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Accumulation characteristics and potential risk of heavy metals in soil-vegetable system under greenhouse cultivation condition in Northern China

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ABSTRACT

Heavy metal pollution in greenhouse vegetable production system is a growing concern for public health. In this study, 87 soil and 72 vegetable samples were collected from greenhouse vegetable production systems in Shanxi province, Northern China, aiming to evaluate the accumulation characteristics and potential risk of heavy metals in soil-vegetable system under greenhouse condition. The results showed that Cd and Pb concentrations in 72.4% and 35.5% of the soil samples were higher, while all of As, Cr, Ni, Cu, Zn samples were lower than the Grade II value in Environmental Quality Standard for Soils (GB15618-1995). Nearly 99% of the total amount Pb existed in the form of residual and could not be absorbed by vegetables. The proportions of As, Cd, Zn in ionic form, bound to carbonates and the exchangeable fraction were 6.21, 13.71, and 13.47% respectively, and were relatively higher than other metals (Cr, Cu, Ni, Pb). The transfer factors (TF) of As, Cr, Ni, Pb were found to be higher in leaf and fruit vegetables than that in tuber vegetables. With a relatively low total concentration and high proportion of available form in soils, Cd showed relatively larger TF in three kinds of vegetables than other metals. The concentrations of Cr, Ni and Pb in three kinds of greenhouse vegetables exceeded the limit in national food safety standards. Especially, Ni in leaf and fruit vegetables showed significantly higher hazard quotient (HQ) than that in tube vegetables. Overall, leaf and fruit vegetables had a relatively higher hazard index (HI) than tube types, and exceeded 1, suggesting that there was larger potential health risk by ingestion of heavy metals through fruit and leaf vegetables. Thus, in order to avoid human body health endangered by heavy metals through the food chain, appropriate management measures should be implemented in greenhouse cultivation, especially tuber vegetables be cultivated instead of leaf and fruit types.
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1. Introduction

Recently, greenhouse vegetable production (GVP) has become extensively widespread in developing countries such as China (Baudoin 1999; Critten and Bailey 2002; Huang and Jin 2008). In 2010, the area of GVP in China was 4.67 million hectare, which accounts for about 50% of China's total vegetable cultivation area and 24% worldwide vegetable cultivation area, respectively (Yang et al., 2013). However, inappropriate strategies including heavy application of fertilizers and pesticides have been adopted in GVP systems to achieve high crop production. This has led to a series of consequences, especially the accumulation of heavy metals in soil-vegetable system under greenhouse condition has exposed serious health risk for human consumption (Liu et al., 2011; Khan et al., 2008; Mansour and Gad 2010). The available metals in greenhouse soils are absorbed by vegetables and accumulated in their edible parts. The heavy metals in vegetables then enter human body by dietary intake and cause several clinical and physiological problems (Sharma et al., 2007; Khan et al., 2008). With increasing awareness for human health, great attention has been paid to heavy metal contamination of greenhouse vegetables. Thus, to protect the health and diet safety of local residents, it is essential to understand the accumulation status and potential risk of heavy metals in soil-vegetable system under greenhouse condition.

Abbreviations: GVP, greenhouse vegetable production; OM, organic matter; TF, transfer factors; HQ, hazard quotient; HI, hazard index.

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Table 1
Basic soil properties from four GVP bases in Shanxi province.

Bases	pH	OM (mg g^{-1})	Soil mechanical composition		
			Sand (%)	Silt (%)	Clay (%)
L1	7.53–8.24	6.22–45.80	60–64	12–21	19–24
L2	7.55–8.52	8.97–34.47	58–62	11–21	21–27
L3	6.95–8.22	15.91–90.88	49–53	19–26	25–28
L4	7.07–7.95	55.10–61.31	45–53	15–28	27–32

Simultaneously, GVP has also become one of the important component for enhancing rural economic development and farm income in Shanxi province, Northern China. In addition, there are numerous coal mines and chemical industries in Shanxi province, which has caused serious local air and soil pollution. The GVP system is under the dual pollution of air deposition and inappropriate management styles in Shanxi province, Northern China. Thus, to prevent heavy metal pollution in GVP system and ensure human health, it is necessary to investigate the accumulating characteristics of heavy metals in soil-vegetable system, and assess the potential health risk by ingestion of heavy metals through greenhouse vegetables.

Accordingly, the study was to (i) investigate the accumulation characteristics of heavy metals in greenhouse soils in Shanxi Province, China; (ii) explore the migration ability of heavy metals from soils to vegetables; (iii) evaluate the concentrations of heavy metals in greenhouse vegetables and their potential health risk. The study could provide a theoretical reference for pollution prevention and control of heavy metals in soil-vegetable system under greenhouse cultivation condition in Northern China.

2. Materials and methods

2.1. Study areas

Shanxi province, located in the western part of Taihang Mountain and eastern part of the Yellow River, Northern China, covers a total area of 156,700 km^2 and has a total population of 36.11 million. In this study, four GVP bases in Shanxi province were selected as the study areas. The annual average temperatures are 9.5, 9.9, 9, 11 °C, and average annual precipitation are 456, 462.9, 550, 550 mm for the four areas, respectively. The first area, Jinyuan (L1) is a typical suburban belt (N 37°36′51″–37°55′41″, E 112°19′04″–112°46′42″) located at the southwest of Taiyuan. The main soil type is Brown Loess, and the dominant greenhouse vegetables are pak choi and cucumber. As a major agricultural county in Central part of Shanxi Province, Taigu (L2) is famous for its modern agriculture demonstration sites. The sampling zone is covered from latitude of 37°27′39″–37°42′46″N and longitude of 112°29′50″–112°53′58″E. The dominant soil is Calcareous cinnamon soil. And the main greenhouse vegetable types are lettuce, cucumber, and pumpkin. Xiangyuan county (L3), with rich mineral resources and convenient traffic, is located in the southeast of Shanxi province. A vegetated area was sampled covering a latitude of 36°28′59″–36°55′45″N and longitude of 112°55′50″–113°02′0″E. With the soil parent material of loess, the main soil type is cinnamon soil. And the dominant greenhouse vegetable types are pepper, tomato, cabbage, pumpkin. Yicheng (L4) belongs to Linfen city, a famous polluted city at about 2010, which is located in the Southwest of Shanxi province. The sampling area is covered from a latitude of 35°44′59″–35°73′45″N and longitude of 111°44′50″–111°68′0″E. The soil parent material is Malan loess from loess hilly-gully region, and the dominant soil is loessal soil. The main greenhouse vegetable types are tomato and cucumber. The basic soil properties from four GVP bases in Shanxi province are listed in Table 1.

Table 2
The sampling dates of different types of greenhouse vegetables.

Types of greenhouse vegetables	Sampling date
Leaf types	9.1–9.16
Fruit types	8.15–8.30
Tuber types	10.1–11.15

According to our investigation, the soil properties outside greenhouse in the four sampling areas were in line with that in greenhouse before the greenhouses were built. The combination of organic fertilizer including chicken manure, and chemical fertilizer comprising of urea and compound fertilizer are applied in the above sampling areas as the main fertilizers for vegetable cultivation. The GVP type in the above four areas is seasonal plastic greenhouse, with growing period of 9 months from March to November and a fallow period of 3 months. The plastic in the greenhouse is uncovered, and soil is ploughed and fertilized with chicken manure in the fallow period. Then the plastic is covered again in the next cultivation period.

2.2. Sample collection

72 vegetable samples including 21 leafy vegetables (3 spinaches, 6 lettuces, 6 Chinese cabbages, 6 pak choies), 15 tuber vegetables (9 carrots, 3 sweet potatoes, 3 kohlrabies) and 36 fruit vegetables (15 tomatoes, 6 peppers, 9cucumbers, 6 zucchinis) were collected in 2015 from four GVP bases in Shanxi province, China (Fig. 1). Only edible parts were sampled for analyses. The sampling dates for different types of greenhouse vegetables are shown in Table 2. The sampling dates were determined according to the manure periods of three types of greenhouse vegetables in Shanxi Province. Simultaneously, 87 soil samples were collected at the vegetable sampling sites and corresponding control areas. Three replicates were collected per sampling unit.

Soil samples were firstly air-dried, then ground to pass through 20-mesh and 100-mesh sieves for the determination of pH value, and concentrations of organic matter (OM) and heavy metals, respectively. Vegetable samples were washed with deionized water, and the fresh weight (FW) were recorded. After oven dried at 75 °C to a constant weight, the vegetable samples were weighed again. Then they were ground into powder for further analysis.

2.3. Analysis of soil and vegetable samples

The concentration of heavy metals in greenhouse soils and vegetables: soil and vegetable samples were firstly digested in a Microwave Digestion System using a nitration mixture (5 ml HNO_3 and 1 ml HF) and 5 ml HNO_3, respectively. Then the digestion solution was transferred to a 50 mL volumetric flask, and then diluted with 1% HNO_3. Finally, the concentration of heavy metals including Cr, Cd, Cu, Ni, Pb, Zn were determined by the inductively coupled plasma-atomic emission spectroscopy (iCAP 6300, Thermo Electron Corporation, USA). The concentration of As was measured by atomic fluorescence spectrophotometer (TitanAFS-830). During the measuring, GSS-1and GSS-2 were used as soil standard reference materials, and GSB-5 and GSB-6 were analyzed as plant standard reference materials in order to ensure the analytical precision within 10% variability.

Chemical forms of heavy metals in greenhouse soils: soil samples were extracted by BCR three-step sequential extraction procedure developed by Davidson et al. (1998). The extracting solutions of different chemical forms of heavy metals were obtained according to the following procedures: (I) ionic form, bound to carbonates and the exchangeable fraction: soil was extracted in 0.11 mol L^{-1} acetic acid at pH 2.8; (II) metals bound to amorphous

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