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Short Communication

An investigation on magnetic susceptibility of hazardous saline-alkaline soils from the contaminated Hai River Basin, China

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ABSTRACT

Magnetic susceptibility can provide rich environmental information, especially for hazardous heavy metals and saline-alkaline in the contaminated soils. Magnetic susceptibility in four vertical profiles from saline-alkaline soils in lower Hai River basin was investigated. Soil sites were extended from alluvial fan to coastal plain areas. They are aligned along a latitudinal strip. Magnetic parameters including low/high frequency susceptibility, frequency-dependent susceptibility was measured. Moreover, some standard pedological parameters such as pH value and organic matter content were also determined. The results showed that low frequency magnetic susceptibility values is very high at the surface and decreases with the profile to a low value. In all profiles from alluvial fan frequency-dependent susceptibility greater than 3% may suggest the presence of relatively more super-paramagnetic particles. Magnetic susceptibility showed obvious vertical distribution in alluvial fan higher than coastal plain. No significant correlations between organic matter, pH and low frequency magnetic susceptibility were found, while there is a negative correlation between organic matter and frequency-dependent susceptibility. A positive correlation between pH and frequency-dependent susceptibility was found in the study areas.

1. Introduction

Magnetic susceptibility (MS) is one of important parameters providing rich environmental information, especially for hazardous saline-alkaline and heavy metals in the contaminated soils [1–3]. Various works present datasets collected to establish the connection between the behavior of magnetic parameters and the variability of soil environments [4–6]. MS variations are influenced by parent material, topography, climate, vegetable and soil physical and chemical characteristics and can reflect the intensity of the soil forming processes and its polluted degree by hazardous heavy metals [7–10]. Researchers found that MS values varied among soils that were formed from the same parent material across different landscape positions [10,11] and developed a broader concept of interaction between pedogenesis and the magnetic mineral system, which includes possibilities of both susceptibility enhancement and "depletion"[12–14]. Pedogenic processes act simultaneously with significant sedimentation. As a consequence, the soil profile formed grew upward during its development. Sedimentary rocks have rather low concentration of magnetic minerals with the mass-specific susceptibility from ca. $0.1 \times 10^{-8}\,m^3\,kg^{-1}$ in the case of limestone to approximately $20 \times 10^{-8}\,m^3\,kg^{-1}$ in the case of siltstone. In some areas the Quaternary glacial tills and fluvial or eolian deposits (loess) may have even higher mass-specific susceptibility up to $50 \times 10^{-8}\,m^3\,kg^{-1}$ due to the presence of Fe-rich clays. Soil minerals present are of both natural (lithogenic, pedogenic) and anthropogenic (cultivation, industrial dusts) origin [13–14]. In most samples, MS value is proportional to the concentration of ferromagnetic oxides (magnetite and maghemite). However, the susceptibility of weakly ferromagnetic samples, which is abundant of water, carbon, calcium carbonate or silica, will be reduced by diamagnetism [15–20].

The purpose of this paper is to test how soil MS are affected by complex geological sites and hazardous saline-alkaline soils. We examine different features in the vertical distribution of soil magnetic susceptibility. Furthermore we investigate the potential correlation between pedological parameters and magnetic susceptibility in the study area.

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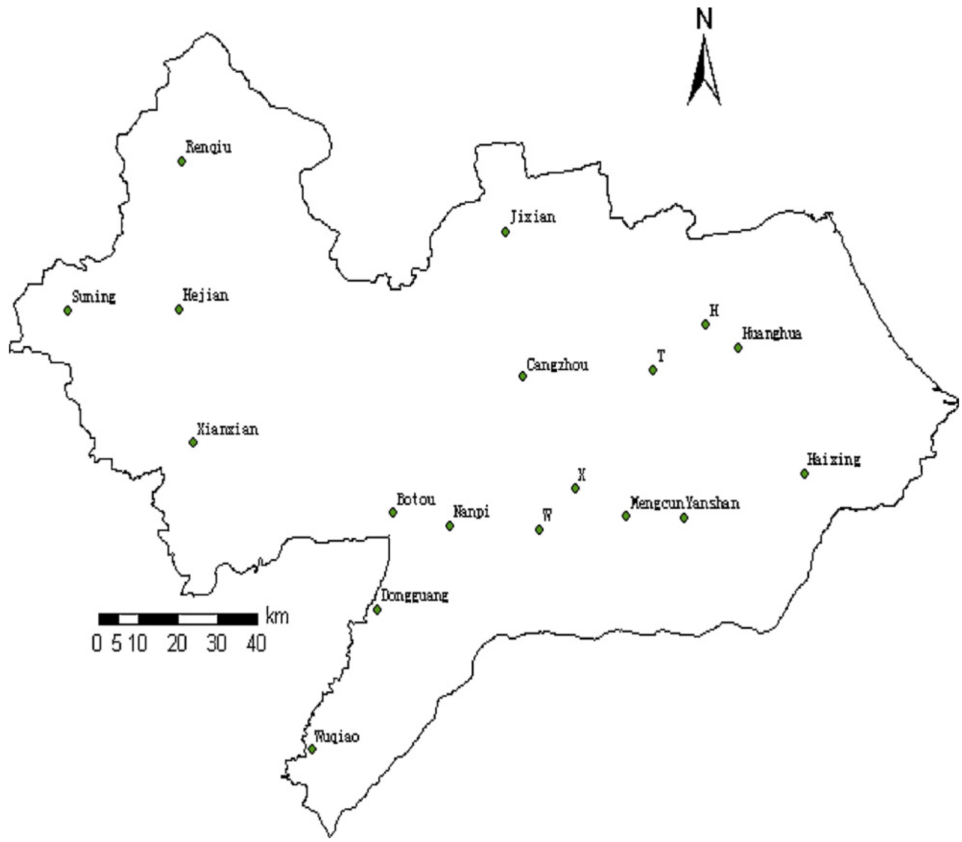

Fig. 1. Distribution of sampling sites: Wangxi (W), Xiaoji(X), Tengzhuang(T) and Huanghua(H).

2. Material and methods

2.1. Area description

The soils of study areas were taken from alluvial plain deposits at 115°42′–117°50′E and 37°28′–38°57′N. The region is low and smooth characteristic, with a deficient freshwater supply, waterlogged land and salty groundwater. Meteorological conditions are dominated by semiarid with a continental monsoon. The parent material of the soils is river alluvium from the Huang and Hai rivers, which overflow and change course from time to time. Both have weakly magnetic parent materials, of which Hydromica is the dominant layer silicate mineral. Smectite, kaolinite and chlorite are subdominant minerals. The typical soil types are meadow cinnamonic soil and salt-waterlogged.

2.2. Soil sampling

Across the study area, four typical vertical soil profiles of 100 cm depth along a latitudinal strip with different geological and environmental site were realized, indexed W, X, T and H (Fig. 1).

Profile W (Wangsi), X (Xiaoji) and T(Tengzhuang) are southwest extremity of transect, which was segmented of Hai River alluvial fan and developed on eluvia loess material.
Profile H (Huanghua) is very saline waterlogged, typical formed in coastal wetland sediments.

In order to avoid any contamination, soil samples were collected from bottom to surface, and put in situ into 8 cm^3 plastic cubes. Samples were stored in a cool place until analysis. Topsoil sample is collected 3–5 times in order to avoid errors in collecting soil.

2.3. Laboratory analysis

The low and high frequency MS was measured by Bartington MS2B probe at frequencies of 0.47 kHz and 4.7 kHz. Samples were packed into 10 cm^3 cylindrical perspex pots for MS analysis. The samples have been measured several times to obtain the mean value. The results were expressed as mass susceptibility X_{LF} and X_{HF}, and the corresponding frequency-dependent susceptibility was calculated as difference percentage

$$\mathrm{XFD} = \frac{X_{LF} - X_{HF}}{X_{LF}} \times 100\%.$$

The pH values were measured with a glass electrode in the supernatant of a 5/1 (w/w) water/soil suspension. A mixture of 10 g of soil samples and 50 ml of distilled water was left 30 min and the pH value was measured. Soil organic matter content was usually measured by means of the dry oxidation ($K_2Cr_2O_7$) outside heated method.

3. Results and discussion

3.1. Low frequency magnetic susceptibility of soil profiles

MS varies across the section in a rather complicated way. Typical vertical profiles of MS are shown in Fig. 2, MS values varied with depth and it could be compared for the same depth across the different landscape. X_{LF} values of X were the highest and those of T were the lowest (Fig. 2). The MS values were found to be consistently higher in well-drained alluvial fan and lower in waterlogged soils, reflecting anaerobic deterioration of both detrital magnetite and soil-formed ferrimagnetics.

X_{LF} of profile X showed significant increase in the surface between 0–10 cm and start to decrease with the depth. The X_{LF}

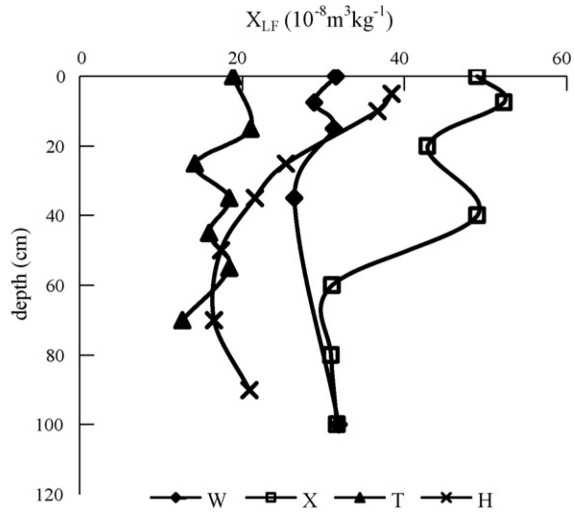

Fig. 2. Change in X_{LF} with depth for soil profiles.

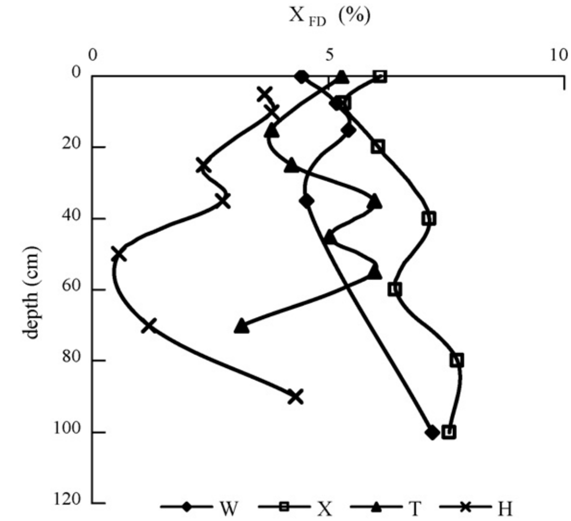

Fig. 3. Change in X_{FD} with depth for soil profiles.

maximum value 52.3×10^{-8} m^3 kg^{-1} was located at 10 cm depth, at 100 cm depth it was minimum 31.0×10^{-8} m^3 kg^{-1}(Fig. 2). It is clear that X_{LF} values variations was larger with depth, but X_{LF} of profile W, T was rather stable showed relative small change trend with depth. X_{LF} values of T ranged from 21.0×10^{-8} m^3 kg^{-1} in the surface soil at 10 cm to12.6 $\times 10^{-8}$ m^3 kg^{-1} at 90 cm depth. The coarse fraction has low and uniform MS regardless of lithology. Fine-grained magnetite of pedogenic origin is the main carrier of the magnetic signal [5,6]. While X_{LF} values of Profile W between 26.4×10^{-8} m^3 kg^{-1} and 31.9×10^{-8} m^3 kg^{-1}, at the 100 cm depth is the highest. X_{LF} values of Profile H changed from 16.5×10^{-8} m^3 kg^{-1} to 36.7×10^{-8} m^3 kg^{-1}, generally decreasing with depth (Fig. 2).

The vertical distribution of the MS shows some enhancement in the topsoil. It is very high at the surface and decreases through the profile to a low value. MS of the upper soil horizons may increase as a result of anthropogenic (agricultural activities). Natural soil formation and especially production of biogenic magnetite by magnetotactic bacteria can increase MS as well. Alternating cycles of reduction and oxidation have been suggested as the main mechanism for the increased MS in the topsoil vs. subsoil of well-aerated soils. MS changed reflecting water played an important role for soil sedimentation cycle. The pedogenic magnetic signal may have been destroyed during gleisation. We speculate that the soil MS is associated with pedogenic environments: topsoil of human activity, and in the middle part of the profile of clay illuviation and weathering. MS increase is the cause of parent bedrock at the bottom.

3.2. Frequency-dependent susceptibility of soil profiles

Frequency-dependent susceptibility (X_{FD}) is supposed to reflect the significant of the grain size of ferromagnetic phase, which are sensitive to the presence of sub-micron sized grains, especially those spanning the super-paramagnetic (SP) and single domain (SD) boundary (0.01–0.03 μm) [1]. Grain size and shape, which determine the domain state of the mineral, are of great importance. X_{FD} can serve as an indicator of the particle origin, thus enable us to distinguish between various sources.

X_{FD} values of X were the highest and that of H were the lowest. X_{FD} values of Profile H ranged from 0.57% to 4.31%, average 2.51%. This suggests no contribution of super-paramagnetic (SP) grains and therefore the dominance of multidomain (MD) particles. It probably Profile H is more youthful soils, having less time for pedogenic magnetite accumulation and more eroded soil.

X_{FD} values of Profile X were found between 5.35% and 7.74% increasing with depth (Fig. 3). X_{FD}>5%, indicating significant amounts of ultrafine ferrimagnetics. X_{FD} value at Profile T was found between 3.17% and 5.98%, changed rather stable with increasing depth. X_{FD} value at Profile W ranged from 4.43% to 7.21% and increased with depth (Fig. 3). X_{FD} of profile T, W, X greater than 3% is suggested to be indicative of the dominance of SP grains and fine SD particles [3] Soil has significant pedogenic magnetite (maghemite) since both fly ash and detrital magnetite are too coarse to account for such high values. On a longer time scale, X_{FD} reflect the weathering, pedogenic, and anthogenic prevailing through the major climate. High X_{FD} may suggest profile T, W, X the presence of relatively more SP magnetite of pedogenic origin.

3.3. Correlation with organic matter content

Soil organic matter (OM) content is higher in the topsoil, where human activities have most influence on soil condition. OM content gradually decreased with increasing depth (Fig. 4). The content of OM was 1.18% at 10 cm depth and then decreased to 0.92% in the profile H. The OM value was between 0.4% and 0.95%, decreased from surface to bottom in the profile X. The OM ranged from 0.22% to 0.92% in the profile W. OM content of profile T between 0.53 and 0.78%. These are relatively low values in profile W, X, T compared to profile H from the same climatic zone.

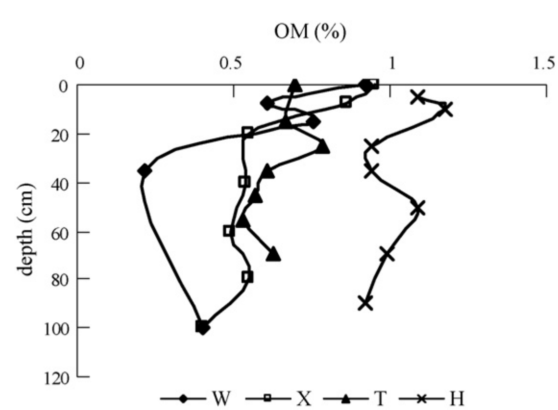

Fig. 4. Change in OM with depth for soil profiles.

Table 1
Correlations between magnetic susceptibility and soil properties in soil profiles.

	X_{FD}	OM	pH
X_{LF}	0.466*	0.050	−0.093
X_{FD}		−0.684**	0.460*

* $p < 0.05$.
** $p < 0.01$.

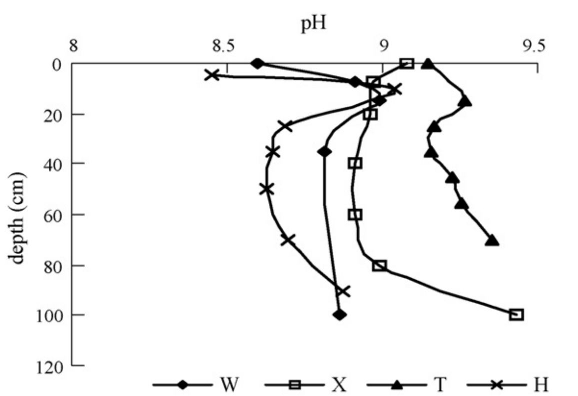

Fig. 5. Change in pH with depth for soil profiles.

No significant correlations were observed for OM and $X_{LF,}$ but there is very negative significant correlations exist between OM and X_{FD} (Table 1). Comparison of data with others highlights some remarkable differences [11–13]. A possible explanation for the difference is that our sample had lower OM (0.22–1.18%) from the saline-alkaline arable soil.

3.4. Correlation with pH value

Fig. 5 showed the results of the pH value in difference profile. According to the pH data available, all the studied soils are alkali (pH varies from 8.45 to 9.43). The pH value of profile T was the highest, while X_{LF} were the lowest. The pH value may have negative correlative with X_{LF}. Because of MS sensitivity to soil pH, ferrimagnetic mineral neoformation and dissolution are the dominant pedogenic processes that affect X_{LF}. Induced hydrolysis mineralization plays a role at room temperature and near neutral pH, while at low value (pH <5 < formation of lepidocrocite and goethite occurs [13]. Since all the studied soils are strongly alkaline, this mechanism seems to be improbable in our case. Table 1 showed positive significant correlations in pH values and $X_{FD.}$

4. Conclusions

The results of our investigation confirm that magnetic susceptibility can provide a basis for discrimination and identification of different soil forming. High MS values occur where topographically higher alluvial fans are present. Low MS values occur where poorly drained coastal waterlogged. MS showed stable changing trend from alluvial fan into coastal plain areas [21–24].

MS enhanced in the topsoil layer over the whole area by human activities. All soil profiles in alluvial fans were dominated by SP grains and fine SD particles, most probably of pedologenic origin. MS values among the study sites seem to be affected by soil organic matter and ambient pH. No significant correlations between OM, pH and X_{LF} were existed, while there is negative correlation between OM and X_{FD} positive correlation between pH and X_{FD} were existed in study areas.

It is impossible to reveal the complexity of soil profile by only one single parameter [18–24]. Further studies of other magnetic parameters throughout the region are required. They might help reconstruct the magnetic mineral sources, the relative role of different sources, and their dynamics, which is necessary to monitor the soil dynamic degree polluted by hazardous saline-alkaline [18–24].

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