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Behavior of farmers in regard to erosion by water as reflected by their farming practices

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HIGHLIGHTS

- Observed and predicted erosion of 8100 fields matched, indicating that farmers should be able to recognize erosion.
- Farmers clearly did not consider erosion in their management decisions like field size or selection of crops.
- Only the minimum level to obtain subsidies was applied in case of protection measures.
- Subsidies for erosion control thus require tight supervision.

GRAPHICAL ABSTRACT

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ABSTRACT

The interplay between natural site conditions and farming raises erosion by water above geological background levels. We examined the hypothesis that farmers take erosion into account in their farming decisions and switch to farming practices with lower erosion risk the higher the site-specific hazard becomes. Erosion since the last tillage was observed from aerial orthorectified photographs for 8100 fields belonging to 1879 farmers distributed across Bavaria (South Germany) and it was modeled by the Universal Soil Loss Equation using highly detailed input data (e.g., digital terrain model with 5×5 m^2 resolution, rain data with 1×1 km^2 and 5 min resolution, crop and cropping method from annual field-specific data from incentive schemes). Observed and predicted soil loss correlated closely, demonstrating the accuracy of this method. The close correlation also indicted that the farmers could easily observe the degree of recent erosion on their fields, even without modelling. Farmers clearly did not consider erosion in their decisions. When natural risk increased, e.g. due to steeper slopes, they neither grew crops with lower erosion potential, nor reduced field size, nor used contouring. In addition, they did not compensate for the cultivation of crops with higher erosion potential by using conservation techniques like mulch tillage or contouring, or by reducing field size. Only subsidized measures, like mulch tillage or organic farming, were applied but only at the absolute minimum that was necessary to obtain subsidies. However, this did not achieve the reduction in erosion that would be possible if these measures had been fully applied. We conclude that subsidies may be an appropriate method of reducing erosion but the present weak supervision, which assumes that farmers themselves will take erosion into account and that subsidies are only needed to compensate for any disadvantages caused by erosion-reducing measures, is clearly not justified.
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Abbreviations: DTM, digital terrain model; SLR, soil loss ratio; USLE, universal soil loss equation.

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1. Introduction

Soil erosion is regarded as being one of the largest threats to soil health and fertility. Although soil erosion is a natural process, it is the interplay between human activities, arable soil use in particular, and natural risk that causes soil erosion to exceed natural rates by several orders of magnitude. Innumerable studies exist that quantify soil erosion, compare different cultivation methods or explore the influence of site properties like soil erodibility, rain and topography on erosion (for an overview see Cerdan et al., 2010; Hill and Peart, 1998; Morgan et al., 1998; Renard et al., 1997). We know from these studies how certain human activities or certain site properties influence the extent of erosion. Erosion models like the frequently used Universal Soil Loss Equation USLE (Wischmeier and Smith, 1978) or the European Soil Erosion Model EUROSEM (Morgan et al., 1998) combine this knowledge of individual influences and make quantitative predictions, even for combinations of conditions that are not covered by experiments.

The USLE predicts soil loss as product of six factors, which again are estimated by partly complex routines:

$$A = R \times K \times L \times S \times C \times P \qquad (1)$$

where A is the long-term mean annual soil loss in t ha^{-1} yr^{-1}, R is rain erosivity in N h^{-1} yr^{-1}, K is soil erodibility in t h ha^{-1} N^{-1}; L, S, C, and P are dimensionless factors that quantify the influences of erosive slope length, slope gradient, crop and cultivation method, and long-term erosion control measures. All factors quantify the influence of the individual parameters under otherwise identical conditions.

While we have gathered enormous knowledge about the influence of all individual factors on the amount of soil erosion, either from field experiments or from modelling, this knowledge applies only under otherwise identical conditions. In contrast, we have only limited knowledge about how farmers respond to different site conditions. The purely physical influence of the slope gradient as quantified in the S factor of the USLE may be different from the influence of slope gradient in the real world, where farmers will probably change their farming practices with changing slope gradient. Poor drainage in flat terrain or very steep slopes may impede tillage and thus lead to these areas being used as grassland, which prevents erosion. The applicability of contouring will depend on the slope gradient. The farmer may experience frequent erosion on moderate slopes and arable erosion control measures may thus be adopted more frequently on moderate slopes. Many other socio-economic and legal conditions also affect their decisions. In particular, laws and subsidies or other incentives to control erosion are intended to have an influence. In turn, the real-world relationship between slope gradient and erosion may differ pronouncedly from the relationship that applies under ceteris paribus conditions.

Since the early studies of Napier and co. (e.g. Napier et al., 1984; Napier and Camboni, 1988) on the influence of socio-economic conditions and farmer attitudes towards risks, comparatively little work has been carried out to quantify the effect of this multitude of influences on farmer behavior relevant to erosion. Wauters and Mathijs (2014) identified only 69 relevant studies since 1980. This low number of socio-economic studies is in contrast to the fundamental socio-economic and technological changes that are taking place in farming (Napier, 2011; Souchère et al., 2003). For instance, there is a worldwide trend of increasing tenant and part-farm ownership that might influence farmer knowledge and behavior (Varble et al., 2016). Hence little is known about how farmers' farming practices in respect to erosion change under the influence of site conditions and socio-economic conditions. We expect that farmers will increasingly adopt less erosion-promoting practices the more the site conditions favor erosion. This erosion-sensitive behavior may further be facilitated by governmental actions like restrictions or subsidies that require erosion control, particularly for erosion-prone sites. Thus, we examine the hypothesis that, under real-world conditions, erosion increases less than in controlled experiments when site conditions increasingly promote erosion.

Many socio-economic or behavioral studies rely on farmer interviews, which reflect what the farmers think they do or what they think they should answer. This may not be the same as what they actually do. Recently Fischer et al. (2017) collected a large data set of 8100 fields distributed across Bavaria (Germany) where they compared soil erosion observed from aerial orthorectified photographs with independently predicted soil erosion on the same fields calculated using the USLE, as parameterized by official agencies in Bavaria. They could show that prediction and observation agree well and they found no indication that the predicted soil loss had substantial bias. We will use this dataset for several reasons: (i) Recent soil loss since the last tillage one to three months ago was easily observable in aerial photographs. Hence farmers must be able to see the erosion on these fields, even without modelling, and we can assume that they must be aware of the problem. (ii) The comparison of observed and predicted soil loss excludes speculations about the validity of the predictions. (iii) The use of both prediction and observation enables the scenarios which lead to high or low soil loss to be identified. (iv) The data cover different regions not only with contrasting site conditions but also with different socio-economic conditions.

In principle, farmers can respond to increasing natural erosion risk in three ways: (i) they can decrease their field size and the erosive slope length, (ii) they can adapt their selection of crops, or (iii) they can change the cultivation method or the cropping direction. Awareness of a high natural erosion risk should lead to smaller field sizes, crops with lower erosion potential, or more frequent application of erosion control measures (contouring, mulch tillage) the steeper the slopes or the higher the soil erodibility becomes. Corresponding changes in crop selection and erosion control would then compensate for any increases in field size that may be preferable due to the farm machinery used.

2. Material and methods

In 2011 and 2012 approximately 2500 aerial photos were taken on 15 days in total between May and September after the most prominent erosive events. The study area covered approximately 250 km × 250 km, including parts of the Bavarian Tertiary Hills, the southwest German cuesta, Upper Palatinate and the Bavarian Forest. Each photo captured on average 3.2 fields (either arable crops or semi-natural grassland) with an average size of 2.5 ha. The 8100 fields belonged to 1879 farmers. The photos were orthorectified and each field was assigned to one of four erosion classes (from 0 to 3) in four independent classification rounds. Classification was supported by superimposing contour lines and field borders in ArcGIS (ESRI, 2015). Only recent erosion that had occurred since the last tillage was considered, while soil truncation and other signs of erosion that could not be assigned to a defined period were not taken into account (for details and accuracy of classification see Fischer et al., 2017). The photos covered about half of the erosivity of an average year (see Results and discussion).

The modelling was based on the official erosion cadastre at a resolution of 5 m × 5 m, which is based on a version of the USLE that allows taking field heterogeneities into consideration and that differentiates within fields (Flacke et al., 1990). The factors were derived following the procedures described by Kagerer and Auerswald (1997). In particular, the topographic factors L and S were derived from the digital terrain model with 5 m lateral resolution of the Bavarian Geodetic Survey (Bayerische Vermessungsverwaltung, 2012). Calculation took into account curvature across and along the slope within a field and the change in erosive capacity along the flow path (Flacke et al., 1990). The factor K was derived from a digitized version of a map with sub-field resolution established mainly in the 1940s for land value taxation purposes (Bodenschätzung) following Auerswald (1986), which agrees with the DIN standard 19708 (DIN, 2017). The factor P was calculated according to Auerswald (1992), which under regional conditions is equivalent to

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