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Magnetic properties of agricultural soil in the Pearl River Delta, South China — Spatial distribution and influencing factor analysis

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A B S T R A C T

Environmental magnetism has been widely applied to soil science due to its speediness, non-destructiveness and cost-effectiveness. However, the magnetic investigation of agricultural soil, so closely related to human activity, is limited, most probably because of its complexity. Here we present a magnetic investigation of 301 agricultural soil samples collected from the Pearl River Delta (PRD, 112°E–115°E and 22°N–24°N), China. The results showed that both low and high coercivity magnetic minerals coexist in agricultural soil. The values of concentration-dependent parameters, low-field susceptibility (χ_{lf}), anhysteretic remanence magnetization susceptibility (χ_{ARM}), and saturation isothermal remanence magnetization (SIRM) were much higher in the PRD plain than in the surrounding areas. The S-ratio (S_{-300}) showed a similar spatial pattern to the aforementioned parameters. By contrast, frequency-dependent susceptibility (χ_{fd}%) and χ_{ARM}/SIRM were higher in the surrounding hilly and mountainous areas than in the PRD plain. Natural and anthropogenic factors such as parent material, soil type and cultivation methods play important roles in determining agricultural soil magnetic properties. Magnetic minerals were coarser grained and overall indicated higher concentrations in soils from river alluvium and deposited materials. Soils which had suffered long-term water submergence have the lowest magnetic mineral concentration, a result consistent with previous studies. The magnetic properties of agricultural soils are strongly influenced by cultivation methods. Other human activities, such as industrial development and concomitant emitted pollutants, might have had an additional impact on the magnetic properties of agricultural soil.

1. Introduction

The recently developed environmental magnetism method is a high-speed, non-destructive and cost-effective technique (Verosub and Roberts, 1995), which has been widely applied in Earth and environmental sciences. Many previous studies have discussed sedimentary provenance and paleoenvironmental change based on the magnetic investigation of lacustrine and marine sediments and loess/paleosol sequences (Chen et al., 1999; Hu et al., 2001; Liu et al., 2003; Hounslow and Morton, 2004; Zhang et al., 2012b). In addition, soil magnetism research has ventured into heavy metal pollution (Gautam et al., 2004; Gladysheva et al., 2007; Hu et al., 2007) and pedogenesis (Grison et al., 2011; Lu et al., 2012a).

The magnetic characteristics of soil have attracted a great deal of attention in the field of environmental magnetism, because they are greatly impacted by diverse natural and anthropogenic processes. For example, soil developed from basalt usually has much higher susceptibility than other bedrock types because of its high background content of iron oxides (Thompson and Oldfield, 1986; Lu, 2000b; Wang et al., 2000; Rao et al., 2007). Previous studies have concluded that, overall, parent material is a critical factor determining the type and concentration of magnetic minerals (Fialova et al., 2006; Blundell et al., 2009a). Other natural factors, such as climate, topography, water regime, organisms, etc. can lead to various magnetic characteristics in soils (Lu, 2000a; Hanesch and Scholger, 2005; Lu et al., 2012a). Besides natural factors, human activity may affect soil magnetism in many ways. Anthropogenic pollutants containing magnetic fractions, mainly derived from industry and transportation vehicles, can enhance soil magnetism in the surface layer (Blundell et al., 2009b; Bucko et al., 2010; Karimi et al., 2011; Meena et al., 2011). Cultivation may be another factor influencing soil magnetic characteristics. Susceptibilities are usually lower in yearly overturned soils than in uncultivated ones (Durza, 1999; Magiera and Zawadzki, 2007).

Agricultural soil is a soil category closely associated with human activities. However, magnetic research focusing on agricultural soil is limited. Magiera and Zawadzki (2007) revealed that magnetic susceptibility in arable land is statistically significantly lower than that in forest land, due to the dilution of magnetic minerals with non-magnetic components, such as organic matter. Magnetic methods can be used as a proxy to detect heavy metal contamination in agricultural soil polluted by either wastewater or atmospheric pollutants (Duan et al., 2010;

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Zhang et al., 2013). Duan et al. (2010) also suggested that the use of pesticides and fertilizers had no effect on the magnetic properties found in polluted topsoil. In China, paddy soil is the agricultural soil which attracts most environmental magnetism studies. Yan et al. (2011) pointed out that paddy soil is an ideal soil type for heavy metal detection using magnetic proxies, due to its low magnetic background and high homogeneity in the top layer. Lu et al. (2012b) and Han and Zhang (2013) conducted detailed investigations into the magnetic properties of paddy soil using both magnetic and non-magnetic methods, in order to advance knowledge of the relation between its pedogenesis and soil magnetism.

The magnetic characteristics of agricultural surface soils of the Pearl River Delta (PRD) are the subject of this study. The PRD, with longitude and latitude ranging from 112°E to 115°E and 22°N to 24°N, respectively, is located in the subtropical Guangdong Province, South China. Fig. 1 displays the location of the PRD and the elevation in this region. The PRD plain area denotes the areas in the core location of the region with elevations lower than 20 m and with major rivers flowing through them. The Pearl River consists of three main branches: the West River, the North River and the East River. After joining together in the PRD drainage basin, they flow into the South China Sea through eight estuaries (Weng, 2007, Fig. 1). Hills and mountains are widely distributed around the Pearl River alluvial plain, which has been in formation since the mid-late Quaternary. Since the ‘Informing and Opening Policy’ launched in the late 1970s, the PRD has progressively become one of the most important economic regions in China, with manufacturing industries developing rapidly. As a result, the population of the studied area has increased substantially. According to the results of the Sixth National Population Census of the country (Statistics Bureau of Guangdong Province, Office for the Population Census of Guangdong Province, 2012), there were nearly 54 million residents in this 41,500 km^2 region in 2010. Moreover, this region is quite suitable for agriculture due to its warm and wet climate. Agriculture has been developed for over 2000 years in the PRD (Weng, 2007). In plain areas, rice and abundant species of vegetables are cropped and fishponds are widely distributed. On the other hand, hilly areas are mainly covered by fruit orchards or forest. However, with the growth of both the economy and population, a lot of agricultural land has been replaced by manufacturing and residential housing, associated with increasing pollutant emissions. In summary, it can be supposed that the magnetic properties of agricultural soils in the PRD are influenced by various factors. The main aim of the present study is to identify the principal factors influencing agricultural soil magnetism in the PRD. The results presented here provide some pointers on which to build further and deeper research in this field.

2. Data and methods

2.1. Sample acquisition

The 301 studied agricultural soil samples were collected from the PRD by the Guangdong Institute of Eco-Environment and Soil Sciences during 2006 and 2009. The sampling sites were relatively evenly distributed across the PRD (Fig. 1). Samples were obtained on well-developed agricultural soils within a depth of 20 cm. All samples were air-dried at room temperature and ground into a powder. The material was then weighed and packed into non-magnetic plastic cubes (with a volume of 8 cm^3). In addition to latitude and longitude, information on parent material, soil type, topography, tillage type, and irrigation type was described for every soil sample. All these items of information are classified in Table 1 and allow for a grouping of variables for statistical analyses.

2.2. Magnetic parameters and measurements

Low-field magnetic susceptibility, which is the composite reflection of all magnetic minerals within a specimen, is the most extensively used parameter in environmental magnetism (Thompson and Oldfield, 1986). Magnetic susceptibility was measured under low fields (200 m/A) at

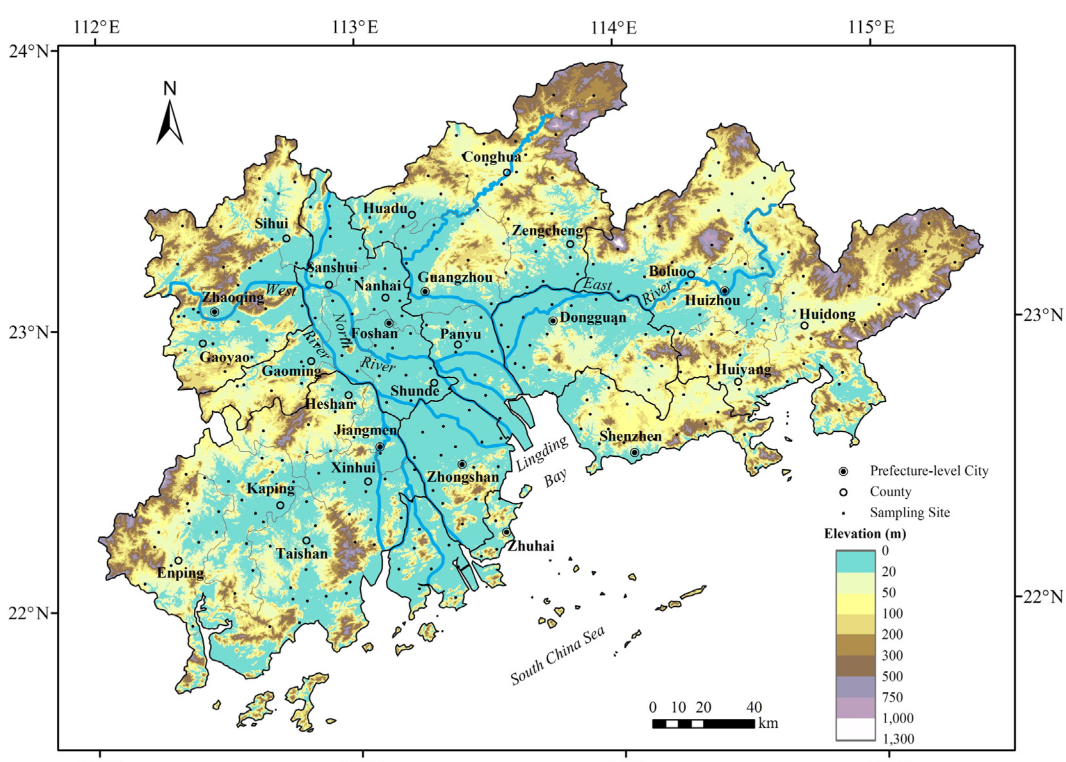

Fig. 1. Geographical location of the Pearl River Delta (PRD) and distribution of sampling sites.