Journal of Integrative Agriculture 2016, 15(10): 2393–2402

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RESEARCH ARTICLE

Prediction model for mercury transfer from soil to corn grain and its cross-species extrapolation

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Abstract
In this study the transfer characteristics of mercury (Hg) from a wide range of Chinese soils to corn grain (cultivar Zhengdan 958) were investigated. Prediction models were developed for determining the Hg bioconcentration factor (BCF) of Zhengdan 958 from soil, including the soil properties, such as pH, organic matter (OM) concentration, cation exchange capacity (CEC), total nitrogen concentration (TN), total phosphorus concentration (TP), total potassium concentration (TK), and total Hg concentration (THg), using multiple stepwise regression analysis. These prediction models were applied to other non-model corn cultivars using a cross-species extrapolation approach. The results indicated that the soil pH was the most important factor associated with the transfer of Hg from soil to corn grain. Hg bioaccumulation in corn grain increased with the decreasing pH. No significant differences were found between two prediction models derived from different rates of Hg applied to the soil as $HgCl_2$. The prediction models established in this study can be applied to other non-model corn cultivars and are useful for predicting Hg bioconcentration in corn grain and assessing the ecological risk of Hg in different soils.

Keywords: soils, corn grain, bioconcentration factor (BCF), prediction model, Hg

1. Introduction

Mercury (Hg) is an extremely toxic pollutant that poses global environmental and human health risks (Selin 2009; Henriques *et al.* 2013). It has received considerable attention as a global contaminant and is one of the most toxic pollutants that can cause adverse ecological and toxicological impacts through the mechanisms of bioaccumulation and biomagnifications (Lin *et al*. 2012). Mercury in agricultural soil usually comes from the continuous use of fertilizer and Hg-containing fungicides in the production of crops and vegetables as well as the widespread application of sewage sludge (Lin *et al*. 2012; Li *et al*. 2013). Mercury accumulation in higher plants results in reduced growth and alteres cellular function which may lead to associated human health risk (Gao *et al*. 2010; Costa *et al*. 2011; Sahu *et al*. 2012). Increasing evidence has shown that Hg in soils can easily accumulate in higher plants (Wang and Greger 2004; Israr *et al*. 2006). Mercury exposure can cause health problems not only at acute high doses as in Minamata disease (Harada 1995),

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Received 11 August, 2015 Accepted 18 December, 2015
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doi: 10.1016/S2095-3119(15)61261-8

but also at chronic low doses (Zahir *et al*. 2005). In China, 20 million ha of cultivated land, accounting for approximately 20% of the total area under cultivation, is contaminated by Hg and other heavy metals from various human activities (Zeng *et al*. 2006). Because of the potential health threat from Hg toxicity, the transfer of Hg from soils to plants, especially to edible parts of plants in agricultural soils, is of great concern (Peng *et al*. 2012; Rodrigues *et al*. 2012).

The ability of plants to absorb metals is mainly evaluated by determining plant content of the metal or the metal transfer factors from soil to plant (Pérez-Sanz *et al*. 2012; Sierra *et al*. 2012; Ding *et al*. 2014). The Hg transfer factor from soil to plant mainly depends on its availability in soils. The availability of Hg to plants varies significantly with soil type due to differences in soil properties. Soil properties exhibiting strong effects on the mobility and availability of Hg in soil include pH, organic matter (OM) content, texture, cation exchange capacity (CEC), and Fe and Al oxide and sulfate content (Pérez-Sanz *et al*. 2012; Sierra *et al*. 2012; Ding *et al*. 2014). Soil pH is a major factor controlling cation mobility and regulating the solubility of heavy metals in soils (Bang and Hesterberg 2004; Rodríguez *et al*. 2008) as heavy metals are often more soluble in soils with low pH (Yang *et al*. 2013; Li *et al*. 2014). The transference of Hg from soil to plant occurs more readily in acidic soils than soils with higher pH (Ding *et al*. 2014). The key for assessing the ecological risk of heavy metals in complex soil types, therefore, is to develop predictive models that take into account the influence of soil factors known to influence the availability and transfer of the metals from soil into crops (Tipping *et al*. 2010).

Species sensitivity distribution (SSD) bioavailability normalization has been a successful and increasingly used method in ecological risk assessment (Larras *et al*. 2012; Zhao *et al*. 2013). However, variability in soils may result in variability in ecological risk assessments in different soils and in the soil quality criteria for heavy metals (Schlekat *et al*. 2010). In addition to soil factors, heavy metal transfer from soil to plant depends on plant cultivars. It has been observed that significant differences exist in heavy metal uptake among plant cultivars (Chen *et al*. 2009). Therefore, the toxicology data from the soils with different soil properties needs to be normalized using prediction models to eliminate the influence of soil factors (Van Sprang *et al*. 2009). Extrapolation of toxicity models across species has been attempted for some pollutants. The basis for cross-species extrapolation is the assumption that the parameters which describe interactions between soil properties such as pH, OM, CEC, and cations (notably Ca^{2+}, Mg^{2+} and H^+) and toxic metals are constant across plant species, and that only intrinsic sensitivity varies among species (Van Sprang *et al*. 2009). This assumption has been supported by previous studies, for example, the biotic ligand model (BLM) from the fish species *Oncorhynchus mykiss* has been applied to other fish species and the BLM from the cladoceran *Daphnia magna* has been applied to other cladocera species (Deleebeeck *et al*. 2007a, b). Chronic nickel BLMs developed for cladocera such as *Daphnia magna* and *Ceriodaphnia dubia* have been used to predict chronic toxicity of nickel in three other invertebrates including snail (*Lymnaea stagnalis*), insect (*Chironomus tentans*) and rotifer (*Brachionus calyciflorus*) (Schlekat *et al*. 2010). We have previously applied the corn grain Cd and Pb BCF prediction models developed for cultivar Zhengdan 958 to other non-model corn cultivars and to wheat grain (Yang *et al*. 2013; Li *et al*. 2014). However, little effort has been committed to developing models to describe the relationship between corn grain Hg uptake and soil properties. Hence, the scientific objectives of this study are as follows: (1) to investigate the transfer characteristics of Hg from 18 soils with different properties to corn grain, (2) to identify the major controlling factors and develop prediction models, and then (3) to assess the feasibility and accuracy of applying these models to other non-model corn cultivars.

2. Materials and methods

2.1. Soil samples

A total of 18 soils covering a wide range of soil properties were collected from typical locations to be representative of the major soil types in China. In each sample site, soil samples were taken from the top 20 cm of the soil profile using a stainless steel spade and then were mixed thoroughly. For analysis of their chemical characteristics, the soil was air-dried at room temperature, homogenized, and ground to pass a 2-mm sieve. Soil pH was measured in deionized water (soil:solution ratio, 1:5) (Sparks *et al*. 1996). The organic matter concentration in soil was measured by dry combustion (Ball 1964), and cation exchange capacity (CEC) was determined by the unbuffered silver-thiourea method (Dohrmann 2006). The total nitrogen concentration in soils (TN) was determined by the Kjeldahl method (Bremner 1996). The total phosphorus concentration in soil (TP) was measured by the colorimetric method described by Bray and Kurtz (1945). The total potassium concentration in soil (TK) was measured by the flame photometry method. The background Hg content in the soils was determined by atomic absorption spectroscopy after aqua regia (1:3 fresh mixture of concentrated HNO_3 and HCl) digestion (Zarcinas *et al*. 1996). Selected physical and chemical characteristics of the 18 soil samples were shown in Table 1.

2.2. Experimental design

Determination of bioaccumulation factors Total 18 soils

Table 1 Selected soil properties of the 18 soils used in the pot trial to assess mercury uptake and transport in corn grain[1)]

Soil no.[2)]	Location	pH	OM (g kg^{-1})	CEC (coml kg^{-1})	TN (g kg^{-1})	TP (g kg^{-1})	TK (g kg^{-1})	Soil classification	Background Hg (mg kg^{-1})
S1	Hunan	4.90	15.52	10.85	1.14	0.47	15.26	Anthrosols	0.079
S2	Chongqing	5.74	17.48	21.34	1.00	0.55	22.61	Cambosols	0.056
S3	Liaoning	5.74	25.84	12.19	1.00	0.73	23.94	Argosols	0.103
S4	Yunnan	5.92	34.26	11.10	2.01	0.81	4.77	Ferrosols	0.092
S5	Jiangxi	6.01	11.69	8.70	0.51	0.52	9.96	Ferrosols	0.070
S6	Anhui	6.25	20.04	19.08	0.99	0.35	15.41	Argosols	0.071
S7	Heilongjiang	6.27	35.69	28.59	1.74	0.48	24.70	Isohumosols	0.064
S8	Jilin	6.82	32.85	31.11	1.75	0.35	24.58	Isohumosols	0.085
S9	Jiangsu	6.93	47.69	26.20	2.44	0.69	21.03	Argosols	0.056
S10	Shaanxi	7.90	16.49	22.37	1.36	0.98	24.37	Anthrosols	0.085
S11	Hebei	7.98	8.57	8.12	0.68	0.53	24.22	Cambosols	0.083
S12	Henan	8.07	17.79	16.01	1.07	0.75	19.86	Cambosols	0.086
S13	Xinjiang	8.12	19.43	25.25	1.32	0.78	25.49	Aridosols	0.065
S14	Shanxi	8.24	23.17	16.80	1.13	0.95	23.70	Cambosols	0.104
S15	Tianjin	8.29	22.02	24.67	1.42	0.92	24.63	Cambosols	0.061
S16	Gansu	8.37	19.27	11.23	1.05	0.74	23.62	Anthrosols	0.090
S17	Shandong	8.65	11.84	13.09	0.93	0.97	21.37	Cambosols	0.067
S18	Neimeng	8.80	16.30	11.61	0.96	0.38	26.40	Isohumosols	0.068

[1)] OM, organic matter; CEC, cation exchange capacity; TN, total nitrogen concentration; TP, total phosphorus concentration; TK, total potassium concentration.

[2)] Soil samples are listed in the order of increasing pH.

with different properties were used to estimate BCF values. The amount of Hg added to the soils of different treatments was calculated according to the Grade Two Standard for Hg in the Soil Environmental Quality Standards of China (GB15618-1995). Except for the control treatment to which no Hg was added, amounts equivalent to the standard level, and twice the standard level were added to the soils to give low and high rates of added Hg, respectively (Table 2). To obtain the required levels, an appropriate amount of Mercuric chloride water solution ($HgCl_2$ solution) was continuously sprayed on the 8 kg of air-dried soils with the constantly blending. The soils were then thoroughly mixed and placed into pots (φ×h, 23 cm×26.5 cm) and moistened with deionized water to make the soil moisture reach to 60% of field moisture capacity. Three replicates were performed for each tested level of Hg. The pots were covered by plastic film with several pores for air ventilation. The soils were left for aging of the added Hg at a temperature of (25±3)°C during the daytime and (20±3)°C at night with a natural light photoperiod in a greenhouse for 3 mon. During the aging period, soil moisture was maintained by adding deionized water every 3 d. After aging, uniform seeds of corn (*Zea may* L. *cv*. Zhengdan 958) were sown in each soil containing Hg. During the growing period, soil moisture content was maintained at approximately 60% of water holding capacity by weighing the pots and adding deionized water as necessary to replace water lost by evaporation and transpiration. The corn plants were harvested at maturity in October and corn grain samples were collected using a random sampling method.

Table 2 The Grade Two Standard in the Soil Environmental Quality Standards of China for Hg (GB15618-1995) and the amounts of Hg added as $HgCl_2$ (mg kg^{-1})

pH	<6.5	6.5–7.5	>7.5
Grade two standard	0.3	0.5	1
Low Hg	0.3	0.5	1
High Hg	0.6	1.0	2

Bioaccumulation factors for Hg for five corn cultivars in two soils In this experiment, two soils sampled from Jiangxi and Shanxi provinces were selected. Three levels of Hg were added to the soils as described in the previous experiment (Table 2). Three replicates were carried out for each treatment. The seeds of the corn cultivars Jingketian 183, Liaodan 565, Tunyu 88, Zhongdan 808, and Nongda 84, were surface sterilized with 1% (v/v) NaOCl, rinsed, and soaked in distilled water for 24 h at 33°C in the dark. After 3-mon aging of soils, these seeds were sown in each soil containing Hg. The pots were placed in the greenhouse at a temperature of (25±3)°C during the daytime and (20±3)°C at night with a natural light photoperiod.

2.3. Soil and plant analysis

After 3-mon aging, soils in each pot of the above two experiments were sampled, air-dried, and passed through a 0.20-mm sieve. 0.25 g of the soil sample was weighed and added into 50-mL glass colorimetric tubes and moistened with a few drops of deionized water and 25 mL 1+1 aqua regia (aqua regia+deionized water) was added. Then the tubes were digested in a boiling water bath for 2 h. After cooling, total Hg was determined in the supernatant.

The corn grain was harvested and oven-dried at 105°C for 30 min and then kept at 70°C until the grain weight was stable. 0.5 g of the soil sample was digested in 6 mL concentrated HNO_3 and 3 mL H_2O_2 in a CEM Mars X microwave oven at a pressure of 3.1 MPa. The concentration of Hg in the digest solution from soil and grain was determined by inductively coupled plasma-mass spectrometry (ICP-MS, Agilent 7500a, Agilent Technologies Co. Ltd., USA).

2.4. Data analysis

The bioconcentration factor (BCF) (also named transfer factor, enrichment factor, uptake factor, and bioaccumulation factor) is used to evaluate the transfer potential of a metal from soil to plant. It was calculated as the ratio of the content of Hg in the corn grain to that in the soil (eq. (1), Baker *et al*. 1994; Raskin *et al*. 1994).

$$BCF=C_{\text{grain}}/C_{\text{soil}} \quad (1)$$

Where, C_{grain} is the Hg concentration in the corn grain and C_{soil} is the total concentration of Hg in the soil.

SPSS 16.0 for Windows® 107 (SPSS Inc, Chicago, IL, USA) was used for the regression analysis and detection of significant differences in the BCF between soils.

2.5. Model

Prediction models for Hg transfer between the soil and corn grain were established through multiple stepwise regression of the Hg BCF values from cultivar Zhengdan 958 in the 18 soils used in the first experiment. These models are based on eq. (2):

$$\text{Log[BCF]}=a\times\text{pH}+b\times\log[\text{OM}]+c\times\log[\text{CEC}]+d\times\log[\text{TN}]$$
$$+e\times\log[\text{TP}]+f\times\log[\text{TK}]+g\times\log[\text{THg}]+k \quad (2)$$

Where, Log[BCF], Log[OM], Log[CEC], Log[TN], Log[TP], Log[TK], and Log[THg], were the logarithm base 10 of the BCF values, the concentration of organic matter (g kg^{-1}) in soils, the cation exchange capacity (cmol kg^{-1}) of soils, the concentration of nitrogen (g kg^{-1}) in soils, the concentration of phosphorus (g kg^{-1}) in soils, the concentration of potassium (g kg^{-1}) in soils, and the concentration of Hg (mg kg^{-1}) in soils, respectively. The soil property parameters *a*, *b*, *c*, *d*, *e*, *f*, and *g* indicate the impacts of the soil properties on Hg accumulation in corn grain, respectively. The intercept *k* is the intrinsic sensitivity that characterizes the ability of corn to absorb Hg.

2.6. Cross-cultivar extrapolation

For cross-cultivar extrapolation, it was assumed that interactions between Hg accumulation in corn grain and soil pH, OM, CEC, TN, TP, TK, and THg were the same among related corn cultivars. That is to say, the model stability constants including *a*, *b*, *c*, *d*, *e*, *f*, and *g* were assumed to be the same among related cultivars, and the only difference between related species was assumed to be their intrinsic sensitivity (*k*) (Schlekat *et al*. 2010). The variation in intrinsic sensitivities within a species among plants reflects residual variation (Van Sprang *et al*. 2009). According to the minimum squared error between the predicted BCF value and the measured BCF value $\sum_{i=1}^{n}(\textit{Measured BCF}_i-\textit{Predicited BCF}_i)^2$, the intercept (*k*) for different models corresponding to various species were obtained through Excel Solver for linear optimization (Wang 2012).

The accuracy of the model predictions was evaluated by comparing the measured BCF of the non-model corn cultivars with the predicted BCF from the model. The predictions for the non-model corn cultivars were calculated with the prediction model derived for cultivar Zhengdan 958.

2.7. Analysis of the reduction of intra-cultivar variability

The Hg BCF values of non-model corn cultivars were normalized to the specific soil conditions through the model obtained for Zhengdan 958 and the intra-cultivar variability was computed by eq. (3) (Wang 2012).

$$f=\sqrt{\frac{\sum_{i=1}^{n}(BCFsi-\overline{BCFs})^2}{(n-1)\times(\overline{BCFs})^2}} \quad (3)$$

Where, the BCF of *i*th condition for specific corn cultivars was normalized to specific soil conditions. *BCFsi* is the value that Hg BCF specific corn species were normalized to *i*th soil conditions. $\overline{BCFs}$ is the mean of *n* BCFs, *n* is the number of different conditions for specific corn cultivars, and *f* is the intra-species variability.

The BCFs for Hg for different corn cultivars were normalized by the prediction models to a set soil condition that should be similar. Therefore, decreased in intra-cultivar variability indicates that the normalization process reduced the influence of soil properties on the BCF.

3. Results

3.1. Major factors affecting Hg accumulation in corn grain in different soils

The accumulation of Hg in corn grain was monitored in three soils with three levels of added Hg. The relationships between Hg concentration in corn grain and soil pH, OM concentration and CEC at the different levels of added Hg are shown in Fig. 1. The Hg content in corn grain decreased with increasing soil pH in the treatments with low and high levels of added Hg ($P<0.01$), but no significant difference was found in the control treatment. No significant correlations were found between Hg concentration in corn grain and soil OM concentration or CEC, which showed that these factors had less effect on plant accumulation of Hg than soil pH. These results indicate that soil pH is an important factor controlling the accumulation of Hg in corn grain from soil.

3.2. Effect of soil type on Hg transfer from soil to corn grain

The accumulation of Hg in corn grain planted in different soils with a wide range of properties was investigated in the corn cultivar Zhengdan 958. Bioconcentration factors differed significantly between the 18 soil types (Fig. 2), the variation between soil types being generally consistent at high and low levels of added Hg. The BCF values decreased with increasing soil pH. Soils from S1 to S9 (pH from 4.90 to 6.93) had significantly higher ($P<0.01$) BCF values than soils S10 to S18 (pH from 7.90 to 8.80) except that S6 had lower BCF value (0.031) than S17 (0.039) at high level added Hg. At the low rate of applied Hg, the maximum BCF value (0.064) among the 18 soils was observed in S4 (pH 5.92), and the minimum value (0.026) was found in S18 (pH 8.80). The maximum value was 2.5-fold greater than the minimum. Similarly, at the high rate of Hg, the highest BCF value (0.069) was observed in S5 (pH 6.01), and the lowest value (0.019) was found in S10 (pH 7.9). At the high Hg rate, the maximum BCF value was 3.6-fold greater than the minimum. There were no significant differences in the BCF values between low levels of added Hg and high levels of added Hg in the same soil sample of 18 soils. These results indicate that Hg under acidic soil conditions is more highly bioavailable and more readily absorbed than under alkaline soil conditions.

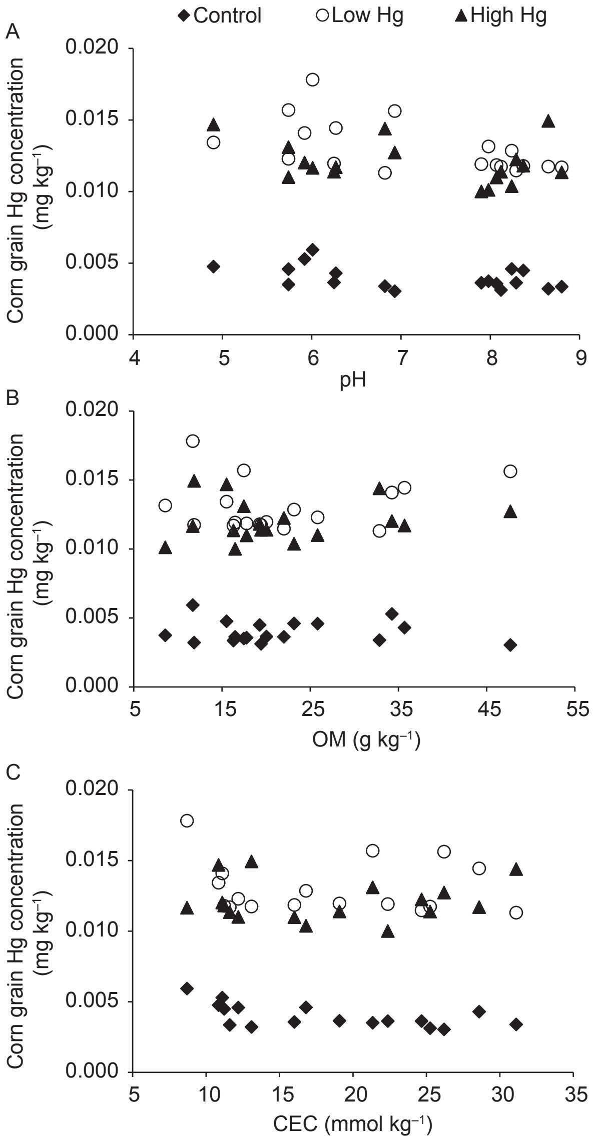

Fig. 1 Relationships between Hg in corn grain and soil pH (A), organic matter concentration (OM, B) and cation exchange capacity (CEC, C).

3.3. Prediction models

The predictive models established by stepwise regression are shown in Table 3. Soil pH was the main factor affecting Hg accumulation in corn grain. The other factors examined (OM content, CEC, TN, TP, TK and THg) did not significantly influence Hg accumulation. A significantly negative correlation existed between the Log[BCF] and soil pH at both low and high rates of added Hg, with the R^2 values of 0.8103 and 0.6831 ($P<0.001$), respectively. There was no significant difference between the equations describing the two Hg treatment levels.

3.4. Cross-species extrapolation

In the predictive model, the intercept (k) indicates the sensitivity of the corn cultivar to Hg accumulation. The intercepts for five different corn cultivars estimated from two different models are shown in Table 4. No significant differences were observed either among the k values of the cultivars estimated by the same model, or between the values of a cultivar estimated by the two different models.

Bioconcentration factors for non-model corn cultivars were predicted by the two models developed from Zhengdan 958. The relationship between the predicted and measured BCF values for non-model corn cultivars is shown in Fig. 3. The ratio between the predicted and measured BCF values was within a 2-fold interval and close to a 1:1 relationship. This result indicates that the two models developed from cultivar

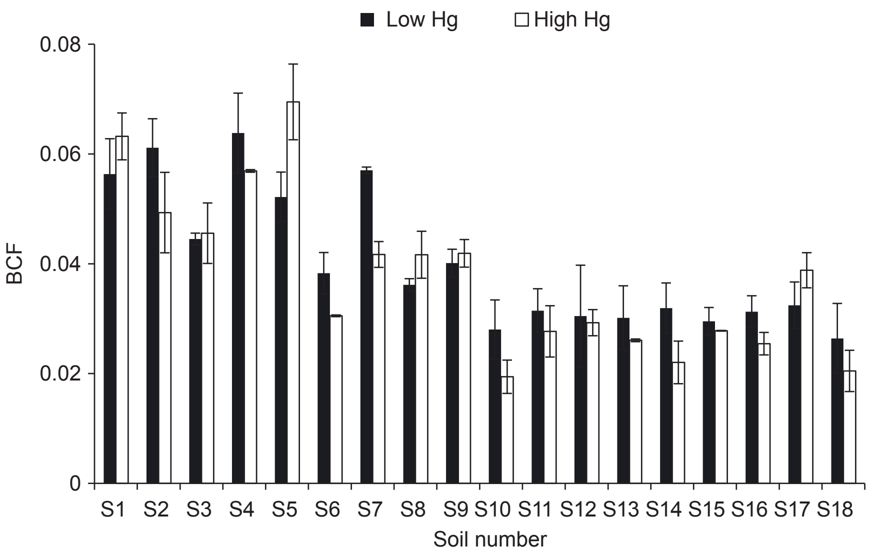

Fig. 2 Effect of different soil types on the bioconcentration factor (BCF) at low and high levels of added Hg. Bars show standard errors.

Table 3 Prediction models for Hg bioconcentration at low and high levels of added Hg

Model no.	Hg level	Prediction models	R^2	P
1	Low	Log[BCF]=–0.094 pH–0.644	0.8103	<0.001
2	High	Log[BCF]=–0.113 pH–0.745	0.6831	<0.001

Table 4 Intrinsic sensitivity (*k*) values for five corn cultivars estimated from two models developed for cultivar Zhengdan 958

Prediction model	Intrinsic sensitivity (*k*)				
	Jingketian 183	Liaodan 565	Tunyu 88	Zhongdan 808	Nongda 84
Model 1	–0.71	–0.76	–0.70	–0.77	–0.76
Model 2	–0.58	–0.64	–0.57	–0.65	–0.63

Zhengdan 958 can be applied to predict the Hg BCF values of non-model corn cultivars.

3.5. Reduction of intra-species variability

The variability of Hg BCF values of non-model cultivars was normalized using the two prediction models listed in Table 3 (Fig. 4). The variability of Hg BCF values for cultivars Jingketian 183, Liaodan 565 and Nongda 84 fitted by model 2 was found to be significantly lower than those by model 1. However, the variability for cultivars Tunyu 88 and Zhongdan 808 normalized with model 1 was much lower than that with model 2. Since these two models are effective in reducing the uncertainty caused by the soil property differences, they can be used to establish soil Hg SSD curves and provide ecological benchmark information for use in China.

4. Discussion

The bioavailable concentration of heavy metals in soil is of more importance for uptake and accumulation in plants than the total concentration in soil (Sarwar *et al*. 2010). Numerous studies have demonstrated that a number of factors affect heavy metal bioavailability in soils, including soil pH, OM concentration, CEC, cultivar of crop plant, and plant age (Chapman *et al*. 2013). In the present study, the results showed that soil pH had a greater influence than OM concentration, CEC, TN, TP, TK, and THg on the bioavailability of Hg in soil. Mercury accumulation in corn grain increased with decreasing soil pH. Soil pH plays a critical role in the control of diverse reactions in soil including dissolution and precipitation of metal solid phases, complexation and acid-base reactions of metal species, all of which influence metal sorption (Fairbrother *et al*. 2007). The pH effects also include its influence on the solution activity and the distribution of heavy metals between the soil phase and the solution phase (Christensen 1984; Naidu R *et al*. 1994). The direct effect of pH is through its influence on Hg speciation in soil solution. Low pH in soil leads to an increase in dissolved, simple ionic forms of Hg, and a corresponding increase in the bioavailable concentration of Hg in soil (Yin *et al*. 1996). In the present study, the BCF values observed in acidic soil (S1 to S9) with low pH values were significantly higher than those in alkaline soils (S10 to S18) with high pH values (Fig. 2). These findings are consistent with previous research results that showed Hg concentration was positively related to soil Hg concentration and negatively related to soil pH and free Al oxide concentration (Ding *et al*. 2014).

It is important to estimate human intake of Hg from crop consumption before developing scientifically sound strategies to control of soil Hg contamination. For this purpose, models describing Hg transfer from soil to crops have to be developed. Both empirical and mechanistic models are currently being developed to describe heavy metal transfer from soil to crops (Francois *et al*. 2009; Rodrigues *et al*. 2012; Ding *et al*. 2014; 2015). In the present study, predictive models were developed for the corn cultivar Zhengdan 958 in soil with two levels of added Hg, through multiple stepwise regressions to examine the relationship between Hg uptake by corn grain and soil pH, OM concentration, CEC, TN, TP, TK, and THg. There were no significant differences between models 1 and 2 at the different Hg levels. Many prediction models have been developed to describe relationships between concentrations of heavy metals in plants and soil properties in terrestrial ecosystems, but these models can't be extrapolated to non-model plant species

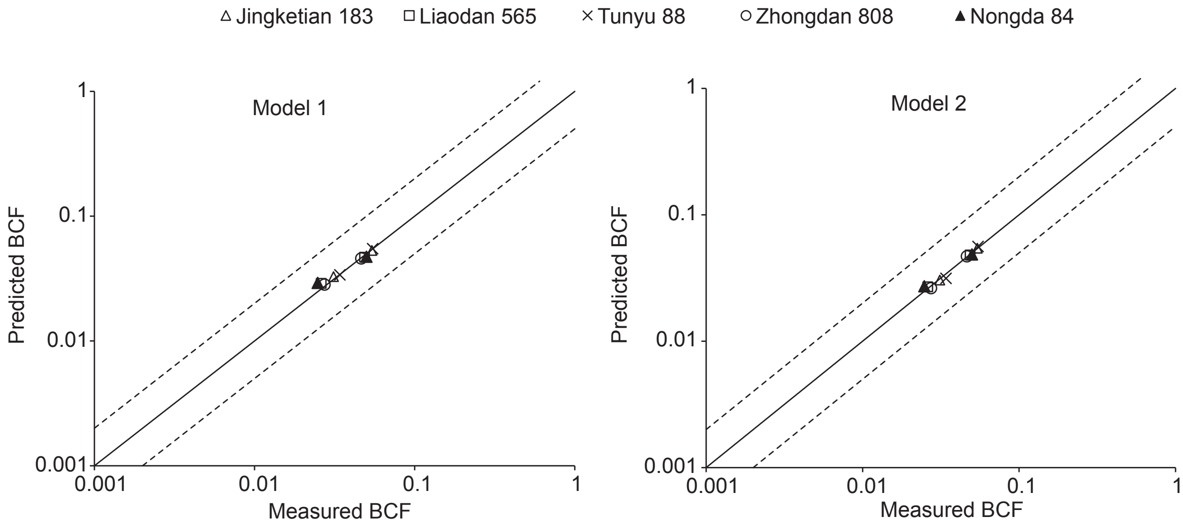

Fig. 3 Relativity between measured and predicted BCF values for Hg in non-model corn cultivars. The predicted BCF values were estimated by models 1 and 2 in Table 3. The solid line represents a 1:1 relationship; the interval between two dashed lines indicates a 2-fold prediction interval between the predicted and measured values.

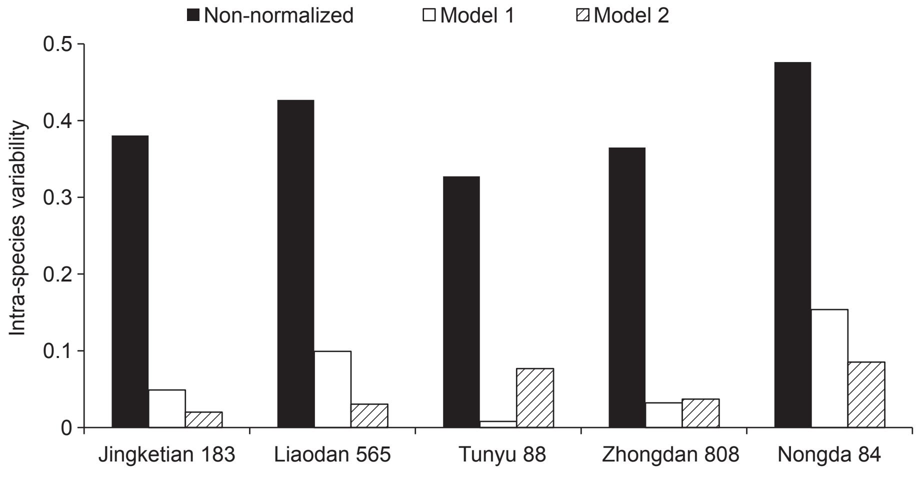

Fig. 4 Cultivar variability of unadjusted and normalized Hg bioconcentration factors. The data from all non-model corn cultivars were normalized with the models 1 and 2 as listed in Table 3.

Table 5 Comparison of bioconcentration predictive models for corn grain for two application rates of each of the heavy metals Hg, Cd and Pb

Metal level	Metal	Prediction models	R^2	P
Low	Hg	Log[BCF]=–0.094pH–0.644	0.8103	<0.001
	Cd	Log[BCF]=–0.104pH–0.170	0.8110	<0.001
	Pb	Log[BCF]=–0.098pH–0.150 log[OM]–1.894	0.9085	<0.001
High	Hg	Log[BCF]=–0.113pH–0.745	0.6831	<0.001
	Cd	Log[BCF]=–0.079pH–0.280	0.7130	<0.001
	Pb	Log[BCF]=–0.108pH–0.178 log[OM]–1.806	0.8603	<0.001

or cultivars (Li *et al*. 2009; Gandoisa *et al*. 2010; Hao *et al*. 2012; Wang 2012). In the present study, the Hg BCF prediction models developed for cultivar Zhengdan 958 could be used to predict Hg BCF values for other non-model corn cultivars, therefor the results from the present study provide further evidence to support the extrapolation of metal BCF to other non-model corn varieties. It suggests that intrinsic sensitivity was species-specific, but interactions among Hg and soil pH, OM concentration, CEC, TN, TP, TK, and THg were the same among related species. Only a few studies have been carried out to develop the prediction models for one species in aquatic ecosystems and subsequently used to normalize ecotoxicity data for other non-model species (Deleebeeck *et al*. 2007a, b, 2009; Worms and Wilkinson 2007; Van Sprang *et al*. 2009; Schlekat *et al*. 2010). Our previous studies with lead and cadmium in corn cultivars indicated that, for these elements, models developed for one cultivar can be extrapolated across to other cultivars (Yang *et al*. 2013; Li *et al*. 2014). The predictive models for Hg, Cd and Pb are shown in Table 5. The models developed for Hg and Cd are significantly different from the model for Pb. The Log[BCF] values for Hg and Cd mainly depend on soil pH values; however the Log[BCF] values for Pb depend on soil organic matter content as well as soil pH. Although the model for Hg has the same equation form as the model for Cd, significant differences were found in the pH coefficients between the models. For example, the pH coefficient in the prediction model for Hg is 0.113, while the parameter for Cd is only 0.079. Soil pH controls the dissolution and sorption of cationic metals such as Hg^{2+} and Cd^{2+} by affecting the species distribution of dissolved ligands and the surface charge. Generally, at low pH, when surface sites are protonated, the sorption of cationic metals decreases, and hence, metal mobility increases (Fairbrother 2007; Ding *et al*. 2014). This may be the main reason for the same equation forms of prediction models for Hg and Cd.

5. Conclusion

Soil pH was more important than OM concentration, CEC, TN, TP, TK, and THg in controlling Hg uptake in core grain. Bioaccumulation of Hg in corn grain was greater in more acid soils than in soils with high pH values. The Hg BCF in corn grain can be well predicted by both models 1 and 2, and both models could be applied to other non-model corn cultivars.

Acknowledgements

This work was jointly supported by the Special Fund of Public Industry in China (Agriculture, 200903015) and the Science and Technology Project of Hebei Province, China (15227504D).

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(Managing editor WANG Ning)