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Soil erosion in Mediterranean landscapes – Experimental investigation on crusted surfaces by means of the Portable Wind and Rainfall Simulator

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ABSTRACT

The influence of wind on raindrops and subsequent processes of soil detachment and transport on natural soil surfaces is an essential gap of knowledge. The urgently required data about reactions, interactions and actual impact on soil erosion rates are generally produced under laboratory conditions on highly disturbed substrates, which cannot reflect natural system responses. The Portable Wind and Rainfall Simulator was applied on autochthonous soils in semi-arid Spain to investigate and quantify the relative impact of wind-driven rain on total erosion.

On highly degraded crusted soils and freshly ploughed orchard soils in semi-arid Spain, total erosion measured during experiments (30 min; 96 mm h^{-1}) were 28.8–150.4 g m^{-2} and 29.5–30.7 g m^{-2}, respectively. Concerning the relative impact of wind-driven rain on total erosion, ambiguous results were obtained: the difference to erosion generated by windless rain ranged from +37.4 to −24.2%, to sediment concentration from +46.7 to −20.6% and to runoff coefficients from +18.8 to −7.4%.

The study indicates a potentially very strong impact of wind-driven rain and underlines the paramount importance of experimental data derived on autochthonous soil surfaces for process understanding, realistic assessment of soil erosion rates and application in soil erosion models.

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1. Introduction

The influence of wind on water erosion is an essential gap of knowledge in soil erosion studies (Ravi et al., 2010; Visser et al., 2004), which is particularly true for the specific reactions of natural soil surfaces to the altered physical properties of wind-driven rain (WDR).

In the semi-arid landscapes of southern Spain, the often depleted and degraded soils are notably threatened by erosion due to high-erosive storm events of combined intensive rain and wind. Overexploitation, a substrate prone to erosion, the specific climatic conditions and not the last the European set-aside politic of arable land in recent years have been leading to the generation of large areas of abandoned land. For the typical vegetation on these areas it takes many years to develop a protective and stabilising coverage (Ries, 2005), and often these effects are severely disturbed by grazing and trampling (Monfreda et al., 2009). Due to Mediterranean farming systems, particularly concerning fruit tree orchards, arable land is often left uncovered and harrowed during the rainy periods and are susceptible to interrill erosive processes. On the bare soil surfaces, the wind-driven raindrops can unfold their full erosive power.

Interrill erosion acts as a combination of different processes: drop impact, shallow overland flow (SOF) and/or drop impacted shallow overland flow (IOF) (Kinnell, 2005). Laboratory studies showed, that wind does influence properties of raindrops, SOF and IOF that are essential for the impact on soil erosion: a modification of velocities and trajectories of falling raindrops (De Lima, 1989; Sharon, 1980) and the number of impacting drops per unit area were observed. The velocity of the drops was found to exceed the terminal fall velocity of windless, vertically falling rain (Pedersen and Hasholt, 1995). The higher kinetic energy of wind-accelerated drops provides a stronger impulse for the movement of soil particles, and the oblique impact angle extends the travelling distance of particles on a flat surface (Cornelis et al., 2004). As a result, a considerably higher kinetic energy could be measured in wind-driven rain under laboratory (Disrud and Krauss, 1971; Erpul

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et al., 2005; Umback and Lembke, 1966) as well as natural conditions (Helming, 2001). Furthermore, the erosivity of the (raindrop impacted) overland flow might be considerably increased by acceleration of flow and induction of turbulences via impacting wind-driven raindrops (Erpul et al., 2011; Samray et al., 2011). The erosion-relevant influences of wind on a falling raindrop and SOF accordingly are plural and haven't been comprehensively assessed yet, which is particularly true for the reactions of natural soil surfaces to wind-driven rain and the actual impact on soil erosion rates: In fact, the wind-driven rain-complex has been studied mainly as a problem of the eroding agents' physical properties only, whereas reactions and interactions of natural soil surfaces exposed to wind-driven rain have been neglected.

For investigation of WDR and its effects on soil erosion, the Portable Wind and Rainfall Simulator (PWRS) was developed at Trier University (Fister, 2011; Fister et al., 2011, 2012) and applied on different sites. Iserloh et al. (2013) measured on cohesionless sandy substrate an increased net-WDR-erosion (the difference to erosion due to windless rain experiments) ranging from +113 to +1108% due to WDR during all tests.

The here presented study with the same experimental device and setting shows the influence of WDR on autochthonous soils and investigates reactions of naturally developed soil surfaces to wind-influenced drops, SOF and IOF, which might count for a significant part of both, yet unexplained erosion-rates and variability of soil erosion on a given plot.

Wind erosion experiments are generally not conducted on substrates of that kind because they are not regarded susceptible to wind erosion, although these are the substrates that are significant for agricultural practices in dry regions (Albert et al., 2005; Fister and Ries, 2009). They can be found on marly locations, fluvial terraces and valley fillings, and also alluvial fans and pediments, and are generally nutrient-richer than and of a superior water balance in terms of food production to the sandy substrates on dunes and drifting sands, that often are the preferred areas of investigations (Albert et al., 2005; Fister and Ries, 2009).

We present the first results of experimental investigations with the PWRS on autochthonous soils with different surface structures in semi-arid Spain that may throw light upon the reactions and interactions of natural soil surfaces to WDR and quantify the actual impact on soil erosion rates.

The measurements aimed at 1. experimental quantification of soil erosion due to simulated high erosive rain events, 2. investigation of the relative impact of wind-driven rain on soil erosion and 3. identification of relevant soil surface parameters.

Two types of soil surface structures were tested: strongly crusted fallow land and recently ploughed orchard soil.

2. Material & methods

2.1. Study area

The experiments were accomplished in semi-arid Spain in the easterly foothills of the Betic cordillera (Fig. 1). The basin and range landscape is shaped by the post orogenic formation of the Guadalquivir basin. The Pliocene-Pleistocene pediment-landscape established on Pliocene sediments and consists mainly of marls with partly strong calcerous crusts (Marzolff et al., 2011).

The climatic conditions are semi-arid with high-erosive torrential rainfalls counting for most of the precipitation throughout the year. The average precipitation per year is 200–350 mm. It occurs dominantly in spring and autumn and is characterized by a high inter-annual variability (Schütt, 2001). The study sites are characterised by large areas of abandoned agricultural land in a region of low shrubland features. Even older fallow land is only patchily

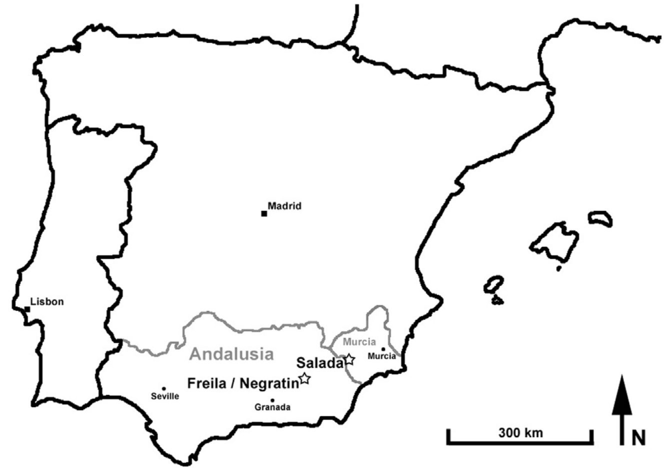

Fig. 1. Study area.

covered by garrigue-vegetation such as *Thymus*, *Genista*, *Rosmarinus*, *Artemisia*, Esparto (*Lygeum spartum*) and Halfagras (*Stipa tenacissima*). The soils are mostly calcaric regosols (Seeger, 2007) and highly degraded: on the silty-loamy soil surfaces, infiltration capacity is severely reduced because of crusts and therefore exceedingly prone to interrill- and rill-erosion (Ries, 2003; Wirtz et al. 2012; Ries et al., in press). Additionally, further degradation by extensive pasturing takes place (Ries et al., in press). The tests were conducted on the sites Freila (FRE), Negratin (NEG) and Salada (SAL). The tested sites feature typical characteristics that are representative for large areas in southeastern Spain.

2.2. Experimental setup

We accomplished the measurements of the effect of WDR on soil erosion with the Portable Wind and Rainfall Simulator (PWRS) (Fig. 2). This device is suitable for wind simulations, rainfall simulations and simulation of rainfall events with the influence of wind. A collector was constructed that is able to catch runoff as well as detached surface material (Fister and Schmidt, 2008).

The analysis of wind and rainfall characteristics showed good results regarding reproducibility of air-stream and rainfall conditions (Fister et al., 2011, 2012). The device is able to simulate the impact of wind on falling raindrops (i.e. acceleration, partly enlargement, oblique impact angle of drops and an increase in number of drops per unit area) when the wind source is applied (Table 1).

2.2.1. Test sequence and procedure of sediment collection

For the assessment of the impact of wind-driven rain on erosion, a defined sequence of tests was developed (Iserloh et al., 2013). During each sequence, erosion experiments with wind, water and wind-driven rain are conducted consecutively. To enable a direct comparison between the amounts of eroded material, all tests within a sequence are carried out on the same plot.

The first test (0) is a wind test run of duration of 10 min that provides information about the susceptibility of the soil surface to wind erosion. This test is followed by a rainfall simulation on dry soil (1) that accounts for susceptibility of soil to an extreme rain event and is also conducted to moisten the soil surface for the next test run to equalise water content of soil surface for comparing wind-driven rain with windless rain. 30 min after this "moistening-run", a rainfall simulation on now moist soil (2) is conducted. The last test run is a simultaneous wind and rainfall simulation (3): additionally to the artificial rain, wind is applied that induces wind-

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