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# Degradation of soil physicochemical quality by ephemeral gully erosion on sloping cropland of the hilly Loess Plateau, China

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ABSTRACT

Ephemeral gully erosion (EGE) is a common type of shallow linear erosion that exerts a major threat to the productivity and sustainability of agricultural systems. The objective of this study was to evaluate the impact of EGE on soil physicochemical properties that determine soil quality. It was hypothesized that sites with EGE exhibit significant changes in soil physiochemical properties compared with sites without EGE. This study used a paired sampling method to compare the soil physiochemical properties of soil at 0–2, 2–5, and 5–10 cm depth of ephemeral gully bottoms to inter-gully areas (CK) in croplands of the hilly Loess Plateau of China. The results showed that EGE posed a threat to soil physicochemical properties and thus the soil quality index was progressively reduced as EGE increased. Reductions in soil quality index were observed as stages of EGE (depth of gully) increased. Three critical EGE stages were defined by $<$10 cm and $\geq$30 cm depths of gully where the soil quality index decreased significantly. Compared with the CK, the 0–2 cm depth of the gully bottom was essentially a net soil deposition layer, especially for the first erosion stage (gully $<$ 10 cm deep). Soil nutrient loss was greatest in the 2–5 cm depth. Soil physical properties were more susceptible and fragile to EGE than soil nutrients. Degradation of soil physical-dominated properties occurred in the first erosion stage, with key factors being erodibility (*K* value), silt content, specific surface area (SSA) and mean weight diameter of aggregates (MWD), whereas soil degradation was mainly caused by losses of soil available nutrients during the subsequent erosion stages. This approach of combining field ground-truth survey with laboratory analysis to study the in-situ impact of ephemeral gully erosion on soil physicochemical properties aids in understanding the features of soil degradation caused by EGE.



## 1. Introduction

Soil erosion has been recognized as the major cause of land degradation and a threat to the sustainability of agricultural ecosystems worldwide. There are three general types of water erosion: sheet erosion, rill erosion and gully erosion (Wischmeier and Smith, 1978). Ephemeral gully erosion (EGE) is a kind of gully erosion whereby a small channel eroded by concentrated flow can be easily filled by normal tillage, only to reform again in the same location by additional runoff events (Laflen et al., 1986). Gully erosion is often the dominant source of sediment transport in cultivated catchments (De Vente et al., 2005; Valentin et al., 2005). Vandaele and Poesen (1995) found that the mean, annual ephemeral gully erosion equaled 70–75% of the mean annual rill erosion. Auzet et al. (1993) found that ephemeral gully erosion during winter equals about 80% of soil loss due to rill erosion.

Previous research on ephemeral gully erosion mainly focused on techniques for monitoring and modeling gully erosion (Poesen et al., 2003; Casalí et al., 2006; Dong et al., 2015), gully retreat rates (Vandekerckhove et al., 2003; Hu et al., 2007), topographic thresholds for gully erosion (Vandaele et al., 1996; Nachtergaele et al., 2001; Poesen et al., 2003; Maugnard et al., 2014), and contribution of gullies to soil loss and sediment yield (Auzet et al., 1993; Vandaele and Poesen, 1995; Li et al., 2003; Taguas et al., 2012). For example, Govers and Poesen (1988) discriminated the contributions of inter rill and rill erosion to total soil loss. Poesen et al. (2003) found that ephemeral gully erosion contributed from 10 to 94% of total field soil loss. Chaplot et al. (2005) quantified the

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spatial and temporal variations of linear erosion at the catchment level and found linear erosion correlating well with the catchment surface area and the mean slope gradient.

EGE usually causes serious soil degradation in arid and semiarid regions, and this kind of soil degradation may be substantially enhanced in response to climate change by increasing intensity and frequency of events (Nachtergaele et al., 2001; Maeda et al., 2010). In slope lands, gully erosion affects soil attributes through: (i) losses of soil nutrients and water storage capacity, (ii) exposure of subsoil material with low fertility and high acidity, and (iii) degradation of soil structural attributes (Smith et al., 2001; Su et al., 2010). Ephemeral gully erosion can decrease soil productivity and interfere with farming operations (Poesen et al., 2003; Liu et al., 2013). Chaplot et al. (2005) reported that linear erosion, including rilling and gullying, irreversibly damages the fertility of cropping systems by the removal of surface soil. Valentin et al. (2005) found a production loss of 37% of the original crop yield induced by gully erosion in a slash and burn system of upland rice in northern Laos. Research from the black soil region of northeast China demonstrated that every 1 cm decrease in soil depth in areas adjacent to ephemeral gullies due to infilling activities resulted in a 2% decrease in yield (Liu et al., 2013). Recent studies have indicated that EGE-induced soil degradation was a gradual process, in which subsurface soil was ploughed up by tillage and mixed with the eroded surface soil year by year. However, the use of cultivars and fertilisers masked the short-term effect of soil erosion (Wang et al., 2009; Su et al., 2010). As a result of several cycles of EGE followed by tillage in-filling, the nutrient-rich topsoil decreases progressively with proximity to the channel. Over the long-term, removal of the topsoil degrades the soil physicochemical properties, thereby creating a nutrient imbalance (Yan and Yue, 2010). For example, Wang et al. (2009) adopted an innovative simulated desurfacing method to evaluate the impact of soil erosion on soil properties, and found that the silt content decreased from 46.5% to 33.6% and thus the nutrient pool reduced to different degrees with erosion depth from 0 cm to 70 cm. However, research on the in-situ effects of ephemeral gully erosion on soil quality is relatively scarce. There has not been a consensus on EGE progression and its subsequent effect on soil quality (i.e., soil properties). The lack of investigations on the impact of EGE on soil quality may exist because, generally speaking, EGE does not affect how the farmer manages the land nor does it lead to sufficient removal or burial of the crop to affect farm profitability in the short term. The in-situ effects of EGE on soil properties, soil quality degradation process and key soil quality factors influenced by EGE are still unclear even with the abundance of research that has been conducted on soil erosion and soil quality.

The Loess Plateau in the northwestern part of China is susceptible to water erosion and the resulting environmental problems occurring for this type of soil are far-reaching (Cai, 2001). The 400–500 mm precipitation belt of the Loess Plateau is characterized by frequent natural disasters of flash floods and landslide/mudflows. More than 70% of the inter gully areas could be impacted by ephemeral gully erosion, which contributed 35–85% of the total soil loss from the slope in the region (Qin et al., 2010; Tang, 2004). The excessive erosion is in response to infrequent intensive rainfalls, steep slopes, and intensively tilled small-scale subsistence farming, combined with the nature of the loess soil (low organic matter content, poor nutrient content and weak soil structure). These factors cause this region to be very prone to ephemeral gully generation, which has selectively deprived the soil of fine particles and posed a threat to soil quality (Su et al., 2010).

The objective of this study was to (1) evaluate the in-situ impact of EGE on soil physicochemical properties in cultivated slope lands of the Loess Plateau, China and (2) link ephemeral gully erosion with soil quality degradation. It was hypothesized that EGE exhibits significant changes in soil physiochemical properties in comparison with inter-gully sites and that the soil quality decreases as EGE depth increases.

## 2. Materials and methods

### 2.1. Study area

The study was conducted within the 400–500 mm rainfall zone of the central Loess Plateau (Fig. 1). This region features low-frequency, high-magnitude rainfall and hilly steep slopes. These factors often cause a large amount of overland flow and high rates of soil erosion in the region. Annually, over 60% of the arable land suffers from various degrees of soil erosion, with rill and EGE as the most common types of erosion on the Loess Plateau (He et al., 2006). The average density of erosion gullies is approximately 0.062 km $ha^{-1}$, with an erosion modulus of 21.8 t $ha^{-1}$ $y^{-1}$ and a sediment load of 1.6 billion tons detected in a headwater catchment of 75.2 million hectare (Zhang et al., 1997; He et al., 2006). As a result, losses of soil organic matter, total nitrogen and total phosphorus could be up to 216 kg $ha^{-1}$ $y^{-1}$, 118 kg $ha^{-1}$ $y^{-1}$ and 255 kg $ha^{-1}$ $y^{-1}$, respectively (Li and Pang, 2008). Therefore, the 400–500 mm precipitation zone of Loess Plateau is an optimal site for studying the relationship between EGE and soil quality.

### 2.2. Field survey and soil sampling

Paired sampling was chosen as the appropriate experimental technique to address differences in soil physical and chemical qualities between ephemeral gully and inter-gully locations (Stavi and Lal, 2011). At each selected site, samples were collected at a single representative gully bottom and a single location adjacent to the gully that was far enough away to be representative of the inter-gully condition. In August 2009, a field ground-truth survey was conducted in which a total of 64 representative soil profiles were identified at 13 sites in the study area (Table 1). The sites selected for sampling were located in different basins but had similar tillage practice (contour tillage), residue management (residue removed), slopes, and fertilization systems. The soil type was loess soil (Entisols in the USDA classification system), which was characterized by silt loams in texture with low organic matter content of $6.15 \pm 2.4$ g $kg^{-1}$ (Xu et al., 2006).

The ephemeral gully (EG) dimensions, such as ephemeral gully width including the top and bottom width and erosion depth (H in Fig. 2), were measured manually using a steel tape to quantify the erosion volume (Prasuhn, 2011). At each site, multiple profiles were selected for sampling (Table 1). For each profile, three bulk soil samples were collected at the gully bottom in depths of 0–2, 2–5, and 5–10 cm (Fig. 2) and combined to form a composite sample for each depth increment. For comparison, composite bulk soil samples were also taken outside the gully at a minimum distance of 10–15 m from the gully edge to represent the inter-gully soil properties. The soil bulk density was also sampled by collecting undisturbed soil cores (stainless steel cylinders with a diameter and a height of 5 cm each) and composite bulk samples in the middle of the 0–10 cm depth increment. Land degradation was determined based upon 17 selected soil physicochemical indicators (Li et al., 2013) that are commonly used to evaluate soil quality (Table 2).

### 2.3. Soil properties measurement and data analysis

The bulk soil samples were taken to the laboratory, and miscellany materials such as roots and small stones were removed.