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Soil threshold values for cadmium based on paired soil-vegetable content analyses of greenhouse vegetable production systems in China: Implications for safe food production

Wenyou Hu [a, b], Biao Huang [a, *], Ole K. Borggaard [b], Mao Ye [a], Kang Tian [a, c], Haidong Zhang [a, c], Peter E. Holm [b, d]

[a] Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, 210008, China
[b] University of Copenhagen, Faculty of Science, Department of Plant and Environmental Sciences, Thorvaldsensvej 40, DK-1871, Frederiksberg C, Denmark
[c] University of Chinese Academy of Sciences, Beijing, 100049, China
[d] Sino-Danish Center for Education and Research (SDC), China

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ABSTRACT

Greenhouse vegetable production (GVP) is the major type of vegetable production in China. However, dietary exposure of heavy metals through vegetable consumption has been identified as a potential risk to human health. To ensure safety of vegetables, soil threshold values (STVs) of cadmium (Cd) in GVP systems were assessed based on analysis of soil-vegetable Cd contents in relation to human health risk. Contents of Cd were determined in 324 sampled soil-vegetable pairs from five GVP systems in three Chinese provinces. Soil Cd contents ranged from 0.07 to 1.32 mg kg^{-1}, with 17.9% of sampled soils exceeding current Chinese threshold values. Vegetable Cd contents ranged from 0.0003 to 0.546 mg kg^{-1}, with 8.6% exceeding permissible maxima. Vegetable type and soil pH significantly affected Cd transfer from soil to vegetable with lower transfer at neutral ($6.5 < pH \leq 7.5$) to alkaline ($pH > 7.5$) soils and uptake decreasing in the order: Leafy > rootstalk > fruit. Consequently, both soil pH and vegetable type should be taken into consideration as suggested when revising current STVs for Cd in GVP systems in order to capture the health risk correctly and ensure safe vegetable consumption.

1. Introduction

Greenhouse vegetable production (GVP) has grown rapidly and become the major type of vegetable production in China. The Chinese GVP areas reached 2.0 million ha in 2013 accounting for 85% of global GVP (Xu et al., 2015; Hu et al., 2017a). In the high-intensity GVP systems, excessive fertilization has resulted in heavy metal accumulation and soil acidification, which, in turn, increase heavy metal accumulation in the vegetables, and the health risk of vegetable consumers (Yang et al., 2014; Sungur et al., 2016; Hu et al., 2017a). Cadmium (Cd) is a non-essential, toxic heavy metal that is easily taken up by plants (Yang et al., 2009; Ding et al., 2013; Yang et al., 2017). Dietary exposure of Cd through vegetable consumption has been identified as a potential risk to human health (Jolly et al., 2013; Lin et al., 2015; Hu et al., 2017a). Nationwide surveys showed that the Cd content in 7% of the soil samples exceeded current Chinese threshold values (soil environmental quality standard, SEQS) emphasizing the need for special precautions with this element (MEP & MLR, 2014; Zhao et al., 2015). However, although several studies have been conducted on heavy metal contents in GVP systems, large-scale survey of influence of soil Cd on corresponding vegetable Cd contents, and hence health risk for vegetable consumers in different GVP systems is lacking (Yang et al., 2014; Xu et al., 2015; Sungur et al., 2016; Hu et al., 2017a).

According to the Chinese SEQS from 2006, which also apply to GVP systems, maximum limited levels (MLLs) of Cd and other pollutants do not take into account the importance of soil characteristics and vegetable types (MEP, 2006; Rafiq et al., 2014; Huang et al., 2015; Xu et al., 2015). Furthermore, although several studies have addressed uptake of Cd (and other heavy metals) by plants under different conditions, these studies were mainly based on pot

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

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experiments with spiked soils (Zhao et al., 2006; Wang et al., 2007; Yang et al., 2009; Sun et al., 2013), which cannot directly be transferred to field including GVP conditions (Lin et al., 2015; Hu et al., 2017a). To ensure safe consumption of the vegetables, it is therefore imperative to develop soil threshold values (STVs) based on relationship between the concentration of Cd in soils and its transfer to the edible parts of vegetables based on field data.

In this study, five typical intensive GVP systems of China were chosen as case study areas to systematically evaluate the transfer characteristic of Cd from soil to vegetables and the corresponding potential health risk. The investigation relied on a large scale field study with paired sampling of soil and vegetables. The objectives of this study are: (1) to characterize and identify the factors that determine the Cd transfer from soil to the edible part of vegetables under different environmental conditions; (2) to assess the potential health risk by consumption of different types of vegetables; and (3) to establish STVs of Cd based on the paired soil-vegetable investigation in different areas. The result of this study will provide a scientific basis for further revision of the SEQS in order to ensure the food safety for GVP in China and elsewhere.

2. Materials and methods

2.1. Description of the case study areas

Five typical sites representing the major types of GVP systems in China were selected in Shandong Province, North China, in Jiangsu Province, East China and in Yunnan Province, Southwest China (Fig. 1). In these sites, greenhouses are used for intensive production of vegetables, accounting for all types of GVP systems in China. Compared with the GVP area in other regions of China, the share of eastern areas, especially along the coast of Yellow Sea accounts for more than 60% of the total GVP area in China (Hu et al., 2017b). The detailed information concerning GVP in the studied areas was described in the accompanying supplementary material.

2.2. Sampling of soil-vegetable pairs

This study was carried out based on a systematic investigation of GVP systems throughout the above-mentioned areas. The selected GVP sites were chosen according to field survey characteristics such as vegetable types, type of greenhouse production systems, years in vegetable production, soil types and properties (Table S1). The information of GVP at each sampling site was recorded through interviews with local agricultural managers and farmers using a structured questionnaire. Based upon the edible parts of collected vegetables, the vegetables were classified into the 3 types: leafy vegetables (N = 163), rootstalk vegetables (N = 66) and fruit vegetables (N = 95). The detailed information about the different types and species of the vegetables has been described by Hu et al. (2017a) and Yang et al. (2014).

A total of 324 paired surface soil (0–20 cm) and corresponding vegetable samples were collected from 2011 to 2014 during the harvest periods. Leafy vegetables were preferred for sampling since past research showed that they accumulate Cd at higher levels than other greenhouse vegetables (Hu et al., 2017a). At each point a representative sample was taken composed of five soils/plants' subsamples within 5 m^2. Only the edible parts of vegetables were collected. An amount of 1 kg fresh soil and 1 kg vegetable samples were totally collected to provide a representative sample of each soil and vegetable. All sampling sites were geo-located in the middle of the locations of the five subsamples using a global positioning system receiver. Soil and vegetable samples were placed in plastic bags and brought to the laboratory for analysis.

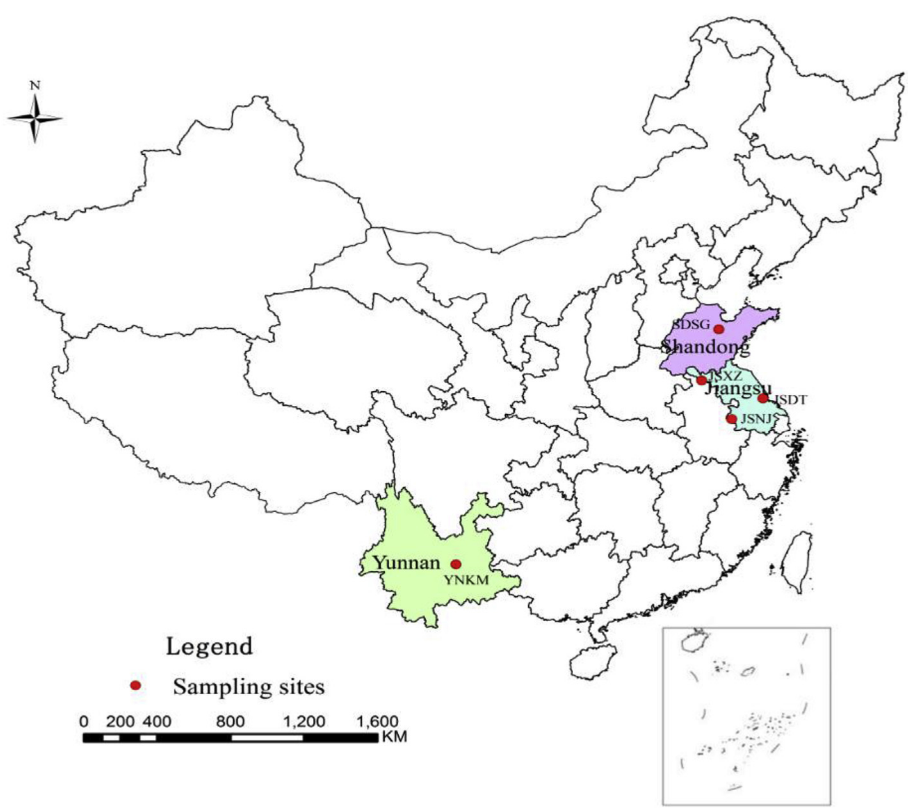

Fig. 1. Locations of the five studied greenhouse vegetable production systems (SDSG: Shandong Shouguang; JSXZ: Jiangsu Xuzhou; JSNJ: Jiangsu Nanjing; JSDT: Jiangsu Dongtai; YNKM: Yunnan Kunming).