs concentrations were measured at 662 keV. Meanwhile, removed organic matter with hydrogen peroxide and used the MS2000 Laser particle size analyzer to measure the soil particle size gradation (Malvern Instruments, Malvern, England). The other part of the soil samples were sieved to pass through a 0.25mm mesh for analysis the soil chemical character.

2.3. Using ^{137}Cs technique to assess net soil loss rates

The improved Mass-balance Model, which was advocated (Zhang et al., 1990) was been used to calculate the quantity of net soil loss rates.

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

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

When the values of ^{137}Cs inventory were more than the ^{137}Cs reference inventory, taken the following function to calculate the ^{137}Cs accumulation velocity model by R. Lowrance (1998):

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

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

2.4 The value of soil erodibility factor (K)

Soil erodibility factor K was a potential erodibility index, which was indicated the soil loss quantity of the standard plot, led by the unit rainfall erosivity (Williams et al., 1984). Lots of related researches were studied by foreign researchers. There existed relationship between the soil erodibility factor K and soil texture, soil organic carbon in the EPIC model (Williams et al., 1984). Also, the value of soil erodibility factor K was calculated by the USLE model, which existed 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 because of the higher value of the soil carbon. So the EPIC model was been adopted when calculated the value of the soil erodibility factor K in the study. The function of the soil erodibility factor K was as follows.

$$K = \left\{ 0.2 + 0.3 \exp \left[-0.0256 S_a \left(1 - \frac{S_i}{100} \right) \right] \right\} \times \left(\frac{S_i}{C_1 + S_i} \right)^{0.3} \left[1 - \frac{0.25C}{C + \exp(3.72 - 2.95C)} \right] \times \left[1 - \frac{0.7S_n}{S_n + \exp(-5.51 + 22.9S_n)} \right]$$

Where, $S_n = 1 - S_a / 100$; S_a was the sand content (0.05-2mm), %; S_i was the silt content (0.002-0.05mm), %; S_l was the clay content (<0.002mm), %; C was 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 down sloping landscapes

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

3.2 ^{137}Cs reference inventory

The value of ^{137}Cs reference inventory was the key point of studying soil erosion by using the ^{137}Cs tracing technique. By comparing the value of ^{137}Cs inventory with the ^{137}Cs reference inventory, then the study site was the erosion site or the accumulation site could be judged. Meanwhile, the quantity of erosion or accumulation intensity also could be evaluated. After the investigation of the whole watershed of the study sites, a natural *Pinus massoniana* woodland on the top of the slope land was chosen to be considered as the site of the ^{137}Cs reference inventory. The natural *Pinus massoniana*

woodland existed more than 50 years and less human activities were carried out. So one soil stratified sample and six soil whole depth samples were adopted and analyzed. The ^{137}Cs inventory changed between 1067.98 to 1504.97 Bqm^{-2} of the seven soil samples (Fig. 3). And the average value of the ^{137}Cs reference inventory was 1296.01 Bqm^{-2} , coefficient variation was 13.3%, which was considered as the ^{137}Cs reference inventory of this study sites. Meanwhile, Zhang et al(1999) enhanced that the runoff of the sloping land could bring part of ^{137}Cs . Thus, using the runoff efficiency to revise the regional ^{137}Cs reference inventory. And the function was that:

$$A = A_o \times (1 - R) \times \left(1 - \frac{\Delta H}{H}\right)^{N-1963}$$

Where, R was the runoff efficiency of the sloping land; $A_o \times (1 - R)$ was the revised ^{137}Cs reference inventory.

When considered the runoff of the sloping land, the ^{137}Cs reference inventory of the studied sites was 907.21 Bqm^{-2} . Also the values of the revised ^{137}Cs reference inventory of this study area and in the nearby regions were showed in Fig. 2(He et al., 2007). The revised reference inventory of ^{137}Cs of this study was similar as in Yanting site, as the main reason was that there had similar soil type and climate condition in these two sites.

3.3 Depth distributions of ^{137}Cs of the lynchets in different slope position

^{137}Cs is a useful tracer to evaluate the soil redistribution, which could be rapidly and strongly adsorbed by fine particles in soil surface horizons when it is deposited in the ground (Ritchie and McCarty, 2003). Therefore, the ^{137}Cs spatial distribution on sloping lands usually reflects the net influence of soil redistribution in soil profiles. So ^{137}Cs nuclear tracing technique was used to estimate the rates of soil redistribution on a sloping field with this traditional erosion control measures. The profiles of ^{137}Cs concentration of the lynchets from the upper to the lower of the slope land clearly showed first increased then decreased trends as the slope depth increased (Fig. 4). Less ^{137}Cs was detected below the depth of 30 cm. The highest values of the lynchets of the upper and middle slope position were in the 10-15cm soil depth. Because the 0-5cm and 5-10cm depth soils of the lynchets of the terracing hedgerow were easier to erosion. While the ^{137}Cs concentration of the highest value of the lynchets of the lower slope position was in the 15-20cm soil depth. As the erosion soils was lost and transport along the slope length then accumulated in the lower slope position. Meanwhile, the ^{137}Cs inventory of the upper, middle and lower lynchets of the slope land were 640.86 Bqm^{-2} , 830.15 Bqm^{-2} and 1134.13 Bqm^{-2} , respectively. It reflected the downwards movement of ^{137}Cs . The mean value of ^{137}Cs inventory of the lynchets of the terracing hedgerow on different slope positions closely approximates the lynchets of the middle slope position. Therefore, the mean inventory of the lynchets of middle slope position could be used as a representation of the whole slope length.

3.4 Depth distributions of ^{137}Cs of different slope position alongside the whole sloping landscape

The results of the trends of each slope position profile along the sloping lands were showed in Fig. 4. And the changes of the ^{137}Cs concentration for each slope position profile that may reflect in part the heterogeneity of the initial ^{137}Cs fallout deposition, and also reflect the comprehensive effects of the erosion, transportation and deposition of the precipitation erosion and tillage erosion(Quine et al., 1999). The peak values of the ^{137}Cs concentration in the 0–30 cm soil depth along the whole sloping cultivated land were become deeper in the soil (Fig. 5). As for the top slope, upside lynchets of upper slope position, lowerside lynchets of upper slope position and middle slope position, the peak values of the ^{137}Cs concentration was in the 5-10cm soil depth. While for the upside lynchets of middle slope position, lowerside lynchets of middle slope position, lower slope position and upside lynchets of lower slope position, the peak values of the ^{137}Cs concentration was in the 10-15cm soil depth. The peak value of the ^{137}Cs concentration was in the 15-20cm soil depth as for the study sits of

lowerside lynchets of lower slope position and slope toe. The main reason was that the erosion soil from the upper sloping land moved with the runoff and then accumulated at the lower slope position.

The results showed that the changes of the ^{137}Cs inventory on different slope positions (Fig. 5). The ^{137}Cs inventories range from 509.78 Bqm^{-2} to 1237.43 Bqm^{-2} . And ^{137}Cs inventories increase as slope length increases until the slope toe position. While at the lower slope position and upside lynchets of lower slope position, the ^{137}Cs inventories were partly decreased, as the main reason was that the slope degree in these two slope position was a little steeper than the other sites and where severe water erosion occurred. So the soil erosion in these two slope position were more serious so the ^{137}Cs inventories were less. And the results of ANOVA analysis showed that there existed no significant difference among middle slope position (MS), upside lynchets of middle slope position (ULMS) and lowerside lynchets of middle slope position (LLMS). And there existed obviously significant difference among the rests of the other slope positions ($p < 0.01$).

The downslope changes of ^{137}Cs inventories in the sloping landscapes showed a rolling increased trend (Fig. 6). The values of ^{137}Cs inventories were 836.63 Bqm^{-2} , 808.06 Bqm^{-2} and 835.17 Bqm^{-2} respectively, when compared the upside lynchets of middle slope position (ULMS), middle slope position (MS) and lowerside lynchets of middle slope position (LLMS). The ^{137}Cs inventory of the upside lynchets of middle slope position was higher than that of the middle slope position (MS) due to the fact that this site is close to the lynchets of the middle slope, where the water erosion occurred and that farmers return part of the deposited sediments back to the upside lynchets of middle slope position. And the highest value at the slope toe was caused by the sediment-returning operation from the lynchets of the lower slope position and sediment transported from the upper slope soil erosion both by rainfall and tillage (Zhang, 1996).

The results of the changes of the annual erosion modulus along the whole slope positions were showed in Fig. 7. The highest annual erosion modulus was reached to $4917.06 \text{ tkm}^{-2}\text{a}^{-1}$ at the top slope site while as the soil erosion was decreased with the slope length increased, the annual erosion modulus were synchronous reduced along the slope landscape. These situations become more intricate with spatial variation in the original micro topography. So the steeper slope gradient of the lower slope position and upside lynchets of lower slope position led to a little higher fluctuation. The result reflected that the changes of micro topography play a key role on the spatial soil redistribution of the sloping land. Meanwhile, the minus values indicated that the lowerside lynchets of lower slope position and slope toe were the deposited sites and were the annual deposition modulus. There existed the negative relationship when compared the annual erosion modulus and the ^{137}Cs inventory of along the whole slope positions.

3.5 K values of soil erodibility

Soil erodibility factor (K) was an effective index to indicate the difficulty level of soil erosion capacity. The K values of soil erodibility were decreased from the top slope to the slope toe (Fig. 8). The K values of soil erodibility were changed from $0.0338 \text{ t}\cdot\text{hm}^2\cdot\text{h} (\text{hm}^{-2}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1})$ to $0.0375 \text{ t}\cdot\text{hm}^2\cdot\text{h} (\text{hm}^{-2}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1})$. And as the existed of the lynchets of terracing hedgerow, the erosion soil were transported from the upper sloping land and intercepted by the lynchets of terracing hedgerow and then accumulated in front of the lynchets. When there was heavy or torrential precipitation, the erosion soil could be lost with runoff and even got across the lynchets, then moved further to the downslope.

4. Discussions

4.1 Soil conservation function of the lynchets of terracing hedgerows on sloping landscapes

In terms of long-term agricultural practice, farmers aware that terracing can efficiently prevent soil and water losses in fields, and have developed a variety of terraces by dissecting long slopes into several short segments, such as level, sloping and reverse sloping terraces (Hien et al., 2013). In the remote mountain areas of southwestern China, lynchets of terracing

hedgerow on the sloping lands are the dominant strategy in the farming system. Despite the lynchets of the terracing hedgerow saved on labour and were cost-efficient, as the original geomorphological shape is only slightly transformed with a small amount of construction engineering required (Zhou et al., 2007). Lynchets were effective at intercepting the soil particles and decreasing soil erosion by water until a leveled surface was created (Brogaard and Zhao, 2002). Although the segmented sloping lands, together with the lynchets of terracing hedgerows and the level surface, acts to reduce erosion to a certain extent, except for intense tillage in combination with seriously rainfall runoff. Maybe at that condition, the compound measurements of soil and water conservation needed to be carried out. 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 scoured the soil nutrients along with the erosion soils, causing the soil nutrients loss and non-point pollution (Geng et al., 2010). So the effective soil and water conservation measurements on the sloping lands were needed in the remote mountain regions of southwestern China.

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 becoming thin. Furthermore, higher clay contents are present in slope toe than in the upper slope positions (Heckrath et al., 2005). Meanwhile, removal of fine particles occurs at the slope scale due to water erosion, suggesting that the lower slope position and slope toe were much richer in fine particles (Kosmas et al., 2001; Salvador et al., 2006). The upper parts of the slope segments are characterized by a thin purple soil layer underlain by 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 (Ritchie et al, 1990). Previous studies showed that 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 (Walling and He, 1999). And the depth distribution of the soil particle size fractions from the upper to the lower alongside the whole slope landscapes were showed in Fig. 9. The soil fine particle fractions exhibited a trend of gradual increase in the line of the toposequence in the whole sloping landscape, with a significant linear increased of the < 0.002 mm clay fraction and 0.002mm to 0.02mm 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 the relative lower bulk density than other study sites (Zhao et al., 2012). As the interception function of the existed lynchets of terracing hedgerows, in front of the sites closed to the lynchets of the terracing hedgerow, the fine particle soils were intercepted and accumulated at these places. When compared the upper lynchets and the lower lynchets of the terracing hedgerow, the percentage of fine particles such as less than 0.002mm and 0.002 to 0.02mm particle levels was more in the former than the later sites (Fig. 7). Also in a certain time interval, the farmers would return part of the deposited sediments back to the upside sloping lands of the lynchets of terracing hedgerow. This farming activity could conserve the soil nutrients, also reduced the non-point pollutions from the agriculture (Zhou et al, 2013). This demonstrates that the lynchets of terracing hedgerows acted to effectively limit sloping lands erosion to some extent. Also, soil redistribution by the existed embanks of the terracing hedgerows could result in severe modifications of landforms, surface/subsurface hydrology, and in turn geomorphic processes (De et al., 2004).

4.3 Micro topography impacted ^{137}Cs concentration and inventory

The study sloping land was segmented by the lynchets of terracing hedgerows from top to slope toe, and the slope gradient within each level of the terracing system had changed over the duration of the development of the lynchets of the terracing hedgerows. As the existed lynchets of the terracing hedgerows on different slope position, the fine soil particles were erosion from the upper slope position and transported along with runoff then intercepted by the lynchets of the terracing hedgerows and accumulated in the front of the lynchets (Zhou et al, 2013). Meanwhile, with the combined function of water erosion and tillage, the soil erosion were more seriously from the top to the lower slope position (Lobb, et al, 1999). Also the slope gradient of the micro topography impacted the soil particles redistribution and ^{137}Cs inventory. As the example of the situations such as the lower slope position and upside lynchets of lower slope position, these two study sites become more intricate with spatial variation in the ^{137}Cs inventory. The steeper slope gradient of these two sites led to a little higher fluctuation as 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 seriously soil erosion. The result reflected that the changes of micro topography played a key role on the spatial soil redistribution of the sloping field (Rowan et al., 1993; Ylipietä et al., 2008).

4.4 Relation between K value and ^{137}Cs inventory

The K values of soil erodibility could effectively indicate the difficulty level of soil erosion capacity (Bryan R B.2000). The soil with higher K values of soil erodibility was easier to erosion. The content of soil organic carbon could influence the K value (Zhang et al, 2006). Meanwhile, the estimation of erosion rates from ^{137}Cs measurements is based on the degree of reduction or increase in the measured ^{137}Cs inventory relative to the local reference inventory in this study (Walling and Quine, 1991). The ^{137}Cs inventory at any sampling point was lower than the reference value, which suggests a net ^{137}Cs loss. While the ^{137}Cs inventory at any sampling point was higher than the reference value, which suggests a net ^{137}Cs accumulation. Meanwhile, there also existed logarithmic relation between the K value of soil erodibility and ^{137}Cs inventory and the logarithmic function between the K value of soil erodibility and ^{137}Cs inventory was described as $y = -6950\ln(x) - 22284$ (Fig. 10). And the correlation coefficient was 0.7858. The higher K value of soil erodibility meant the lower ^{137}Cs inventory; also the lower K value of soil erodibility meant the higher ^{137}Cs inventory. It indicated that when the K value of soil erodibility was higher, the soils of the sloping lands were easier to erosion and the soil anti-erodibility capacity was also lower, and vice versa. Also, the K value and ^{137}Cs inventory could be influenced by the climate change, local topography changes and human activities (Su et al., 2012; Li, et al, 2006), which were considered as complex research fields. Even the further and intensive studies were critical needed to carried out in this and similar mountain regions.

5. Conclusions

Part of the fine sediment was deposited in the front of the lynchets of terracing hedgerows, especially the fine particle size sediments (particle size < 0.002mm and 0.002-0.02mm). and the profiles of ^{137}Cs concentration of the lynchets from the upper to the lower of the slope land clearly showed first increased then decreased trends as the slope depth increase, little ^{137}Cs was detected below the depth of 30 cm. Alongside the whole sloping landscapes, the ^{137}Cs inventory generally increases from the upper to the lower edge of the slope toe, whereas the soil erosion were decreased. The mean ^{137}Cs inventory and erosion rate could be represented by the mean value of the middle slope position. The annual erosion modulus was synchronous reduced along the slope landscape. Also the K values were decreased from the top slope to the slope toe. Meanwhile, the relation between the K value of soil erodibility and ^{137}Cs inventory could be described as the logarithmic function. Through the investigation of the spatial patterns of soil erosion of different slope positions with the lynchets of terracing hedgerows of the whole sloping landscape is important for implementing land use management processes to allow sustainable cultivation of the purple soils in the remote mountain regions of southwestern China.

Declarations

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Figures

Figure 1

Location of the study area and diagrammatic sketch of different slope position alongside the whole sloping landscape. Notes: TS- top slope; ULUS- upside lynchets of upper slope position; LLUS- lowerside lynchets of upper slope position; MS- middle slope position; ULMS- upside lynchets of middle slope position; LLMS- lowerside lynchets of middle slope position; LS- lower slope position; ULLS- upside lynchets of lower slope position; LLLS- lowerside lynchets of lower slope position; ST- slope toe.(photo by P. Zhou). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

The characters of distribution of the soil particles fraction down sloping landscapes

Figure 3

Revised reference inventory of ¹³⁷Cs of this study and nearby regions

Figure 4

¹³⁷Cs 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.

Figure 5

^{137}Cs profile from upper to the lower along the whole sloping landscape

Figure 6

the ^{137}Cs inventory along the whole sloping land. Note: the meanings of the capital letters abbreviation were showed in figure 1.

Figure 7

Annual erosion/accumulation modulus on different slope positions. Note: the meanings of the capital letters abbreviation were showed in figure 1.

Figure 8

The K values of soil erodibility of different slope position along the study slope landscape

Figure 9

Depth distribution characters of the soil particle size fractions at different landscape positions.

Figure 10

Correlation between the K value of soil erodibility and ¹³⁷Cs inventory