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Application of a modeling approach to designate soil and soil organic carbon loss to wind erosion on long-term monitoring sites (BDF) in Northern Germany

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ABSTRACT

Soil organic carbon (SOC) loss is a serious problem in maize monoculture areas of Northern Germany. Sites of the soil monitoring network (SMN) "Boden-Dauerbeobachtung" show long-term soil and SOC losses, which cannot be explained by conventional SOC balances nor by other non-Aeolian causes. Using a process-based model, the main objective was to determine whether these losses can be explained by wind erosion.

In the long-term context of 10 years, wind erosion was not measured directly but often observed. A suitable estimation approach linked high-quality soil/farming monitoring data with wind erosion modeling results. The model SWEEP, validated for German sandy soils, was selected using 10-minute wind speed data. Two similar local SMN study sites were compared, however, site A was characterized by high SOC loss and often affected by wind erosion, while the reference site B was not.

At site A soil mass and SOC stock decreased by 49.4 and 2.44 kg m^{-2} from 1999 to 2009. Using SWEEP, a total soil loss of 48.9 kg m^{-2} resulted for 16 erosion events (max. single event 12.6 kg m^{-2}). A share of 78% was transported by suspension with a SOC enrichment ratio (ER) of 2.96 (saltation ER 0.98), comparable to the literature. At the reference site measured and modeled topsoil losses were minimal.

The good agreement between monitoring and modeling results suggested that wind erosion caused significant long-term soil and SOC losses. The approach uses results of prior studies and is applicable to similar well-studied sites without other noteworthy SOC losses.

1. Introduction

1.1. Background and research gap

Soil organic carbon (SOC) loss of arable soils is one of the main impacts of land degradation, triggered by a variety of physical and chemical factors, but finally caused by inappropriate land use (FAO and ITPS, 2015; Lal, 2003, 2014; Louwagie et al., 2009; Verheijen et al., 2009). Wind erosion can be a reason of gradual soil degradation, but the processes themselves are difficult to recognize or measure in the field.

In the flat sandy lowlands of Schleswig-Holstein in Northern Germany wind erosion is also a common process (Hassenpflug, 1998; Duttmann and Bach, 2006; Duttmann et al., 2011). SOC-rich sandy soils were developed on formerly heathland by Plaggen fertilization of livestock residues from stables (Giani et al., 2014; Blume and Leinweber, 2004; Springob et al., 2001; Springob and Kirchmann, 2002), characterized as Plaggic Anthrosols (IUSS, 2006). Used as arable land these sites are highly susceptible to wind erosion (Riksen and de Graaff, 2001). Quantitative and qualitative effects of wind erosion on these soils were investigated sporadically only in a few studies. Direct field measurements of wind erosion are sparsely available for the region (Funk et al., 2004; Goossens and Gross, 2002; Goossens, 2004), even less is known about the amount of SOC loss by wind erosion (Bach, 2008) and

Abbreviations: BDF, Boden-Dauerbeobachtungsfläche (long-term soil monitoring site); DIN, German industry standard (Deutsches Institut für Normung); DWD, German meteorological service (Deutscher Wetterdienst); ER, enrichment ratio; GMD, geometric mean diameter; GSD, geometric standard deviation; LAI, leaf area index; LLUR, state agency; SAI, stem area index; SMN, soil monitoring network; SOC, soil organic carbon; SWEEP, single-event wind erosion evaluation program; TEAM, Texas tech erosion analysis model; WEPS, wind erosion prediction system.

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nothing about the long-term losses over decades. For the latter, the most plausible reasons are the high technical and organizational efforts to measure wind erosion over long periods.

However, some soils exhibit decreased soil mass and SOC stock in the topsoil, i.e. the Ap horizon (LLUR, 2010; Ad-Hoc-AG Boden, 2005). Several authors recommend to consider these changes for estimating erosion losses in combination with modeling approaches (e.g. Post et al., 2001; Kibblewhite et al., 2012; Lal, 2005). Kibblewhite et al. (2012) state that soil erosion reduces topsoil depth, soil mass and SOC in the Ap horizon and suggests the use of long-term soil monitoring data to identify these changes. Even without direct measurements of wind erosion, the long-term monitoring of these soil parameters enables the assessment of the changes over decades (Post et al., 2001). Chappell and Viscarra Rossel (2013) and Chappell and Baldock (2016) describe the importance of soil monitoring, sampling design on the detection of wind erosion and the absence of aeolian SOC losses from management-focused SOC balances. To conclude all these studies; reproducing measured SOC changes with a process-based wind erosion model may help to identify the contribution of wind erosion on SOC losses, which is not included in SOC balances so far. Using this approach, it is necessary to exclude other possible sources of SOC loss. Dust emission by tillage, was considered negligible for typical soil moisture conditions in the periods of wind erosion (Öttl and Funk, 2007; Funk et al., 2008), and water erosion has no relevance in the flat lowlands. A possible thinning effect resulting of an intrusion of subsoil material by tillage can lead to an underestimation of SOC in the topsoil. Therefore, topsoil and tillage depths need to be observed to exclude such causes of detected SOC changes.

To link topsoil measurements with Aeolian losses previous region-specific direct wind erosion measurements and other erosion studies are advantageous to define a range of usual soil and SOC loss. Bach (2008) measured soil and SOC losses by saltation in laboratory wind tunnel experiments investigating sandy top soil material from the same erosion-affected site as reported in this study. Using the TEAM model (Gregory et al., 2004) the author determined a high erodibility of that soil material resulting in a total soil loss of 13.08 kg m^{-2} within four days in March 1969, and a maximum single-event loss of 5.49 kg m^{-2}. Hassenpflug (1998) estimated a total soil loss of 10.0–15.0 kg m^{-2} by aerial photograph analysis for the same erosion events and in the same area. In Northwestern Germany Goossens (2004) found >5 kg soil m^2 eroded at a sandy field (lengths 125–200 m) during an erosion event of 11 h. Studying an alluvial sandy soil in Northeastern Germany Funk et al. (2004) determined surface roughness and measured and simulated up to 10.5 kg m^{-2} of single-event total soil loss blown by erosive west winds. With this study the authors successfully validated the process-based erosion model SWEEP (Hagen et al., 1995) for German sandy soils. Measurements and modeling on a 150 m long field resulted in 35 and 46% of suspension, respectively. It was possible to show, that after setting the initial conditions very carefully, changing soil surface conditions and corresponding soil losses could be modeled by SWEEP with good accuracy. The studies of Bach (2008) and Funk et al. (2004) are the only available comparisons between measured and modeled soil losses by wind erosion in Germany.

To avoid wind erosion, the surface application of cattle slurry is a widely used erosion control method in agricultural areas with high wind erosion risk in Northern Germany (Duttmann et al., 2011; Bach, 2008; Riksen et al., 2003a). Especially liquid cattle manure contains many fibers and adhesive substances forming a stable crust after drying (Riksen et al., 2003b). Heavy rainfall can destroy the protective effect of these crusts. Alternatively, erosion control by surface-applied solid manure or dung (Blanco-Canqui and Lal, 2008; de Rouw and Rajot, 2004b) can be used.

1.2. SOC and wind erosion

Wind erosion is a very effective material sorting and SOC-removing process; as a result, fine particles in the suspension transport can be enriched in organic matter (Zobeck and Fryrear, 1986). This is expressed through enrichment ratios (ERs), the ratio of SOC content in the eroded material to the SOC content in the parent soil (Sterk et al., 1996). ERs for SOC are expected to be ≤ 1 in the saltation layer (<≈30 cm) and ≥ 1 in the suspension layer (>≈30 cm). Bach (2008) derived an ER of 0.98 in the saltation layer by wind tunnel studies using soil material of site A and surroundings.

A comprehensive overview of the importance of SOC enrichment in dust emissions on a continental scale was provided by Chappell et al. (2013). The authors present results from soil sampling and modeling. In the semiarid Canadian prairies Larney et al. (1998) reported ERs for saltation ranging between 1.02 and 1.05 (25 cm height). At semiarid environments in southwest Niger Sterk et al. (1996) found a saltation ER of 1.33 at 5 cm height. Funk et al. (2004) described increasing ER with height, ranging from 0.92 to 1.7 from 5 to 45 cm height at a sandy test site of low SOC stock in Eastern Germany. Similar was observed by Mendez et al. (2011) presenting measured ERs of 0.97 (5 cm height), 1.03 (15 cm), 3.7 (45 cm) and 4.6 (80 cm). Sterk et al. (1996) stated ERs of 2.39 and 3.02 for heights of 26 and 50 cm, respectively. They remarked that those heights include material transported by both, saltation and suspension processes.

Studying the arid region of southern New Mexico Li et al. (2007) found ERs (1.2 m height) between 3.24 without coverage, increasing continuously to 6.33 (75% cover). Ramsperger et al. (1998) measured ERs of SOC of 3–4 for dust samples trapped in 2 and 4 m height, Funk (1995) estimated an ER of 5 for dust sampled in 6 m height. ERs depend as well of the parent material's SOC content. For Australia Webb et al. (2012) reported suspension ERs (2 m height) of 1.67 in grass downs, 3.63 at a sand plain and ~7 at a dune.

Analyzing the SOC losses per area requires greater efforts and is based on flux measurements with a high spatial resolution (Buschiazzo and Funk, 2015) or indirect evidences as radionuclide concentration of ^{137}Cs (Funk et al., 2012). For Australian soils Harper et al. (2010) found average losses of 0.36 and 0.51 kg C m^{-2} eroded by wind, for 1 or 2 years, respectively.

1.3. Soil monitoring

The soil properties affected by environmental impacts, e.g. wind erosion, have been observed on long-term soil monitoring sites ("Boden-Dauerbeobachtungsflächen", BDF sites) in Germany since 1985 (Nerger et al., 2016; Prechtel et al., 2009; Schröder et al., 2004; Barth et al., 2001). A detailed description of the BDF-SH SMN (Boden-Dauerbeobachtung Schleswig-Holstein soil monitoring network) methods and quality was provided in Nerger et al. (2016). The BDF-SH SMN was evaluated as highly suitable to detect long-term changes in soil and in farming management.

The BDF sites are part of larger fields and managed by farmers with contractual obligation to report all realized management actions. The top soil material of the BDF is sampled and analyzed at regular time intervals. These sites offer the unique opportunity to study long-term effects on soil properties, especially the gradual degradation by wind erosion, which is difficult to detect at a site itself through short-term measurements. On an international scale, comprehensive wind erosion monitoring networks which include soil and faming monitoring are still in the build-up phase (Webb et al., 2016). Thus, the already existing soil monitoring networks could be used to study the past impact of wind erosion on the soil.