Ecotoxicology and Environmental Safety 96 (2013) 182–190

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

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

Prediction of cadmium concentration in selected home-produced vegetables

Petra Karo Bešter[a,*], Franc Lobnik[b], Ivan Eržen[c], Damijana Kastelec[b], Marko Zupan[b]

[a] OIKOS Development Consulting Ltd., Glavni trg 19, 1241 Kamnik, Slovenia
[b] University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, 1000 Ljubljana, Slovenia
[c] University of Ljubljana, Faculty of Medicine, Vrazov trg 2, 1104 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 20 February 2013
Received in revised form
4 June 2013
Accepted 7 June 2013
Available online 22 July 2013

Keywords:
Contamination
Cadmium
Soil
Vegetables
Regression models

ABSTRACT

Soil contaminated with cadmium presents a potential hazard for humans, animals and plants. The latter play a major role in the transfer of cadmium to the food chain. The uptake of cadmium and its accumulation by plants is dependent on various soil, plants and environmental factors. In order to identify soil properties with statistically significant influence on cadmium concentration in vegetables and to reduce the collection of data, time and costs, regression models can be applied. The main objective of this research was to develop regression models to predict the concentration of cadmium in 9-vegetable species: zucchini, tomato, cabbage, onion, potato, carrot, red beet, endive and chicory, based on soil properties. Soil samples were collected from 123 home gardens of the Municipality of Celje and 59 of these gardens were also included in vegetable sampling. The concentration of elements (e.g. arsenic, cadmium, copper, lead, and zinc) in the samples was determined by Inductively Coupled Plasma Mass Spectrometry. Single (for cabbage, potato, red beet and chicory) and multiple (for tomato, onion, carrot and endive) linear regression models were developed. There was no statistically significant regression model for zucchini. The most significant parameter for the influencing the cadmium concentration in vegetables was the concentration of cadmium in soil. Other important soil properties were the content of organic matter, pH-value and the concentration of manganese. It was concluded that consuming carrots, red beets, endives, onions, potatoes and chicory which are grown in gardens with Cd concentrations (mg kg^{-1} DW) above 2.4, 3.2, 6.3, 7.9, 8.3 and 10.9, respectively, might represent an important contribution to dietary Cd exposure.

1. Introduction

Cadmium (Cd) is an important environmental pollutant due to its wide application. It is used in nickel-Cd batteries, pigments, stabilizers, coatings, alloys (ICdA, 2012) and in modern technology, such as the communication, electronics, power generation, aerospace and vehicle industries (WHO, 2000). Cd is also used as a component in some types of compost, agricultural fertilizers and as sewage sludge to soil, which may also lead to contamination of soil and later to crops. A number of studies have reported that vegetables (especially leafy vegetables) grown in soils contaminated with heavy metals such as Cd have higher concentrations of heavy metals compared to vegetables grown in uncontaminated soil (Dowdy and Larson, 1975; Guttormsen et al., 1995; McLaughlin and Singh, 1999). When safe concentrations of heavy metals in soils are exceeded, the yield and quality of vegetable produce are decreased. Moreover, contaminated soil presents a potential health hazard for humans, animals and plants. The latter plays a major role in the transfer of Cd to the food chain, via their edible parts (McLaughlin and Singh, 1999) and may be hazardous to human and animal health even at a concentration level which is not phytotoxic (Bergmann, 1992).

Mechanisms of Cd uptake by plant roots and Cd accumulation in plants are very complex as the mobility of Cd in the soil and transport to the plant depends on various factors (e.g. soil, plant and environment). For example, the plant uptake of Cd is increased when the total and available concentration of Cd in soil is high, salinity is high, temperature is high, or pH, clay, organic matter, cation exchange capacity, iron(Fe) and zinc (Zn) are low (Meeus et al., 2002). The plant uptake of Cd is also affected by plant factors e.g. plant tissue and species, age and root activity (McLaughlin and Singh, 1999). Various plants accumulate Cd at different concentrations. Several researchers have reported the orders of Cd accumulation by plants. He and Singh (1994) concluded the following order: leafy vegetables > root vegetables > grain crops. Alexander et al. (2006) determined that concentrations of cadmium in plants

* Corresponding author.
E-mail addresses: petra_karo@yahoo.com, petra_karo@hotmail.com.(P.K. Bešter)

0147-6513/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
10.1016/j.ecoenv.2013.06.011

decreased in relative order: lettuce > spinach > onion > carrot > pea > French bean. Yang et al. (2010) demonstrated the following order of accumulation of Cd by vegetables: leafy vegetables > solanaceous vegetables > kale vegetables > root vegetables > alliums > melon vegetables > legumes.

Given the above, and as time and funding in risk assessments (human and ecological) are often limited, regression models can be a very useful tool for estimating the concentration of Cd in vegetables, based on soil properties. Moreover, regression models identify statistically significant soil properties, which have an influence on the accumulation of Cd by the plant. Identifying these soil properties enables one to significantly reduce the transfer of Cd in the food-chain and hence reduce the risk to human and animal health. Regression models in the literature mainly identify the concentration of Cd and pH-value of soil as the main statistically significant influences on Cd concentration on plants (Alloway et al., 1990; McBride, 2002; Zupan, 2003)

The Research area of this study was the Municipality of Celje, which is the third largest city in Slovenia. The population of the city is approximately 48.682 people (SURS, 2013). Several studies (Domitrovič-Uranjek, 1988; Lobnik et al., 1989; Šajn,1999) have concluded that the soil of the area is in some areas polluted with heavy metals, like Cd, lead and zinc as a consequence of the past zinc smelter and industry in the city. Other important sources of pollution in the Municipality are residential combustion, road traffic, waste management and agriculture. Moreover, the Municipality of Celje is located in Celje basin, where a temperature inversion occurs in wintertime, which causes trapping of cold air at the bottom of the basin and hence increases pollution. Due to various influences on air pollution in municipality the spatial variation of the Cd concentration in soil is large. Therefore, this area is appropriate for researching the relationship between soil properties and Cd concentration in vegetables. In the past Zupan et al. (1996), Klavs (2004) and Eržen et al. (2005) determined the concentration of Cd in plants grown in the Municipality. The highest concentrations of Cd were determined for spinach (0.648 mg kg^{-1} FW), carrot (0.143 mg kg^{-1} FW) and lettuce (0.375 mg kg^{-1} FW) and the lowest for Brussels sprouts (< 0.011 mg kg^{-1} FW), cucumber (0.006 mg kg^{-1} FW) and bean (0.015 mg kg^{-1} FW), respectively. Eržen et al. (2005) concluded that the average concentrations of Cd in plants produced in the Municipality of Celje were much higher than the average concentration of Cd in Slovenian vegetables. Their results are summarized in Table 1.

This study was conducted as a part of the research project titled "Risk assessment of Cd intake from home grown vegetables on the local population of the Municipality of Celje". The main goal was to design statistical models which include soil properties as explanatory variables in order to predict the concentration of Cd in 9 selected vegetable species. Hence, in the future in many cases only information about soil properties will be needed to assess the concentration of Cd in selected vegetables and to further assess the intake of Cd in the food chain. Contamination of soil with heavy metals due to smelters or other sources of metals is an environmental problem on a global scale (Salvatore et al., 2009). Therefore, the findings of this research might be important during the evaluation of potential health hazard on garden owners who are producing vegetables in such areas (Cui et al., 2004; Zheng et al., 2007). It is of great practical interest to know which soil properties affect most the concentration of Cd in vegetables and when garden owners might expect an excessive Cd concentration in vegetables.

2. Materials and methods

Locations for soil and vegetables sampling were selected based on potential contamination (Lobnik et al., 1989; Eržen et al., 2005; Zupan et al., 1996; Klavs, 2004), density and distribution of gardens in the research area. Fig. 1 illustrates the locations where soil and vegetable samples were collected. The sampling took place in August and September in 2008. Soil samples were collected from 123 home gardens of the Municipality of Celje and 59 of these gardens were also included in vegetable sampling. One composite soil sample was collected in each garden. Two samples were collected in gardens where the soil was partially flooded or replaced and where vegetables were grown in two separate gardens. Therefore, the total number of soil samples was 141 and the total number of vegetable samples was 287 of 9 vegetable species. Only the edible parts of the vegetables were sampled as the research was focused on the pathway of Cd from soil via vegetable to human.

2.1. Soil samples

The following characteristics of garden soils sampled at 0–20 cm depth and prepared according to SIST ISO 10381-5, 2006 and SIST ISO 11464, 2006 were determined:

- pH-value (electrometrically in suspension of 10 ml soil sample and 50 ml of 0.01 M $CaCl_2$, according to SIST ISO 10390, 1996);
- texture according to the American Soil Classification (the sediment pipette method, according to Janitzky (1986), Soil Survey Manual (1992));

Table 1
The average concentrations of Cd (mg kg^{-1} FW) in vegetables reported by the authors, who studied the research area of the Municipality of Celje.

Vegetables	Zupan et al. (1996)			Klavs (2004)		Eržen et al. (2005)					
	The control site-outside Municipality	Site 1—Medlog	Site 2 —Oblakova	The Municipality of Celje		Local community Teharje		Local Community Medlog		Slovenia	
	$\bar{x}$	$\bar{x}$	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
Endive	0.007	0.108	0.552	16	0.114						
Chicory				22	0.111						
Lettuce	0.010	0.047	0.074			12	0.375	7	0.128	68	0.026
Spinach	0.051	0.249	0.648								
Cabbage	< 0.010	< 0.010	0.014			12	0.037	7	0.012	54	0.005
Brussels sprouts	< 0.011	< 0.011	0.013								
Carrot	0.022	0.216	0.241	29	0.143	14	0.261	6	0.121	63	0.021
Red beet	< 0.013	0.048	0.234			12	0.282	7	0.184	59	0.015
Radish	< 0.006	0.037	0.062								
Tomato	< 0.007	0.028	0.074	28	0.034	9	0.061	4	0.029	55	0.007
Cucumber				20	0.006	9	0.026	3	0.006	61	0.004
Potato	0.024	0.029	0.103			9	0.121	4	0.087	60	0.022
Kohlrabi	< 0.022	< 0.022	< 0.022								
Bean	< 0.022					13	0.015	4	0.016	57	0.007

Where $\bar{x}$—average concentration; n—number of samples.