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CADMIUM UPTAKE BY PLANTS*

ERIK SMOLDERS

Laboratory of Soil Fertility and Soil Biology
The Catholic University of Leuven
Leuven, Belgium

Abstract. Food chain contamination by cadmium (Cd) is the most important pathway of Cd exposure to the general population, excluding smokers. Factors affecting transfer of Cd from soil and air to plants are reviewed. The direct deposition of airborne Cd in the plants has only a marginal influence on the crop Cd concentrations in rural areas with low atmospheric Cd deposition, i.e. < 2 g Cd ha^{-1} y^{-1}. However, the indirect evidence is presented, predicting that airborne Cd may be the major source of crop Cd and dietary Cd in conditions where atmospheric Cd deposition is well above 10 g Cd ha^{-1} y^{-1}. This situation may occur around pyrometallurgic smelters with high Cd emissions. The absorption of Cd by plant roots is more influenced by soil factors, controlling Cd bioavailability than by total soil Cd. Elevated soil-plant Cd transfer is observed in soils with chloride salinity, in zinc deficient soils and acid soils.

Key words:
Cadmium, Bioavailability, Soil solution, Deposition, Dietary intake

It is generally acknowledged that dietary intake of Cd is the major source of Cd exposure for the general population, excluding smokers [1]. The tolerable daily intake of Cd is 1 μg Cd kg^{-1}/body weight, an equivalent to a daily intake of 70 μg Cd for an adult of 70 kg [2]. The more recent western European diet studies show that average dietary Cd intake by adults in western Europe ranges from 7 to 32 μg/day^{-1} with the lowest values in the Scandinavian countries and the highest values in the Mediterranean countries [3]. These data do not include studies performed around point metal sources. The limited data of the UK, the Netherlands, Denmark and Sweden indicate that upper percentiles (95th or higher) of dietary Cd intake ranges between 24 and 40 μg/day^{-1}. Individual average diets exceeding 70 μg/day^{-1} are rarely found.

The food groups that contribute largely to dietary Cd intake are cereals, potato, vegetables and fruit, with some exceptions [4]. Levels of Cd in food items are typically high in offal, organs, equine products, shellfish, crustacean, cocoa, mushrooms and some seeds [4–7]. The presence of these products in the average dietary Cd intake is low because of their low average consumption (excluding areas with high fish consumption [8].

A rather small difference between actual dietary Cd intake and the WHO tolerable daily intake warrants that food chain contamination should be primarily addressed in risk assessment of Cd in soil. Food chain contamination by Cd starts with soil-plant transfer of Cd. Cadmium is a metal with unknown essential function in higher plants but which is easily absorbed by plant roots and transferred to the above-ground parts. The risk assessment of food chain contamination is complicated by the lack of a consistent relationship between soil Cd and crop Cd. The population studies in contaminated areas do show that the correlation between soil Cd and indicators of Cd exposure (U-Cd or B-Cd) is weak or insignificant

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Address reprint requests to Prof. E. Smolders, Laboratory of Soil Fertility and Soil Biology, The Catholic University of Leuven, K. Mercierlaan 92, 3001 Leuven, Belgium.

[9]. Soil or crop specific Cd transfer data should, therefore, be included in the risk assessment of Cd.

THE RELATIVE CONTRIBUTION OF ROOT UPTAKE AND ATMOSPHERIC DEPOSITION OF Cd IN CROPS

Even washed crops may contain Cd that is deposited from air in the plants during their growth. The contribution of airborne Cd to crop Cd may be one of the factors obscuring the relationship between soil Cd and crop Cd. There are, however, few studies on the contribution of airborne metal to plant Cd in agricultural crops. Harrison and Chirgawi [10] estimated the atmospheric contribution to plant Cd from the differences in Cd concentrations in plants grown in growth cabinets with either filtered or unfiltered air. The four kinds of soil that were used had background Cd concentrations (0.12–0.28 µg Cd g^{-1}). and air Cd concentrations were either maximal 0.2 ng m^{-3} (filtered) or 1.9–2.1 ng m^{-3} (unfiltered). The air Cd concentration in the unfiltered compartment is representative for rural areas. The atmospheric contributions to different plants (radish, turnip, pea, spinach, carrot and lettuce) varied from 0% to 48% (average 20%) between plant organs, crop type and soil (Table 1). The atmospheric contribution to Cd in the unexposed plant parts (e.g. carrot roots, pea) was lower than 10% except for radish roots. No information was given if plants were washed prior to the analysis and if yields were similar in the two growth cabinets.

Hovmand et al. [11] report a field experiment in Denmark in which the soil-borne contribution to crop Cd was estimated on the basis of the isotope dilution of radioactive ^{109}Cd that was incorporated in soil. The crops grown were grass, carrots, kale, barley, wheat and rye. The air Cd concentrations (1.3 ng m^{-3}) and atmospheric Cd deposition during plant growth (1.4–3.1 g ha^{-1} y^{-1}) are representative for a rural area. Two uncontaminated agricultural soils (0.08–0.11 µg Cd g^{-1}) and one sludge amended soil (0.26 µg Cd g^{-1}) were potted in 16 L containers and placed in existing fields. The assumption was made that the soil-borne Cd in the crop has the same ^{109}Cd/Cd ratio (the specific activity – SA) as that in the total soil or in the soil extract. However, SA in soil extracts was 20–40 % higher than in the total soil. The uncertainty of SA of Cd absorbed in roots was included in the calculations by using the range of SA among soil extracts, yielding a range of estimated atmospheric contributions to soil Cd. The results show that the atmospheric contribution to crop Cd varied between 10% and 60% (mean 39%) depending on crops, soils or SA of the root absorbed Cd (Table 1). This contribution is large, taking into account the low air Cd concentrations in these conditions. The crops were not washed prior to analysis (except for carrot roots), therefore the atmospheric contribution may be somewhat overestimated for e.g. kale or carrot leaves. It is surprising to note that the atmospheric contribution to Cd carrot leaves (36–51%) is similar as to carrot roots (37–52%) or that the contribution to grain Cd sometimes exceeded that to

Table 1. The fraction airborne Cd in different crops. Selected data from three studies

Crop	Method	% Airborne	Air Cd ng Cd m^{-3}	Soil Cd mg kg^{-1}	Reference
Barley grain	ID*	41–58	1.3	0.08	11
Carrot root	ID	37–52	1.3	0.08	11
Wheat grain	ID	21	1.3	0.08	11
Rye grain	ID	17–28	1.3	0.26	11
Pea leaves	F-UF**	38–48	2.1(UF)/0.2(F)	0.12–0.28	10
Pea (peas)	F-UF	0	2.1(UF)/0.2(F)	0.12–0.28	10
Carrot root	F-UF	4–8	2.1(UF)/0.2(F)	0.12–0.28	10
Spinach	F-UF	23	2.1(UF)/0.2(F)	0.12–0.28	10
Pea	F-UF	0	2.1(UF)/0.2(F)	0.12–0.28	10
Spinach	ID + F-UF	n.s.	0.3–0.5	0.3	12
Carrot root	ID + F-UF	n.s.	0.3–0.5	0.3	12
Wheat flour	ID + F-UF	21	0.3–0.5	0.3	12

* ID – isotope dilution; ** F-UF – filtered – unfiltered air comparison.

straw Cd. Almost no airborne Cd was detected in the carrot roots by Harrison and Chirgawi [10]. It is possible that the data of Hovmand and Tjell are influenced by the analytical uncertainties in estimating small differences in SA between plants and soil.

Dalenberg and Van Driel [12] measured the relative contribution of air Cd to the Cd concentration in different field crops grown in a rural area of the northern Netherlands. The calculation of the fraction soil-borne Cd was based on the isotope dilution but the SA of soil-borne Cd was measured in a separate experiment where plants were grown in a dust-free cabinet on the same ^{109}Cd labeled soil. This study is probably more reliable than the preceding two studies since it does not rely on an assumption on the SA of soil-borne Cd. In addition, the differences in the yield between plant grown in a cabinet and in the field are not critical for the calculation of the fraction airborne Cd. The airborne fraction of Cd varied from insignificant (grass, spinach, carrot roots and shoots) to maximum 21% in wheat flour and 48% in wheat straw (Table 1). The higher contribution in wheat was ascribed to the longer growing period of that crop. These plants were grown in field conditions where the Cd deposition rate was 1.6–2.1 g Cd ha^{-1} y^{-1}, a value typical of rural areas in central Europe. Soils contained background Cd (0.16-0.29 mg Cd kg^{-1}).

These three studies show that crop Cd is primarily derived from soil, especially if the data of the third study are considered as the most reliable. It can be anticipated from these data that the fraction airborne Cd can be neglected in crops grown in contaminated soils and if the atmospheric Cd deposition is low (e.g. soils contaminated by high metal sludge). However, these data can also be used to predict that airborne Cd may be a significant source of Cd for crops grown in areas where atmospheric Cd is at least tenfold higher and where soil Cd is not high (or not available). As an example, based on the wheat grain data of Dalenberg and Van Driel (21% airborne Cd at about 2 g Cd ha^{-1} y^{-1}) it is predicted that grain Cd would double at an atmospheric Cd deposition of only 12 g Cd ha^{-1} y^{-1} at which the fraction airborne Cd would be 60% (assuming similar uptake from soil). It can be demonstrated that the historic build-up of soil Cd around old metal smelters from background (~0.5 mg Cd kg^{-1}) to current concentrations of e.g. 5 mg kg^{-1} should have been associated with an average Cd deposition rate exceeding 100 g Cd ha^{-1} y^{-1} during 100 years. This deposition rate is more than 30-fold higher than the actual concentrations in rural areas. The studies of Cd concentrations in crops at these deposition rates are not known. If the airborne Cd in crops is proportional to the atmospheric deposition rate, then it is obvious that crop Cd concentration should be dominated by airborne Cd and should be well above the background concentrations at Cd deposition rates 30-fold above those at which the three studies were performed. The air-crop foodchain pathway may therefore dominate Cd exposure in the general population at high atmospheric Cd deposition (e.g. >10 g Cd ha^{-1} y^{-1}).

CADMIUM UPTAKE FROM SOIL

This section briefly reviews the crop uptake of Cd from soil, thereby ignoring the contribution from air. This assumption may be acceptable for rural areas at Cd deposition rates typically below 2 g Cd ha^{-1} y^{-1}.

Cadmium is a trace element with unknown essential functions for plants. Cadmium is, however, readily absorbed by plant roots and translocated to above-ground parts. Cadmium concentrations (dry weight-based) are typically higher in the plant leaves than in fruits or storage organs. The uptake of Cd by plant increases proportionally to increasing soil Cd when soil contains substantial concentration of Cd^{2+} salts. The Cd^{2+} salt linear increase has been observed in different greenhouse studies and field trials [13–15]. This linear trend is maintained within the environmentally relevant range (up to about 20 mg kg^{-1}) above which curvilinear trends are found [16]. The Cd transfer factor (TF) is the ratio of Cd concentration in the plant to that in the soil and is the slope of the proportional line between plant and soil Cd (Fig. 1a). Table 2 summarises some transfer factors that were calculated from surveys of agricultural crops. The Cd TF (fresh weight--based concentration ratios) range between 0.01 and 0.3 for the selected data. Dry weight-based concentration

Table 2. Cd transfer factor (TF, plant to soil Cd concentration ratio) in selected agricultural crops calculated from mean or median values of soil and plant Cd concentrations in unpolluted areas

Crop	Crop Cd† μg kg^{-1}fresh weight	Soil Cd μg kg^{-1}	TF (dimensionless)	Comments	Reference
Wheat grain	38 (M*, dry weight based)	700(m)	0.055	UK, n=393 for grain and n=5692 for soils. Soils and crop do not correspond	28 – grain; 29 – soils
	58-M-(15–150)	435-m-(170–3500)	0.11-M-(0.02–0.3)	France, mean (or median) and range, n=16; soils with elevated Cd of geological origin; TF calculation based on means of five districts	18
	60 (m**)	400 (m)	0.15	The Netherlands, n = 84 for grain and n = 708 for soils	30
	40–69 (M)	270–420(M)	0.14–0.20	Sweden, n = 354, range of averages from three data sets; TF calculation based on means in the three data sets	17
	56 (M)	440(M)	0.13	Germany, n = 886 for grain. Soils and crops do not correspond	31 – grain; 32 – soil
Potato tuber	51 (M)	270(M)	0.19	Sweden, n = 69	17)
	30 (m)	400(m)	0.08	The Netherlands, n = 94 (crops) and n = 708 (soils)	30
	30 (m)	440(M)	0.07	Germany, n = 133. Soils and crops do not correspond.	31 – tuber; 32 – soil
				The Netherlands, n = 100 (crops) and n = 708 (soils)	17
Carrot	30(m)	400(m)	0.08	Sweden, median and range, n = 72; TF	33
	27(7–90)	300(110–830)	0.11(0.03–0.33)	(median and range) calculation based on 7 county medians for 2 subsequent years	
Lettuce	40(m)	400(m)	0.10	The Netherlands, n = 75 and n = 708 (soils)	30
Spinach	60(m)	400(m)	0.15	The Netherlands, n = 82 and n = 708 (soils)	30
Cabbage	4(m)	400(m)	0.01	The Netherlands, n = 86 and n = 708 (soils)	30
Cauliflower	6(m)	400(m)	0.015	The Netherlands, n = 84 and n = 708 (soils)	30
Tomato	10(m)	400(m)	0.025	The Netherlands, n = 40 and n = 708 (soils)	30
Onion	13(m)	400(m)	0.032	The Netherlands, n = 83 and n = 708 (soils)	30

* M – mean, ** m – median.

ratios (not shown) indicate that leafy vegetables have higher Cd concentrations than storage organs or fruits.

The TF concept (Fig. 1a) suggests that plant Cd can be properly predicted from soil Cd. However, the Cd TF varies with soil properties (Fig. 1b). The variability in Cd availability across soil types often overrules the variability in crop Cd due to difference in soil Cd, yielding insignificant correlations between crop Cd and soil Cd (points in Fig. 1b). This lack of correlation justifies the consideration of bioavailability issues in risk assessment of soil Cd. Field surveys carried out in different parts of the world did show that soil Cd usually explains less than 20% of the variability of crop Cd [17–19]. Different surveys of crop Cd concentrations have identified correlations between crop Cd and other soil properties such as soil pH, % carbon, soil Zn, etc. [17]. Multiple regression models relating crop Cd concentrations to soil properties have been proposed and rarely explain over 80% of the variability in crop Cd in field surveys. Dividing these models by soil Cd yields models showing the relationship between TF and soil properties. Table 3 illustrates some of these TF models.

Soil tests are an alternative way to predict the crop Cd concentrations. It is often observed that Cd concentration in soil solution or Cd concentrations in neutral salt extracts of soil (NH_4NO_3, $NaNO_3$ or $CaCl_2$ extracts) are better predictors for crop Cd than total soil Cd [20]. This indicates that Cd availability is linked with Cd mobility. The discussion on soil pH affecting crop Cd (see below) has, however, shown that mobility and plant availability do not always go hand in hand.

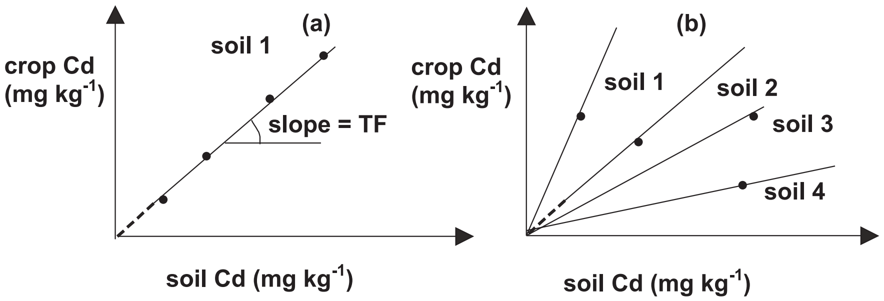

Fig. 1. (a) The Cd^{2+} salt linear response. The slope of the proportional line between crop and soil Cd is the transfer factor; (b) the transfer factor is largely influenced by soil properties thereby obscuring effects of soil Cd on crop Cd (points only) as found in many surveys around the world.

ELEVATED TRANSFER OF CD FROM SOIL TO PLANTS

Of particular interest are soil and crop combinations where Cd soil-plant transfer is high. Comprehensive review of the soil, plant and agronomic factors affecting Cd uptake by crops can be found elsewhere [21–22]. This section summarises only the most important factors for field grown crops.

The factor soil salinity increasing Cd uptake in field crops was probably first identified in irrigated potato crops in South Australia [19]. Tuber Cd exceeded the maximum permitted concentration in many parts of that state, and field surveys showed that this was unrelated to soil Cd. However, tuber Cd showed a significant positive relationship with soil Cd concentrations and was about fivefold higher at the highest soil Cd concentration compared to the not saline soils. Similar observations were made later in a survey of Cd in sunflower kernels in central USA [23]. A review of the solid-liquid partitioning of Cd in soil shows that the mobility of Cd in soil consistently increases with decreasing soil pH [24]. The effects of soil pH on Cd uptake by crops are, however, less consistent. Greenhouse trials with Cd enriched soils or sludged soils show increased availability at lower soil pH [21]. Cadmium concentrations in field grown crops are usually negatively related to soil pH but the effects are often small or even insignificant [17–18]. Grain Cd concentrations of wheat from 8 long-term field trials decreased about 4-fold between pH 4.9 and pH 6.2

Table 3. Cd transfer factor (TF, plant to soil Cd concentration ratio) in selected agricultural crops calculated from predicted crop Cd concentrations (empirical models) and mean or median Cd concentrations in corresponding soils. All Cd concentrations in μg kg^{-1}

Crop	TF (predicted Cd crop concentration)/soil Cd; (µg kg^{-1} fresh weight/µg kg^{-1})	Predicted TF pH 5.5	pH 6.5	Comments	Reference
Wheat grain	TF = (92 - 10.3 pH + 0.10 Cdsoil - 0.26Znsoil)/290 TF = (181–27 pH)/100 (pH 5 - 6.2)TF = 0.1 (pH >6.2)	0.190.32	0.150.10	Sweden, n = 192. Soil Cd concentration is mean of corresponding soils. Mean soil Zn concentration (Zn_{soil}) is 42 mg kg^{-1} US data from 7 long-term wheat experiments (n = 93). Soil Cd ranges between 30–160 μg kg-1 and most samples contain about 100 μg kg^{-1}	17 25
Carrot	TF = (3.39 - 0.29 pH - 0.01(%C) + 3.5 E-4Cdsoil)/300	0.22	0.12	Sweden, n = 72. Soil Cd concentration is mean of corresponding soils. Median % C is 7% in these soils.	33
Potatoes	TF = (193 – 24 pH - 0.94(%OM) + 0.039Cdsoil)/270	0.21	0.12	Sweden, n = 69. Soil Cd concentration is mean of corresponding soils. Median % OM is 17% in these soils.	17

%C – the percentage of carbon in soil
%OM – the percentage of organic matter in soil

but did not show any further trend at pH >6.2 or pH <4.9 [25]. Liming soil is used to increase soil pH but has often shown no, or even stimulating effect on crop Cd concentrations [26 and references therein]. Lime-induced Zn deficiency may be one of the reasons for increased uptake of Cd^{2+} by roots. Further work is, however, required to explain the inconsistency between Cd mobility and plant Cd uptake at varied soil pH.

Zinc deficiency increases Cd uptake by crops. In Australia, the treatment of near Zn deficient wheat with application of small quantities of Zn (up to 10 kg Zn/ha) reduced wheat grain Cd by approximately two times [27]. High wheat grain Cd concentrations exceeding 0.1 mg Cd/kg grown in uncontaminated soils in France was explained by marginal Zn deficiency in that area [18].

Some agricultural crops usually contain high Cd concentrations. Durum wheat, sunflower kernels and flax have been identified as high Cd crops compared to spring wheat, barley, corn or oats [22].

CONCLUSION

Crop Cd concentrations are strongly influenced by soil properties that control Cd availability in soil. Even at background Cd concentrations in soil, it is likely that crop Cd concentration exceeds marketable limits. This situation has been found in soils with chloride salinity and Zn deficiency and in crops such as sunflower kernels and durum wheat grain that usually contain high Cd concentrations. Direct deposition of Cd from air is a potential direct route by which Cd may enter the human food chain. The experimental evidence reviewed here indicates that this pathway can be neglected in areas with low Cd deposition rates (<2 g Cd ha^{-1} y^{-1}, typical of most rural areas in Europe). However, airborne Cd can be a dominant source of Cd in crops if Cd deposition is clearly elevated (>10 g Cd ha^{-1} y^{-1}), a situation that may occur around pyrometallurgic smelters.

REFERENCES

1. IPCS, International Programme on Chemical Safety. *Cadmium. Environmental Health Criteria,* No. 134. Geneva: World Health Organization; 1992.
2. FAO/WHO. *Evaluation of certain food additives and contaminants.* Thirty-third report of the joint FAO/WHO expert committee on food additives. WHO Technical Report Series 776. Geneva: WHO; 1989.
3. *Risk assessment report CdO. Draft text submitted to the European Chemical Bureau*. Brussels: Belgian Federal Government, Ministry of Public Health and the Environment; 1999.
4. EUR 17527. *Dietary exposure to cadmium.* European Commission, DG 3. Luxembourg: Office for Official Publications of the European Communities; 1997.
5. Fouassin A, Fondu M. *The average lead and cadmium concentrations in food items collected in Belgium.* Bel Archief Sociale Geneeskunde Hyg Arbeidsgeneeskunde Gerechterlijke Geneeskunde 1981; 39: 1–14 [in Dutch].
6. Jorhem L, Sundström B. *Levels of lead, cadmium, zinc, copper, nickel, chromium, manganese and cobalt in foods on the Swedish market 1983–1990.* J Food Comp Anal 1993; 6: 223–41.
7. Tahvonen R. *Contents of lead and cadmium in foods and diets.* Food Rev Int 1996; 12: 1–70.
8. Cuadrado C, Kumpulainen J, Moreiras O. *Contaminants and nutrients in total diets in Spain*. Eur J Clin Nutr 1995; 49: 767–78.
9. Staessen JA et al. T*ransfer of cadmium from a sandy acidic soil to man: a population study.* Environ Res 1992; 58: 25–34.
10. Harrison RM, Chirgawi MB. *The assessment of air and soil as contributors of some trace metals to vegetable plants. I. Use of a filtered air growth cabinet*. Sci Total Environ 1989; 83: 13–34.
11. Hovmand MF, Tjell JC, Mosbaek H. *Plant uptake of airborne cadmium.* Environ Pollut 1983; 30: 27–38.
12. Dalenberg JW, Vandriel W. *Contribution of atmospheric deposition to heavy-metal concentrations in field crops.* Neth J Agric Sci 1990; 38: 369–79.
13. Brown SL, Chaney RL, Angle JS,Ryan JA. *The phytoavailability of cadmium to lettuce in long-term biosolids-amended soils.* J Environ Qual 1998; 27: 1–8.
14. Reber HH. *Threshold levels of cadmium for soil respiration and growth of spring wheat (Triticum aestivum L.), and difficulties with their determination.* Biol Fertil Soils 1989: 7: 152–7.
15. Kádár I. *Effect of heavy metal load on soil and crop.* Acta Agr Hung 1995; 43: 3–9.
16. Haghiri F. *Cadmium uptake by plants.* J Environ Qual 1973; 2: 93–95.
17. Eriksson J, Öborn I, Jansson G, Andersson A. *Factors influencing Cd-content in crops. Results from Swedish field investigations*. Swed J Agric Res 1996; 26: 125–33.

18. Mench M, Baize D, Mocquot B. *Cadmium availability to wheat in five soil series from the Yonne district, Burgundy, France.* Environ Pollut 1997; 95: 93–103.
19. McLaughlin MJ, Palmer LT, Tiller KG, Beech TA, Smart MK. *Increased soil salinity causes elevated cadmium concentrations in field-grown potato tubers.* J Environ Qual 1994; 23: 1013–8.
20. McLaughlin MJ, Zarcinas BA, Stevens DP, Cook N. *Soil testing for heavy metals.* Commun Soil Sci Plant Anal 2000; 31: 1661–1700.
21. McLaughlin MJ, Tiller KG, Naidu R, Stevens DP. R*eview: the behaviour and environmental impact of contaminants in fertilizers.* Aust J Soil Res 1996; 34: 1–54.
22. Li YH, Chaney RL, Schneiter AA. *Effect of soil chloride level on cadmium concentration in sunflower kernels*. Plant Soil 1994; 167: 275–80.
23. Sauvé S, Hendershot W, Allen HE. *Solid-solution partitioning of metals in contaminated soils: dependence on pH, total metal burden, and organic matter.* Environ Sci Technol 2000; 34: 1125–31.
24. Maier NA, McLaughlin MJ, Heap M, Butt M, Smart MK,Williams CMJ. *Effect of current-season application of calcitic lime on soil pH, yield and cadmium concentration in potato (Solanum tuberosum L.) tubers.* Nutr Cycl Agroecosyst 1997; 47: 29–40.
25. Oliver DP, Hannam R, Tiller KG, Wilhelm NS, Merry RH, Cozens GD. T*he effects of zinc fertilization on cadmium concentration in wheat grain.* J Environ Qual 1994; 23: 705–11.
26. Chaudri AM, Zhao SP, McGrath SP, Crosland AR. *The cadmium content of British wheat grain.* J Environ Qual 1995; 24: 850–5.
27. McGrath SP, Loveland PJ. *The Soil Geochemical atlas of England and Wales.* Glasgow: Blackie Academic and Professiolnal; 1992.
28. Wiersma D, van Goor BJ, van der Veen NG. *Cadmium, lead, mercury and arsenic concentrations in crops and corresponding soils in The Netherlands*. J Agric Food Chem 1986; 34: 1067–74.
29. Weigert P, Muller J, Klein H, Zufelde KP, Hillebrand J. *Arsen, Blei, Cadmium und Quecksilber in und auf Lebensmitteln*. Federal Republic of Germany: ZEBS Hefte 1: 1984.
30. Crössman G, Wüstemann M. B*elastung in Haus und Kleingärten durch anorganische und organische Stoffe mit Schadstoffpotential. Sachstandsdocumentation.* Münster: Landwirtschaftliche Untersuchung und Forschungsanstalt des Landwirtschaftskammer Westfalen-Lippe; 1992.
31. Jansson G, Öborn I. *A field study on cadmium content in carrots and the influence of soil factors.* In: Iskander IK et al, editors. *Proceedings of the Fourth International Conference on the Biogeochemistry of Trace Elements, US Army Cold Regions Research and Engineering Laboratory;* Hanover: NH; 1997. p. 123–4.

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