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Soil profile improvement as a by-product of gully stabilization measures

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ABSTRACT

In this paper, we characterize the long-term effect of reforestation on the stabilization of soils affected by strong gully erosion in Prietrž village in South-Western Slovakia. Permanent gullies there were reforested a century ago with the black locust (*Robinia pseudoacacia*). Reforestation measures induced soil profile development on the gully slopes with distinct humus horizons. Soil-forming processes caused organic matter accumulation, carbonate leaching and a decrease in pH in the surface horizons. One century after reforestation, the key properties of the gully soils closely resemble those of the surrounding agricultural soils. Soil aggregate stability was used as a useful indicator which reflected the impact of reforestation on soil stabilization over the last hundred years. The overall effect of the observed changes is an increase in the aggregate stability of these reforested gully soils. Soil aggregate stability measured by the rainfall simulator method positively correlated with the organic carbon content, and it had negative correlations with carbonate content and soil pH. The values determined for these gully soils do not differ significantly from those in the surrounding non-eroded agricultural soils. The extreme difference in aggregate stability between the topsoils and the parent marl material is responsible for this landscape's susceptibility to severe gully erosion.

1. Introduction

In many landscapes under different climatic conditions and with different land uses, the presence and dynamics of various types of gully erosion can be observed (Poesen et al., 2003). Gully erosion is defined as the erosion process whereby runoff-water accumulates and often recurs in narrow channels, and over short periods it removes the soil to considerable depths from this narrow area. For agricultural land purposes, permanent gullies are often defined as channels which are too deep to easily ameliorate with ordinary farm tillage equipment, and they typically range from 0.5 to as much as 25–30 m in depth (Soil Science Society of America, 2001).

It is recognized that gully erosion can considerably complicate peoples' lives in some landscapes by decreasing the area of utilizable soils and by disrupting transport routes. Although researchers noted the necessity to address these problems and investigate the effectiveness of various soil stabilization measures in degraded landscapes (Burri et al., 2009), there still remains a lack of knowledge of the long-term effect of these various stabilization measures.

The study site investigated in this paper is located in Central Europe, where gully erosion initiation and development was generally caused by land-use pressure and climatic fluctuations (Stankoviansky, 2003a). Land-use pressure is associated with the deforestation which occurred when the region was settled, while the climatic factor is mainly associated with colder and wetter fluctuations during “The Little Ice Age” in Central Europe. Both these factors overlapped in the region between the mid-16th and the mid-19th centuries (Stankoviansky, 2003b).

Reforestation with black locust (*Robinia pseudoacacia*) was performed to stabilize steep walls of gullies in this region between the mid-19th and early 20th centuries. Its strong spreading root system makes black locust a valuable tree for checking soil erosion. Thus, reforestation either stabilized permanent gullies or at least restricted their growth (Stankoviansky, 2003b). Permanent reforested gullies form a characteristic landscape pattern as shown in Fig. 1.

The vegetation cover is often undervalued when concentrated flow erosion is considered. Traditional vegetative techniques to control gully development rely mainly on the effects of the above ground biomass, whereas little attention has been paid to the role of belowground biomass (De Baets et al., 2006). Increased resistance to erosion due to the presence of vegetation has been mainly attributed to the impact of aboveground biomass on the overland energy flow-dissipation caused by increased hydraulic resistance (Poesen et al., 2003). Few studies have investigated the impact of natural vegetation-roots on the resistance of topsoils in the concentrated flow erosion zones (e.g. De Baets et al., 2006; Li, 1995; Sidorchuk and Grigorev, 1998). Pollen (2007) has shown considerable effect of mechanical root-reinforcement on soil stability of streambanks. Root networks also have effect on the hydrologic and hydraulic processes acting on steep streambanks (Pollen-Bankhead and Simon,

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Fig. 1. Satellite view of the region with gullies masked with recent forests.

2010). Overall, the impacts of vegetation and the effects of below-ground biomass on the resistance of topsoils to concentrated flow erosion remain under-researched areas (Poesen et al., 2003).

Some authors consider that soil aggregate stability is the most appropriate indicator in protecting slopes from erosion and shallow mass movements (Barthes and Roose, 2002; Burri et al., 2009; Canton et al., 2009). Many authors consider soil aggregation as a synthetic parameter reflecting soil health, as it depends on chemical, physical and biological factors. In fact, it has been used as a parameter indicative of soil system perturbation, and potential soil erosion since 1940 (Imeson, 1984). Most studies have been carried out on agricultural soils (e.g. Chenu et al., 2000; Degens et al., 1994; Idowu, 2003; Milne and Haynes, 2004), and far fewer on soils on steep slopes affected by erosion (Barthes and Roose, 2002; Canton et al., 2009; Gros et al., 2004; Pohl et al., 2009). According to Shrestha et al. (2007), the knowledge of soil aggregate stability is useful in the evaluation of soil properties with regard to land-use systems. Unfortunately, as soil aggregation depends on many site-specific factors such as geology and climate, the values gained in the case studies cannot be used as a reference for other areas (Burri et al., 2009). Moreover, different methods are used to determine this property and the results obtained with these different methodologies are not comparable since each method uses different energies and/or sources to apply the energy. These include ultrasound, water immersion and sieving and water-drop impacts (Mataix-Solera et al., 2011).

The objective of this study is to determine whether aggregate stability increased with soil and vegetation development on the sloping gully walls. This helped us to evaluate whether the measures against gully erosion, such as reforestation at the end of the 19th century, were effective in the stabilization of gully soils. Therefore our goal was to determine whether changes in soil management over long periods had a significant impact on aggregate stability. Finally, we also analyzed properties of the agricultural and gully soils in this region to understand why this region is so susceptible to gully erosion.

2. Material and methods

2.1. Study area and soil sampling

The study site is located in the Prietrž village in South-Western Slovakia, where an old gully system is located next to the village church which was built in the first half of the 18th century. The gully system is about 450 m long and up to 20 m deep. The mean annual precipitation ranges from 600 to 700 mm in this region, while the mean annual temperature varies between 9 and 10 °C. The hottest month is July which has mean temperatures of 18–19 °C while January is the coldest month, with mean temperatures of −2 to −3 °C.

Following past strong gully erosion, the parent soil material was exposed on the walls of this deep permanent gully system. Before reforestation, the steep parts of the gully walls lacked tree vegetation and the gully walls were therefore extremely labile and subject to erosion. According to Stankoviansky (2003b), the gully walls here were reforested with the black locust (*R. pseudoacacia*) at the end of the 19th century. This was carried out to avoid expected advancing erosion processes. It should be noted that the gully soils developed gradually from marl material which was originally calcareous with a high pH and almost completely lacking in organic carbon.

Two adjacent sites were compared for soil properties and aggregate stability: (i) sloping gully walls with biological stabilization measures through reforestation dating back one century, and (ii) the adjacent agricultural soils unaffected by gully erosion. Samples from different soil horizons have also been compared in order to evaluate how soil properties have changed over time. Gully soils in the C horizon were considered to be the reference point for the initial soil conditions existing before reforestation measures.

Samples were taken of 10 profiles of agricultural soils and 10 profiles of gully soils (Fig. 2). Processes stabilizing soils in the middle and upper parts of the steep walls of gullies were preferred for this sampling and investigation. This choice eliminated the effects of accumulation processes on topsoil development at the foot of the walls and on the gully floors. A total of 50 soil samples were collected from genetic horizons and the various parameters which described changes in stabilized soils on the steep walls were then measured. Here, the changes caused by partial soil-forming processes were especially addressed. These included the soil organic carbon content, the soil pH, carbonate content, soil texture and the aggregate stability.

2.2. Analytical methods

The samples were air-dried and ground to pass through a 2 mm sieve before analysis. The determinations of soil pH, the total organic carbon content and particle size distribution were achieved by the