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Spatial variability of soil magnetic susceptibility, organic carbon and total nitrogen from farmland in northern China

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ABSTRACT

Spatial variability of magnetic susceptibility (χ), soil organic carbon (SOC) and total nitrogen (TN) concentrations were analyzed using geostatistics method in different soil horizons from farmland in the North China. Results showed that a significant difference in SOC and TN contents, while no significant difference in χ was observed at two soil horizons using the *t*-test. The average values of χ 93.0 $\times$ $10^{-8}m^3\ kg^{-1}$, SOC 11.25 g kg^{-1} and TN 1.03 g kg^{-1} were higher at the 0–20 cm than those measured at the 20–40 cm depth, respectively. The value of frequency dependent susceptibility (χ_{fd}) was greater than 6% indicated the formation of superparamagnetic particles through pedogenesis and/or human activities. The isotropic semivariogram models of χ, SOC and TN were fitted to spherical model. A clear variogram of soil properties with a medium spatial dependent was observed. The range of spatial correlations was determined to be approximately12 km, which seemed to be characteristic for a regional scale. The kriging interpolated maps provided information for soil monitoring and management. Geometric and small spherical magnetic particles were identified by microscopy. Vertical distributions of soil properties proved that soil magnetic signature mainly originated from lithogenic and anthropogenic contribution.

1. Introduction

Spatial variability of soil properties has been shown to be an effective approach for defining the spatial distribution using geostatistics method (Goovaerts, 1997; Zawadzki and Fabijańczyk, 2007; Yang et al.,2009). Soil organic carbon (SOC) and total nitrogen (TN) and other geochemical properties of farmland are critical for the determination of soil quality and ecosystem productivity (Yang et al., 2015). Maher (1998) reported a correlation between organic carbon/clay content and magnetic susceptibility (χ) for cambisol profiles in UK. Several studies have subsequently proposed strong correlations between organic matter content and the magnetic mineral parameters (Xie et al., 2001; Hanesch and Scholger, 2005; Shilton et al., 2005).

Magnetic susceptibility can be used to probe the mineralogy concentration and grain-size distribution of several different Fe-oxides in soils or sediments (Thompson et al., 1980). The technique has also proved to be a useful indicator in assessing soil properties in terms of various environmental conditions (Lourenco et al., 2014). Soil magnetic susceptibility has also been shown to be influenced by parent materials, climate change and anthropogenic activities such as industrial pollution, burning of fossil fuels, transportation and agro-chemistry (Singer et al., 1996; Fontes et al., 2000; Lu et al., 2012).

Spatial estimation of SOC and TN has been studied extensively, but relatively few studies involved the spatial variability of soil magnetic susceptibility were conducted in arable soils (Zawadzki et al., 2015). The aims of this study were thus to (1) investigate concentrations of soil magnetic susceptibility, organic carbon, and total nitrogen at two soil horizons, (2) evaluate spatial variability and kriging interpolation maps of soil properties, (3) identify the morphology and grain size of soil magnetic particles and to distinguish anthropogenic and lithogenic contribution.

2. Materials and methods

2.1. Study area and soil sampling

The study area was located 111°04′–111° 39′ E and 35° 42′–36 °02′ N in the North China and the total area is about 1034 km^2 (Fig. 1). The site belongs to a climate with a mean annual temperature of 12.6 °C and annual rainfall of 500 mm. The study area is an agricultural region for cereals, vegetables, fruit etc. and also contains an industrial center which is only 20 km south away from Linfen city. Linfen city is well known for intense coal mining, coke, iron-steel heavy industry (Cao et

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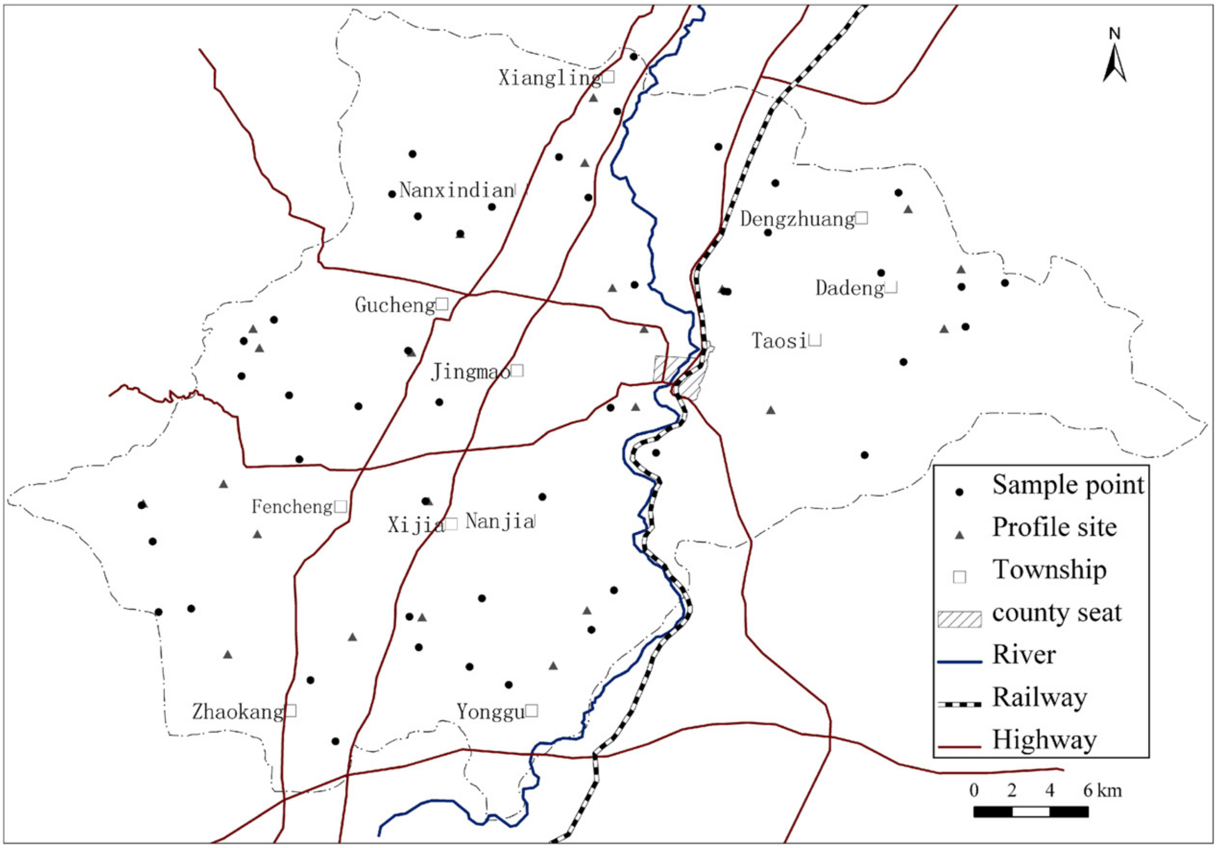

Fig. 1. Location of the study area and soil sample points.

al., 2015). The soil types are Calciustepts and Haplustepts referencing to USD soil Taxonomy 2014, which developed on Quaternary loess and alluvial deposits (Yang et al., 2016).

Soil samples were collected from arable soils during summer 2013 at random locations with an average density of approximately one sample per 9 km^2. Seventy sampling sites were selected and the positions were recorded by GPS with samples extracted from two depth intervals denoted topsoil (0–20 cm) and subsoil (20–40 cm). Six representative samples of each layer were taken at random intervals between 2 m and 5 m from the grid point along cardinal directions at each site. Samples were then mixed to a mass of approximately 1 kg and taken to the laboratory for further analysis. Soil typical profiles exhibit a sequence of genetic horizons: Ap-A(AB)-B-C according to guidelines for soil description and Taxonomy of Shanxi Soils (Table 1).

2.2. Laboratory analyses

Soil samples were air dried and passed through 2 mm mesh sieves before analysis. Samples used for magnetic properties were prepared in standard non-magnetic 10 cm^3 cylindrical pots and measured with a Bartington magnetic susceptibility meter MS 2B sensor at low (χ_{lf}) and high (χ_{hf}) field (0.47 kHz and 4.7 kHz), respectively (Bartington Instruments Ltd., Oxford, UK). Frequency dependent susceptibility (χ_{fd}%) was calculated as: $\chi_{fd}\% = (\chi_{lf} - \chi_{hf}) / \chi_{lf} \times 100$.

Soil pH was measured after suspending the soil solution in a 1:5 soil to water ratio using a pH-meter and a combined glass electrode (Institute of Soil Science, Chinese Academy of Sciences, 1978). Soil organic carbon (SOC) was measured using the Walkley-Black wet oxidation method, after the samples had been passed through a 0.18-mm nylon sieve (Nelson and Sommers, 1982). Soil total nitrogen (TN) was determined using the Kjeldahl method (Bremner and Mulvaney, 1982).

Magnetic particles were extracted by rubbing a strong hand magnet directly through the air dried, sieved soil spread on a large glass plate in order to prepare for Scanning Electron Microscope (SEM) examination (Grimley and Arruda, 2007). Energy dispersive X-ray (EDX) spectra were used to estimate the composed of particles observed in SEM. The morphological of soil magnetic particles were analyzed using a JSM-7500F (Japan) SEM.

2.3. Data analysis

An experimental semivariogram was calculated and used to obtain the nugget (C_0), sill ($C + C_0$) and range parameters using Variowin 2.2 software. A spatial dependence structure was well adjusted by a theoretical semivariogram model and a spatial distribution map was

Table 1
Soil type and location of the four profiles.

Profile	Location	Soil horizon	Depth cm	Geological background	Structure	Soil type
1	111°23′06″E; 35°58′54″N	Ap	0–18	Alluvial	Loam	Haplustepts
		AB	18–45		Clay loam	
		B	45–77		Clay loam	
		C	77–120		Loamy Sand	
2	111°12′21″E; 35°51′25″N	Ap	0–17	Quaternary loess	Loam	Calciustept
		A	17–42		Loam	
		B	42–70		Loam	
		C	70–120		Loam	
3	111°14′54″E; 35°48′17″N	Ap	0–20	Quaternary loess	Loam	Calciustept
		A	20–47		Loam	
		B	47–73		Loam	
		C	73–120		Loam	
4	111°24′37″E; 35°52′07″N	Ap	0–20	Quaternary loess	Loam	Calciustept
		A	20–50		Loam Loam	
		B	50–70		Loam	
		C	70–120			

p stands for plough.