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Geochemical assessment of agricultural soil: A case study in Songnen-Plain (Northeastern China)

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ABSTRACT

Agricultural soil pollution is a serious problem that can endanger ecology, food safety, and human health. The study evaluated the accumulation and distribution of major and trace elements in the agricultural soil of the Gannan area in the northwest Songnen-Plain, a very important base of grain production in northeastern China. To identify the concentrations and sources of pollutants and also to assess the soil environmental quality, a total of 2400 topsoil (0–20 cm) samples and 10 subsoil (180–200 cm) samples were collected. Then 6 major elements (CaO, Fe_2O_3, K_2O, MgO, Na_2O, SiO_2), 18 trace elements (As, B, Cd, Co, Cr, Cu, F, Hg, I, Mo, Mn, N, Ni, P, Pb, Se, S, and Zn), pH, and C_{org} (organic carbon) were analyzed. The accumulation of Cd, Cu, Pb, Zn, Hg, and F was apparent in the agricultural soils. Correlation coefficient analysis showed that most major and trace elements, as well as pH and C_{org}, were significantly positive correlated in agricultural soil. Principal component analysis (PCA) indicated two main anthropogenic sources for trace elements in agricultural topsoil. The first component including B, Cr, Cu, Mg, Ni, and Zn, represented a mixture of atmospheric deposition and livestock manures; whereas the second component, relating to Ca, F, Cd, Hg, Se, and P, suggested the inorganic fertilizers and lime, as well as agrochemicals. Spatial distribution patterns using GIS contour maps and an integrated soil pollution index were established for the selected metal concentrations. In general, the range of *RI* (the potential ecological risk index) was from 43.6 to 556, with a mean value of 106, indicating low ecological risk in this study area. This study indicated that more attention should be paid to metal pollution of agricultural soil in the rural area to safeguard both soil and food safety.

1. Introduction

Contaminants in agricultural soil may bioaccumulate in crops and possibly interfere with crop growth, while exposure to contaminants may impair human health (Luo et al., 2009; Sun et al., 2010). In China, rapid industrialization and urbanization and increasing reliance on agro-chemicals have increased agricultural soil pollution, which threatens food security (Liu et al., 2006; Luo et al., 2009). The contamination of the soil has long-term environmental and human health implications (Su and Zhu, 2008). Therefore, reduction of toxic trace element inputs in soil has been a focus in agriculture policies in China (State Council of PRC, 2005).

The largest pollution inputs into agricultural soils are mainly from atmospheric deposition, sewage sludge and livestock manures, whereas other sources, such as inorganic fertilizers and lime, agrochemicals, irrigation water, industrial by-product 'wastes' and composts are responsible for a relatively small contribution (Luo et al., 2009; Nicholson et al., 2003). Understanding the sources of pollutants is critical for environmental management and decision-making.

Songnen-Plain is an important part of the northern Songliao-Plain, one of the world's 10 greatest plain. Songnen-Plain is surrounded by Da Hinggan Mountains, Xiao Hinggan Mountains, Changbai Mountains and Songliao watershed. The plain space spans more than 103,000 km^2. The soil of the plain is fertile and thick, and consequently it has been a traditional grain production area of China. Grain yields account for 6.4%, more or less, in China (ECCAY, 2011). Songnen-Plain is a very important zone from both agricultural and socio-economic viewpoints.

The selected area is relatively complex, with a great diversity of soils and crops, and both villages and small towns were included. Accordingly, selection on typical land quality geochemical assessment has been carried out in the multi-target geochemical survey in Gannan County in Songnen-Plain.

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The anthropogenic activity could have strong negative impacts not only on the soil, but also on the quality of agricultural products. Despite of its regional importance, few researchers have investigated potential pollution sources in this area.

2. Materials and methods

2.1. The study area

The research area (47°40′–48°00′, 123°15′–124°00′, see Fig. 1) is located in Gannan County of Heilongjiang province, northeastern China. Gannan County is situated in the northwest region of Songnen-Plain. The study area includes Yinhe Town and Shuanghe Farm (SHF), with a total area of roughly about 600 km^2. The climate is semi-arid, with an average annual temperature of 3.5 °C, including a long and cold winter and short summer. Monthly mean temperature varies from 22.4 °C in July to −18.4 °C in January. The average annual precipitation is 462 mm and most rains occur in the summer season. Semi-arid agriculture is the dominant farm land usage in this region, with two staple crops, including rice and corn.

2.2. Sample collection and analysis

Between March 2009 and March 2010, totally 2410 samples were collected from the Gannan agricultural area, including 2400 samples from topsoil (0–20 cm) and 10 samples from subsoil (180–200 cm). Sampling was based on the specifications of the National Multipurpose Regional Geochemical Survey carried out by China Geological Survey (CGS) in 2005. For topsoil, about 1 kg was collected from a 0.5 × 0.5 km grid (plowing layer, 0–20 cm) and each sample consisted of about 3–5 subsamples obtained in a 2 m × 2 m grid from the sample plot using a stainless steel hand auger. For subsoil, about 500 g were also collected at depth (180–200 cm) in order to understand the soil parent material geochemical characteristics. The locations chosen were based on soil types and the sample was numbered according to the order of collection. The coordinates of the sample locations were recorded with a portable GPS, and the sampling sites were shown in Fig. 1.

All samples were air-dried at room temperature (20–25 °C) and then sieved to 2 mm to remove large plant roots and gravel-sized materials before analysis. Soil chemical properties were analyzed following standard procedures given in Page et al. (1982). The pH values were determined in water with a soil to solution ratio of 1:2.5 (w:w). Percentage of organic carbon (C_{org}) in soil was measured by the oxidation using $K_2Cr_2O_7$. Cation exchange capacity (CEC) was determined by using a standard extracting solution method (US-EPA, 1986). Elemental contents in soil were extracted by digestion (HF, HNO_3 and $HClO_4$) in a microwave (Xia et al., 2011) in accordance with the ISO 11466 procedure (International Organization for Standardization, 1995). The total concentrations of Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, and Zn were determined by inductively coupled plasma mass spectrometry (ICP-MS, GV Instruments), whereas As, Se, and Hg were measured by atomic fluorescence spectrometry (AFS, AFS-230E). The elements (Al_2O_3, B, CaO, Fe_2O_3, I, K_2O, MgO, Na_2O, and P) in soil samples were analyzed by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES, Therrmo Fisher Scientific). F concentration was determined by ion selective electrode (Boyle, 1981). Sulfur and nitrogen were determined by dry combustion (at 1350 °C), with a LECO CNS-2000 Nitrogen and Sulfur analyzer. SiO_2 was determined by X-ray fluorescence analysis (Indresand and Dillner, 2012).

The precision and quality accuracy of all the methods were determined by the analysis of duplicate samples, blanks and reference materials (about 20% of the total number of samples was used for this purpose). Standard reference materials for soil (GBW-07401, GBW(E) 070043) were obtained from the China National Center for Standard Reference. To verify the accuracy and precision of digestion and subsequent analysis procedure, blanks and reference materials were included in every batch of microwave acid digest along with the samples. For these procedures, analytical quality control showed good precision throughout. The recovery rates in the standard reference materials ranged from 91% to 110% for trace and major elements. Standard

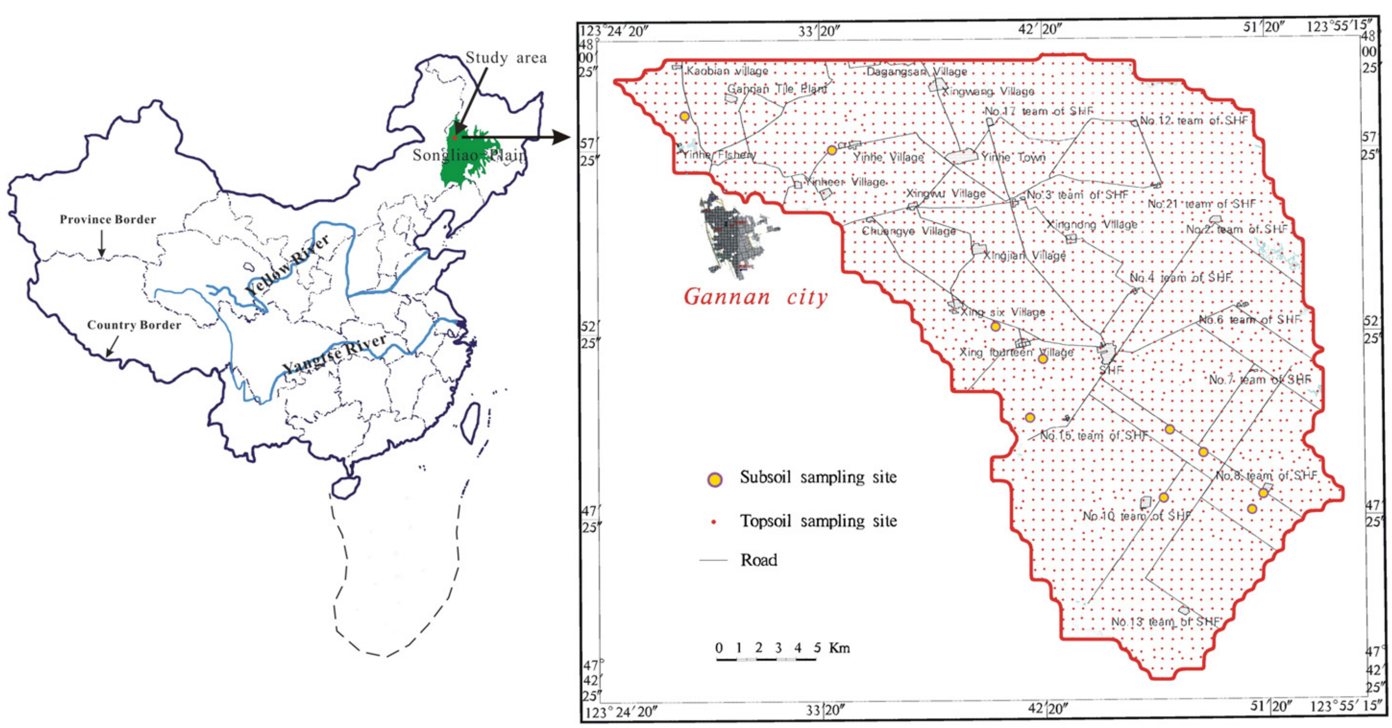

Fig. 1. Sampling locations of topsoil and subsoil in Gannan area.