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Magnetic susceptibility characteristics of surface soils in the Xilingele grassland and their implication for soil redistribution in wind-dominated landscapes: A preliminary study

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ABSTRACT

Wind erosion processes in the typical temperate Xilingele grassland of North China result in significant regional surface soil fine particle and carbon loss. They increasingly restrict local grass industry sustainable production and grassland ecosystem protection. It is challenging to link wind erosion and deposition at landscape scale using classical field monitoring or the expensive fallout environmental radionuclides tracing techniques. The low-cost but efficient magnetic susceptibility (MS) technique has been successfully demonstrated to have great potential to trace soil water erosion processes and patterns at large spatial and temporal scales. However, so far soil wind erosion research using MS technique has not been reported. This study had a trial to determine the variations of soil magnetic susceptibility on relative flat grassland by a grid soil sampling and to establish the relationship between wind erosion parameters and variations of MS in surface soils. 160 grid sampling sites were spaced at an interval of 400 m across a study transect with 12.8 km long and 1.6 km wide. 319 soil samples were collected from the surface soils (0–1 cm and 1–6 cm layers). Grazing intensity of the sampling sites were investigated, and the samples were measured for mass-specific low-frequency magnetic susceptibility (χ_{lf}), absolute frequency-dependent magnetic susceptibility (χ_{fd}), percentage frequency-dependent magnetic susceptibility (χ_{fd}%), soil grain size and organic carbon concentrations. The results showed that the χ_{lf}, χ_{fd} and χ_{fd}% values in surface soils ranged from 30.0 to 97.8 $\times$ 10^{-8} m^3 kg^{-1}, 1.2 to 6.1 $\times$ 10^{-8} m^3 kg^{-1} and from 3.2 to 8.0%, respectively. The variations of soil χ_{lf} values were closely related to grazing intensity, soil grain size and organic carbon concentrations, suggesting that soil erosion processes were very sensitive to soil properties. Moreover, the MS parameters (χ_{lf}, χ_{fd}%) were positively correlated with the soil erosion rates and negatively correlated with the dust deposition rates, indicating that MS parameters could potentially identify the erosion and dust deposition stages of wind dominated erosion processes in semi-arid grassland, respectively. These preliminary experimental results implied that magnetic susceptibility signals in surface soils will hopefully serve as a useful tool in the accuracy assessment of wind dominated erosion and deposition in the temperate grassland regions.

1. Introduction

Wind erosion is a dynamic soil degradation process that comprises the detachment, transport and deposition of soil particles (Skidmore, 1986). Measurement and quantification of wind erosion are difficult at larger scales because they involve complex and dynamic processes that are random and without specific boundaries (Shao, 2000). Conventional methods such as field monitoring (Musick and Gillette, 1990; Hoffmann et al., 2011) and wind tunnel experiments (Burri et al., 2013; Wang et al., 2013) can provide data at the plot scale and for short term, and wind erosion models developed from these data also have the same limitations (Van Pelt et al., 2007). Alternative technologies are needed to determine wind erosion for larger spatial scales (i.e., landscape scale to regional scale) and longer temporal scales (i.e., tens to

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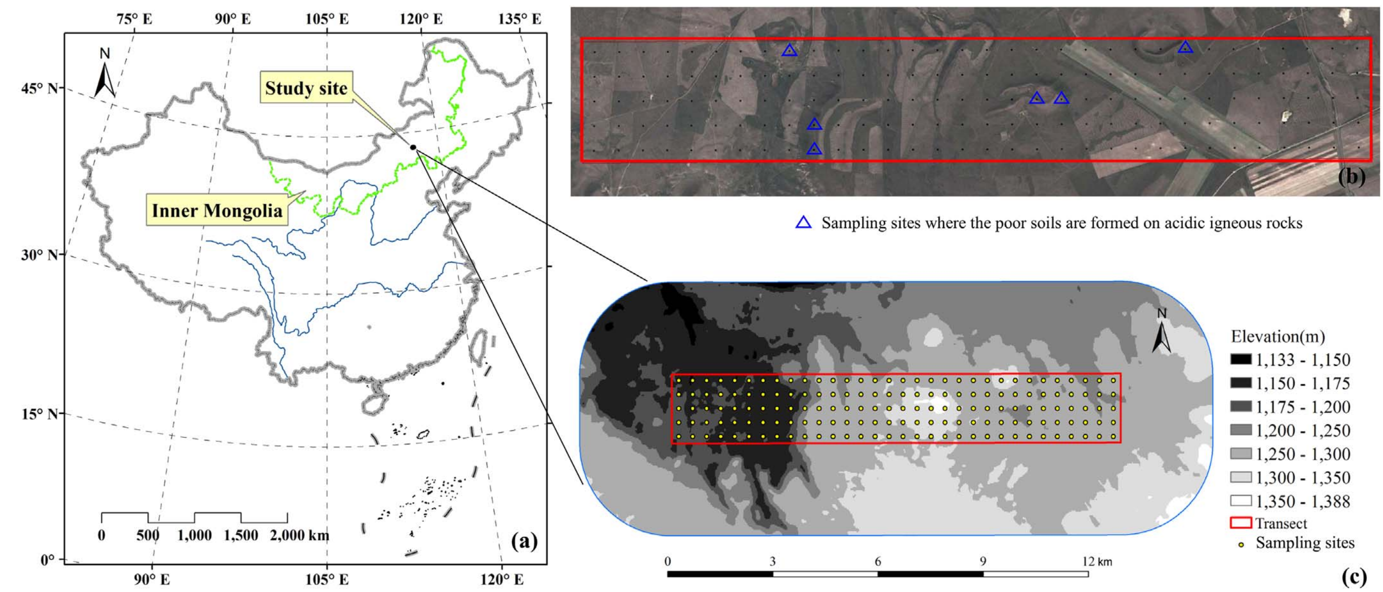

Fig. 1. Map of the study area (a) and sampling sites (b, c) in the study. (b) is a satellite image acquired on September 10, 2012.

hundreds of years) to identify the spatial pattern of soil redistribution induced by wind, which is important for a better understanding of regional dust sources and sink patterns and implementing more rational land management. The use of the tracing technique is an effective means to meet these needs.

Fallout environmental radionuclides (FRNs) have been employed as reliable tracers for soil redistribution induced by water (Zapata et al., 2002; Ritchie and Ritchie, 2007). FRNs recent application in wind erosion studies confirms its feasibility and implied potential in wind erosion research (Yan and Shi, 2004; Van Pelt et al., 2007; Liu et al., 2008; Funk et al., 2012; Yang et al., 2013), although there are some limitations in this field such as the challenge to find appropriate reference sites (Chappell, 1999). The FRN technique has been considered a cost-effective method (Ritchie and McHenry, 1990); however, it still requires high costs in terms of both equipment and measuring time (Liu et al., 2016). Another restriction of using FRNs in evaluating soil redistribution is their fixed and limited time spans. For example, the use of ^{137}Cs has been limited to evaluation of soil erosion and deposition since the 1960s.

Soil magnetic susceptibility (MS) can also serve as a tracing tool for soil redistribution and it is a commonly used magnetic property that is measured easily and economically (Jordanova, 2017). MS does not require time spans that are as specific as those associated with FRNs, and it can be notably flexible in its interpretation. In general, natural soil magnetism originates from soil forming process, which is mainly influenced by regional hydrothermal environment. On the basis of the same soil parent material, the stronger the pedogenesis is, the stronger the soil magnetism is. This is a long-term process lasting hundreds of or thousands of years at least (Jordanova, 2017). Additionally, enhancement of MS in natural surface soils worldwide is a common phenomenon (Mullins, 1977; Thompson and Oldfield, 1986). By comparison, short-term accelerated erosion events can induce the redistribution of MS profiles in original natural surface soils. This new features of MS profiles are usually connected with soil redistribution process. Therefore, the MS variation between topsoil and subsoil can be used to quickly infer a link with water erosion and deposition on a hillslope (Sadiki et al., 2009; Jordanova et al., 2014; Liu et al., 2015). Considerable effort has been devoted in evaluating the performance of MS in tracing soil redistribution since its initial application. So far, MS has been proven to be an effective and efficient tracing property in soils in different regions, such as Eastern Rif, Morocco (Sadiki et al., 2009), hilly regions in Iran (Mokhtari Karchegani et al., 2011; Ayoubi et al., 2012a), Northeast Bulgaria (Jordanova et al., 2014) and Northeast China (Liu et al., 2015). However, the MS technique has only been employed for soil redistribution induced by water and its application in assessing wind dominated erosion has not been reported. This process is similar to the development of a process in which FRNs are initially used to trace the soil redistribution associated with water erosion and then to trace the soil redistribution associated with wind erosion. To our knowledge, as a natural property of soil, the use of MS should be feasible in tracing wind erosion as well as water erosion, and it needs to be tested and verified.

Major wind erosion studies focus on croplands and desert regions. In the last two decades, there has been increased attention regarding temperate grasslands, which have better vegetation cover than deserts and are located in the mid-latitude regions with continental climate (Archibold, 1995) because they are sensitive and vulnerable to wind erosion induced by climate change and anthropogenic influences such as overgrazing (Shinoda et al., 2011; Wang et al., 2015). The Xilingele grassland is a typical temperate grassland that is severely impacted by wind dominated erosion. It has changed from a best-preserved grassland to one of the seven most severe wind erosion districts in North China (Han et al., 2008). The physical and chemical properties of soil have been considerably influenced by soil erosion in this area (Kölbl et al., 2011). Wind erosion at landscape scale is hindering sustainable ecology and agricultural development in the Xilingele grassland.

The objectives of this study were preliminarily to (i) investigate the spatial distribution and variations of MS in the surface soils at the landscape scale, (ii) understand the links between MS and soil redistribution dominated by wind erosion; and (iii) further assess the feasibility of MS technique to study wind erosion to complement our present research methods.

2. Materials and methods

2.1. Description of the study site

The study area is a semi-arid grassland transect 12.8 km long and 1.6 km wide (Fig. 1c), located in the southern part of the Xilin River Catchment, 70 km southeast of the district capital city, Xilinhot, Inner Mongolia (Fig. 1a). Its terrain is typically undulating, with an elevation ranging from 1150 to 1350 m above sea level (Fig. 1c). The area is dominated by a mid-latitude continental semi-arid climate that features dry and cold winters and warm summers, with an average annual