Metals in urban soils of Sevilla: seasonal changes and relations with other soil components and plant contents

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Summary

Soils of the urban area of Sevilla have been scarcely studied, especially concerning their concentrations of potentially toxic metals. A previous paper has shown that moderate pollution exists in soils from some public green areas of the city, and a common pattern was found in the distribution of the concentrations of some particular metals. The present paper is aimed at (i) determining possible seasonal changes in the measured concentrations; (ii) checking possible effects of the observed pollution on plant metal contents, and (iii) finding possible relations between metals by statistical techniques.

Samples of 35 soils from the urban area of Sevilla were studied. Comparison with previous data shows that samples from a depth of 0–20 cm are representative of the measured soil properties for the city. We show that in most cases differences in the EDTA- and *aqua regia*-extractable metal contents between autumn 2000 and summer 2001 are not significant. Only Zn shows significant decreases ($P < 0.05$), probably because it is more mobile than the other metals studied. Electrical conductivity and pH also show significant changes related to leaching of soluble salts. We found a strong association between 'urban' metals (as defined in the literature) and organic matter, as shown by factor analysis, whereas 'non-urban' metals could be related to clay and carbonate contents, perhaps coming from the soil parent materials. The behaviour of the urban metals means that organic matter contributes to their accumulation, either by retention of the incoming metals from the atmosphere, dust or various human activities, or from addition of organic amendments that might provide significant amounts of such metals. Although concentrations of Cu, Pb and Zn at several sites exceeded the limits established elsewhere as acceptable in residential areas, the values in the grass were less than those considered as normal in the literature. This implies that fairly large concentrations in the soil do not necessarily make metals more available.

Introduction

Pollution of soil by potentially toxic metals is often assessed in terms of total concentrations. However, many forms of metal are strongly held in soil and generally become immobile, although several factors (changes in pH or redox conditions, soluble organic complexing agents, etc.) may mobilize such forms (Adriano, 1986; Madrid, 1999).

In both agricultural and horticultural soils, the availability of a given metal is crucial, as this determines uptake by food crops and the consequent risk to the food chain. Soils in urban environments receive considerable pollution from industry, traffic, refuse and vandalism, and are easily inhaled or ingested as suspended matter or by direct contact. Here too, depending on the metal, its speciation and its toxicity mechanism, the

most mobile (or soluble) forms are more likely to be harmful than those held strongly in the soil matrix.

The chemistry of pollutants, including metals, in urban soils is far from understood, and several aspects of the dynamics of metal pollutants in urban soils need further study, for example the degree of interaction of contaminants with the soil constituents. In the last few years, soils in many cities have been studied, for example in Salamanca, Valladolid and Madrid (De Miguel *et al.*, 1997, 1998; Sánchez Martín *et al.*, 2000), Aberdeen (Paterson *et al.*, 1996), Athens (Chronopoulos *et al.*, 1997), Kiel (Beyer *et al.*, 1996), and Rostock (Kahle, 2000). After statistical analysis of their data, De Miguel *et al.* (1997) concluded that metals in urban soil could be divided into three groups according to their source. They defined 'natural' elements (Al, Ga, Mn, Y, etc.) as those showing concentrations dependent upon the parent material. Elements of anthropogenic origin (from traffic, building, etc.), such as Ba, Cu, Pb, Zn, etc.,

Figure 1 Location of the sampling points within the urban area of Sevilla.

were defined as 'urban'. They identified a third group (Ca, Fe, Ni, U, etc.) including both those elements likely to have undergone geochemical changes from their original form and those of mixed origin. Similarly, Birke & Rauch (2000) suggested that some metals were of natural origin whereas others could be attributed to industry. Mielke *et al.* (2000) found different degrees of association among metals in urban soils of New Orleans, with Pb, Zn, Cr and Cu as dominant metals strongly correlated with one another. They also found positive correlations for Cd, Mn, Ni and V, but these differed from the first group in their distribution within the city. In the case of Pb, Mellor & Bevan (1999) found that in a Tyneside catchment in Great Britain the greatest concentrations of Pb were in the more urban and industrialized areas.

Recently, a wide survey, URBISOIL, has been initiated in several European cities, including Sevilla, to define the main variables for a comprehensive description of urban soil quality. Madrid *et al.* (2002) described a preliminary sampling designed to identify the distribution of heavy metals in the city, and their possible relations with the various soil components. Samples of soils were taken from 0–10 cm and 10–20 cm depth in September to December 2000, and concentrations of metals extracted by 0.05 M EDTA and *aqua regia* were determined. Some patterns in their spatial distribution suggested

moderate pollution, partly related to traffic density, in several parks and gardens, particularly those closer to the historic centre of the city. At such sites, the concentrations of some metals exceeded the limits established elsewhere as acceptable in residential areas (Moen *et al.*, 1986; Ministère de l'Environnement du Québec, 2001). Marked differences in the EDTA and *aqua regia* data for Pb, Zn and Cu are attributed to the 'urban' nature of these elements, as concluded by De Miguel *et al.* (1997) for urban soils in Madrid. Chromium extracted by EDTA also shows a positive relationship with traffic density. This suggests an urban origin for the more available fractions of this metal.

The continuing cycle of construction, use and renewal of urban structures, as well as management and accidental or incidental pollution, lead to far higher rates of change in urban environments than is common elsewhere (Thornton, 1991). To observe any possible seasonal changes due to human activities and to the marked differences in temperature between winter and late spring/early summer in Sevilla, we undertook a new sampling campaign in June and July 2001. Samples of grass were also taken at each sampling point so that we could check whether the metal concentrations in the soil affected those in the plants. In this paper we describe our results and compare them with those of Madrid *et al.* (2002).

By combining the data from the two studies we aimed to provide a useful basis for planning and developing the URB-SOIL project. Statistical evidence of the different behaviour of the various metals, in relation to their 'urban' or 'natural' origin (as defined by De Miguel *et al.*, 1997), is also given.

Methods

Thirty-five samples were collected in the main public parks and gardens in Sevilla (Figure 1). Within the larger sites (>4 ha), sampling points were fairly evenly distributed with a density of one per 2–3 ha. The smaller sites (<4 ha) were sampled at one single, central point. Wherever possible the same sites sampled by Madrid *et al.* (2002) were selected, but some of the sites in the previous study had to be discarded, as they were affected by public works in progress or were inaccessible for other reasons. Additional points were sampled in the main parks to match the chosen density of sampling. For these reasons, only 26 sampling points coincide with points of those sampled earlier. At each point, grass samples (leaves and stems) of *Cynodon* spp., *Paspalum* spp. and *Lolium* spp. were also taken.

A paired *t*-test was applied to data from Madrid *et al.* (2002) to check the significance of the differences between samples from 0–10 cm and 10–20 cm depth. No significant differences between depths were found for most general descriptive variables and the *aqua regia*- and EDTA-extractable metals ($P > 0.05$). Only calcium carbonate equivalent (CCE), organic C, available K and EDTA-extractable Mn and Ni showed significant differences between depths ($P < 0.05$). The relations between EDTA-extractable Cu, Pb and Zn for the 0–10 cm and 10–20 cm samples and the calculated reduced major axis for the scatter of each metal are shown in Figure 2 as an example. Similar relationships obtained for other metals are not shown here. Slopes close to 1 and small intercepts suggest

Figure 2 Relationships between EDTA-extractable Cu, Pb and Zn at 0–10 cm and 10–20 cm depth. Similar patterns are obtained with other metals (not shown). The straight lines are the reduced major axes.

that, on average, the concentrations at the two depths are similar. We therefore consider samples at 0–20 cm depth to be representative of soil surface metal concentrations. Composite soil samples were taken by mixing three subsamples of about 2 kg from three random excavations within 1 m² around each sampling point.

Stones and foreign objects were removed from the samples by hand. The samples were air-dried, gently crushed, and sieved to <2 mm. A portion of each sample was ground further to <0.5 mm for *aqua regia* digestion. Particle-size distribution was determined by the hydrometer method (Gee & Bauder, 1986). Soil chemical properties were determined following standard procedures (Page *et al.*, 1982), pH in water (1:2.5) extract, electrical conductivity in 1:5 extract, calcium carbonate equivalent by a manometric method, organic matter by K₂Cr₂O₇ oxidation, available P by extraction with 0.5 M NaHCO₃ at pH 8.5 (1 g:20 ml) and available K by extraction of 5 g with 50 ml of 1 M NH₄CH₃COO at pH 7. Metals were extracted for 1 hour from 1 g of soil by 10 ml of 0.05 M EDTA (Ure *et al.*, 1993) and by digestion of 1 g of soil with 4 ml of *aqua regia* for 15 minutes in a microwave oven (Kingston & Haswell, 1997). The former method gives good estimates of the availabilities of heavy metals to plants (Quevauviller *et al.*, 1997; Arambarri *et al.*, 1999). The *aqua regia* digestion procedure is judged adequate for analysing total recoverable metals in soils (Vercoetere *et al.*, 1995). The residual elements not released by *aqua regia* are mostly bound to silicate minerals, and are considered unimportant when estimating the mobility and behaviour of the elements (Niskavaara *et al.*, 1997; Chen & Ma, 2001). The amount extracted by *aqua regia* is sometimes called the 'pseudo total content', and has been used to assess the risks of direct intake of metals from soil by children and animals (Gupta *et al.*, 1996).

We analysed the grass samples after washing and drying them at 70°C for 48 hours, grinding them and then digesting 0.5 g in 4 ml of concentrated HNO₃ for 15 minutes in a microwave oven (Jones & Case, 1990). The mixtures were then filtered through Whatman No 2 paper, and their volumes were made up to 50 ml.

Metal concentrations were determined by ICP-OES. Analytical grade reagents were used throughout, and blank samples were included in each extraction procedure. We used plastic sieves and trays when handling soil samples and avoided stainless steel tools. Quality control was periodically carried out with IRMM reference materials CRM-600 for EDTA extraction, CRM-141R for *aqua regia* digestion, and CRM-281 for plant digestion. Deviations were within $\pm 10\%$ of the certified values.

Results and discussion

Soil data: Comparison with the previous sampling

Table 1 shows the mean values, medians, standard deviations (SD) and ranges of the data of the general descriptive variables

Table 1 Means, medians, standard deviations (SD) and ranges for the general descriptive properties of the 35 soil samples

	Mean	Median	SD	Range
pH	8.0	8.0	0.13	7.6–8.3
EC /dS m ^{-1a}	0.18	0.19	0.05	0.11–0.31
CCE /g kg ^{-1b}	208	220	77	10–360
OC /g kg ^{-1c}	16.2	15.4	0.72	5.0–30.0
N /g kg ⁻¹	1.3	1.4	0.55	0.4–2.5
Available P /mg kg ⁻¹	32	19	36	2–172
Available K /mg kg ⁻¹	341	291	205	131–1160
Coarse sand /g kg ⁻¹	278	238	150	38–577
Fine sand /g kg ⁻¹	115	106	62	38–359
Silt /g kg ⁻¹	355	350	110	182–563
Clay /g kg ⁻¹	251	245	88	95–453

^aElectrical conductivity.

^bCalcium carbonate equivalent.

^cOrganic C.

for the soil samples. Figure 3 shows the particle-size distribution of all samples according to the USDA scheme. Most samples fall into the clay loam, loam or sandy loam classes. The exceptions are haphazardly distributed throughout the city, indicating that soil texture is not related to geographical location. In fact most sites have a common geological origin. Information on urban soils (Bullock & Gregory, 1991; De Kimpe & Morel, 2000) suggests that the average contents in Sevilla for organic C and total N (Table 1) were rather small, as were the values for the C/N ratio. The mean organic C and total N values were 20% and 30% less than in the first sampling, 20 and 1.9 g kg⁻¹, respectively (averages of the two depths studied by Madrid *et al.*, 2002), but the differences are not significant (see Table 3).

Table 2 shows the means, medians, SD, ranges and skewness for the metals extracted by EDTA and *aqua regia*. The SD of the log-transformed data are also given. The metal data summarized in Table 2 are similar to those from the earlier study. In most cases, the ranges show a rather large dispersion of the data, although somewhat smaller in the case of Mn, Ni and Fe. Many metals have positively skewed distributions, except EDTA Cr and *aqua regia* Cr, Ni and Fe. However, only Cu, Pb and Zn extracted by both methods showed medians considerably smaller than the means. When data are log-transformed, the SD for these three metals and for EDTA Cr are noticeably larger than those for *aqua regia* Cr or for Mn, Ni or Fe by both methods. Large relative SD, both for the raw and for the log-transformed data, together with the large ranges and skewness coefficients observed in the data for Cu, Pb and Zn must be a consequence of the large concentrations found at several sampling points. In fact, as found previously, in many cases the *aqua regia* concentrations of Cu, Pb and Zn exceeded the values established in several countries as ‘background’ concentrations in soils for non-agricultural uses

Figure 3 Particle-size distribution of all samples.

(called level A by Moen *et al.*, 1986; and Ministère de l'Environnement du Québec, 2001). Within these cases, several sites had concentrations greater than the maximum acceptable values for recreational areas (level B in those references), and in some places the concentrations of the three metals were greater than the acceptable limits for commercial or industrial areas (level C). As for the first sampling, the largest contents of Cu, Zn and Pb were found in the older green areas, within the inner, historic quarters of the city. Those historic quarters traditionally supported the most intense urban activity and traffic until about 12 years ago. Since then, new outer highways have been built and some of the existing roads have been widened, so that intense urban activity and large traffic densities are now widespread throughout the city and less limited to the centre. The geographical distribution of the metal concentrations (not shown here) is similar to that found by Madrid *et al.* (2002). The concentrations of the other metals we studied are all less than the acceptable maxima.

To give a more detailed view of possible seasonal changes between the samplings, a paired *t*-test was applied to the data for the 26 points common to both. Table 3 summarizes the results of the test. There are significant differences ($P < 0.05$) between samplings for Zn extracted by the two methods, and highly significant differences ($P < 0.01$) were found for conductivity, pH, and Mn and Fe extracted by EDTA. The decrease in Zn extracted by both methods suggests that some of this metal was removed by rain or irrigation in winter and spring of 2000–2001. Similarly, changes in electrical conductivity and pH are probably related to the leaching of soluble salts for the same reason. The highly significant differences for EDTA Mn and Fe are not easily explained. The possibility

Table 2 Means, medians, standard deviations (SD), ranges and skewness coefficients for metal concentrations extractable by EDTA and *aqua regia* for the 35 soil samples, and SD of the log-transformed data

Extractant	Metal	Mean /mg kg ⁻¹	Median	SD	Range /mg kg ⁻¹	Skewness coefficient	SD of log- transformed
EDTA	Cr	0.118	0.120	0.104	0.01–0.39	0.8	0.56
	Cu	16.7	7.63	24.7	2.2–128	3.3	0.46
	Pb	39.6	24.0	42.2	5.6–198	2.1	0.43
	Zn	16.7	10.6	20.0	1.3–102	2.7	0.49
	Mn	47.7	42.3	30.4	18.5–202	4.1	0.18
	Ni	0.611	0.540	0.41	0.16–2.63	3.7	0.20
	Fe	69.3	66.6	24.3	32.4–149	1.9	0.14
<i>Aqua regia</i>	Cr	42.8	42.0	8.8	23.7–67.3	0.4	0.09
	Cu	64.6	41.7	74.8	11.4–374	2.8	0.35
	Pb	161	103	184	14.1–791	2.0	0.47
	Zn	107	86	82	25.8–450	2.6	0.30
	Mn	480	468	108	335–893	1.9	0.09
	Ni	23.5	23.1	4.1	16.4–32.3	0.1	0.08
	Fe	21000	20900	2790	14450–27100	0.1	0.06

that they are an effect of redox processes (caused by changes in water contents of the soils from winter to summer) seems unlikely, as changes in the metals occur in opposite directions, as shown by the signs for *t* in Table 3.

Soil data: Rotated principal component analysis

Madrid *et al.* (2002) suggested that Cu, Pb and Zn extracted by either method behaved differently from the other metals. To determine whether a similar distinction can be applied to the new data, we used Varimax-rotated principal component analysis to reveal possible associations among variables. As mentioned above, many metal concentrations (marked in the first column of Table 4) showed a significant skewness, and they were transformed to logarithms for the analysis.

The results are summarized in Table 4, in which the more important contributions of the variables, represented by the correlation coefficients for the first four rotated factors, are shown in bold. The eigenvalues and per cent of variance accounted for by each factor are also shown. About 78.6% of the total variance was accounted for. A strong association was found between both EDTA- and *aqua regia*-extractable Cu, Pb and Zn and organic C content in Factor 1, whereas the clay content was associated with *aqua regia*-extractable Cr, Mn, Ni and Fe. The EDTA contents of Mn, Ni and Fe showed a separate negative association with calcium carbonate equivalent, CCE, in Factor 3. EDTA-extractable Cr does not show a marked association with any factor, and pH is isolated in Factor 4. A large proportion of the variance of most variables was accounted for by the factor analysis, so that only CCE, EDTA Cr and *aqua regia* Mn showed communalities with values less than 0.6, which means that less than 60% of their

Table 3 Paired *t*-test for the comparison between two samplings (2000 and 2001). Those cases showing *P* < 0.05 are printed in bold

Analyte	Student's <i>t</i>	<i>P</i>
EC ^a	−3.042	0.005
pH	5.981	0.000
CCE ^b	1.269	0.216
OC ^c	−0.494	0.625
Coarse sand	1.305	0.204
Fine sand	−0.982	0.335
Silt	−0.658	0.516
Clay	−0.419	0.679
Total N	−1.802	0.084
Available P	−1.212	0.237
Available K	1.885	0.071
EDTA Cr	−2.045	0.052
EDTA Cu	−1.590	0.124
EDTA Pb	0.207	0.838
EDTA Zn	−2.134	0.043
<i>Aqua regia</i> Cr	1.397	0.175
<i>Aqua regia</i> Cu	−1.069	0.295
<i>Aqua regia</i> Pb	−0.095	0.925
<i>Aqua regia</i> Zn	−2.619	0.015
EDTA Mn	−3.068	0.005
EDTA Ni	0.075	0.941
EDTA Fe	3.083	0.005
<i>Aqua regia</i> Mn	−1.034	0.311
<i>Aqua regia</i> Ni	0.455	0.653
<i>Aqua regia</i> Fe	0.269	0.790

^aElectrical conductivity.

^bCalcium carbonate equivalent.

^cOrganic C.

Table 4 Correlation coefficients between extracted metals, organic C, clay and CCE contents, and pH and the first four factors of the analysis, and eigenvalues and per cent of variance accounted for. Components with absolute values ≥ 0.6 are printed in bold. Communalities show the proportion of each variable variance accounted for by the factors

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Communalities
OC ^a	0.845	0.104	−0.011	−0.102	0.736
Clay	−0.379	0.767	0.090	−0.334	0.851
CCE ^b	0.388	−0.153	−0.600	−0.164	0.539
EDTA Cu ^c	0.969	−0.012	0.087	0.022	0.948
<i>Aqua regia</i> Cu ^c	0.962	0.020	−0.103	0.014	0.937
EDTA Pb ^c	0.975	0.030	−0.035	−0.035	0.953
<i>Aqua regia</i> Pb ^c	0.905	0.122	−0.143	−0.009	0.855
EDTA Zn ^c	0.941	0.031	−0.025	0.171	0.917
<i>Aqua regia</i> Zn ^c	0.963	0.066	−0.120	0.098	0.955
EDTA Cr	0.018	0.524	−0.045	0.207	0.320
<i>Aqua regia</i> Cr	0.086	0.883	0.135	0.168	0.833
EDTA Mn ^c	−0.401	−0.084	0.777	−0.107	0.782
<i>Aqua regia</i> Mn ^c	0.040	0.600	0.380	−0.227	0.539
EDTA Ni ^c	0.073	0.056	0.930	−0.173	0.904
<i>Aqua regia</i> Ni	0.074	0.891	0.004	0.064	0.804
EDTA Fe ^c	0.375	0.125	0.645	0.353	0.697
<i>Aqua regia</i> Fe	0.427	0.720	−0.082	0.045	0.709
pH	−0.014	0.133	−0.023	0.910	0.847
Eigenvalue	6.96	3.40	2.46	1.31	
Per cent variance	39.7	18.9	13.7	7.3	
Cumulative percentage	39.7	57.6	71.3	78.6	

^aOrganic C.

^bCalcium carbonate equivalent.

^cThese variables were log₁₀-transformed to obtain an approximate normal distribution.

variance was accounted for. Inclusion of other soil variables in the analysis did not cause any further improvements in the results. Figure 4(a,b) shows the measured variables plotted in the unit circle as their correlation coefficients between them and (a) the first two factors and (b) the first and third factors. The association between the concentrations of the three urban metals and organic C is clearly suggested by the position of the corresponding points close to the Factor 1 axis far from the origin in both figures. The different behaviours of the *aqua regia* and EDTA data for Cr, Mn, Ni and Fe are also evident from their positions.

Thus our analysis shows strong relations between Cu, Pb and Zn. In contrast, the concentrations of other metals, namely Cr, Mn, Ni and Fe, showed clearly different patterns. There are several possible explanations for the association of the ‘urban’ metals with organic matter. First, some organic amendments, especially those derived from urban wastes, sewage sludge, etc., can have large concentrations of metals. Second, organic matter helps to retain metals that enter the soil (McBride, 1989). As there are no records of waste materials added to these soils and there are no early studies of metal contamination, the first possibility cannot be excluded. Both explanations are therefore plausible in the present case. The

association of the other metals, especially their *aqua regia* contents, with the clay fraction cannot be attributed simply to sorption on materials with a large surface area, as such an association is not found for the urban metals. The opposite signs of the association of EDTA-extractable Mn, Ni or Fe and carbonate contents in Factor 3 exclude co-precipitation as a reason for the association between these variables. Thus a genetic relation of these metals with the original soil materials is possible.

Plant data

Table 5 lists the mean values, medians, standard deviations and ranges of the metal concentrations for the grass samples taken at each sampling point. The contents of Pb were very small, erratic, and clearly less than the value for the reference material CRM-281 (2.38 mg kg^{−1}), and thus probably within the experimental errors of the analysis. We therefore exclude Pb from this discussion. The strong variation observed for the other ‘urban’ elements in the soil samples was not found in the plants (compare Tables 2 and 5). In fact the ratios standard deviation/mean for Cu and Zn in the plants were comparable

Figure 4 Scatter of the metal contents and some soil properties in the unit circle for (a) the first two factors and (b) the first and third factors. Coordinates are correlation coefficients after Varimax rotation. Subscript 'E' is metal extracted by EDTA. Subscript 'a' is metal extracted by *aqua regia*.

to those for Cr, Mn, Ni and Fe and those found in the soils for the latter group of metals.

The relations between the metal contents of soil and plant were expressed by determining the correlation for each metal between the EDTA or *aqua regia* soil contents and the plant data. Table 6 shows the coefficients and significance of each correlation. The Cu and Zn contents in the grass samples were significantly related to the EDTA- and *aqua regia*-extractable

Table 5 Mean values, medians, standard deviations (SD) and ranges for metal concentrations in the grass samples

Metal	Mean /mg kg ⁻¹	Median /mg kg ⁻¹	SD	Range /mg kg ⁻¹
Cr	3.49	3.59	1.57	0.30–6.89
Cu	9.99	10.3	2.40	6.69–16.6
Zn	54.5	51.3	19.0	27.5–99.7
Mn	53.7	44.5	24.0	15.1–109
Ni	2.10	2.02	0.84	0.37–4.17
Fe	135	121	58	68.0–340

concentrations in the soil. In contrast, the elements of 'natural' origin show no relation. Despite the significant relation between the concentrations of urban metals in soils and grass, in those sites with relatively large metal concentrations (Madrid *et al.*, 2002) the plants did not show especially large concentrations. Thus the means in Table 5 are comparable to the concentrations reported for wild weeds in unpolluted areas in Europe (Bargagli, 1998), and to those considered as normal in plants (Greger, 1999). By factor analysis including the plant data (Table 7) we concluded that associations between the plant data and any soil variable are weak or do not exist. Only plant Mn is negatively related with the urban metals in Factor 1.

Conclusions

Comparison of our two surveys shows that a sampling depth of 0–20 cm is suitable for the study of the urban soils of Sevilla. However, sampling to a shallower depth might be more suitable for other urban areas with different soil characteristics, which cause more variation of metals with depth. Variation of the results from autumn to summer was not significant, except for easily leached soil components. The largest concentrations of Cu, Pb and Zn are found in the sites closest to the historic quarters of the city, suggesting a relation with human activities. Accumulation of these metals, which are some of the so-called urban metals, in the soils studied is clearly favoured by organic matter. Other metals are much more uniform in content, probably coming from the parent materials of the soils.

Although fairly large concentrations of the urban metals were found at some sites, the availability of these metals for plants does not seem significant, considering there is little effect on their contents in grass. However, this does not exclude the possibility that they are transferred to humans through ingestion or by inhaling as suspended matter. There is no information about the nature and quality of organic amendments used on these soils in the past. However, the fairly large concentrations at some sites lead us to suggest that care should be taken not to apply any further amendments contaminated with metals.

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