Lead in urban soils: Improvement of soil – plant transfer models to predict human exposure

Römkens, P.F.A.M.[1], R.P.J.J. Rietra[1], P.F. Otte[2], and S.M. Rodrigues[3]
[1]Alterra – Wageningen University and Research Center, PO Box 47, Wageningen, 6700 AA, The Netherlands
[2]RIVM, PO Box 1, 3720 BA Bilthoven, The Netherlands
[3]Department of Chemistry & CESAM, University of Aveiro, 3810-193 Aveiro, Portugal

Key words: C-Soil, exposure, food safety, lead, risk assessment, vegetables

Abstract
Lead (Pb) is a toxic element which is ubiquitous in urban soils due to diffuse inputs from traffic and industry. Despite the presence of elevated levels of Pb (100 – 3000 mg kg^{-1}), soils in urban environments are frequently used for vegetable gardens as well as parks. The consumption of home-grown food as well as intake of soil by children playing in parks, therefore, leads to a direct exposure to Pb. To prevent excess exposure, risk assessment protocols have been developed that model the exposure through intake of food, air, soil and water. In the Netherlands, C-Soil is used to derive maximum levels of Pb in soil. Traditional risk assessment tools to assess risks of Pb in soil however tend to be rather strict resulting in low maximum values for Pb in soil. Recent studies confirm that the current maximum levels used in the Dutch Risk Assessment model (C-Soil) are too strict mainly due to the overestimation of Pb uptake by crops. To improve the accuracy of the model, i.e. generate more reliable estimates of levels of Pb in crops, a new database was created. This database contains more than 2600 records of combined soil–plant data including soil properties like pH, organic matter and clay content. Using information from this database, an improved soil-to-plant transfer coefficient was derived for crops including vegetables, potato and other common crops grown in vegetable gardens. The results were validated using recent field data where the actual exposure was calculated using field data on Pb levels in crops. The approach presented in this paper is also developed in other countries including Portugal to set-up new guidelines for soil protection. As such the approach presented here seems promising in view of harmonization of risk assessment protocols in the EU.

Introduction

Assessment of the content of toxic elements in crops is essential in order to predict the exposure of people to metals like lead (Pb). Uptake of Pb from soil through consumption of vegetables is a major exposure pathway which urges the need for reliable tools to assess levels of Pb in vegetables and other arable products. Uptake of Pb, however is difficult to assess since our understanding of the plant physiological processes governing the uptake of Pb is limited. Also, a considerable part of Pb in crops is believed to originate from atmospheric deposition and not from uptake by roots. Present models to assess the level of Pb in case of the Dutch risk assessment tool (C-Soil, Otte et al., 2001) are based on a linear soil to plant Bioconcentration factor (BCF):

$$BCF_{lead} = [Pb_{crop}]/[Pb_{soil}] \quad (1)$$

With $lead_{crop}$ = lead content in crops in mg kg^{-1} dm, and $lead_{soil}$ = total lead content in soil in mg kg^{-1} dm. One of the consequences of this approach is that predicted levels of Pb in crops increase with the level of Pb in soil. In view of human health protection, this assumption is rather protective, but in reality this will lead to very strict maximum levels of Pb in soil. Based on the present BCF in C-Soil, the maximum soil level for use as 'vegetable garden', equals 140 mg kg^{-1}.

Materials and Methods

Existing data from field studies throughout the Netherlands were collected in a single database. Requirements for data to be included in the database are: (i) field data only (no pot experiments); (ii) samples from regular agriculture or private allotment only (no experiments including metal spiking), (iii) known analytical procedures (extraction), (iv) known crop type. Both arable crops and fodder crops (maize, grass) were included to extend the exposure modeling to animal husbandry as well.

This resulted in a database of 2650 records. All data were grouped according to the crops types distinguished in C-Soil. In addition, fodder crops and grains were added as additional groups.

Eliminato: ¶

After ample statistical analysis on the impact of soil properties affecting the transfer of Pb from soil to crop, a log-linear BCF was used corrected for the Pb content of the soil according to:

$$^{10}\log[BCF_{lead}] = \text{Intercept} + a \cdot {}^{10}\log[Pb_{soil}] \quad (2)$$

Using Eq. (2), levels of Pb in crops were calculated to derive the Risk Index (RI) by C-Soil. An RI > 1 indicates that the actual exposure exceeds the maximum tolerable intake of Pb. Field data from a recent study in 15 different gardens were used as an independent validation study to compare the calculated RI with the RI based on data.

Results and Discussion

For Pb, levels of the BCF in the various crops differ widely, ranging from less than 0.0002 (5 percentile) for potato to more than 0.28 for fodder (95 percentile).

Analysis of the data in the database also shows that Pb levels in crops indeed increase as a function of Pb in soils, but the level of the BCF decreases with increasing Pb levels as is illustrated in Figure 1. This confirms our hypothesis that a linear BCF leads to an overestimation of the Pb levels in crops.

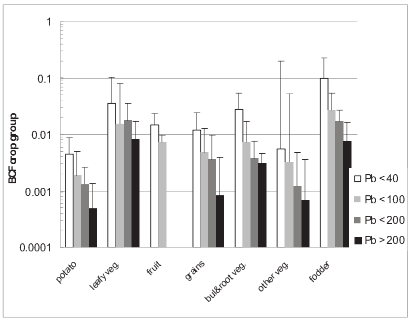

Figure 1. Impact of Pb in soil on (average) BCF for Pb in different crop groups.

The results confirm that it is essential to distinguish between crop (type) and degree of pollution to obtain a reliable estimate of the actual BCF. The influence of pH and soil organic matter on the BCF proved to be non-consistent and both were not included in the final model (Eq. 2). Using Eq. 2 it was possible to assess the BCF in individual soil-crop samples quite well as is shown in Figure 2.

Field data from a study performed in 2010 (Römkens and Rietra., 2011) were used to validate the use of Eq. 2 in the Dutch Risk Assessment tool C-Soil. Results in Figure 3 of the measured (green dots) RI versus predicted RI (solid black line) confirm that the revised model gives a much more reliable estimate compared to the original estimates of the RI presented by the red line.

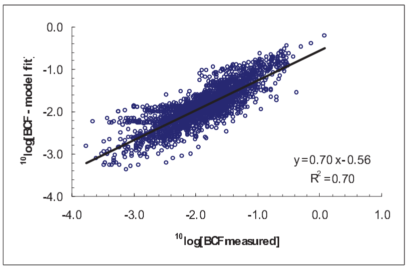

Figure 2. Model fit of calculated BCF values using Eq. 2, all crops.

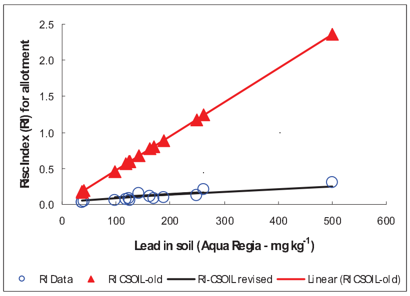

Figure 3. Comparison of measured RI (circles) with predicted RI using the revised BCF (black line) and old (red triangles and line) version in C-Soil.

Conclusions

Uptake of Pb by crops can be predicted sufficiently well by a revised BCF after correction for the Pb content in the soil. Based on this procedure, which seems applicable in different countries, reliable estimates of human exposure to lead resulting from consumption of vegetables can be obtained.

References

Otte, P.F., J.P.A. Lijzen, J.G. Otte, F.A. Swartjes, and C.W. Versluijs. 2001. Evaluation and revision of the CSOIL parameter set. RIVM report 711701021.

Römkens, P.F.A.M., and R.P.J.J. Rietra. 2011. Levels of lead in soil and crops of allotments in Heerenveen, the Netherlands. Alterra report 2107, Alterra, Wageningen UR.