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Mulching effects on erosion from steep slopes and sediment particle size distributions of gully colluvial deposits

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ABSTRACT

Mulching is an effective soil conservation practice for permanent gullies in southern China. Knowledge of the sediment characteristics that occur in mulched soils of colluvial deposits could improve the utility of mulching for soil conservation. A rainfall simulation experiment was designed to evaluate the effects of mulch on the runoff, erosion, and particle size distribution of eroded sediments. Straw mulch coverage of 0, 25, 50, 75, and 95% was tested with simulated rainfall. The effective particle size distribution of the sediment was compared with the ultimate particle size distribution to investigate the detachment and transport mechanisms involved in sediment mobilization. Mulching delayed the runoff initiation time and reduced the average runoff rate. Compared with bare soil, the increased mulch coverage decreased the soil loss rate by 13.0 to 90.3%. Moreover, the peak sediment concentration decreased from 80 to 200 g L^{-1} under the different mulch coverage conditions. The optimal straw application rate was 1.5 to 3.0 Mg ha^{-1} in the permanent gully's deposits. The relationship between instantaneous kinetic energy of rainfall and the proportion of effective clay- and sand-sized particles was well represented using an exponential equation. The effective clay-sized sediments under the different mulch coverage conditions were 2 to 4 times more common than those of the original soil, although there were only 13.9% sand-sized particles in the sediment when the mulch coverage was 95%. The silt-sized sediment was transported as primary particles under the different mulch coverage conditions. The effective to ultimate ratio of silt-sized particles fluctuated around 1. There were depletions of clay and silt in the colluvial deposit soil with mulch cover, and the enrichment ratios of clay and silt were larger than 1 while most of the enrichment ratios for sand were < 1.

1. Introduction

Southeastern China is speckled with permanent gullies (Xu, 1996), with > 239,100 throughout southern China (Jiang et al., 2014). The topography of a permanent gully is similar to that of the "*lavaka*" in Madagascar (Cox et al., 2010; Voarintsoa et al., 2012) or the "*calanchi*" in central Italy (Moretti and Rodolfi, 2000). The average annual erosion of sediments in these areas exceeds 50 Gg per km^2 (Zhong et al., 2013). These particular types of gullies are generally composed of an upper catchment, a collapsing wall, a colluvial deposit, a scour channel, and an alluvial fan (Fig. 1). Colluvial deposits are the packed materials under the collapsing wall that form the collapsing wall or the original mountain slope surface under hydraulic pressure and gravity (Jiang et al., 2014). Colluvial deposits have high contents of gravel, sand, and loose materials that have a weak structure; low cohesion; poor stability; and high erodibility. After water immersion, colluvial deposits disintegrate rapidly, and the particle sizes become more ideal for transport by water. A large amount of sediment is generated and flows out of the permanent gully through scour channels; colluvial deposits contribute approximately 60–80% of the total soil loss (Gong et al., 2011; Jiang et al., 2014; Lin et al., 2017). To reduce the soil loss from a colluvial deposit, mulching has been determined to be an effective soil conservation practice for permanent gullies. However, the erosion process of a permanent gully's colluvial deposits under mulch cover has rarely been reported. Knowledge of the erosion mechanisms that occur in mulched soils of colluvial deposits is essential if conservation measures are to be properly planned (Lin et al., 2017).

Mulch functions as a permanent or semi-permanent protective cover over the soil surface (Prosdocimi et al., 2016). Vegetative residues, biological geotextiles, gravel, and crushed stones can be used as mulching materials (Robichaud et al., 2013; Xu et al., 2012; Zhao et al., 2015). Mulching can also protect the soil against raindrop impact

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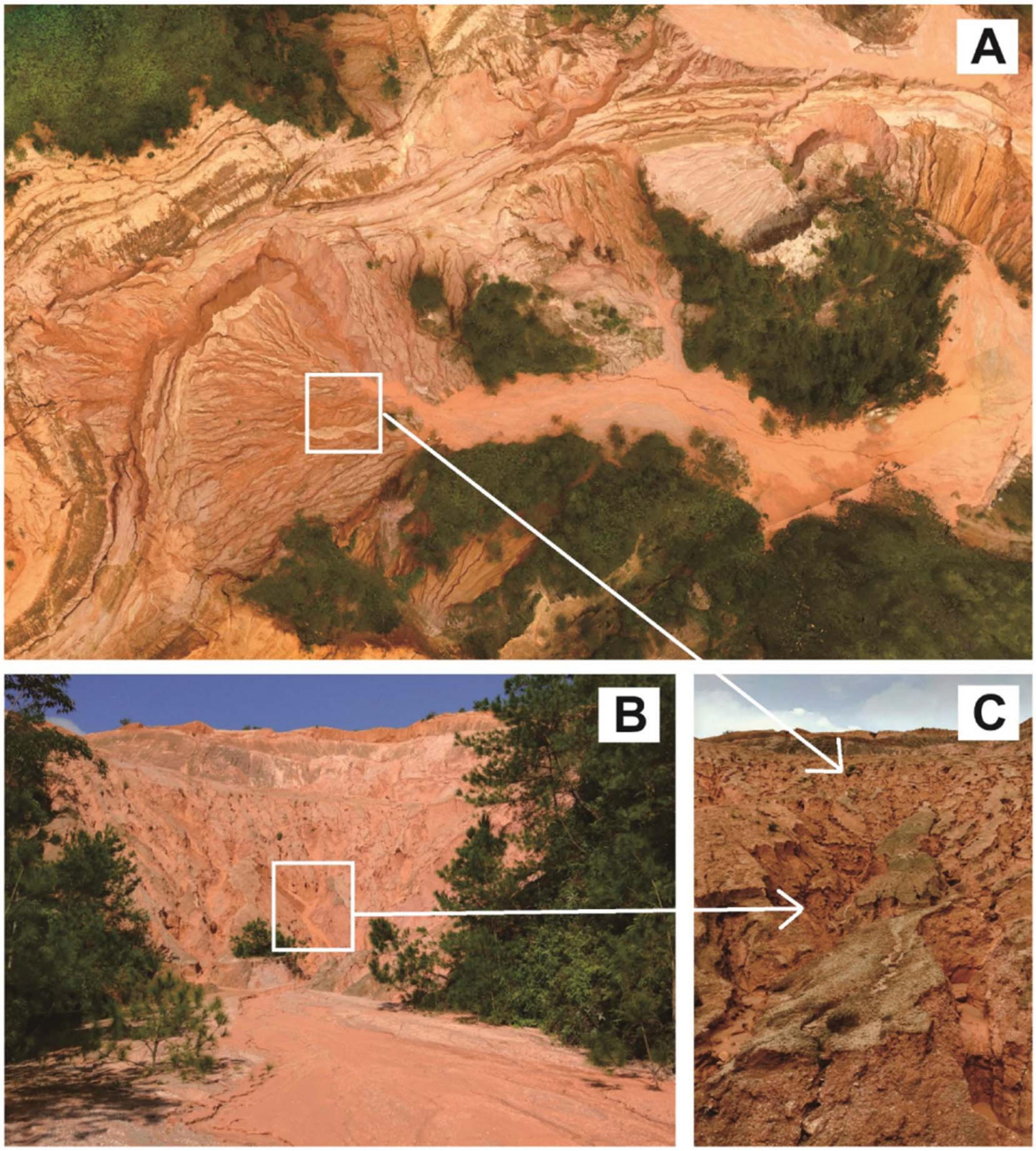

Fig. 1. A typical permanent gully in the study area, locally called "Benggang": (A) aerial photo of a permanent gully in the study area; (B) permanent gully with collapsing wall, colluvial deposit, and alluvial fan; and (C) colluvial deposit.

(Blavet et al., 2009; Sadeghi et al., 2015), reduce both the overland flow rate and velocity by increasing roughness (Jordán et al., 2010), and improve the infiltration capacity (Wang et al., 2015). Among these beneficial mulching effects, the reduction of water and soil loss rates is one of the most significant and remarkable (Groen and Woods, 2008; Liu et al., 2012; Shi et al., 2013). Shi et al. (2013) examined the effect of mulch cover on the particle size distribution of eroded sediment. They found that silt-sized particles were transported mainly as primary particles under different straw mulch applications and that clay was eroded in the form of aggregates. Mulching can cause different size selectivities during erosion, although erosion processes in permanent gullies under various mulch coverage conditions are poorly understood. Therefore, additional information on the relationships between mulching and sediment characteristics (especially the particle size distribution) is needed to better understand the erosion processes.

The particle size distribution of eroded sediment can provide basic information regarding erosion processes (Meyer et al., 1992; Proffitt and Rose, 1991). However, most sediment moves in the form of aggregates rather than as primary particles (Martinez-Mena et al., 2000; Walling and Moorehead, 1989; Zhang et al., 2011); thus, it is crucial to consider the effective particle size of a sediment because this will govern its transport behavior. Cogo et al. (1983) found that there was a decrease in particle size with increasing cover on smooth surfaces, although the effect of cover on particle size was negligible on rough surfaces. Walling and Moorehead (1989) found that the particle size distributions of eroded sediments may differ significantly due to the preferential mobilization of finer particles and the preferential deposition of the coarser fraction during transport. Shi et al. (2017) examined the particle size selectivity of purple soil, showing that most of the mobilized and exported sediment was transported as primary particles. Both effective and ultimate particle size distributions can provide an improved understanding of the size selectivity of erosion and sediment delivery processes. Due to the potential differences between composite and primary particles, information on the effective to ultimate ratio of particle size distribution is important when investigating the dynamics of sediment mobilization and transport (Beuselinck et al., 2000; Shi et al., 2012, 2017).

The erosion of colluvial deposits can affect the redistribution of materials within a permanent gully, and mulching functions as a semi-permanent protective cover over the colluvial deposit. However, the