Chemosphere 165 (2016) 555–563

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Determination and evaluation of heavy metals in soils under two different greenhouse vegetable production systems in eastern China

Kang Tian [a, b], Wenyou Hu [a], Zhe Xing [b], Biao Huang [a, b, *], Mengmeng Jia [a, b], Mengxue Wan [a, b]

[a] Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

HIGHLIGHTS

- A comparative study between solar greenhouse and plastic greenhouse was conducted.
- Cd and Hg could be potential environmental problems in greenhouse soils.
- Accumulation of Cd, Hg, Cu and Zn was ascribed to intensive farming practices.
- Soil properties play a more important role in metal concentrations in SG than in PG.

ARTICLE INFO

Article history:
Received 24 May 2016
Received in revised form
16 August 2016
Accepted 3 September 2016
Available online 30 September 2016

Handling Editor: Shane Snyder

Keywords:
Greenhouse vegetable production
Soils
Heavy metals
Risk assessment
Source identification

ABSTRACT

The evaluation of heavy metals (HMs) in greenhouse soils is crucial for both environmental monitoring and human health; thus, it is imperative to determine their concentrations, identify their sources and assess their potential risks. In this study, eight metals (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) in 167 surface soils were investigated in two representative greenhouse vegetable systems of China: perennial solar greenhouse (SG) and seasonal plastic greenhouse (PG). The results indicated accumulations of Cd, Cu, Hg and Zn in the SG soils and Cd, Pb, Hg and Zn in the PG soils, with higher concentrations than the background values. In particular, Cd and Hg exhibited high levels of pollution under both GVP systems due to their positive Igeo values. Principle component analysis (PCA) and correlation analysis suggested that Cd, Cu, Hg and Zn in the SG soils and Cd, Hg and Zn in the PG soils were mainly related to intensive farming practices; Pb in the PG soils was significantly affected by atmospheric deposition. The results showed that soil characteristics, in particular soil organic matter, total nitrogen and total phosphorus, exerted significant influence on Hg, Cu, Cd, and Zn under the SG system. However, the HMs in the PG soils were weakly affected by soil properties. Overall, this study provides comparative research on the accumulation, potential risks and sources of HMs in two typical greenhouse soils in China, and our findings suggest that, Cd and Hg in both greenhouse soils could potentially represent environmental problems.

1. Introduction

Increasing demand for more nutritious foods has resulted in the intensification of agricultural production (Tilman et al., 2011), which promotes the establishment of greenhouse vegetable production (GVP) (Wang et al., 2011). Currently, GVP accounts for approximately 20% of global total vegetable cultivation area (Hickman, 2011). In China, greenhouses occupied more than 4.1 million hm^2 by the end of 2014. Although GVP has been considered to be a promising contributor to vegetable yields (Wu et al., 2015), this intense agricultural practice, which involves large chemical inputs, a high multi-cropping index, and high productivity, has caused some environmental issues (Gil et al., 2004; Zeng et al., 2008; Rodríguez Martín et al., 2013; Chen et al., 2014; Sungur et al., 2016). One of the most common problems is the increasing accumulation of heavy metals (HMs) in soils due to the

---

* Corresponding author. Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China.
E-mail address: bhuang@issas.ac.cn (B. Huang).

http://dx.doi.org/10.1016/j.chemosphere.2016.09.012

anthropogenic activities, such as excessive use of fertilizers, manures and agrochemicals, irrigation and atmospheric deposition (Gil et al., 2004; Bai et al., 2015). For example, Xu et al. (2015) reported that elevated levels of As and Cd might be attributable to the application of manures and fertilizers and that elevated Cr concentrations mainly come from wastewater irrigation in a GVP system in Beijing. Thus, GVP faces great challenges associated with ensuring vegetable security while increasing yields and reducing environmental costs (Yang et al., 2013).

China is the country with largest vegetable production, accounting for 51.6% of the total production worldwide in 2009 (Yan et al., 2013). The dominant types of greenhouse are the solar greenhouse (SG) in moderately temperate to warm temperate regions and plastic greenhouse (PG) in the northern subtropical regions (Wang et al., 2011; Wu et al., 2015). Considerable research has mainly focused on the assessment of HMs in single greenhouse types or at single sites (Yang et al., 2014; Bai et al., 2015; Xu et al., 2015), whereas a comparative research between SG and PG is relatively lacking. For example, Chen et al. (2013) observed that the accumulation of HMs was caused by the application of large amounts of chicken manures in GVP in Nanjing. Similar results were also found by Hu et al. (2014), who reported that high concentrations of HMs in soils mainly came from anthropogenic activities. Therefore, it is imperative to assess the potential risk of HMs and identify their sources in different greenhouses to provide a scientific basis for developing sustainable greenhouses while minimizing environmental impacts.

Generally, HMs are known to originate from parent materials and can be enriched by anthropogenic activities (Rodríguez Martín et al., 2006). The major anthropogenic sources of HMs to agricultural soils included inorganic fertilizers, manures, sewage sludge, agrochemicals, irrigation water and atmospheric deposition (Bai et al., 2015). Nanos and Rodríguez Martín (2012) also reported that agricultural practices may cause enrichment of HMs. Atmospheric deposition has been identified as the main sources of HMs entering soils (Xia et al., 2014). Hou et al. (2014) observed that irrigation water and atmospheric deposition were important sources of HMs in the Yangtze River Delta. Previous studies indicated that multiple sources of HMs were present simultaneously (Franco-Uría et al., 2009; Sun et al., 2013). Therefore, it is not feasible to identify sources of HMs because it is hard to differentiate among these sources (Li et al., 2015). The most commonly used approach for identifying the major sources of HMs is to classify metals into several groups using multivariate statistical analysis, e.g., correlation analysis, PCA (principal component analysis) and CA (cluster analysis), and perform a simple comparison with their background values (BVs) (Facchinelli et al., 2001; Chai et al., 2015). Although such a method can succeeded at source identification, it should be noted that this method has mainly been conducted to qualitatively determine sources and rarely performed for quantitative source identification (Luo et al., 2015). Currently, some quantitative methods have been developed for source identification (Li et al., 2015; Luo et al., 2015). For example, a receptor model (Absolute principal component scores-multiple linear regression, APCS-MLR) was developed to quantify the source contributions for HMs in urban soils (Luo et al., 2015). However, contribution values greater than 100% and less than zero were found using this method, which confused the analysis. Li et al. (2015) developed a feasible method for quantitative source identification by introducing an index, enrichment factor (EF), to the conventional multiple linear regression (MLR). EF, representing the effects of anthropogenic sources, was defined as the relative ratio of the concentrations of the target metal to a reference metal (Karim et al., 2015; Li et al., 2015). However, there was always a positive correlation between concentrations of HMs and their EFs because the concentrations of the reference metals (e.g., Al, Fe, Ca, K, and Mg) were considerably higher than that of target metal. Therefore, we use the principal component scores instead of EFs as the independent variables in MLR to quantify the contributor of sources. In addition, understanding the levels and HM sources in greenhouse soils requires taking into account that soil properties can influence the fate of these metals in the soils (Gil et al., 2004; Rodríguez Martín et al., 2013; Li et al., 2015). Therefore, quantifying general relationships between concentration levels of HMs and their sources and soil properties is of critical importance for predicting how these metals will be affected by their sources and soil environmental factors.

The objectives of this study were to assess the accumulation and potential risk of HMs in different greenhouses, to identify their major sources by multivariate statistical analysis, and to quantify the effects of the sources and soil environmental factors on these metals.

2. Materials and methods

2.1. Site characteristics

In China, the leading GVP systems are mostly concentrated in eastern China, which is economically developed and has a large population and arable land. Therefore, two representative GVP systems along the coast of the Yellow Sea were selected to represent the dominant types of greenhouses (Fig. 1). One site was located in Dongtai of Jiangsu Province. This area belongs to the transition from a subtropical to warm temperate zone with a monsoon climate; it has a mean annual precipitation of 1061 mm and a mean annual temperature of 15 °C. The dominant soils are Halosols (Gong et al., 2003), which developed from the marine deposits. The other site was located in Shouguang of Shandong province, with a warm temperate continental monsoon climate. On average, the region receives 708.4 mm of precipitation per year, and the mean temperature is 13.2 °C, ranging from −3.1 °C in January to 26.5 °C in July. The soil parent material is composed of alluvium from Mount Tai-Yi, and the main soil type is Cambosols (Gong et al., 2003). Topographically, both sites are coastal plains with low elevations. According to previous studies, the soils in both areas exhibited low concentrations of HMs (Chen et al., 1985; Fang et al., 1991).

The perennial SG was located in Shouguang, where the greenhouse is operated with continuous cultivation by local farmers. The vegetables are generally grown year-round, with growing periods of 10 months from August to June of the next year and a fallow period of approximately 2 months. The dominant greenhouse vegetables are pepper, eggplant, tomato, cucumber, and melon. Unlike the SG in Shouguang, the greenhouse type in Dongtai is seasonal PG, which is used only during winter (from October to the following April). A rotation system of alternating greenhouse and conventional farming is practiced by individual families. Vegetables are grown in rotation, i.e., vegetable–vegetable rotation and then wheat–rice/maize rotation. Alternatively, vegetable–corn/bean rotation is also used. Some major vegetables include cauliflower, cabbage, carrot, radish, turnip, lettuce, broccoli, pepper and watermelon.

According to our investigation, chicken manure, compound fertilizer and urea are the three main fertilizers used for vegetable cultivation in both areas. Chicken manure is applied as a basal fertilizer. Compound fertilizer and urea are applied each year as basal and topdressing fertilizers. Similar quantities of compound fertilizers were used at both site, but the amounts of chicken manure and urea were much higher in the SG than in the PG (Table A. 1). This difference was mainly due to the different cultivation systems between the two greenhouses. Irrigation was