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Research article

Extensive management of field margins enhances their potential for off-site soil erosion mitigation

Hamada E. Ali [a, b, *], Björn Reineking [a, c, d]

[a] Biogeographical Modelling, Bayreuth Center of Ecology and Environmental Research BayCEER, University of Bayreuth, Universitätsstraße 30, D-95440 Bayreuth, Germany
[b] Botany Department, Faculty of Science, Suez Canal University, 41522 Ismailia, Egypt
[c] Irstea, UR EMGR, 2 rue de la Papeterie-BP 76, F-38402 St-Martin-d'Hères, France
[d] Univ. Grenoble Alpes, F-38402 Grenoble, France

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ABSTRACT

Soil erosion is a widespread problem in agricultural landscapes, particularly in regions with strong rainfall events. Vegetated field margins can mitigate negative impacts of soil erosion off-site by trapping eroded material. Here we analyse how local management affects the trapping capacity of field margins in a monsoon region of South Korea, contrasting intensively and extensively managed field margins on both steep and shallow slopes. Prior to the beginning of monsoon season, we equipped a total of 12 sites representing three replicates for each of four different types of field margins ("intensive managed flat", "intensive managed steep", "extensive managed flat" and "extensive managed steep") with Astroturf mats. The mats ($n = 15$/site) were placed before, within and after the field margin. Sediment was collected after each rain event until the end of the monsoon season.

The effect of management and slope on sediment trapping was analysed using linear mixed effects models, using as response variable either the sediment collected within the field margin or the difference in sediment collected after and before the field margin.

There was no difference in the amount of sediment reaching the different field margin types. In contrast, extensively managed field margins showed a large reduction in collected sediment before and after the field margins. This effect was pronounced in steep field margins, and increased with the size of rainfall events. We conclude that a field margin management promoting a dense vegetation cover is a key to mitigating negative off-site effects of soil erosion in monsoon regions, particularly in field margins with steep slopes.

1. Introduction

Soil erosion is a widespread problem in agricultural landscapes, especially in areas subjected to intensive rainfall events. Soil erosion has been intensifying in recent years (Pimentel et al., 1995), and causes potentially severe reductions in productivity (Eswaran et al., 2001). Due to the summer monsoon, East Asian countries such as South Korea receive large amounts of rainfall during a comparatively short time period, which impacts both the agriculture and economy (Chen et al., 1988). These rains along with human activities cause water erosion that, in addition to production losses, produces severe problems in agricultural landscapes, e.g. sedimentation downstream of fields in flood plains and water bodies, which as a result affects water quality (Van Oost et al., 2007; Xu et al., 2013). Water erosion is responsible for degradation of a total 441 M ha or 59% of the total degraded soil in Asia (Oldeman, 1994).

Preventing and controlling soil erosion can principally be achieved by reducing the erosive impact of rainfall and by maintaining soil infiltration rates, which consequently will prevent surface flow. This can be done using several methods; e.g. within the field via crop rotation and tillage practices (Raclot and Albergel, 2006; Wang et al., 2010); by improving soil stability which will help in soil erosion control in the longer term (Barthès and Roose, 2002), or between fields by using vegetated field margins (Wei et al., 2014; Zheng, 2006).

* Corresponding author. Botany Department, Faculty of Science, Suez Canal University, 41522 Ismailia, Egypt.
E-mail address: helsayedali@gmail.com (H.E. Ali).

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Several studies have shown that field margins can assist in off-site sediment retention by trapping as much as 70–90% of the inflowing sediment, consequently reducing sediment loads to rivers and streams (Duzant et al., 2010). The vegetation of the field margin efficiently removes large heavy particles (Hickey and Doran, 2004). Owens et al. (2007), in their study on field margins in southwest England, found that field margins were effective in trapping the coarse sediment fractions, and that soil type, slope, land-use and management influence the amount of sediment that can be trapped by field margins. Heede (1990), in a study on natural vegetated buffer strips in pine forests in Arizona, showed that the vegetated buffer strips trapped 61 times more sediment than sites where buffer strips were missing.

Two important determinants of how effectively field margins mitigate the negative effects of soil erosion are the characteristics of their vegetation and the slope of the field margin. Vegetation traps sediments and protects soil against erosion mainly by reducing runoff and by increasing the infiltration rate into soil (Fu et al., 2011; Zheng, 2006). Moreover, plants protect soil using their roots, which bind the soil particles via the root excretions (de Baets et al., 2007; Gyssels et al., 2005; Traore et al., 2000), by reducing the raindrops' effect on the soil with their canopy (Durán Zuazo et al., 2008; Gray and Sortir, 1996), acting as a physical barrier to change sediment flow at the soil surface (Lee et al., 2000; Martínez et al., 2006; Van Dijk et al., 1996). The spatial distribution of vegetation along the slope is an important factor for reducing the sediment runoff (Calvo-Cases et al., 2003; Francia Martínez et al., 2006; Lavee et al., 1998). While Abrahams et al. (1996) have shown that the effect of slope steepness on soil loss is complex, erosion is expected to increase as the slope steepens (Fu et al., 2011; Zheng, 2006), as a result of the respective increase in velocity and volume of surface runoff (Ziadat and Taimeh, 2013). The effect of slope is modulated by other factors like soil properties (Singer and Blackard, 1982), surface conditions (Martínez et al., 2006) and vegetation cover (Hancock et al., 2015; Singer and Blackard, 1982). While thus important elements exist for understanding how field margin vegetation structure and slope interact in mitigating erosion effects, there is a knowledge gap on how alternative management of the field margin translates into reduced or enhanced soil erosion effects.

The aim of this paper is therefore to investigate how the local management of field margins affects their potential to mitigate the negative effects of soil erosion in a monsoon area. In particular, we compare the amount of sediment trapped off-site between intensively managed field margins (i.e. by cutting) and extensively managed field margins (no management for at least one year). First, we analyse the effects of the two field margin management intensities, on both shallow and steep slopes, on the sediment differences collected after and before the field margins, which is related to the net uptake or release of sediment of the field margin. Second, we analyse the amount of sediment collected within the different field margins, which will give us a broader picture on the amount of sediment that will be trapped by the different types of the field margins.

2. Material and methods

2.1. Study site

The study was conducted in the Haean-myun catchment in the Kangwon Province located in the northeast of South Korea (128°05′ to 128°11′ E, 38°13′ to 38°20′ N; Fig. 1). Elevation in the study site varies from 500 to 750 m a.s.l. The mean annual air temperature is 10.5 °C; the mean monthly temperature varies between −10 °C in January and 27 °C in August (1999–2013). The average precipitation is 1500 mm, with 70% of the rain falling during the summer monsoon from July to August; with rainfall events >50 mm/day being common (Fig. 2) (Berger et al., 2013). The catchment is part of the watershed of the Soyang Lake, which is the largest reservoir in South Korea (Kim et al., 2000). The Haean-myun catchment is a major agricultural hotspot that substantially affects the trophic state of the reservoir (Park et al., 2010). The total catchment area is 64 km^2 with 58% of the catchment classified as forested mountains and 30% as agricultural areas (22% dryland fields and 8% rice paddy fields), while the remaining 12% are residential areas and semi-natural areas including grassland, field margins, riparian areas, channels, and farm roads (Seo et al., 2014). The topography of the research area is characterized by flat areas and moderately steep slopes in the centre of the catchment and steep slopes at the forest edges. The terrain is highly complex with a variety of different hill slopes and flow directions.

In the Haean-myun catchment, soils are strongly affected by human activities; especially dry fields are modified by the addition of the excavated materials from nearby mountain slopes in order to offset annual erosion losses (Park et al., 2010). Average annual soil erosion rate ranges from 30 to 54 t ha^{-1} yr^{-1} (Arnhold et al., 2014).

2.2. Study design and sediment collection

To test the effect of management ("intensively managed", hereafter "managed" or "extensively managed", hereafter "natural") and slope degree ("steep" or "flat") of the field margin in erosion control, 12 sites were installed in Haean-myun catchment for our four different combinations, which are "managed-flat", "managed-steep", "natural-flat" and "natural-steep" with three replicates for each treatment (Fig. 1). Managed field margins were continuously managed by cutting for the whole season, while the natural ones were left without any type of management. Steep slopes were selected to have approximately a 35° slope, while the flat slopes ranged from 1° to 2°. To reduce potential confounding factors other than management and slope, all sites were selected to be next to radish fields, which are considered to have the highest average annual soil erosion rate within our study catchment (Arnhold et al., 2014), with the same age and field slope degree from 2° to 5°.

To trap the sediment that reached the field margins, Astroturf mats with a size of 34 cm × 25 cm (850 cm^2) (for more details see (Lambert and Walling, 1987; Walling and Owens, 2003)), were installed at three levels: upslope, immediately before the field margin to quantify the sediments that reach it, in the middle of the field margin to quantify the locally trapped sediments, and after the field margin at the downslope edge to quantify the sediments that leave the field margin to the next field or to the stream. In total, 15 mats were installed at each site, with five mats at each level (Fig. 3). Mats were installed in May 2013 and were monitored after each rain event until the end of the monsoon season. Mats containing sediments were collected and transferred to the laboratory, where sediments were dried at room temperature, removed from the mats and weighed.

2.3. Statistical analysis

To quantify the average effect of management type on the amount of collected sediment, we used random effects analysis of variance, with "position within the field margin" (before, within, after) and "management" (intensively vs. extensively managed) as fixed effects; field margin ID was used as random effect variable. Further, we used linear mixed effects models (LME) to analyse three response variables: (1) the sediment amount collected before the field margin, with "rainfall amount" and "field margin type" as well