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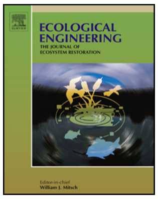

The succession characteristics of soil erosion during different vegetation succession stages in dry-hot river valley of Jinsha River, upper reaches of Yangtze River

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ABSTRACT

Declining vegetation coverage caused by serious soil erosion in dry-hot river valley of the Jinsha River has resulted in a vicious cycle of environmental deterioration and aggravated soil erosion. In order to identify the relationship between vegetation succession and transformation of soil erosion, the methods of "space replacing time" and ^{137}Cs technique have been used to analyze community structure of vegetation and distribution characteristics of ^{137}Cs contents in the slopes and vegetation units of five succession stages, which included native grassland, shrub, sapling forest, half-mature forest and near mature forest in Jiangjiagou gully, Dongchuan city, Yunnan province. We found, during the course of succession, the number of species in communities increased with vegetation development and succession, but the ^{137}Cs loss decreased with vegetation succession. Following the succession, near mature forest had the highest ^{137}Cs inventory and native grassland had the lowest ^{137}Cs inventory in both slopes and vegetation units. Principal component analysis showed that ^{137}Cs inventory was significantly positively correlated with average crown diameter of tree (ACDT), species number, tree coverage and average tree height. Average crown diameter of shrub (ACDS) and average shrub height were also positively related to ^{137}Cs inventory but to a lesser extent. Based on the results of our study, we illustrated the improvement of soil erosion control through soil conservation and water regulation with vegetation succession. Consequently, the results suggest that community features significantly affect soil erosion, through which we can evaluate and predict the soil erosion intensity of different vegetation.

1. Introduction

Soils can sustain mature ecosystems in sustainable and stable equilibrium with their environmental conditions (Rodríguez Rodríguez et al., 2005), but their functions degrade due to soil erosion, which rank as main environmental issues in many lands (Morgan, 1995; Pimentel and Kounang, 1998; Burylo et al., 2012). Soil erosion causes the problem of rivers' sedimentation and increases the possibility of flooding (Bilotta et al., 2007). Furthermore, severe soil erosion results not only in the decline of vegetation productivity, but also in the loss of organic matter of soils, reduction of porosity and aggregate stability that in turn leads to ecological degradation (Rhoton et al., 2002; Dou et al., 2013). Due to this degradation, a decrease in soil quality is caused together with reverse ecological succession (Arbelo et al., 2002; Rodríguez Rodríguez et al., 2002a,b; Cui et al., 2012). Therefore, Erosion control and sediment retention has become one of the 17 major ecosystem services contributing to human welfare and development (Costanza et al., 1997).

Ecological restoration has been carried out in eroded lands induced by soil erosion (Stokes et al., 2010). As a regular measure to protect soils and prevent water erosion, vegetation protects the soil against erosion by physical binding of soil, and the retention of surface water. The relationship between soil and vegetation has become an important scientific issue in the fields of ecology and erosion. In order to study the relationship between soil and vegetation, in recent years, scientists focused in two main research areas: (1) soil quality change in the process of vegetation succession and (2) the effects of vegetation on erosion control and soil stability.

At present, the relationship between soil quality change and vegetation succession has been studied in typical regions. For

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example, Rodríguez Rodríguez et al. (2005) studied vegetation succession and soil degradation in desertified areas (Fuerteventura, Canary Islands, Spain) and found that the vegetation may remain degraded due to the effect of drought, saline–sodic soils and wind. However, plant succession regression only implies changes in soil properties as a consequence of the intensified physical and biological degradation processes, without causing a significant loss of quality in soils that already have poor soil quality. In Changting county of China, after 25 years of monitoring vegetation recovery, the degraded sites with the lowest levels of vegetation cover (a degradation threshold at about 20%) have shifted to a new state that cannot recover naturally to their original conditions even after further human disturbance was prevented (Gao et al., 2011). Hence, successful ecological restoration should require innovative management such as reforestation and artificially adding organic matter to mitigate the constraints imposed by abiotic conditions in the degraded system (McVicar et al., 2010).

Indeed, degraded areas can restore vegetation through human intervention (reforestation) and natural regeneration (spontaneous succession) (Wang et al., 2007). With increased vegetation cover, reforestation can control soil erosion and accelerate vegetation succession by providing an understory environment favorable for native plant recruitment (Parrotta et al., 1997; Parrotta and Knowlesb, 2001; Duncan and Chapman, 2003; Fernandez-Abascal et al., 2003). Then soil erosion intensity decreased with the longer time of reforestation (Wang et al., 2007). However, due to incomplete, uncertain, sparse, empirical and non-formalized ecological knowledge, it is difficult to study and have quantitative analyses on vegetation succession processes and the effects on soil erosion (Salles and Bredeweg, 2006). Thus, studies have mostly focused on the changing characteristics of community structure, species composition and vegetation cover (El-Sheikh, 2005; Degn, 2001; Wen et al., 2005), but little is known about the quantitative interaction between vegetation succession and soil erosion.

The effects of vegetation on erosion control and soil stability have been of great concern in recent years. Burylo et al. (2012) divided the effects into two main categories: active and passive protection. On the one hand, the components of plant can control hydrological and mechanical processes of soil erosion in active protection as follows: (1) Plant canopy reduces surface runoff and erosion rates by intercepting rainfall, and by increasing water infiltration and surface roughness (Styzcen and Morgan, 1995). (2) Plant roots lower pore water pressure, increase soil aggregate stability and provide additional soil cohesion through root reinforcement (Gyssels et al., 2005; Hubble et al., 2013; Graf and Frei, 2013). (3) Thicker litter layer protect soil surface, thus preventing soil detachment, and provided surface roughness that minimized soil particle movement down the slope (Hartanto et al., 2003). (4) Canopy completeness, leaf morphology and plant shape influence sediment retention by plants (Burylo et al., 2012). On the other hand, plant does not prevent erosion from occurring but reduce soil loss at a larger scale by sediments trapping in exclosures (Descheemaeker et al., 2006), upslope of shrubs and trees and micro topographic mounds, which are interpreted as filtering barriers (Bergkamp, 1998; Sanchez and Puigdefábregas, 1994; Bochet et al., 2000).

Despite the well-known relationships between soil and vegetation have been reported, to date, because of the paucity of field studies, changes in soil erosion intensity during vegetation succession are still poorly understood and documented (Walker et al., 2006). The Chinese government has listed Jinsha River as a key area of ecological environmental construction and promoted vegetation restoration (Fu et al., 1997; Luo and Wang, 2006; Li and Zeng, 1999; Yang et al., 2003). However, we still lack a sophisticated understanding of the benefits from soil and water conservation in different succession stages in qualitative analyses but only in overall trend analyses (Cui et al., 2005; Wang et al., 2004a,c).

In this study, our objectives were (1) to quantitatively analyze the dynamics of soil erosion during different succession stages and (2) to identify community features that significantly affect ^{137}Cs concentration. We have carried out monitoring of soil erosion and vegetation recovery in five succession stages in Jiangjiagou gully, on the right bank of Xiaojiang river (a tributary of the downstream of Jinsha River), Southwest China. The methods of "space replacing time" and ^{137}Cs technique were used to analyze the control effect of different succession stages on soil erosion with regard to community structure and species composition of succession stages. Analyses were performed to compare the control ability of different succession stages for evaluating the effects of ecological restoration in that area.

2. Study areas

Our research area is the Jiangjiagou gully located on the right bank of the Xiaojiang River as shown by Fig. 1 (Land use and plots distribution in Jiangjiagou gully in 2006). The Xiaojiang deep fault zone joins its zone branch downstream of the Jiangjiagou gully. Based on topographical mapping and digital elevation model (DEM) in the study area, the highest elevation is 3629 m, about 2227 m higher than the lowest elevation at the junction of Jiangjiagou gully and Xiaojiang River. The length of Jiangjiagou gully's main channel is 13.9 km with an average gradient of 18%, and the average slope gradient of hillside is 43°. Jiangjiagou gully has vertical climate differences as follows: (1) The part with an elevation of 1042–1600 m belongs to dry-hot river valley, is the deposit area with annual precipitation of 600–700 mm year^{-1}, mean annual temperature of 20 °C and mean annual potential evapotranspiration of 3700 mm year^{-1}. (2) The part with an elevation of 1600–2200 m belongs to subtropical and sub-humid warm temperate, is the main source of debris flow materials with annual precipitation of 700–850 mm year^{-1}, mean annual temperature of 13 °C and average annual potential evapotranspiration of about 1700 mm year^{-1}. (3) The part with an elevation of >2200 m belongs to humid warm temperate, is the source of water and moving region of debris flow with annual precipitation of about 1200 mm year^{-1}, mean annual temperature of 7 °C and average annual potential evapotranspiration of about 1350 mm year^{-1}. Moreover, active neotectonic led to cracked rock and severe soil and water loss, suffered by frequent debris flow, the area of over severe intensity soil erosion reached 17.32 km^2, accounting for 35.7% of the total area, leading to heavy economic loss and claiming the lives of many local people. Due to severe intensity soil erosion, 440 debris flows have occurred from 1965 to 2003, which caused Jiangjiagou gully to be considered as a typical debris flow basin.

Due to perennial disasters and deforestation by humans for farmland and firewood, vegetation in most of Jiangjiagou gully was destroyed in the period of 1950–1970, resulting in serious ecological degradation, severe soil erosion, as well as serious destruction of native vegetation. After 1974, reforestation projects including aerial seeding were applied to restore vegetation. At present, the vegetation of Jiangjiagou gully consists of man-made forests and second growth forests, such as *Pinus yunnanensis*, *Pinus armandii* and mixed coniferous and broadleaf forest. Vegetation restoration and protection measures have been launched to improve vegetation cover, especially the protection of second meadow and evergreen shrub under natural conditions in the upper stream of Jiangjiagou gully. However, forest coverage occupied only 11.47% of the total area in 2006. Therefore, typical types of erosion and representative types of vegetation restoration make Jiangjiagou