Bull. Environ. Contam. Toxicol. (1994) 53:204–210

Bulletin of Environmental Contamination and Toxicology

Concentrations of Pb, Zn, and Cu in *Taraxacum* spp. in Relation to Urban Pollution

C. M. Cook,[1] S. P. Sgardelis,[2] J. D. Pantis,[2] T. Lanaras[1]

[1]Department of Botany, University of Thessaloniki, P.O. Box 109, GR-540 06 Thessaloniki, Greece
[2]Department of Ecology, University of Thessaloniki, P.O. Box 119, GR-540 06 Thessaloniki, Greece

Received: 14 October 1993/Accepted: 14 January 1994

The combustion of petroleum fuel and exhaust emissions are major sources of atmospheric pollution in cities which result in the deposition of toxic substances, particularly heavy metals, in the surface layers of soils (Albasel and Cottenie; 1985 Seaward and Richardson 1990). Lead in particular enters the environment from the use of tetraethyl lead as an antiknock agent for petrol engines and constitutes 21% of the fine particles emitted from cars burning leaded petrol (Seaward and Richardson 1990; Markert 1992). Antiwear protectants incorporated in lubricants often contain Cd, Cr, Cu, Hg, Ni, Pb and/or Zn which are also released into the environment by inefficient engines and through irresponsible dumping of engine oils (Seaward and Richardson 1990). Zn from tyre wear and Cu from diesel engines also add considerably to the environmental metal burden (Seaward and Richardson 1990). The lowering of the permitted lead content of petrol and the growing use of unleaded fuel are expected to lead to reductions in the environmental lead burden, however, until unleaded fuel becomes universally accepted lead contamination, particularly of roadside soils and vegetation is a major cause for concern (Seaward and Richardson 1990). A direct relationship between car exhaust, the Pb content of needles of *Abies alba* and reduced growth has been observed (Braun and Fluckiger 1988) and lead pollution can extend hundreds of metres from major highways (Albasel and Cottenie 1985; Braun and Fluckiger 1988). Lead tolerance has been observed in higher plants growing on mine waste soils (see Kabata-Pendias and Pendias 1984; Brown and Brinkmann 1992; Morishita and Boratynski 1992) and to a lesser extent on lead-contaminated roadside soils (Tam et al. 1987; Kabata-Pendias and Pendias 1984). Automobiles which are responsible for line sources of pollution emissions in rural and suburban areas have a more far-reaching impact on roadside vegetation, already under considerable stress, in urban areas (Seaward and Richardson 1990; Tam et al. 1987). Information on heavy metal effects on vegetation in urban environments however, are scarce. Modeling and multivariate analysis of a few of the factors involved have provided only limited data relating to plant performance in these complex environments (see Seaward and Richardson 1990). Therefore in this study, the extent of heavy metal pollution by Pb, Zn, Cu and Cd in soils and in dandelion plants in the city of Thessaloniki has been examined. Plants of *Taraxacum* spp. were chosen for analysis due to their prolific nature and ubiquitous distribution.

Correspondence to: C. M. Cook

MATERIALS AND METHODS

Soil and plant samples were collected from sites throughout the city of Thessaloniki, Greece located mainly along three major roads carrying traffic flow along the East-West axis of the city (Fig. 1). Plants (5 from each site) of the same developmental stage (flowering) were transferred to the laboratory, separated into roots and leaves and dried to constant weight at 80 ^{o}C for 12 h. Soil collected from the immediate vicinity of the roots (a depth of about 10 cm) was dried to constant weight at 80 ^{o}C for 12 h.

Dried plant material (1 g) and soil (1 g) were digested with a nitric-perchloric acid solution (4:1 v/v) for 5 h at 150 ^{o}C and the concentration of Pb, Zn, Cu and Cd were determined in an atomic absorption spectrophotometer (Perkin Elmer 2380) using SpectrasoL (BDH Chemicals Ltd, Poole, England) as a standard solution.

Regression analysis, followed by analysis of covariance (Sokal and Rohlf 1981), was used for testing the relationship between the concentration of each metal in the plant tissue and the concentration of the same metal in the soil.

RESULTS AND DISCUSSION

The soil concentrations of Pb, Zn and Cu at the sampling sites ranged from 1-620 mg kg^{-1} DW for Pb, 29-590 mg kg^{-1} DW for Zn and 25-210 mg kg^{-1} DW for Cu (Fig. 1). Cd concentrations (<0.5 mg kg^{-1} DW) were below the detectable limit of the method used. The concentrations of the metals measured in the soil followed the order Pb>Zn>Cu at 15 sites and Zn>Pb>Cu at 9 others. The soil concentrations of Pb, Zn and Cu were highest in the commercial centre of the city (sites A1, A2, A3, B1 and B2) and generally decreased as the distance from the commercial centre increased. The soil concentrations of Pb, Zn and Cu covariate and the correlation between them is highly significant (Table 1). The plant tissue metal concentrations ranged from 9-114 and 18-85 for Pb, 5-102 and 59-130 for Zn and 4-71 and 13-57 for Cu, in the roots and leaves respectively (Fig. 2). There was a positive, significant correlation between the metal concentration in the plant tissues (roots and leaves) and the metal concentration in the soil, with the exception of the Zn concentration in the leaves, which in almost all cases did not correlate significantly with any of the variants (Table 1).

Table 1. Correlation analysis of the Pb, Zn and Cu concentrations in the soil (s) and plant tissues: roots (r) and leaves (l).

	Pb l	Pb s	Cu r	Cu l	Cu s	Zn r	Zn l	Zn s
Pb r	**	**	**	*	*	**	-	**
Pb l		**	**	**	**	*	*	**
Pb s			*	-	**	**	-	**
Cu r				**	**	**	-	**
Cu l					**	*	-	**
Cu s						**	-	**
Zn r							-	*
Zn l								-

All correlations are positive. **: highly significant, $P<0.01$; *: significant, $P<0.05$; -: not significant, $P>0.05$.

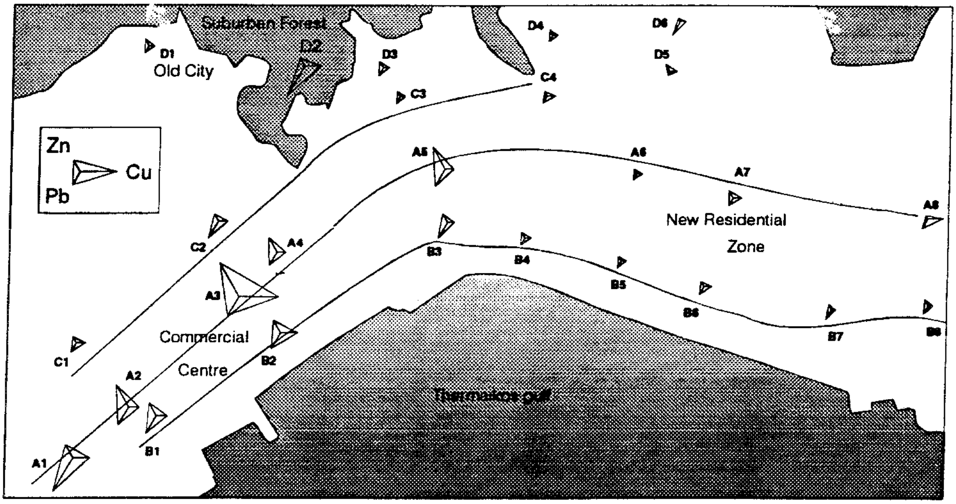

Figure 1. Map of Thessaloniki indicating the concentration of Pb, Zn and Cu in the soil at each of the sampling sites. Each metal and its concentration is represented by the direction and length of the line extending from the top of the pyramid as shown in the inset, where each line represents 300 mg kg^{-1} DW.

The best-fit regression model describing the relationship between the concentration of each metal in the plant tissue (roots and leaves) and the respective metal concentration in the soil (Fig. 2, dotted lines) is $P_t = a + bS$, where P_t is the metal concentration in the plant tissue, S the concentration of the same metal in the soil, a the intercept and b the slope of the regression line. The values of a and b of the fitted model are given in Table 2. A very good fit exists between the model and the data (analysis of covariance) with the exception of the Zn concentration in the leaves. The slopes of the regression lines are significantly greater than zero in all cases and do not differ significantly between them (covariance analysis), while there are significant differences between the values of the intercepts. The average concentration of Zn was greater than that of Pb and Cu in both roots and leaves, and was greater in the leaves than in the roots, where it is essential for the synthesis of chlorophyll and as a component of several leaf

Table 2. Parameters of the regression model $P_t=a+bS$ where, P_t is the metal concentration in the plant tissue, S the concentration of the same metal in the soil, a the intercept, b the slope, R^2 the determination coefficient and P the significance level, for Pb, Zn and Cu (Fig. 2, dotted lines).

	Pb		Zn		Cu	
Parameter	Roots	Leaves	Roots	Leaves	Roots	Leaves
a	16.40	25.06	42.86	81.48	12.47	12.35
b	0.11	0.07	0.09	0.04	0.27	0.19
R^2	41.50	32.41	23.70	7.90	54.20	70.60
P	0.00	0.02	0.09	0.15	0.00	0.00

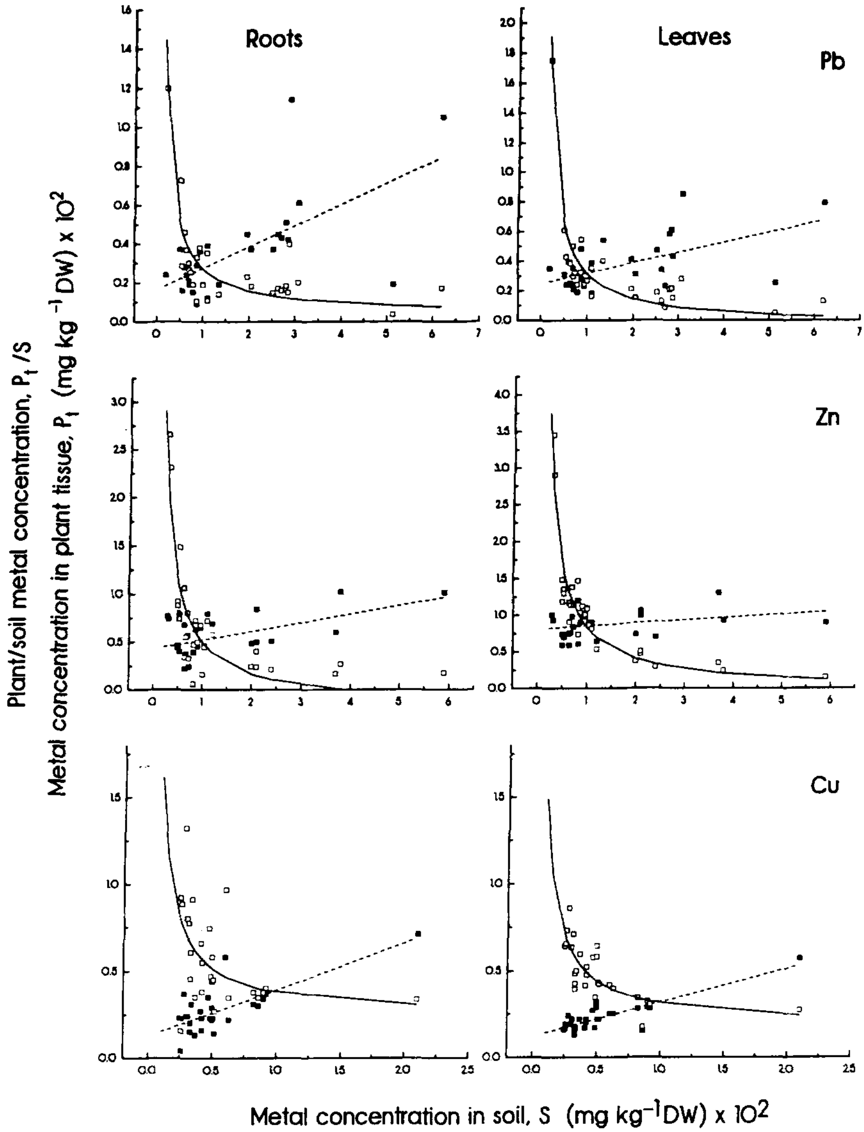

Figure 2. Relationship between the metal (Pb, Zn, Cu) concentration in the soil, S and (1) the metal concentration in the plant tissue, Pt (solid squares, dotted line) and (2) the plant/soil concentration ratio, Pt/S (open squares, solid line).

enzymes (Kabata-Pendias and Pendias 1984; Van Assche and Clijsters 1990; Markert 1992). The linear relationship observed between the Pb, Zn and Cu concentration in the plant tissue and the respective metal concentration in the soil is characteristic of plants having indicator strategy. In indicator plants the uptake of metals and their transport to the shoot are either regulated or passive uptake occurs, such that internal metal concentrations accurately reflect external metal concentrations (Baker 1981).

The relative accumulation or biological absorption coefficient (plant/soil concentration ratio) when plotted against soil metal concentration has been used to reveal whether elements are essential or non-essential in plant nutrition and whether the substrate-plant relationship reflects metal deficiency, tolerance or toxicity over the measured metal concentrations (Timperley et al. 1970; Baker and Walker 1990). The model that best fitted the relationship between the plant/soil concentration ratio and the soil concentration of Pb, Zn and Cu (Fig 2, closed squares) is $P_t/S=a+b(1/S)$. Parameters derived from covariance analysis are given in Table 3. The slope for each metal and tissue differs significantly from zero and to a greater extent the model describes the variation in P_t/S (R^2 vary between 23.70 and 99.90). According to the model the ratio of P_t/S is greater than one for soil concentrations (mg kg^{-1} DW) less than 25 and 34 for Pb, 57 and 84 for Zn, 19 and 15 for Cu and for roots and leaves, respectively. Below these concentrations it would appear that the plants experience a deficiency in the respective metal and actively take up metal from the soil. P_t/S is greater than one for Zn at several collection sites indicating a general Zn deficiency in the soil, while in the case of Cu and Pb there are few or no such observations. For plants experiencing higher soil metal concentrations (>100-250 mg kg^{-1} DW depending on the metal) P_t/S tends to a lower limit which is in the range of 0.2-0.4 for Cu and Zn and 0.1 for Pb indicating that the concentration of the metal in the plant is up to 40% of that in the soil. Timperley et al. (1970) suggest that the leveling out of the curve, after the rapid change in the gradient corresponding to metal deficiency, represents the range of soil concentrations over which metal tolerance is exhibited by the plants. The same authors suggest that hyperbolic shaped curves are characteristic of essential elements, such as Cu and Zn, and linear plots parallel to the soil concentration axis are characteristic of non-essential elements such as Ni.

Table 3. Parameters of the regression model $P_t/S=a+b(1/S)$ where, P_t/S is the plant/soil concentration ratio, S the concentration of the same metal in the soil, a the intercept, b the slope, R^2 the determination coefficient and P the significance level, for Pb, Zn and Cu (Fig. 2, solid lines).

	Pb		Zn		Cu	
Parameter	Roots	Leaves	Roots	Leaves	Roots	Leaves
a	0.04	-0.03	-0.18	-0.03	0.24	0.18
b	23.95	35.02	67.94	86.87	13.74	13.11
R^2	9.90	99.90	77.10	89.50	23.70	61.40
P	0.00	0.00	0.00	0.00	0.01	0.00

Pb occurs naturally in all plants but has not been shown to be essential in plant nutrition or metabolism (Broyer et al. 1972; Kabata-Pendias and Pendias 1984) and is probably taken up passively by the roots (Hughes et al. 1980; Kabata-Pendias and Pendias 1984). By the criteria of Timperley et al. (1970) Pb would appear to behave as an essential element in this study. However, other studies have shown that the simple distinction between essential and non-essential elements does not always hold, as a number of elements including U, Ca, Ra, Pb and Po have been demonstrated to behave anomalously (Sheppard and Sheppard 1985; Simon and Ibrahim 1987). No further reduction in P_t/S indicative of toxicity (Timperley et al. 1970) was observed for any of the metals, however the soil metal concentration range was perhaps not wide enough for this to be observed.

Kabata-Pendias and Pendias (1984) have compiled tables of metal concentrations in different soil types and plant tissues from various countries. The mean concentrations of Pb, Zn and Cu in non-contaminated soils range from 0.1-189 mg kg^{-1} DW for Pb, 17-125 mg kg^{-1} DW for Zn and 6-60 mg kg^{-1} DW for Cu. The highest metal concentrations measured in the city soils are 3.3 for Pb, 4.7 for Zn and 3.5 for Cu times higher than the highest value given for natural ranges of non-contaminated soils, indicating that considerable toxic levels of these metals occur in the city. This heavy metal loading of city soils occurred in areas associated with a high traffic density and car emissions. Pb contamination of roadside soils elsewhere have been reported to range from 115-7000 mg kg^{-1} DW with plant toxicity occuring in a range of 100-500 mg kg^{-1} DW and above (Kabata-Pendias and Pendias 1984). Zn and Cu contamination in urban gardens and parks have been reported to range from 15-1200 ppm DW for Zn and 3-300 ppm DW for Cu (Kabata-Pendias and Pendias 1984). Levels of Zn (>300 ppm DW) and Cu (>100 ppm DW) in surface soils are considered to be phytotoxic (see Kabata-Pendias and Pendias 1984).

Plant tissue metal concentrations are generally a function of the metal concentration in the soil but the relationship differs according to plant species and tissue (Kabata-Pendias and Pendias 1984). Natural Pb, Zn and Cu concentrations in plants growing in uncontaminated and unmineralised areas range from 0.1-10 mg kg^{-1} DW for Pb, 12-47 mg kg^{-1} DW for Zn and 1-10 mg kg^{-1} DW for Cu (Kabata-Pendias and Pendias 1984). The Pb, Zn and Cu concentrations in *Taraxacum* exceed the naturally ocurring levels of these metals in other plants. Concentrations of Pb ranging from 56-950 mg kg^{-1} DW have been reported in other roadside grown plants and in Poland the Cu content of dandelion tops and roots ranged from 73-274 and 22-199 ppm DW, respectively at a distance of 0.5-2.5 km from a metal smelter (see Kabata-Pendias and Pendias 1984). However in urban gardens, although the Zn content of radish roots ranged from 27-708 ppm DW and leafy vegetables from 35-470 ppm DW, the respective Cu content was 2-14 and 4-19 ppm DW (Kabata-Pendias and Pendias 1984).

In conclusion, many of the measured Pb, Zn and Cu soil concentrations were in excess of reported values for naturally occurring levels in uncontaminated soils. There were considerable differences in the metal concentrations throughout the city with a distribution related to traffic density and car emissions. Plant tissue metal concentrations were a function of the soil metal concentration and therefore exhibited a similar distribution and relation to traffic density. There was a heavy metal loading in the city centre particularly of Pb, but also of Zn and Cu and the highest concentrations are in the range known to be phytotoxic. Elevated levels of Pb, Zn and Cu may lead to the inhibition of plant processes (Rolfe and Bazzaz 1975; Kabata-Pendias and Pendias 1984; Van Assche and Clijsters 1990; Brown and Brinkmann 1992) and measurements of fluorescence parameters have demonstrated that *Taraxacum* plants are stressed by pollution in areas of heavy traffic density (Lanaras et al. 1994).

Acknowledgments: Part of this research was supported by MEDALUS II (Mediterranean Desertification and Land Use) collaborative research project. MEDALUS II was funded by the EC under its Environment Programme, contract number EV5V 0128 and the support is gratefully acknowledged. We thank L. Valeri for technical assistance.

REFERENCES

Albasel N, Cottenie A (1985) Heavy metal contamination near major highways, industrial and urban areas in Belgian grassland. Water Air Soil Pollut 24: 103-110

Baker AJM (1981) Accumulators and excluders - strategies in the response of plants to heavy metals. J Plant Nutr 3: 643-645

Baker AJM, Walker PL (1990) Ecophysiology of metal uptake by tolerant plants. In: Shaw AJ (ed) Heavy metal tolerance in plants: evolutionary aspects. CRC Press Inc, Boca Raton, Florida, p 155-177

Braun S, Fluckiger W (1988) Does exhaust air from motorway tunnels affect the surrounding vegetation? In: Mathy P (ed) Air Pollution and Ecosystems. D Reidel, Dordrecht p 665-670

Brown G, Brinkmann K (1992) Heavy metal tolerance in *Festuca ovina* L. from contaminated sites in the Eifel Mountains, Germany. Plant Soil 143: 239-247

Broyer TC, Johnson CN, Paull RE (1972) Some aspects of lead in plant nutrition. Plant Soil 36: 301-313

Godbold DL, Kettner C (1991) Lead influences root growth and mineral nutrition of *Picea abies* seedlings. J Plant Physiol 139: 95-99

Hughes MK, Lepp NW, Phipps DA (1980) Aerial heavy metal pollution and terrestial ecosystems. Adv Ecol Res 11: 217-327

Kabata-Pendias A, Pendias H (1984) Trace elements in soils and plants. CRC Press Inc, Boca Raton, Florida, USA

Lanaras T, Sgardelis SP, Pantis JD (1994) Chlorophyll fluorescence in dandelion (*Taraxacum* spp.): a probe for screening urban pollution. Sci Tot Environ in press

Markert B (1992) Presence and significance of naturally occurring chemical elements of the periodic system in the plant organism and consequences for future investigations on inorganic environmental chemistry in ecosystems. Vegetatio 103: 1-30

Morishita T, Boratynski JK (1992) Accumulation of cadmium and other metals in organs of plants growing around metal smelters in Japan. Soil Sci Plant Nutr 38: 781-785

Rolfe GL, Bazzaz FA (1975) Effect of lead contamination on transpiration and photosynthesis of Loblolly Pine and Autumn Olive. Forest Sci 21: 33-35

Sokal RR, Rohlf FJ (1981) Biometry. W. H. Freeman and Company, New York, USA

Seaward MRD, Richardson DHS (1990) Atmospheric sources of metal pollution and effects on vegetation. In: Shaw AJ (ed) Heavy metal tolerance in plants: evolutionary aspects. CRC Press Inc, Boca Raton, Florida, p 75-92

Sheppard MI, Sheppard SC (1985) The plant concentration ratio concept applied to natural U. Health Phys 48: 494-500

Simon SL, Ibrahim SA (1987) The plant/soil concentration ratio for calcium, radium, lead and polonium: evidence for non-linearity with reference to substrate concentration. J Environ Radioact 5: 123-142

Tam NFY, Liu WK, Wong MH, Wong YS (1987) Heavy metal pollution in roadside urban parks and gardens in Hong Kong. Sci Total Environ 59: 325-328

Timperley MH, Brooks RR, Peterson PJ (1970) The significance of essential and non-essential trace elements in plants in relation to biogeochemical prospecting. J Appl Ecol 7: 429-439

Van Assche F, Clijsters H (1990) Effects of metals on enzyme activity in plants. Plant Cell Environ 13: 195-206