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Morphology and influencing factors of rills in the steep slope in Yuanmou Dry-Hot Valley (SW China)

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ABSTRACT

It is very important to understand rill morphology in order to understand its dynamics. To reveal the morphology and influencing factors of rills in the steep slope (RSS) in the Yuanmou Dry-Hot Valley, the total station, photogrammetric technique and microtopographic profiler were used to obtain the parameters of the cross sections and longitudinal profiles of the RSS, and 12 parameters were used to characterize the rill morphology. The results show that the morphology of rills clearly varied between each layer; the topography, soil properties and ferruginous cemented layer all exerted important influences on the rill morphology. The average depth decreased with increasing slope length, and the depths dominated by silt and sand were larger than that dominated by clay. The average width and average width/depth ratio increased with increasing slope length, and the width and the width/depth ratio that was dominated by clay was larger than that dominated by silt and sand. The shape ratio of the rill cross section ranged from 0.50 to 0.58, and the shape of the cross-section gradually changed from narrow and deep to wide and shallow with increasing slope length. Concave–convex degree tended to be larger in the segment with ferruginous cement. In the longitudinal profile, the gradient gradually decreased with decreasing slope gradient and increasing slope length. The presence of the ferruginous cemented layer and topsoil crust resulted in abnormal changes in the shape of the rill. It is helpful to further understand the mechanisms of rill erosion under different conditions.

1. Introduction

A rill is a shallow channel that is cut into unprotected soil by the erosive action of hillslope runoff. Due to wide variations in their widths (*W*), the variable of depth (*D*) is always used to classify rills. There are four types of rill dimensions: small (≤15 cm in depth), medium (16–30 cm), large (31–45 cm) and very large (≥46 cm) (Bewket and Sterk, 2003). Generally, the values of *W* and *D* are < 30 cm and 20 cm, respectively (Zheng et al., 1987), but the values of *W* and *D* can extend beyond this normal range when lateral and downward erosion are strong (Shen et al., 2015). Rill erosion is an important type of soil erosion; it is also an important cause of losses in topsoil and nutrients in slope farmlands (Wirtz et al., 2012). Rill erosion accounts for over 70% of the volume of slope erosion (Cai et al., 2004). As splash and sheet erosion turns into rill erosion, the volume and rate of erosion will significantly increase (Auerswald et al., 2009; Dunkerley, 2008; Meyer et al., 1975). Rills that experience the processes of branching, merging and connecting on slopes can form complex morphologies. The rill morphology, in turn, will affect the erosion process (Rao and Kavvas, 1994). Rill morphology connects the past, present and future of gully erosion together and has become a hotspot for studies of hill slope geomorphology in recent years (Auerswald et al., 2009; Torri et al., 2012).

Rills represent the initial form of gully erosion (Berger et al., 2010). Rill morphology can be characterized by geometrical parameters (Kimaro et al., 2008; Stefano and Ferro, 2011) (such as *L* (length), *W* and *D*) and shape indexes (e.g., density, gradient, split degree and complexity) (Berger et al., 2010; Bewket and Sterk, 2003). The average density, depth and width of rills can be used to describe the development of rill erosion. As rainfall duration increases, scouring, lateral and headward erosion occur, which result in the increases of *L*, *W* and *D*. Continued branching and merging will ultimately form a rill network. There is always a power function relationship between the volume and length of a rill (Bruno et al., 2008; Capra et al., 2009; Kinnell, 2000). Rill morphology shows obvious spatial and temporal variability (Bewket and Sterk, 2003; Lei et al., 1998).With the development of a rill network in a loess area, the rill density first increases and then decreases, but the numbers of rill branches and joints basically increase. With increasing slope length, the distribution density and numbers of branches and joints of rills also first increase and then decrease. The

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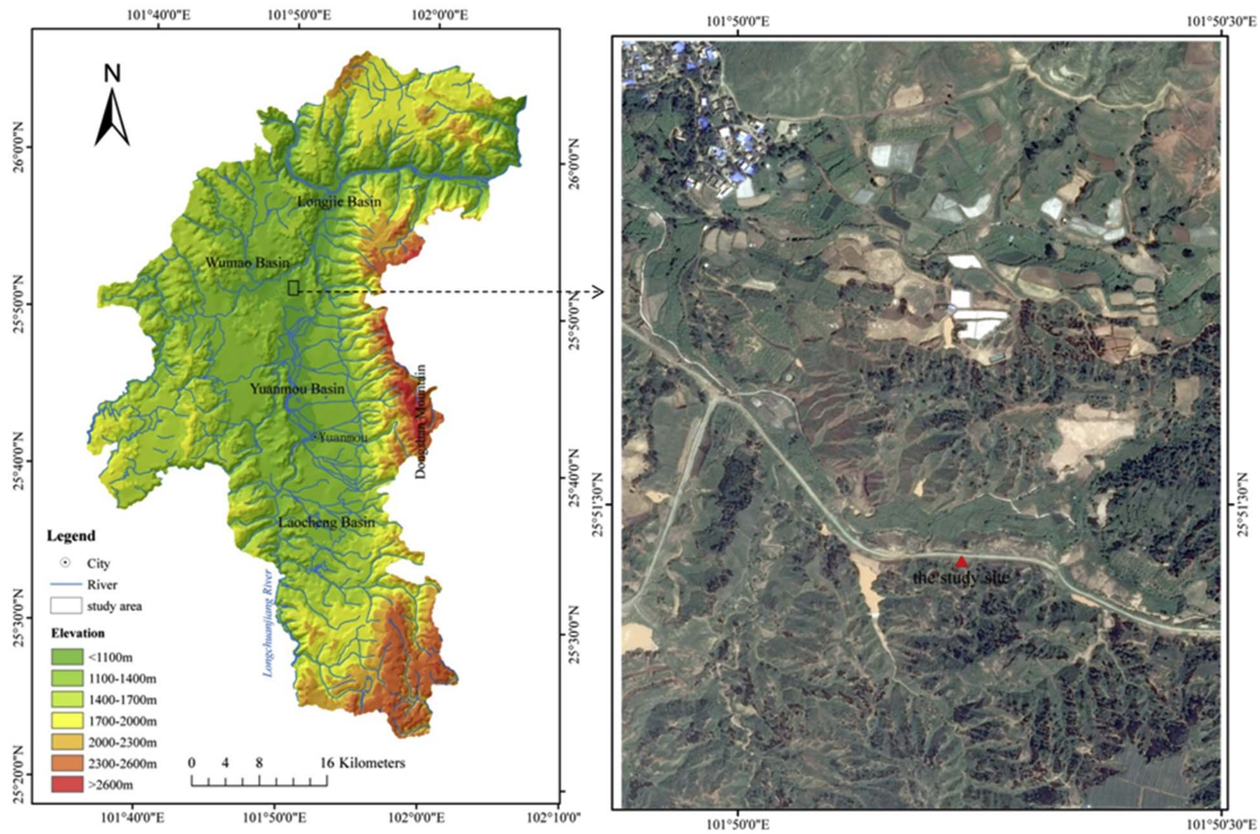

Fig. 1. The study area.

gradient, density, split degree and complexity of rills increase with the development of the rill network (Shen et al., 2016). The shape ratio (η), which is a value between 0 and 1, can be used to characterize the cross-section morphology of rills: the closer this value is to 0.5, the closer the cross-section shape will be to an inverted triangle; the closer this value is to 1, the closer the cross-section tends to be to a rectangle (Zhang and Tang, 2000). In addition, the morphological features of rills can also be described using hydraulics (Gilley et al., 1990; Meyer et al., 1984; Nadal-Romero et al., 2013), the rare earth element (REE) tracer technique (Zhu et al., 2010) and DEM contour deviation statistics (Yan et al., 2011).

The main factors affecting rill morphology include rainfall (Bryan and Rockwell, 1998; Cerdan et al., 2002; Gilley et al., 1990), soil (Deng et al., 2015b; Nord and Esteves, 2010; Rosa et al., 2005) and topography (Deng et al., 2015a; Rieke-Zapp and Nearing, 2005; Shen et al., 2016). Under certain rainfall conditions, the greater the rainfall intensity is, the larger the rill width and depth will be. The contrast between soil erodibility and anti-erodibility depends on the type and properties of soil (Chen, 2013). Different soil types may vary significantly in their soil structure stability, erosion resistibility and soil crust. Lou soil is mainly composed of silt and clay, and its erodibility is higher than that of silt-based loessial soil; furthermore, rills with Lou soil are distributed in parallel, while those in loessial soil are distributed in wide branches (Chen, 2013). The clay content can affect the soil cohesion. Soil with better cohesion has better defenses against raindrop splash and runoff shear (Fox et al., 1998). There is a strong correlation between the clay content and the degree of cracking (Xiong et al., 2013). Seventy-one percent of the change in the CLOE (coefficient of linear expansion) is related to the clay content (Simon et al., 1987). Moreover, the topsoil crust will reduce infiltration (McIntyre, 1958; Tackett and Pearson, 1965) and aggravate the erosion volume (Singer and Le, 1998). The impact of topography on rill morphology is mainly reflected in the slope gradient and length. On a hill slope with a gentle gradient, the rill is wide and shallow; as the gradient increases, the rill becomes narrow and deep (Wang et al., 2015). The law that rill erosion increases with the increasing slope gradient is established within a certain range; when the gradient exceeds that range, the erodibility of a rill will decrease with the increase of the slope gradient (Wu et al., 1997). The impact of slope length on rill morphology is not a single linear relationship, but more often a fluctuating one (Gabriels, 1999). When the gradient increases, the critical slope length for rill triggering will also increase, and there is a quadratic parabolic relationship (with a minimum value) between the slope gradient and slope length.

Although many studies have made great progress in studying rill morphology and its controlling factors, most of them were based on indoor experiments. The soil properties, slope gradient and rainfall conditions in such experiments existed in a human-controlled ideal state. However, the soil and topography in natural environments are more complex. In the Yuanmou Dry-Hot Valley, the bulk excavation due to infrastructure construction (e.g., road construction) and the development of industry and agriculture have produced high-gradient steep slopes, and rills have developed on steep slopes by runoff and caused serious soil erosion. The objectives of this study are: 1) to reveal the morphological characteristics of rill systems in a steep slope (RSS); and 2) to explore the effects of soil properties and topography on their morphology.

2. Materials and methods

2.1. The study area

The Yuanmou Dry-Hot Valley is located in the lower reaches of the Longchuan River. It falls between 25°23′–26°06′ N and 101°35′–102°06′ E and is located 980–1600 m above sea level. The climate is hot and dry due to the foehn effect, with contrasting seasons of rain and drought: the average annual precipitation in the valley is approximately

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