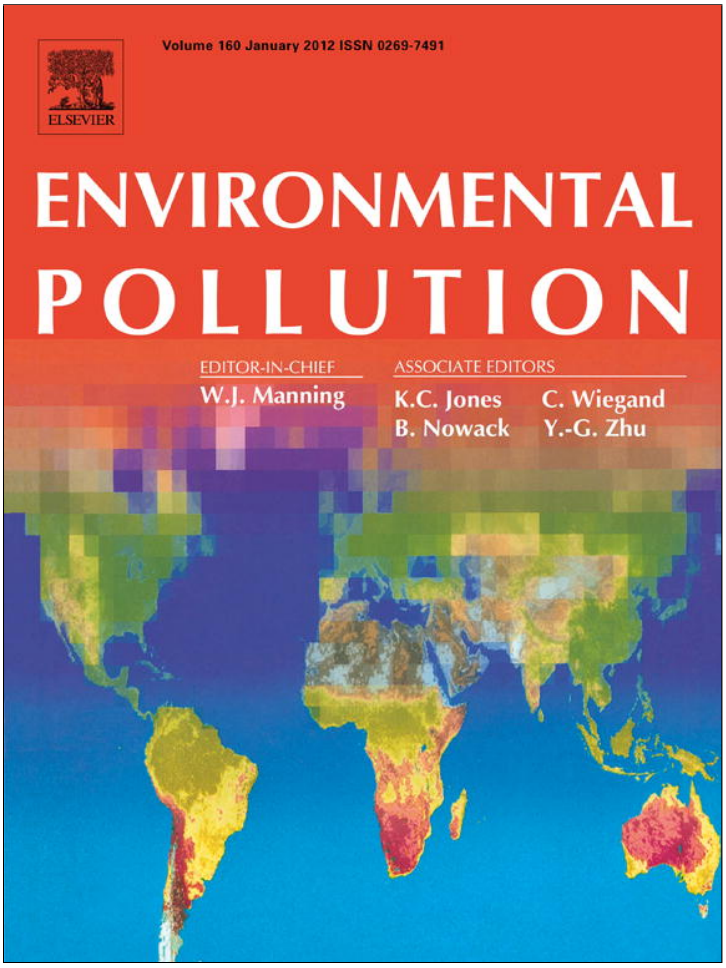
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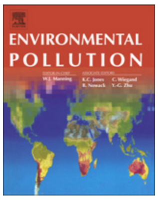

How healthy is urban horticulture in high traffic areas? Trace metal concentrations in vegetable crops from plantings within inner city neighbourhoods in Berlin, Germany

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ABSTRACT

Food production by urban dwellers is of growing importance in developing and developed countries. Urban horticulture is associated with health risks as crops in urban settings are generally exposed to higher levels of pollutants than those in rural areas. We determined the concentration of trace metals in the biomass of different horticultural crops grown in the inner city of Berlin, Germany, and analysed how the local setting shaped the concentration patterns. We revealed significant differences in trace metal concentrations depending on local traffic, crop species, planting style and building structures, but not on vegetable type. Higher overall traffic burden increased trace metal content in the biomass. The presence of buildings and large masses of vegetation as barriers between crops and roads reduced trace metal content in the biomass. Based on this we discuss consequences for urban horticulture, risk assessment, and planting and monitoring guidelines for cultivation and consumption of crops.

1. Introduction

Currently, across all socioeconomic groups and around the world, urban horticulture is booming. Depending on the local situation of gardeners, (peri-) urban horticulture fulfils diverse functions including food production and community building and may contribute to reducing socio-economic and environmental problems (e.g., Brown and Jameton, 2000; Waliczek et al., 2005; Wakefield et al., 2007; Leake et al., 2009).

In developing countries, urban horticulture is mainly a strategy for achieving food security. Urban gardeners generally have low incomes and need to cultivate vegetables for food supply and as a source of income (FAO, 2010). However, food insecurity is an increasing phenomenon in developed countries and food-banks are increasingly used in developed countries worldwide (e.g., Riches, 1997; Dowler, 2001; Temple, 2008). As an example from Italy, urban allotment gardens are offered by local governments encouraging low income senior citizens to produce their own food and increase social interactions (Tei et al., 2010).

Compared to crops from rural sites, horticultural crops in urban or peri-urban areas are generally exposed to a higher level of pollutants including trace metals and organic contaminants (Shinn et al., 2000; Alloway, 2004; Clark et al., 2006). Contamination of urban horticultural products can exceed the precautionary values, and a dietary exposure to trace metals can result in significant human health risks. A meta-study of German garden crops revealed that critical trace metal concentrations are frequently exceeded in leafy, stem and root vegetables (UBA, 1995). Various studies have revealed that consuming crops from polluted sites can lead to serious public health problems in both developing and developed countries (e.g. Qadir et al., 2000; Hough et al., 2004; Finster et al., 2004; Pruvot et al., 2006; Kachenko and Singh, 2006; Sharma et al., 2007; Khan et al., 2008). For these reasons, health benefits of urban horticulture products can be questioned. Interestingly, the potential health risks contrast sharply with the motivation of urban or peri-urban gardeners: about 60% of the gardeners aim to produce fresh and healthy fruits and vegetables (Burda GmbH, 1993).

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There is broad evidence that urban and garden soils can contain high amounts of trace metals (Alloway, 2004; Charlesworth et al., 2010). These soils are therefore considered the main sites for human exposure to trace metals (De Miguel et al., 2007). Yet the debate on quantitative guidelines for assessing risks associated with urban horticulture is ongoing. Different approaches have been established such as EU standards for maximum acceptable metal concentrations in soils to be used for crop production (Council of the European Communities, 1986) or the calculation of a bioconcentration factor (Antunes et al., 2006) or hazard quotient (Pierzynski et al., 2005). However, these approaches are considered both too costly and labour-intensive and to possibly over- or underestimate risks which depend on site conditions and crop type (Murray et al., 2011).

Risk assessment models, based on site-specific soil contamination data and predicted metal uptake by vegetables, have assigned the highest hazard indices to areas adjacent to junctions of major roads, railways and canals as these function as major sources of toxic metals in the urban environment (Hough et al., 2004). The human health impacts associated with traffic-related pollutants in urban areas have recently gained broad attention from policy makers and politicians (WHO, 2006; UNEP, 2007). Depending on local conditions such as slope, wind and building structures, the influence of roads as pollution sources extends from a few metres to kilometres (Forman and Alexander, 1998).

However, the correlation between trace metal content in soils and trace metal content in crops cultivated in these soils is often poor or inconsistent (Peris et al., 2007). Non-toxic concentrations of trace metals have been found in vegetables grown in contaminated soils (Sipter et al., 2008). In contrast, another study found toxic levels of trace metals in vegetables cultivated in uncontaminated soils (Murray et al., 2009). Such divergent results have often been explained in terms of the functioning of pathways other than plant uptake from the soil such as atmospheric deposition (e.g. Alegría et al., 1991). In addition, the use of compost to fertilize urban soils, a process common among urban gardeners, can enhance metal solubility under certain conditions, and crops grown in uncontaminated soils can thereby accumulate hazardous levels of trace metals (Murray et al., 2011). However, this effect was not reported after the application of biological waste such as leaf litter from urban street or park trees in Berlin on crops (Strumpf et al., 2004).

In addition, the capacity for uptake, accumulation and tolerance of trace metals differs among the parts of a given plant, among crop species (e.g., Kloke et al., 1984; Turner, 1994; Jinadasa et al., 1997; Angelova et al., 2004; Alexander et al., 2006; Peris et al., 2007) and among cultivars and varieties of the same crop species (Alexander et al., 2006). Thus far, little is known about the underlying mechanisms of these diverse patterns of trace metal uptake, root-to-shoot transfer and redistribution within vegetables

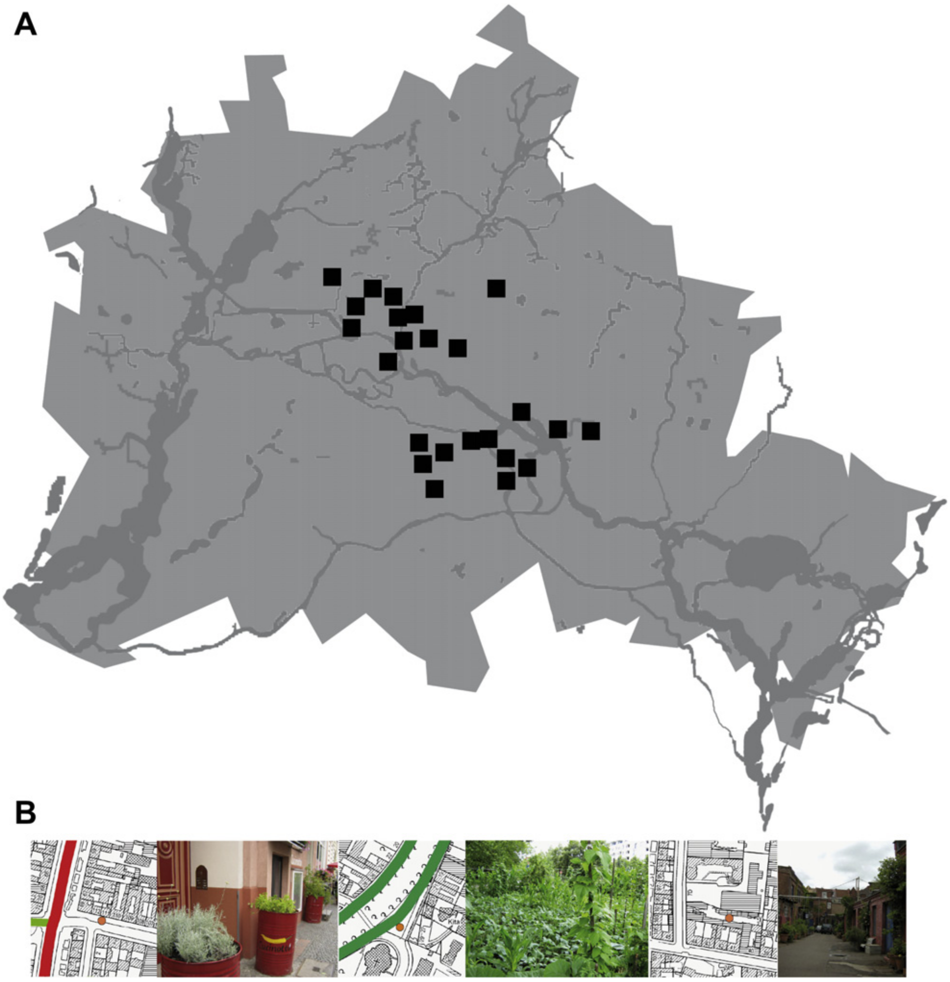

Fig. 1. A Overview of sampling sites within inner city neighbourhoods in Berlin, Germany, and B) examples of the different local conditions at the sampling sites [e.g. planting style (pot or direct), soil type (local or garden soil), traffic burden per day (red: 40 000–50 000, light green 5000–10 000, dark green < 5000 vehicles a day) or building structures] (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

(Murray et al., 2009). Metabolic differences among species have been proposed as an explanation for the high trace metal contents found in leafy crops compared to other crop types (Ge et al., 2000). There is empirical evidence that legumes accumulate low amounts, root vegetables moderate amounts and leafy vegetables high amounts of trace metals (Kloke et al., 1984; Ge et al., 2000; Finster et al., 2004; Alexander et al., 2006). As a result leafy vegetables and herbs have been described as accumulator crops (Fleming and Parle, 1977; Ross and Kaye, 1994; Alexander et al., 2006).

Considering the possible health risks associated with urban horticulture, there is a great need for a better understanding of the mechanisms that drive trace metal accumulation in urban crops; this knowledge can be used to develop guidelines for urban gardeners. The three major sources of trace metal accumulation in urban crops are (i) use of contaminated soils for cultivation (Mielke and Reagan, 1998; Shinn et al., 2000; Ge et al., 2000; Finster et al., 2004; Alloway, 2004), (ii) crop irrigation with wastewater (Qadir et al., 2000; Mandapa et al., 2005; Khan et al., 2008; Arora et al., 2008) and (iii) airborne pollution by traffic or industrial emissions (e.g., Chaney et al., 1984; for the US see recent review by Mielke et al., 2011).

In our study, we aimed to explore the relationship between local traffic burden and the trace metal concentration in the edible biomass of different horticultural crops cultivated by gardeners in the inner city of Berlin, Germany. We focused on trace metals in edible tissues of crops as these directly determine the human health risk associated with consuming the products of urban horticulture.

Studies from the 1970s suggested that adjacency to roads matters for trace metal accumulation in vegetation: the contents of Pb, Zn and Cd in plants and soils decrease asymptotically with increasing distance from the road depending on traffic burden, exposure time, wind characteristics and the existence of barriers to traffic-related air pollution (Kloke, 1974; Lagerwerf and Specht, 1970). While traffic-related air contaminants can travel far from their source (Tiller et al., 1987), buildings as vertical barriers can hinder the dispersion of particulates (Capannesi et al., 1993). In addition, the capacity of vegetation to filter air and immobilise particulates, which has come recently into the scientific focus (Jim and Chen, 2008; Litschke and Kuttler, 2008; Langner et al., 2011; Escobedo et al., 2011), could reduce traffic-related pollutant influxes.

We analysed trace metal accumulation in crops and the influence of traffic burden and other characteristics of the sampling sites (planting style, soil type and the existence of barriers between cultivation sites and nearby streets) on the concentration of trace metals in different species and types of crops. In detail we tested the following hypotheses: 1) leafy vegetables show higher trace metal content than other vegetable types; 2) higher traffic burden and proximity to roads increase trace metal content in edible biomass; and 3) buildings between roads and cultivation sites reduce trace metal content in edible biomass. Finally, we discuss the need for species-specific planting guidelines for urban horticulture to foster healthy food production.

2. Materials and methods

Horticultural crop samples were collected from 28 randomly chosen sites within inner city neighbourhoods in Berlin, Germany (Fig. 1A) in 2009. These sites represent a mixture of different local settings of horticultural plantings within Berlin's centre (Fig. 1B) and were characterized according to the following parameters: (a) overall traffic burden (otb) within a radius of 1 km around planting sites (low: low traffic burden and barriers between plantings and streets exist; medium: low traffic burden but barriers between plantings and streets are lacking,

Table 1
Content of trace metals in vegetables and herbs grown in the inner city of Berlin [mg/kg biomass dry weight (DW): median (Med), minimum (Min), maximum (Max); values for N garden samples and the control value (C) refers to the average concentrations from supermarket products ($N = 3$) are given. bd indicates values that were below the detection limit of the measurement instruments.

	Element	*N*	Content of trace metals in mg/kg DW																							
			Zn				Pb				Cu				Ni				Cr				Cd			
	Species		Min	Med	Max	C	Min	Med	Max	C	Min	Med	Max	C	Min	Med	Max	C	Min	Med	Max	C	Min	Med	Max	C
Fruits	Tomato	28	15.8	21.7	84.7	17.1	0.1	1.1	6.7	0.4	3.5	7.9	16.0	9.6	0.03	0.17	0.70	0.03	bd	0.11	0.63	0.05	0.01	0.12	0.79	0.01
	Green beans	7	32.4	39.0	44.2	52.2	0.1	0.4	3.5	1.3	3.5	7.5	10.5	14.7	0.27	0.46	1.30	3.10	0.08	0.10	0.46	0.37	bd	0.01	0.04	0.02
Root and stem vegetables	Carrot	10	23.3	37.0	122.8	23.3	1.3	2.3	28.5	0.4	5.4	8.3	23.2	3.3	0.07	0.4	1.93	0.47	0.1	0.39	2.39	0.09	0.06	0.21	0.41	0.05
	Potato	13	11.7	22.1	78.2	14.9	0.3	1.4	31.3	0.6	3.4	7.7	20.1	3.4	0.03	0.15	3.25	0.16	0.03	0.15	4.69	0.06	0.02	0.07	0.42	0.09
	Kohlrabi	11	20.6	30.3	50.3	32.1	0.1	0.6	3.1	5.6	3.2	6.4	11.6	7.9	bd	0.29	0.91	0.67	0.07	0.17	0.54	0.3	0.03	0.05	0.15	0.42
Leafy vegetables and herbs	White cabbage	7	26.4	32.5	46.5	12.9	0.6	1.0	2.6	0.5	3.2	4.8	6.6	2.1	0.01	0.58	1	1.01	0.25	0.48	0.81	0.11	0.06	0.21	0.41	0.05
	Nasturtium	7	78.5	100.3	172.7	68.4	0.8	0.8	1.4	0.8	7.2	11.6	16.0	9	bd	0.05	1.29	bd	0.08	0.19	4.01	0.07	0.08	0.1	0.27	0.07
	Parsley	7	53.0	105.7	224.3	82.4	1.3	2.4	15.7	1.5	6.3	11.2	15.8	11.0	0.22	0.42	1.21	3.6	0.33	0.7	2.26	0.24	0.04	0.16	1.23	0.22
	Chard	7	31.2	99.5	175.2	13.9	1.7	5.3	30.8	0.8	4.7	20.2	29.3	6.48	0.49	0.59	3.28	0.59	0.38	1.37	4.52	0.9	0.07	0.31	0.47	0.2
	Basil	7	92.6	105.0	138.8	121.6	1.0	1.4	1.9	1.9	10.7	14.8	17.3	7.9	0.19	0.36	1.21	0.39	0.16	0.38	0.46	0.07	0.03	0.22	0.42	0.37
	Mint	8	32.3	112.7	464.8	98.8	0.9	4.6	32.2	2.5	12.1	17.0	29.8	25.2	0.98	1.41	2.16	7.42	0.47	1.29	5.06	1.47	0.01	0.06	0.19	0.04
	Thyme	7	30.6	52.3	100.2	124.1	1.4	1.7	1.8	2.1	8.9	12.4	15.5	12.3	0.23	0.65	0.87	0.85	0.6	1.08	1.78	0.24	0.04	0.1	0.33	0.34

or high traffic burden and barriers between plantings and streets exist; high: high traffic burden and barriers between plantings and streets are lacking); (b) traffic burden of the nearest road per day (tb; classification according to the number of vehicles per day including trucks and motorcycles from Berlin Department for Urban Development (2010): 1 (low) = ≤5000; 2 = 5001–10 000; 3 = 10 001–15 000; 4 = 20 001–30 000; 5 = 30 001–40 000; 6 (high) = 40 001–50 000 vehicles per day); (c) distance to nearest road (d; in meters); and (d) presence or absence of barriers between planting sites and next street which might reduce airborne pollution [building (bb) or tall vegetation such as hedges or trees (bp)]. In addition, we recorded planting style (ps; crops planted in pots or directly in bed) and soil type (s; local soil or commercial garden soil).

In total, we harvested 12 different horticultural crop species, which were randomly sampled at least at seven sites per crop species. The sampled vegetable types included fruits: tomato (*Lycopersicon* var. *esculentum*, $N = 28$), green beans (*Phaseolus vulgaris*, $N = 7$); root and stem vegetables: carrot (*Daucus carota* subsp. *sativa*., $N = 10$), potato (*Solanum tuberosum*, $N = 13$), kohlrabi (*Brassica oleracea* var. *gongylodes* L.; $N = 11$); leafy vegetables and herbs: white cabbage (*Brassica oleracea* convar. *capitata* var. *alba*, $N = 7$), nasturtium (*Tropaeolum majus*, $N = 7$), parsley (*Petroselinum crispum*, $N = 7$), chard (*Beta vulgaris* subsp. *vulgaris* var. *cicla*, $N = 7$), basil (*Ocimum basilicum*, $N = 7$), mint (*Mentha spicata*, $N = 8$), thyme (*Thymus vulgaris*, $N = 7$). In addition, for each crop we collected mixed samples of common supermarket products or, in the case of nasturtium, which was not available in supermarkets, from rural sites with nearly no traffic. We used these samples to compare the potential dietary exposure to trace metals of someone consuming urban horticulture products versus supermarket products.

The edible parts of the vegetables were thoroughly washed before the plant samples were frozen after harvest. Prior to analyses, plant samples were mechanically crushed and dried at 105 °C for 12–48 h depending on sample size. Dried samples were weighed and milled (<100 μm) and stored in a dehydrator for digestion. A 500 mg portion of the dry vegetable powder was digested in 10 ml HNO3 (69%) using a microwave digestion system (MARS 5 and MARS Xpress, CEM Corporation). We used MARS 5 Program 1 for tomato and potato samples, MARS 5 Program 2 for herbs and MARS Xpress Program 3 for the other vegetable samples.

After digestion, the volume of each sample was adjusted to 25 ml using double de-ionized water at 20 °C. We determined the concentration of trace metals in the biomass by using atomic absorption spectroscopy [AAS; for Zn and for Cu concentrations >0.15 mg/l, Atomic Absorption Spectrometer AAS1100B (Perkin–Elmer, USA) was used and for Pb, Cd, Cr and Ni and Cu concentrations <0.15 mg/l, Atomic Absorption Spectrometer AA880Z (Varian, Australia) was used]. We used a hay powder as multi-element standard to assess the quality of our measurement (reference/measured values in mg/kg DW for $N = 8$: Zn: 31.29/ 33.91; Cd: 0.038/ 0.04; Cu: 5.12/6.64; Pb: 1.48/2.2; Ni: 2.69/2.64; Cr: 7.57:7.10). The wave lengths used/ the detection limits of the elements/ spectrometer used were: Zn: 213.9/ 0.05 mg/l/ AAS1100B; Cd: 228.8/2.0 mg/l/AA880Z; Cu > 0.15 mg/l: 324.8/0.05 mg/l/AAS1100B; Cu < 0.15 mg/l: 324.8/4.0 mg/l/AA880Z; Pb: 217.0/3.0/AA880Z; Ni: 232.0/4.0 mg/l/ AA880Z; Cr: 357.9/2,0mg/l/AA880Z.

Biomass metal content, crop species, vegetable type and local settings were analysed by analysis of variance (ANOVA). The concentration of trace metals in the crop biomass was taken as the response variable and crop species, vegetable type and parameters which characterise the local settings (e.g., planting style, soil type, traffic burden per day, presence of barriers) were taken as explanatory variables. Normal distribution of data (Shapiro–Wilk test) and homogeneity of data (Brown–Forsythe's test) were tested before applying ANOVA. Transformations were made if necessary to meet the assumptions of the residual normality and variance homogeneity needed for the analyses. We used Tukey test for comparison of means. In general, treatment effects were considered significant at the $p < 0.05$ level. All statistical analyses were done using R version 2.9.0 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

The trace metal contents differed widely among crop species (Table 1) and in relation to site characteristics (Table 2). Only a few samples had concentrations below the detection limit of 10 ppm (three for Ni and one for Cr and Cd). We revealed significant differences in Zn, Pb, Cr and Cd concentrations depending on crop species, parameters related to the mode of cultivation (planting style, soil type) and characteristics of the adjacent urban environment (local traffic burden, presence of buildings or vegetation as barriers between cultivation site and street). Yet in contrast to our expectations, we found no significant differences between vegetable types (Table 2).

The Zn content in green beans, tomato, potato, kohlrabi and carrots was significantly lower than in leafy vegetables except white cabbage (Fig. 2A). The Cd content of kohlrabi and green beans was significantly lower compared to chard and parsley (Fig. 2B). The Pb content in tomatoes was significantly lower than in chard (Fig. 2C). The Cu content in mint and in chard was significantly higher than in all other species except basil and thyme. The lowest Cu contents were measured in white cabbage and green beans (Fig. 2D). Ni content in mint was significantly lower than in the

Table 2
ANOVA results of the crop species and site effects as well as the interactions between crop species and site effects on content of trace metals [in mg/kg biomass dry weight (DW)]. Minimum adequate linear models were chosen using a step-by-step reduction of the maximum model to find the minimum value of Akaike's information criterion (AIC). The maximum model considered trace metal content of biomass [mg/kg DW] in relation to crop species (sp), vegetable type (vt), planting style (ps), soil (s), overall traffic burden (otb), number of vehicles per day on the nearest road (tb), distance (m) to the nearest road (d), barrier of buildings (bb) or barrier of plantings (bp) between crop and streets and relevant interactions between parameters. The model with the lowest AIC value was the full model minus vegetable type (vt), which had no effect on trace metal content of biomass: trace metal ∼ sp × ps × s × otb × tb × d × bb × bp. Degrees of freedom (df), mean squares (MS) and *p* values are given (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; ns, not significant).

		Content of trace metals in mg/kg DW					
Element		Zn	Pb	Cu	Ni	Cr	Cd
Parameter		*p*	*p*	*p*	*p*	*p*	*p*
Crop species (sp)		0.002**	<0.001***	0.010*	<0.015*	0.002**	0.004**
Planting style (ps)		0.003**	0.002**	0.691ns	0.324ns	0.052ns	0.022*
Soil (s)		0.113ns	<0.001***	0.573ns	0.011*	0.001**	0.845ns
Overall traffic burden (otb)		0.031*	<0.001***	0.429ns	0.032*	0.033*	0.574ns
Number of vehicles per day on the nearest road (tb)		0.451ns	0.004**	0.038*	0.243ns	0.965ns	0.011*
Distance (m) to nearest road (d)		0.067ns	0.007**	0.128ns	0.079ns	0.019*	0.038*
Buildings as barrier (bb)		0.049*	0.012*	0.070ns	0.137ns	0.054ns	0.434ns
Plantings as barrier (bp)		0.026*	0.009**	0.556ns	0.591ns	0.009**	0.005**
Relevant interactions between parameters							
sp × ps		0.011*	0.002**	0.294ns	0.101ns	0.005**	0.042*
sp × s		0.113ns	0.001**	<0.001***	0.056ns	0.018*	0.040*
sp × tb		0.031*	<0.001***	<0.001***	0.093ns	0.007**	0.011**
sp × otb		0.048*	<0.001***	0.201ns	0.144ns	0.030*	0.019*
sp × d		0.014*	<0.001***	0.242ns	0.042*	0.007**	0.014*
sp × bb		0.030*	<0.001***	0.149ns	0.016*	0.008**	0.027**
sp × ps × otb		0.081ns	<0.001***	0.069ns	0.062ns	0.006**	0.877ns
Residuals	df	3	2	3	3	3	3
	Mean square	185	1	6	0.1	0.1	0.1
Model	*F*	19	1052	5	5	28	18
	p	0.016	<0.001	0.108	0.108	0.009	0.017

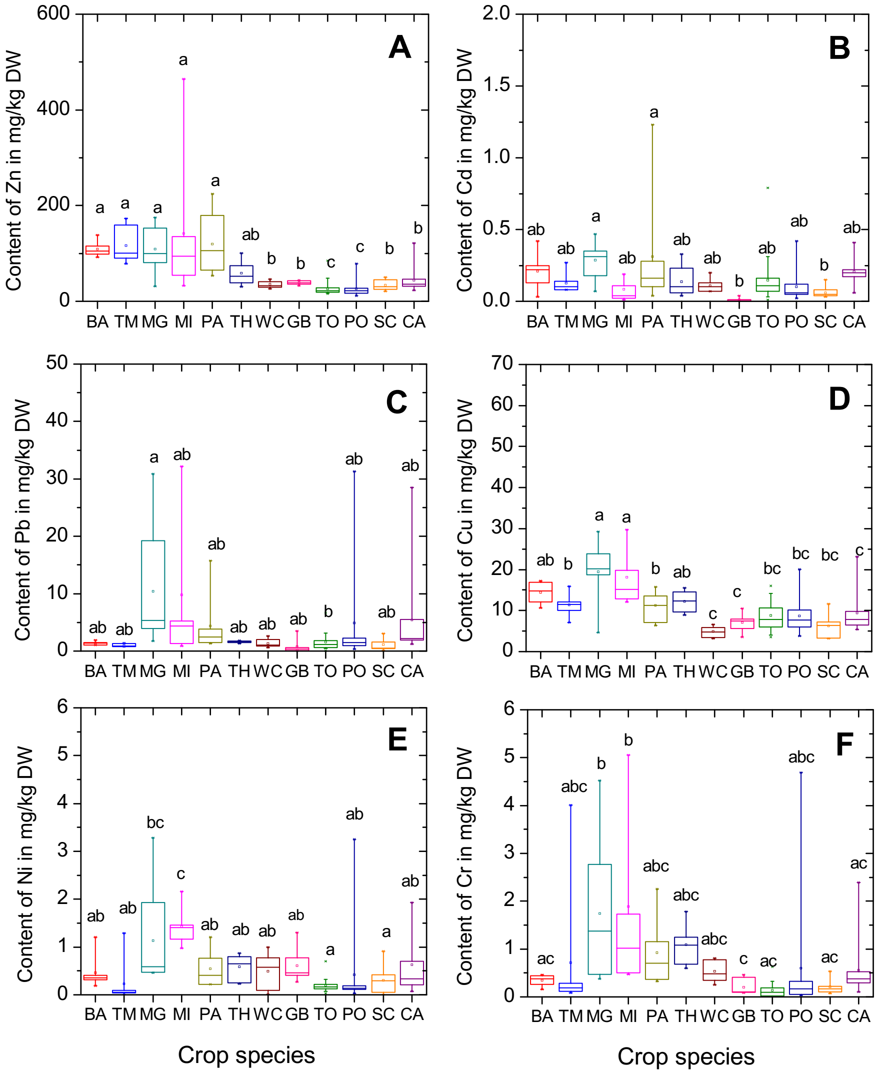

Fig. 2. Content of trace metals in the crop biomass in mg/kg biomass dry weight (DW). The boxplots indicate the 25th and 75th percentiles and means of the distribution. Lower case letters associated with the boxplots indicate significant interspecific differences. The sampled vegetable types are tomato (TO), green beans (GB), carrot (CA), potato (PO), kohlrabi (SC); white cabbage (WC), nasturtium (TM), parsley (PA), chard (MG), basil (BA), mint (MI), thyme (TH). The significance level is $p < 0.05$. For ANOVA results see Table 2.

other crop species except chard (Fig. 2E). Cr content of chard and mint leaves was significantly higher than basil, green beans and tomato as well as kohlrabi and carrots (Fig. 2F).

Crop samples from inner city sites had trace metal contents many times higher than the samples from the supermarket (e.g., basil 4.4, nasturtium 1.7, thyme 3.5 and parsley 1.9 times more Cr; potato 1.2 times more Cu, 1.3 times more Pb, 1.4 times more Cr; carrots 1.5 times more Cu, 4.7 times more Pb, 3.2 times more Cd, and 3.3 times more Cr; white cabbage 1.5 times more Zn, 1.3 times more Cu, 1.2 times more Pb, 1.5 times more Cd, and 3.4 times more Cr; tomatoes 1.7 times more Pb, 11 times more Cd, 4.7 times more Ni, 1.1 times more Cr; chard 6.1 times more Zn, 2.1 times more Cu, 5.3 times more Pb, see Table 1).

Vegetables harvested at planting sites in neighbourhoods with a high overall traffic burden showed significantly higher lead in the edible biomass; this was true for all vegetable types (Fig. 3A–C). Low overall traffic burden corresponded with low Zn content in fruits (Fig. 3E) and low Cr and Ni content in stem and root vegetables (Fig. 3I, L). However, our models did not sufficiently explain the measured variance of Cu and Ni content in crop biomass (Table 2). High traffic burden near the planting site, i.e. <10 m, resulted in 67% of crops having Pb values which exceeded the standards of the European Union. In contrast, only 38% of the crops grown at the distance of more than 10 m from the nearest street exceeded these values. Only 37% of samples had critical Pb values when crops were grown behind a barrier (buildings and/or tall vegetation) between the cultivation site and the next street, while more than half (52%) of all samples collected at sampling sites without such a barrier had critical Pb values. Almost no sample collected in this study exceeded the standards of the European Union for cadmium concentration in food crops. Surprisingly, vegetables which had been planted directly in urban soil beds had lead values above the critical value less often (40%) than vegetables planted in beds filled with commercial soils or planted in pots (50%).

4. Discussion

In general, the range of trace metal contents in the edible parts of the analysed vegetables was similar to concentrations reported

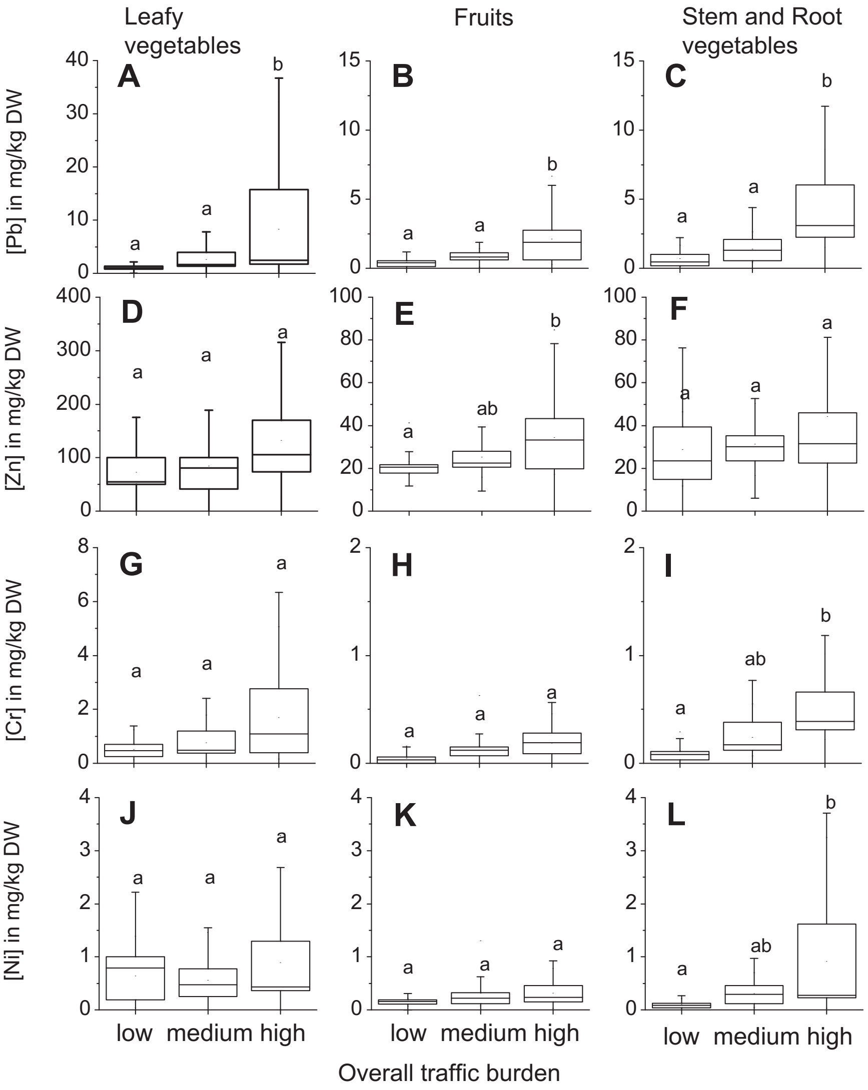

Fig. 3. Content of trace metals in the crop biomass in mg/kg biomass dry weight (DW) in relation to the overall traffic burden at each site. The boxplots indicate the 25th and 75th percentiles of the distribution. Lower case letters associated with the boxplots indicate significant differences in overall traffic burden (low, medium and high). The significance level is $p < 0.05$. For ANOVA results see Table 2.

in previous studies (e.g., Kloke et al., 1984; Finster et al., 2004; Peris et al., 2007; UBA, 1995; Kachenko and Singh, 2006; Alexander et al., 2006; Murray et al., 2009 and 2011). The majority of these studies used controlled experimental approaches, which attempt to mimic 'real' garden situations (e.g., Alexander et al., 2006; Murray et al., 2009, 2011) or took place on rural sites (Peris et al., 2007). Field surveys in urban areas are scarce but crucial to determine health risks of urban horticulture. The few existing studies did not focus on inner city neighbourhoods (e.g., Kloke et al., 1984; Schönhard and von Laar, 1992; UBA, 1995; Ge et al., 2002; Finster et al., 2004; Kachenko and Singh, 2006), where urban horticulture is currently booming (e.g., Meyer-Renschhausen and Holl, 2000; Viljoen, 2005; Mougeout, 2006; van Veenhuizen, 2006). Traffic related lead exposure has been reduced in recent years by the introduction of unleaded gasoline (Mielke et al., 2011). To our knowledge, our study is the first within the last two decades which focused explicitly on crops grown in inner city neighbourhoods and which related trace metal content of crop samples to traffic-related parameters.

Surprisingly, vegetables planted in urban soil beds were less likely to have lead values above the critical values than vegetables planted in pots or beds that had been supplemented with commercial garden soil. This might result from the use of compost, which increases metal solubility (Murray et al., 2011), but more research is needed to reveal underlying causes as we could not analyse soil trace metal contents. Thus, the high variability of trace metal content in the biomass across different sites might have reflected the general heterogeneity of urban soils. Some of the extreme levels of trace metals might indicate additional point pollutant sources related to previous uses of the sites or from paint particles (Alloway, 2004). In Berlin, the patchiness of trace metal contamination is exacerbated by the haphazard distribution of debris resulting from bombing in World War II (Mekiffer et al., 2000; Alloway, 2004).

In contrast to other studies (e.g., Ge et al., 2000; Finster et al., 2004; Alexander et al., 2006), we did not find that the vegetable type, i.e. fruit, root, stem or leafy vegetable, significantly affected the trace metal contents of the edible biomass. Some of the frequently planted leaf crops showed significantly higher levels of Cu, Zn, Ni or Cr compared to fruit, stem or root vegetables, but this pattern was not consistent across all leafy crop species (Fig. 2). As an example, chard was a high accumulator crop with frequently elevated contents of all trace metals analysed in this study, while basil, nasturtium and white cabbage showed low accumulation of metals. The low trace metal accumulation in white cabbage is also in contrast to what might be expected considering the high soil–plant transfer coefficients for Pb reported in literature (Kloke et al., 1984; Kachenko and Singh, 2006).

Another important finding of our study was that a number of crop samples from inner city sites had trace metal contents many times higher than the samples from the supermarket. Only the supermarket samples of green beans, kohlrabi, basil and thyme had higher trace metal contents than the field samples from the inner city, except Cr in basil and thyme (see result section). With the exception of cadmium, the elevated trace metal concentrations measured in our study were comparable with results from studies on trace metal contents of vegetables grown in the vicinity of smelters (Kachenko and Singh, 2006) or irrigated by wastewater (Arora et al., 2008). This clearly underlines potential health risks associated with urban horticulture in inner city areas.

In total, 52% of all samples analysed in this study exceeded European Union standards for Pb concentration in food crops (EC, 2006), with clear differences among species. More than half of the samples of carrot, chard, thyme, mint, potato and parsley exceeded the critical values. In contrast, less than one-third of samples of tomato, kohlrabi, green beans, white cabbage exceeded these values and no sample of basil or nasturtium did so. Thus, our results partially contrast with other empirical evidence that legumes accumulate low amounts, root vegetables moderate amounts and leafy vegetables high amounts of trace metals (Ge et al., 2000; Finster et al., 2004; Alexander et al., 2006). Moderate accumulators such as carrots and potatoes frequently exceeded the critical Pb values in our study. In summary, our data do not support generalisations regarding “risky high accumulators” or “safe low accumulators”. In addition, information on cultivar level is needed (Alexander et al., 2006).

Depending on the average consumption pattern and the consumer, daily intakes might be too high for some trace metals. The WHO dietary intake limits for adults are 3.0 mg for Cu, 22.0 mg for Zn, 0.060 mg for Cd and 0.214 mg for Pb (Joint FAO/WHO Expert Committee on Food Additives, 1999). The recommended daily vegetable consumption (excluding potatoes) is 400 g for adult and 200 g for children younger than 6 years. The daily consumption of potatoes is estimated at 100 g for adults and 50 g for children. Thus, an adult consuming an average of 100 g each of carrots, tomatoes, kohlrabi, chard, and potatoes would be ingesting 3%, 17%, 5% and 5% of the accepted daily intake of Zn, Pb, Cu, and Cd, respectively. Children younger than 6 years consuming 50 g each of the vegetables would be ingesting 6%, 35%, 11% and 10% respectively of the accepted daily intake. At several sites, the contents of trace metals were significantly higher and would increase these ingestion values sharply.

One major result of our study was the finding that—beyond the general urban pollution load—site-specific effects significantly affected trace metal contents. In particular, traffic-related parameters were important. High Pb contents in edible crop tissues were mainly associated with high traffic burdens in the neighbourhood and a planting site adjacent to a street without buildings or vegetation to serve as barriers to traffic-related pollutants (Table 2). Correspondingly, a high overall traffic burden at a planting site was related to higher contents of trace metals in different types of vegetables (Fig. 3). Our data add evidence to the importance of air deposition as a pathway for the contamination of vegetables grown in inner city neighbourhoods and thus support estimates of the high risk of metal exposure to urban populations from consumption of vegetables grown adjacent to roads (Hough et al., 2004). Atmospheric deposition during production, transportation and sale of vegetables can lead to elevated levels of trace metals in vegetables (Al-Jassir et al., 2005; Sharma et al., 2009).

5. Conclusions

In general, our study indicated that a higher overall traffic burden increases trace metal content in the crop biomass while the presence of barriers between cultivation site and roads strongly reduces trace metal content. Considering existing recommendations or guidelines for urban gardeners (e.g., Finster et al., 2004) the traffic-related contamination of inner city crops can be markedly reduced by undertaking cultivation at sites where buildings and large stands of vegetation reduce airborne pollutant influxes. Even in high traffic areas, the precautionary use of mulch or weed tarp might be useful to reduce the airborne pollution (Finster et al., 2004). However, the effectiveness of these or other measures to be developed must be tested.

Furthermore, the high variability in trace metal content across vegetable types and sites underlines the importance of crop- and site-specific monitoring to assess the potential impact of each type of crop on human health. In our study, green beans, kohlrabi and basil showed a lower trace metal accumulation compared to other crops (e.g., carrot, chard, potato or parsley). At the same time our data clearly illustrate constraints in generalising patterns of metal accumulation for different types of vegetables and associated challenges in modelling or predicting species-specific health risks (Murray et al., 2009) and deriving adequate guidelines for urban gardeners. Simple guidance about problematic or non-problematic vegetable types is thus difficult to develop. Our study suggests that urban crops are not automatically ‘healthy’ or ‘safe’ compared to supermarket products. Additional studies are warranted to develop pollution monitoring, risk assessment and species-specific planting guidelines for urban horticulture and to enhance food safety and food security in urban horticulture.

In contrast to the classical views on food safety, which mainly focus on contamination of urban crops, some studies have suggested that these risks must be considered and judged in light of the overall human health benefits associated with ‘growing your own’ food in urban areas (e.g., Leake et al., 2009). Hence, combining perspectives on pollution risks and societal benefits is a challenge for the further development of urban horticulture.

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