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Evaluation of the influence of cultivation period on soil redistribution in northeastern China using magnetic susceptibility

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ABSTRACT

Magnetic susceptibility has been shown to be a reliable, economic and rapid method for tracking soil redistribution; however, more case studies are necessary to verify the link between soil movement and magnetic susceptibility. In this study, we sought to evaluate soil redistribution in northeastern China using magnetic susceptibility on the basis of data collected from croplands with different cultivation periods. The results showed that the magnetic susceptibility values, whether low-frequency magnetic susceptibility (χ_{lf}) or frequency-dependent magnetic susceptibility (χ_{fd}), were markedly different between forestland and cropland, with larger differences for longer cultivation periods. The magnetic susceptibility increased dramatically in topsoils on forest slope, whereas the difference in magnetic susceptibility between topsoils and subsoils decreased in cropland as the cultivation period increased. The magnetic susceptibility values varied significantly across sites on a given slope, increasing gradually from the upperslope to the lowerslope, regardless of whether the slope was forestland or cropland. Longer cultivation periods resulted in larger differences between the upperslopes and lowerslopes which were particularly notable when the cultivation period was longer than 50 years. For middleslopes and lowerslopes, the soil loss of an 110-year cultivated slope was approximately two times higher than that of a 30-year cultivated slope. These findings suggest that the use of magnetic susceptibility is feasible for tracking soil redistribution and soil loss.

1. Introduction

Soil erosion is a global environmental issue that involves the removal of fertile topsoils, resulting in a reduction in the land productivity and an increase in the sediment load of rivers (Zhang et al., 2004). To control soil loss, data collected from field plots are necessary to thoroughly understand the erosion processes and to establish a soil loss prediction model. However, data collection is cumbersome and time-consuming for plot maintenance using conventional methods, such as field plot or rainfall simulations. As a milestone in soil loss research methods, radioactive fallout tracer techniques have been successfully applied in soil erosion research during the past few decades as a way to more effectively collect research data (de Jong et al., 1986; Ritchie and McHenry, 2009; Gharibreza et al., 2013; Zhang et al., 2009; Zhang, 2015). Nevertheless, in practice, the radioactive fallout tracer method is limited by the cost of the equipment, such as gamma spectrometers, and by time-consuming sample determinations. For these reasons, it is imperative to find a new method of data collection for erosion research, especially at the large scale. Fortunately, the technique of magnetic susceptibility (MS) offers a potential alternative for scientists who wish to evaluate soil loss.

Compared with conventional approaches, MS is a reliable, economical and rapid method for measuring soil magnetic indexes (Evans and Heller, 2003; Thompson and Oldfield, 1986; Lecoanet et al., 1999). MS values are generally enhanced in topsoil, owing to the formation of secondary ferrimagnetic minerals (Dearing et al., 1986; Evans and Heller, 2003; Le Borgne, 1955; Mullins, 1977). In 1985, Dearing et al. (1985) were the first to apply soil magnetism to evaluate soil redistribution, beginning a new chapter in soil magnetic research. Later, de Jong et al. (1998) measured magnetic susceptibility in long-term cultivated fields and concluded that magnetic susceptibility is feasible for estimating soil erosion and deposition based on variable values in the profiles of different slope positions. Olson et al. (2002) estimated erosion patterns using magnetic susceptibility on cultivated

Abbreviations: MS, magnetic susceptibility; SD, standard deviation; CV, coefficient of variation; R, reduction rate

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and reforested hill slopes and found that reforested slopes invariably had higher MS values in all positions. Gennadiev et al. (2002) considered the magnetic susceptibility method to be suitable for quantitatively estimating the intensity of erosion and deposition processes. Artificial magnetic material has also been used to trace soil redistribution. Ventura et al. (2001) studied spatial variation in soil redistribution in field plots using an artificial tracer. A study group depicted soil redistribution on slopes using fly ash (Hussain et al., 1998; Olson et al., 2004). Then, Jones and Olson (2009) studied a buried fly ash layer in Illinois and concluded that it was a possible way to determine sedimentation rate. Other researchers combined the ^{137}Cs technique and magnetic susceptibility measurements; for example, Karchegani et al. (2011), Ayoubi et al. (2012), Rahimi et al. (2013) and Olson et al. (2013) employed these two burgeoning methods to assess soil redistribution in Iran and concluded that magnetic susceptibility is a viable substitute for the ^{137}Cs technique in the monitoring of soil redistribution along slopes. In recent years, magnetic susceptibility has been tested in the quantification of soil erosion rates. Jordanova et al. (2014) utilized magnetic susceptibility to estimate the spatial patterns of cumulative soil erosion and soil loss in Bulgaria.

Our group first employed magnetic susceptibility as a tracer to corroborate soil redistribution and evaluate soil loss on farmland in northeastern China (Liu et al., 2015). The results were promising and consistent with current scientific understanding; however, the study remained incomplete because the soil samples were derived from only one slope profile. Further studies at different slopes and landscapes are needed to confirm the reliability of this method. The investigation of magnetic susceptibility on more slopes with different cultivation periods is expected to verify the feasibility of the magnetic susceptibility method for evaluating soil erosion.

In this study, we sought to clarify whether magnetic susceptibility is a reliable tracer for evaluating soil erosion using data obtained from croplands with different cultivation periods and data from a natural forest in northeastern China.

2. Materials and methods

2.1. Study area

The study area was part of Heshan Farm in Nenjiang County, Heilongjiang Province, located between 125°9′ and 125°21′E longitude and 48°56′ and 49°1′N latitude in the black soil region of northeastern China (Fig. 1). The elevation is between 260 and 360 m above sea level, and the region features primarily gentle long slopes that range from 2% to 14% in slope gradient and from 500 m to 4000 m in slope length (Zhang et al., 2007). The climate is semi-humid with a mean annual temperature of 0 °C, and an annual precipitation of 534 mm. More than 90% of precipitation occurs between May and September (Liu et al., 2013). Due to heavy erosion, the study site is covered with black soil with an average thickness of less than 30 cm (Sun and Liu, 2001). According to Chinese soil taxonomy, the soils in this study are classified as Udic Isohumisols, which are called Udic Argiboroll in the U.S. soil taxonomy. The soils developed on similar parent materials, including lacustrine and fluvial sand beds or loess sediments formed during the Quaternary period (Sun and Liu, 2001).

Heshan Farm located in a region that cultivates corn and beans. The original land cover was forest or grassland before the population dramatically increased in 1949, the year Heshan Farm was founded. Compared with other regions, the history of cultivation in northeastern China is short: before the 1860s, cultivation was forbidden, and the total cropland area was therefore small and limited to the residential areas (Ye et al., 2009; Liu, 2010). During the period of the later Qing Dynasty and the Republic of China, an increasing number of people moved into the northeast from other provinces and cultivated grasslands for farming. Thus, the oldest cropland in the study area has been cultivated for only 100 to 110 years. After Heshan Farm began, the cultivation period of each cropland was recorded in detail, and these data can be used as evidence for determining other cultivation periods.

2.2. Field sampling

Information regarded the cultivation period was obtained from the literature, local official reports, and interviews with elderly farmers. From the end of the 19th century to the beginning of the 20th century, the cultivated land vastly expanded northwards. Until the beginning of the 20th century, the northern boundary of the cultivated area in northeastern China reached to the middle of Heilongjiang Province (Ye et al., 2009), where Heshan Farm is located. Therefore, the longest cultivation period in the study area was approximately 110 years. After Heshan Farm was founded in 1949, large-scale reclamation began immediately. The cultivation period of selected croplands during the 65 years since Heshan Farm was founded was determined by interviewing elderly farmers who lived on Heshan Farm starting in 1949.

In our study, 5 typical slope transects with various cultivation periods were selected (110 years, 50–60 years, 30 years, 20 years and 0 year were coded as A, B, C, D and E, respectively) (Fig. 1). Transects A, B, C and D were cultivated land, whereas transect E was natural forestland (Table 1). The forest transect was covered with arbors, shrubs, and litter, and the cropland transects were covered with beans. The high canopy density and low human disturbance in the forest protected the soil from erosion. We therefore used the forest slope transect as a reference slope.

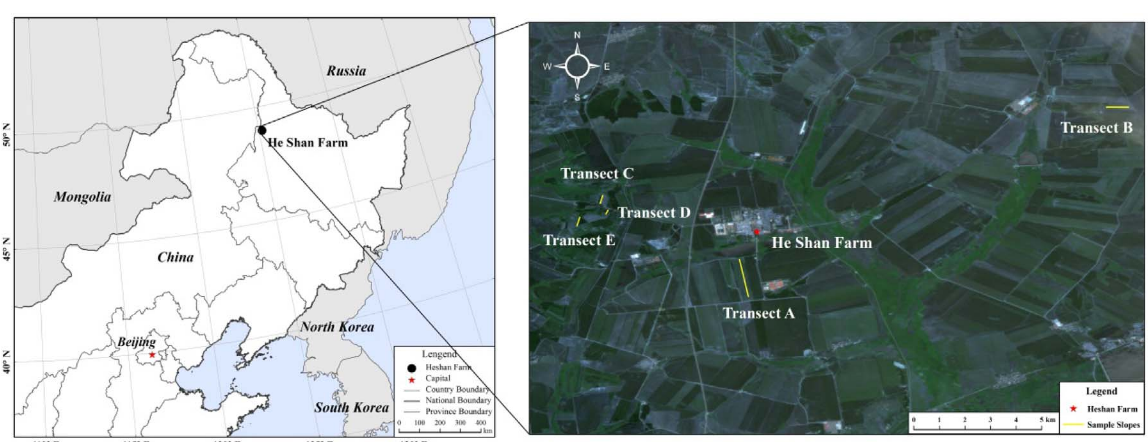

Fig. 1. Location of the study site and sample slopes.
Note: a GF-1 image was used in the spatial resolution of 16 m and it is acquired on July 2015.