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Identifying soil redistribution patterns by magnetic susceptibility on the black soil farmland in Northeast China

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ABSTRACT

Erosion processes in the black soil region of Northeast China result in significant regional soil redistribution and crop production heterogeneity along slopes. It is difficult to link soil erosion and redistribution on a long-term scale using classical field plot monitoring or the costly ^{137}Cs technique; however, magnetic susceptibility measurements can provide an economical tool to quantify soil redistribution over a large area and over a long duration. This study attempts to determine the variations of soil magnetic susceptibility on sloped farmland using soil sampling and to establish the relationship between patterns of soil redistribution and variations of magnetic susceptibility at different locations on a slope. Soil cores were collected along two typical transects on a cultivated slope and a reforested slope, respectively. The cores were 100 cm deep and were spaced at an interval of 10 cm; the samples were measured for mass-specific low-frequency magnetic susceptibility (χ_{lf}) and frequency-dependent magnetic susceptibility (χ_{fd}). The results showed that the χ_{lf} profiles at different slope positions on uncultivated reforested land were relatively homogeneous, revealing a similar pedogenic process across the entire slope. However, the χ_{lf} profiles at different slope positions on cultivated land were significantly different, exhibiting signs of a soil erosion and deposition process. Maximum soil loss (15.8%) occurred at the shoulder segment, and maximum soil deposition (25.1%) was observed at the footslope. However, at least 10.6% of the topsoil had been eroded and lost due to cultivation over the past 60 years in the study area. The results imply that magnetic susceptibility can be used to determine soil redistribution.

1. Introduction

Covered by black soil with high organic matter content, Northeast China is a primary and important food production area in China. However, land degradation caused by soil erosion is now a serious threat (Fang et al., 2012; H.H. Liu et al., 2013; Zhang et al., 2007) to crop production in this region. Compared with other regions of China, significantly eroded topsoil is transported downslope and deposited at the toe of slopes rather than being removed to rivers. This soil redistribution has been identified as the leading influence of erosion on crop production, and as a result, many studies have been performed to understand this phenomenon. However, few studies have focused on the relationship between erosion and soil redistribution. Fang et al. (2012) attempted to identify soil redistribution at the watershed scale in Northeast China using ^{137}Cs technique; however, it is difficult to link soil erosion and soil redistribution that occurred during the earlier cultivation history (over 50 years) using field plot monitoring or the costly ^{137}Cs technique in this region. However, over the past 30 years there has been a more concern in the use of magnetic measurements, which can be successfully used to quantify soil redistribution over a large area and for long durations (de Jong et al., 1998; Dearing et al., 1985, 1986; Olson et al., 2002).

Magnetic susceptibility is one of the most easily and commonly measured magnetic parameters of soils (Evans and Heller, 2003; Thompson and Oldfield, 1986). Enhancement of magnetic susceptibility of topsoils across the world has been widely reported (Evans and Heller, 2003; Le Borgne, 1955; Mullins, 1977), which thus be used to quickly identify differences between topsoil and subsoil and is available to trace the long term processes of soil erosion and deposition on hillslopes (de Jong et al., 1998; Dearing et al., 1985, 1986).

Le Borgne (1955) first applied magnetic techniques to soils and discovered the enhancement of magnetic susceptibility in topsoils. Mullins (1977) comprehensively summarized the mechanisms of this enhancement. Dearing et al. (1985) initially applied the approaches of soil magnetism to study soil redistribution. de Jong et al. (1998) reported that magnetic susceptibility in most topsoils in the upper and middle portions of a slope is higher than that of subsoils in the Canadian Prairies. de Jong et al. (2000) noted that magnetic susceptibility enhancement of the A horizon in comparison to the B and C horizons is observed only in the upper and middle regions of slopes in native grasslands in the black soil zone near Lanigan, Canada. In Illinois, US, Hussain et al. (1998) reported that magnetic susceptibility decreases regularly with depth at all sites and is higher on uncultivated land than on cultivated

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land for all slope positions except at the lower footslope. Similar results were found by Olson et al. (2002) in a Moscow suburb in Russia; magnetic susceptibility values in reforested soils are higher than in cultivated lands for all landscape positions. Sadiki et al. (2009) also found that χ_{lf} values of soil profiles in cultivated land are significantly lower than those of uncultivated land in the Eastern Rif, Morocco. Gennadiev et al. (2002) showed that this magnetic method can quantitatively estimate the intensity of erosion and deposition processes. Studies conducted by Mokhtari Karchegani et al. (2011), Ayoubi et al. (2012) and Rahimi et al. (2013) in a hilly region in western Iran showed that slope position significantly influenced the variation of magnetic susceptibility on a slope due to variations in soil redistribution across the slope. Jordanova et al. (2014) used magnetic susceptibility to estimate patterns of cumulative soil erosion in Northeast Bulgaria.

Compared with environmental radionuclide techniques, magnetic measurements are cheap, simple, rapid and non-destructive. And previous studies have proved that the magnetic technique is promising for assessing soil redistribution in many landscapes and regions in the world. However, the further understanding of soil magnetic techniques to trace soil erosion and deposition process is needed for the evaluation of the applicability of this new tracer technique.

The objective of this study is to investigate and determine the variations of soil magnetic susceptibility along the slopes in different land use and to prove that magnetic susceptibility can be used to identify soil redistribution on black soil farmland slopes, a regional landscape icon, in the northeastern China.

2. Materials and methods

2.1. Study site

The study site is located in the black soil region of Nenjiang County, Heilongjiang province, China (Fig. 1). The elevation of the area is 260–360 m above sea level. The undulating topography of the study area is dominated by gentle, long slopes, which range from 2% to 14%, with an average of 6%. The lengths of most slopes are between 500 and 4000 m (Zhang et al., 2007). The climate is semi-humid with a mean annual temperature of 0 °C, and the lowest and highest temperatures are −20 °C in January and 20 °C in July, respectively. The annual precipitation ranges from 300 to 750 mm with an average of 534 mm, and more than 90% precipitation falls between May and September (H.H. Liu et al., 2013).

The primary soil type in this area is black soil (Table 1), according to the Chinese genetic classification of soil, which is classified as Udic Isohumisols in the Chinese Soil Taxonomy, and Udic Argiboroll in the US Soil Taxonomy, or Luvic Phaeozem in the FAO/UNESCO Soil Taxonomy (Gong et al., 1999). At present, the average depth of black topsoil is less than 30 cm due to serious soil erosion in the area; the parent materials are primarily lacustrine and fluvial sand beds, which were formed during the Quaternary period (Sun and Liu, 2001).

The study site was originally covered by natural forests and pastures and began to be converted into cultivated lands particularly on the gentlest slopes due to the needs of dramatically increasing populations and expropriation by ranches in the 1950s. Then some cultivated lands were replanted with trees due to barren topsoils. Intensive use of farm machinery and deepening of plowing have accelerated soil erosion (Fang et al., 2012; H.H. Liu et al., 2013; Zhang et al., 2007).

At present, cultivated land and reforested land are the primary land use types in the region. In this study, the selected reforested land was covered with *Pinus sylvestris* planted in the 1960s, while the selected cultivated land was cropped since the 1950s.

2.2. Field sampling

Two slope transects were selected in a region of typical reforested land and in a region of cultivated land, respectively (Table 2). In the

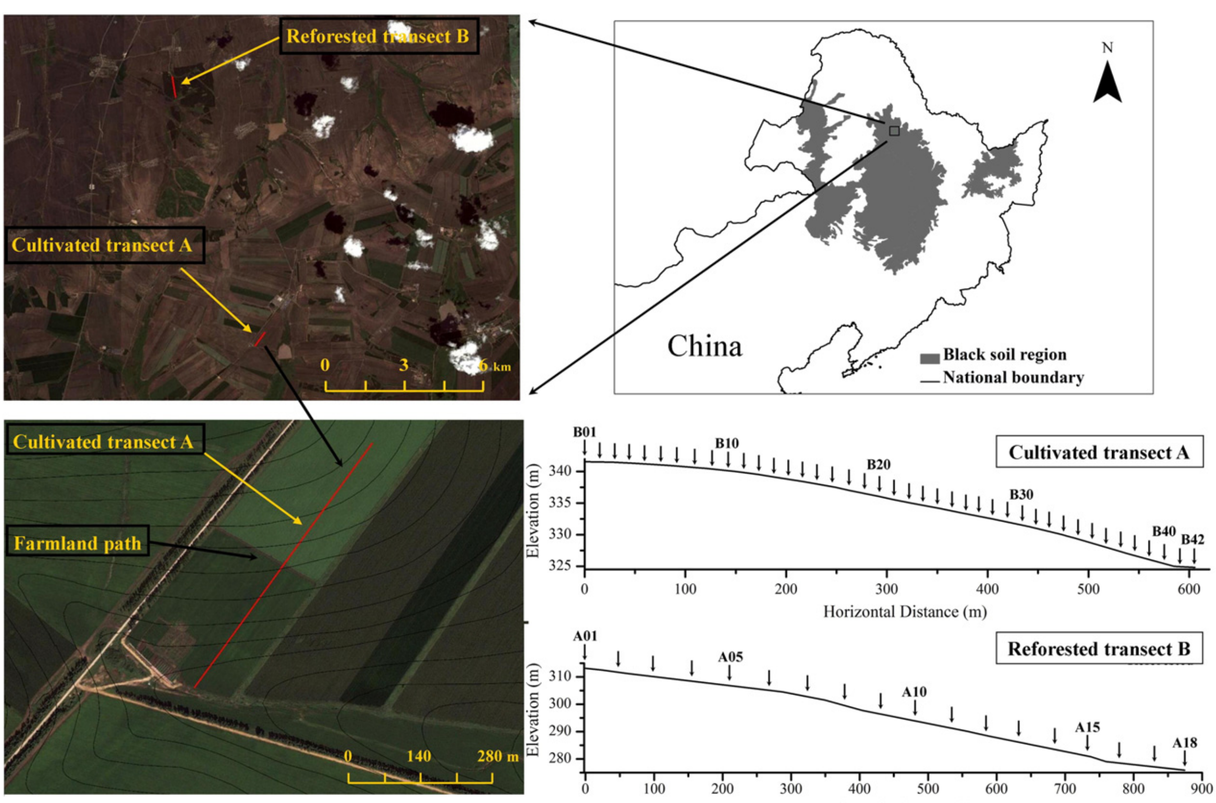

Fig. 1. Location of the study site and sampling maps along the two transects in the reforested and cultivated areas. Image source: Google Earth. (Software used: ArcGIS, Microsoft Paint and Microsoft Office Picture Manager).