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Effects of low-scale landscape structures on aeolian transport processes on arable land

Nicole Siegmund[a,b,*], Roger Funk[a], Sylvia Koszinsky[a], Daniel Eduardo Buschiazzo[c,d,e], Michael Sommer[a,b]

[a] Leibniz-Centre for Agricultural Landscape Research (ZALF), Research Area 1 "Landscape Functioning", Eberswalder Str. 84, D-15374 Müncheberg, Germany
[b] Institute of Earth and Environmental Science, University of Potsdam, Karl-Liebknecht-Straße 24-25, 14476 Potsdam-Golm, Germany
[c] Faculty of Agronomy, National University of La Pampa (UNLPam), cc 300, 6300 Santa Rosa, Argentina
[d] Institute for Earth and Environmental Sciences of La Pampa (INCITAP), National Council of Scientific and Technical Research (CONICET), cc 300, 6300 Santa Rosa, Argentina
[e] National Institute for Agricultural Technology (INTA), cc 11, 6326 Anguil, Argentina

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ABSTRACT

The landscape of the semiarid Pampa in central Argentina is characterized by late Pleistocene aeolian deposits, covering large plains with sporadic dune structures. Since the current land use changed from extensive livestock production within the Caldenal forest ecosystem to arable land, the wind erosion risk increased distinctly. We measured wind erosion and deposition patterns at the plot scale and investigated the spatial variability of the erosion processes. The wind-induced mass-transport was measured with 18 Modified Wilson and Cooke samplers (MWAC), installed on a 1.44 ha large field in a 20 × 40 m grid. Physical and chemical soil properties from the upper soil as well as a digital elevation model were recorded in a 20 × 20 m grid. In a 5-month measuring campaign data from seven storms with three different wind directions was obtained. Results show very heterogeneous patterns of erosion and deposition for each storm and indicate favoured erosion on windward and deposits on leeward terrain positions. Furthermore, a multiple regression model was build, explaining up to 70% of the spatial variance of erosion by just using four predictors: topsoil thickness, relative elevation, soil organic carbon content and slope direction. Our findings suggest a structure-process-structure complex where the landscape structure determines the effects of recent wind erosion processes which again slowly influence the structure, leading to a gradual increase of soil heterogeneity.

1. Introduction

The land surface of the western parts of La Pampa, Argentina has in large parts been formed by aeolian processes. Intensive winds led to a distribution of sandy and silty aeolian sediment deposits, building the parent material of the soil in the study area (Zarate and Tripaldi, 2012; Zarate, 2003). Today's landscape structure is characterized by large plains with sporadic dune structures. Because of the semiarid climatic conditions, La Pampa is in the transition zone between steppe pasture and rainfed agriculture. In the last decade the share of arable land has increased considerably, accelerated by the good prices for soy beans and corn at the world market. Under cultivation the soils of La Pampa are affected by wind erosion again. Soil losses of 0.9 t ha^{-1} were measured on soils of loess material by Buschiazzo et al. (2007) and 1.8 t ha^{-1} on a sandy soil, which is in the same order of magnitude like annual dust depositions in this region (0.4 to 0.8 t ha^{-1}, Buschiazzo et al., 1999; Ramsperger et al., 1998). Yet, areas of the Pampa with sandy soils show much higher erosion rates which can be seen by fresh dunes, buried fences or roads covered by sand. Extreme events are also documented by satellite images as in March 2009 and January 2010 (NASA Earth Observatory). Michelena and Irurtia (1995) estimated annual potential soil loss rates up to 178 t ha^{-1} t in the Province La Pampa caused by wind erosion, which are in better agreement to the observed soil relocations. Besides those singular strong events, wind erosion has been recognized as a gradual soil degradation process which predominantly removes the finest and most valuable particles of a soil like silt and clay particles as well as the soil organic matter (Funk et al., 2008; Iturri et al., 2017).

While landscape structures resulting from aeolian processes are already quite well understood, the recent wind-soil interactions at the

* Corresponding author at: Leibniz-Centre for Agricultural Landscape Research (ZALF), Research Area 1 "Landscape Functioning", Eberswalder Str. 84, D-15374 Müncheberg, Germany.
E-mail address: siegmund@zalf.de (N. Siegmund).

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local scale have rarely been addressed in scientific investigations so far. Erosion and deposition processes take place at the same locations and are therefore difficult to separate, because diverse factors condition erosion/deposition patterns in landscapes. Local investigations have been limited by the availability of appropriate methods for measuring aeolian sediment transport dynamics (Thomas and Wiggs, 2008; Zobeck et al., 2003). The usage of sediment catchers in large number provides a profound method for quantifying horizontal sediment transport in a high spatial resolution as shown in some studies (Sterk et al., 2012; Sterk and Raats, 1996; Uzun et al., 2016; Zobeck et al., 2003). Many studies investigated wind erosion processes on sand dunes in desert or coastal environments including topographic characteristics (Bauer et al., 2009; Hesp, 2002; Tsoar et al., 2004; Walker and Nickling, 2002). Other studies analyzed wind erosion on plane agricultural plots or only with low elevation change (Buschiazzo et al., 2007; Colazo and Buschiazzo, 2015; Uzun et al., 2016; Zhao et al., 2006) but the number of these studies still remains small (Zobeck et al., 2003; Hoffmann et al., 2008a).

The aim of this study is to investigate the effect of small local landscape structures on the spatial variability of aeolian transport processes. Special emphasis is given to the variability of transport intensity, the dynamic patterns of erosion and deposition areas and theirs relation to the topographical variability on the plot. We will investigate upon the hypothesis that wind events parallel to the topographical structure result in low aeolian transport yet high material net loss and wind events orthogonal to the topographical structure result in high transport and low net loss.

2. Materials and methods

2.1. Study area and experimental Design

The study site is located at 63.9885° W and 36.577° S (165 m asl.) in the north-eastern part of Argentina's province La Pampa (Fig. 1, left).

The site is part of the Anguil Experimental Station of the Instituto Nacional de Tecnología Agropecuarias (INTA) and has been under continuous agricultural management since the 1950s. Aeolian sediments of Holocene origin cover the entire region (INTA, 1980). In the group of 'Chaqueño' vegetation classes the natural vegetation of the study area is classified as 'Pampeana'. This class is characterized by predominant grass steppes altering with semi-open Calden forests, *Prosopis caldenia* (Cabrera, 1976). In the study region the mean annual temperature is 16 °C and the mean annual rainfall is 550 mm, most of it during summer (between December to March) with about 80 mm per month (Aliaga et al., 2016; Casagrande and Vergara, 1996).

The experimental setup was aligned to the dominance of northern and southern winds in La Pampa. The plot was 240 m long, orientated to the main wind directions from N and S, and 60 m wide (Fig. S1). At the field site the small scale topography is hardly noticeable, but can be identified already at the larger scale by areas of lower plant cover on the aerial image of Fig. 1, taken few years ago before our measurements.

The area is dominated by Typic Ustipsamment according to the USDA classification, i.e. weakly developed A-C-profiles from sandy sediments. The mean thickness of Ah horizons is 20 cm; a petrocalcic horizon (Ck, Tosca) is partly present at around 100 cm. For the selected plot a detailed soil survey has been performed by Pürckhauer augerings in a 20 × 20 m raster (Fig. 1, right panel) to determine thicknesses and morphological properties of soil horizons and sediment layers. In this study "topsoil thickness" is defined as the sum of layers with dominating Ah characteristics. Further, 48 samples from the topsoil were taken for physical and chemical analysis. Soil texture was determined for a transect passing the plot and its topographical structure from north to south (Fig. 1, right panel). The location of the transect was chosen in the middle part of the plot, assuming that the variations in carbon content, nitrogen content and pH value are determined by topographical influences.

The equipment for measuring wind erosion was placed on the plot once a wind event of erosive magnitude ($v > 6$ m/s, de Oro and Buschiazzo, 2008) was expected to come. The setup of the erosion measurement was as follows: 24 MWAC samplers on a 20 × 40 m grid and two meteorological stations which measure wind velocity, wind direction, temperature and air humidity in 1 m height were installed at the northern and southern part.

The experimental setup is orientated on the predominance of northern and southern winds, shown in Fig. 2. Especially during the

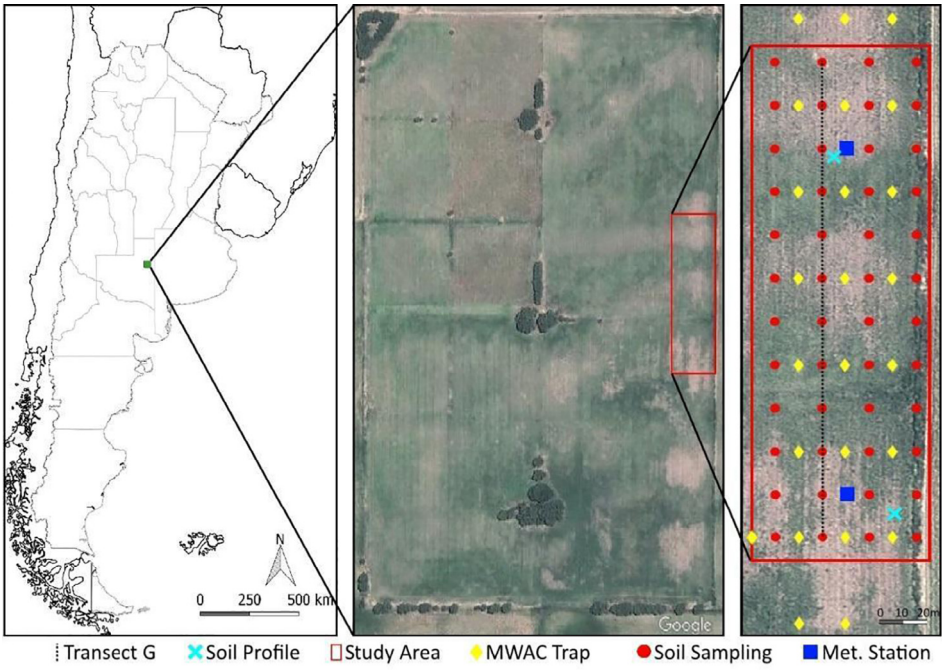

Fig. 1. Left: location of the study area in the central plateau of Argentina, South America. Center: Aerial photography of the study area. Right: experimental setup with the locations of the MWAC samplers, the soil profile pits, the transect G for texture analysis, and the meteorological stations. Source of the aerial photos: © Google Earth (2013).