Heavy metal accumulation in vegetables grown in urban gardens

LIVIA VITTORI ANTISARI,
DIPSA, University of Bologna, Bologna, Italy

FRANCESCO ORSINI*,
DIPSA, University of Bologna, Bologna, Italy

LIVIA MARCHETTI,
DIPSA, University of Bologna, Bologna, Italy

GILMO VIANELLO,
DIPSA, University of Bologna, Bologna, Italy

GIORGIO GIANQUINTO
DIPSA, University of Bologna, Bologna, Italy

*corresponding author: Francesco Orsini. Dipartimento di Scienze Agrarie (DIPSA), Alma Mater Studiorum – Università of Bologna Via Fanin, 44 40127 Bologna Italy. E-mail: f.orsini@unibo.it

Abstract

Urban agriculture is increasingly popular for social and economical benefits. However, edible crops grown in cities can be contaminated by airborne pollutants, thuse leading to serious heatlh risks. Therefore we need a better understanding of contamination risks of urban cultivation to define safe practices. Here we study heavy metal risk in horticultural crops grown in urban gardens of Bologna, Italy. We investigated the effect of proximity to different pollution sources such as roads and railways, and the effect of the growing system used, that is soil versus soilless cultivation. We compared heavy metals concentration in urban and rural crops. We focussed on surface deposition and tissue accumulation of pollutants during three years. Results show that in the city crops near the road were polluted by heavy metals, with up to 160 mg per Kg dry weight for lettuce and 210 mg/Kg for basil. The highest Cd accumulation of up to 1.2 mg/Kg was found in rural tomato. Soilless planting systems enabled a reduction of heavy metal accumulation in plant tissue, of up to -71% for rosemary leaves.

Keywords: horticultural crops, urban and rural gardens, heavy metals, leaf leaching test, soilless

1 Introduction

Urban horticulture is spreading and becoming an essential feature of city planning in most cities of the world. Born as a complementary food-providing initiative, urban horticulture is now gaining value for many other essential roles it plays in the urban context (Ghosh et al. 2008; van Veenhuizen 2006). It provides ecosystem services, contributing to increase urban life quality through mitigation of the city climate, preservation and enhancement of biodiversity, reuse of urban wastes and contribution to the aesthetic satisfaction given by a greener urban environment (La Greca et al. 2011). Besides, urban horticulture has a wide field of social implications, for instance in the rehabilitation of people with addictions of various nature (alcohol, drugs), or for supporting and helping the elderly or the physically and mentally disabled (Muganu et al. 2010). Overall, its multifunctional role is recognized (Orsini et al. 2013), ranging from its contribution to food security, economic and environmental sustainability, preservation and implementation of the green space (Zasada 2011). However, growing food in the urban environment relies on different conditions as compared to traditional farming. In cities, horticultural gardens are distributed according to the available space (generally on marginal areas, e.g. close to railways, main roads, or nearby industrial areas) (Alloway 2004), rather than following rational and agronomical considerations (e.g. potential pollution, access to light, proximity to residential neighbourhoods).

It is recognized that the risk of contaminants accumulating in air, soil and water can influence the product quality and healthiness (Al Jassir et al. 2005; Leake et al. 2009). Given the health risk associated with their consumption, the European Union has defined maximum levels of lead and cadmium to be found in vegetables. Consistently, lead concentration should always be under 0.10, 0.30 and 0.20 mg kg^{-1} of fresh weight respectively in legumes, brassica and all other vegetables. Cadmium threshold limits expressed by European Union regulation are set at 0.05, 0.1 and 0.2 mg kg^{-1} of fresh weight respectively in vegetables whose edible part is the fruit, the stem/root or the leaf (EU 2009).

Common pollutants in the urban environment are mainly anthropogenic, especially caused by emissions from road traffic, previous industrial use of the sites, atmospheric deposition from industrial activities and incinerators (Chen et al. 2005; Vittori Antisari et al. 2013). The main risk associated with urban soils is the presence of heavy metals deriving from intense human activities (Khan et al. 2008) and, more specifically, road traffic (Salvagio Manta et al. 2002). These elements may be absorbed by plants (Tei et al. 2010), although their accumulation across plant organs and between plant species may dramatically vary (Säumel et al. 2012). Within the city, areas with different load of pollutants can be distinguished: a garden settled nearby a road or a railway presents different conditions from one located in a courtyard or on a rooftop. Consistently, studies on heavy metals concentration have demonstrated that distance from the road and contamination are generally inversely correlated (Gherardi et al. 2009). Yet in the seventies, Lagerweff and Specht (1970) found that concentration of Cd, Ni, Pb and Zn in roadside soil and grass samples from several locations decreased with distance from traffic and with depth in the soil profile. Similar results were more recently obtained by Naszradi et al. (2004) and Bakirdere and Yaman (2008). Furthermore, the presence of buildings and trees as barriers for the pollutants was found to remarkably reduce road-induced pollution in the nearby gardens (Säumel et al. 2012). A weak point of previous researches is the absence of appropriate control when comparing urban to rural horticultural production. Most of the available cases addressed contaminations in urban- (Bakirdere and Yaman 2008; Bretzel and Calderisi 2006; Khan et al. 2008; Vittori Antisari et al. 2009), or rural- (Peris et al. 2007) cases only. On the other hand, when a comparison of urban *vs* rural horticultural good is claimed (Säumel et al. 2012), no reference to the growing conditions and provenance of the rural product is given.

In the present work, three years of experiments are presented, including results on rural *vs* urban products, distribution within the city and within gardens (proximity to different pollution sources, and distance from road), and adoption of different cultivation systems (soil *vs.* soilless).

2 Materials and Methods

A range of experiments was conducted between 2011 and 2013 in several sites within and nearby the city of Bologna (Fig. 1). Prior experimentation soil samples were collected from all study sites and analysed as follows. Soil samples were air-dried and sieved (<2 mm). pH (pHmeter, Crison, Barcelona, Spain) measures were performed with distilled water on 1:2.5 w:v. Total Organic Carbon was measured by Dumas combustion with a EA 1110 CHN elemental analyser (Thermo Fisher Scientific, Waltham, MA USA) after dissolution of carbonates with 2M HCl and the organic matter was obtained using 1.72 factors. Soil particle size distribution was determined by the pipette method (Gee and Bauder 1986) and total carbonates ($CaCO_3$) were quantified by a volumetric method, according to Dietrich-Fruehing. The sites used for experimentation were:

- A rural control (coordinates 44°28’33’’ N, 11°40’45’’ E) from now on called CONTROL/RURAL, located nearby the small town of Medicina (about 16,000 inhabitants, 35 km from Bologna, known as a vegetable crop cultivation area). The soil is UDIC CALCIUSTEPT Fine Silty, Superactive, Mesic (SSS, 2014), Cambic CALCISOL, Siltic, Hypocalcic (IUSS, 2014), with the following physic-chemical properties: sand (2-0.05 mm Ø) = 120 g kg^{-1}; silt (0.05-0,002 mm Ø) = 580 g kg^{-1}; Clay (>0,002 mm Ø) = 300 g kg^{-1}; pH = 7.8; organic matter = 23.2 g kg^{-1}; total $CaCO_3$ = 90.7 g kg^{-1}.
- A traditional garden within the old city centre (coordinates 44°29’16’’ N, 11°20’51’’ E, from now on called CENTRE), in the old district were few ancient traditional gardens still exists. The soil is UDIFLUVENTIC HAPLUSTEPT Fine Silty, Superactive, Mesic (SSS, 2014), Terric, Calcaric, CAMBISOL, Siltic, (IUSS, 2014), with the following physic-chemical properties: sand = 190 g kg^{-1}; silt = 560 g kg^{-1}; Clay = 250 g kg^{-1}; pH = 7.9; organic matter = 18.3 g kg^{-1}; total $CaCO_3$ = 120.5 g kg^{-1}.
- Two gardens nearby the main railway (about 800 trains per day): a traditional one (coordinates 44°30’17’’ N, 11°21’28’’ E, from now on called RAILWAY/SOIL), and a

nearby rooftop soilless garden (coordinates 44°30’17’’ N, 11°21’20’’ E, from now on called RAILWAY/SOILLESS). Aerial distance between these two gardens is about 200 m. In traditional garden, the soil is UDIFLUVENTIC HAPLUSTEPT Fine Silty, Superactive, Mesic (SSS, 2014), Fluvic, Eutric, CAMBISOL, Siltic (IUSS, 2014), with the following physic-chemical properties: sand = 250 g kg^{-1}; silt = 550 g kg^{-1}; Clay = 200 g kg^{-1}; pH = 7.5; organic matter = 16.8 g kg^{-1}; total $CaCO_3$ = 10.9 g kg^{-1}. The soilless garden uses coir as substrate (features provided by the supplier: bulk density = 0.06 g cm^{-3}; pH = 7.4; EC = 1.7 dS m^{-1}).

- Two gardens nearby a main road of the city (via San Donato, 10^3-10^4 vehicles day^{-1}): two traditional gardens, placed 10 m from the street (coordinates 44°30’54’’ N, 11°23’29’’ E, from now on called ROAD/10) and 60 m from the street (coordinates 44°30’55’’ N, 11°23’33’’ E, from now on called ROAD/60). Aerial distance between these two gardens is about 80 m. The soil in both gardens is UDIFLUVENTIC HAPLUSTEPT Loamy, Superactive, Mesic (SSS, 2014), Irragric, Fluvic, Calcaric, CAMBISOL, Loamic, (IUSS, 2014), with the following physic-chemical properties: sand = 150 g kg^{-1}; silt = 620 g kg^{-1}; Clay = 230 g kg^{-1}; pH = 8.0; organic matter = 21.6 g kg^{-1}; total $CaCO_3$ = 181.7 g kg^{-1}.

2.1 Plant material

During years 2011 and 2012, plant samples were collected from crops already grown in the gardens, according to their availability in each site. In these years, plant species considered included vegetable and aromatic plants, namely tomato (*Lycopersicon esculentum*), zucchini (*Cucurbita pepo* L.), chicory (*Cichorium intybus* L.), strawberry (*Fragaria* x *Ananassa*), eggplant (*Solanum melongena* L.), sage (*Salvia officinalis* L.), basil (*Ocimum basilicum* L.), rosemary (*Rosmarinus officinalis* L.), and chilli pepper (*Capsicum annuum* L.), as well as some tree species, such as cherry

(*Prunus avium* L.), peach (*Prunus persica* L. Batsch), poplar (*Populus alba* L.), lime (*Tilia* L.), and maple (*Acer campestre* L.).

In 2013, plantlets of three species, namely tomato (cv Caramba 281, Seminis Inc., Oxnard, CA, USA), lettuce (cv Brasiliana, Eurosementi, Avellino, Italy) and basil (cv. Aromatico della Riviera Ligure, Arcoiris, Modena, Italia), were purchased from a local nursery (LACME, Medicina, Bologna, Italy). Transplanting was conducted in CONTROL/RURAL, ROAD/10, ROAD/60, RAILWAY/SOIL and CENTRE on April 15th (tomato and lettuce) and May 15th (basil). Each garden was provided with 9 plants per species.

2.2 Experimental protocols

- *Test#1: determination of pollutants as function of the distance of the road*. Plant samples were collected in 2011 and 2013 in ROAD/10 and ROAD/60 sites. Species considered in both gardens were tomato and zucchini in 2011 and tomato, lettuce and basil in 2013.
- *Test#2: comparison between different sources of pollution*. Two sites were selected for different sources of pollution: ROAD/10 and RAILWAY/SOIL. In 2011, leaves of lime, poplar and maple were sampled in ROAD/10, while in the RAILWAY/SOIL leaves of cherry, peach and poplar were collected. In 2013, tomato, lettuce and basil were collected from both gardens.
- *Test#3: comparison between the pollutants of horticultural crops grown in soilless and in soil.* In 2012 samples of sage, tomato, strawberry, basil, eggplant, rosemary, and chilli pepper grown in RAILWAY/SOIL and RAILWAY/SOILLESS were collected.
- *Test#4: urban vs. rural horticulture.* In 2013, according to the promising results obtained in the first two years and in order to overcome possible errors linked to differential mineral uptake due to species/cultivar, the analysis was extended to a great number of gardens within the city (CENTRE, RAILWAY/SOIL, ROAD/10 and ROAD/60). Furthermore, with

the aim of having a reference value in a rural environment, also the CONTROL/RURAL site was included. In all sites, same cultivars of tomato, lettuce and basil obtained from the same nursery were simultaneously grown.

2.3 Lab determinations

Leaf leaching test. The leaves of different species were sampled in glass jars of known tare weight. In the laboratory, leaves were weighed and then washed with water acidulated with HCl (pH ~5) (Vittori Antisari et al. 2012). Samples were shaken for 15 minutes and then water samples were collected in polyethylene beakers, evaporated in ventilated oven, and brought to 100 mL. Samples were then filtered, acidified with HNO_3 (65 % Suprapur, E. Merck, Germany; 1:100 v/v) and stored at 4°C until analysis. The major and trace elements were determined by Inductive Coupled Plasma Optical Emission Spectrometry (ICP-OES, Spectro Ametek, Arcos). The ICP-OES setting followed multi-standard solutions (CPI-International-Amsterdam) that reproduce the matrix effect present in samples and allow the lowering of Detection Limits (DL). Instrument response was assessed by measuring a standard sample (CRM 609 - Community Bureau of Reference – BCR).

In order to evaluate the deposition rate of pollutants the leaf area was determined in function of the leaf weight for three leaf samples. The calculated area/weight ratio ranges from 5.5 to 3.9 $m^2 kg^{-1}$ (Rutter et al. 2011).

Analysis of leaf samples. Clean leaves were dried in ventilated oven (T<40°C) and ground in a blender with blades made of pure titanium, carefully avoiding to introduce any further metal contamination to the samples (Vittori Antisari et al. 2012). Briefly, approximately 0.4 g of leaves sub-sample, weighted in Teflon bombs, were dissolved in 8 ml of H_3NO_3 (suprapure, Merck, Roma, Italy) + 2 ml of H_2O_2 (Carlo Erba, Milano, Italia) using a microwave oven (Milestone 2100, Sorisone, Bergamo, Italy). After cooling, solutions were made up to 20 ml with milli-Q water and then filtered with Whatmann 42 filter paper. The accuracy of the instrumental method and analytical procedures used was checked by triplication of the samples, as well as by using reference material, which was run after every 10 samples to check for drift in the sensitivity. The analytical quality of the results was checked against the following reference materials, which certify values of the studied elements close to the measured ones: CRM 060 (aquatic plants), CRM 062 (Olive leaves) provided by the European Commission Institute for Reference Materials and Measurements.

Statistical analysis. The experimental data were treated statistically using software packages (i.e. Excel, Statgraphic plus 5.0, Systat 12.0). The used one-way analysis of variance (ANOVA) test (Tukey's test, $p \leq 0.05$) is a general technique that can be used to test the hypothesis that the means among two or more groups are equal. This is a non-parametric test used to determine if one of several groups of data tends to have more widely dispersed values than the other.

3 Results and discussion

Horticultural crops in urban or peri-urban areas are generally exposed to pollution risks, which include trace elements and organic contaminants (Säumel et al. 2012). The recent increase of areas for urban gardens in cities as well as the adoption of innovative (e.g. soilless) growing systems for urban cultivation arises the public concern on the produce safety. Overall, the range of trace elements concentration in the epigeous parts of the vegetables analyzed in the present study was similar to concentrations reported in previous studies (Alexander et al. 2006; Finster et al. 2004; Kachenko and Singh 2006; Murray et al. 2009), and always below limits expressed by European Union regulation (EU 2009) (Table 1). Field surveys in urban areas are to date scarce but crucial to determine health risks of urban horticulture (Säumel et al. 2012; Wong et al. 2006) and few studies have evaluated the role of exposition at different pollutant sources (Kelly et al. 1996; Li et al. 2001). Differences in heavy metal pollution were however observed among study sites as reported in the following sections.

3.1 Heavy metal risk as affected by the garden distance from the road

A noticeable evidence related to traffic exposure has recently confirmed how lead concentration in plant tissue has been successfully reduced by the adoption of unleaded gasoline (Mielke et al. 2011). However, environmental pollution associated to other metals (e.g. Ag, Cd, Ce, Ba) that are generally added to fuel as preservatives, result to be highly correlated with traffic exposure. Consistently, in order to assess the influence of the road distance on pollutant enrichment of horticultural crops, the trace elements concentration in leaf tissues from plants grown nearby the road (ROAD/10) was compared to the concentration found in vegetables grown on a more remote area of the urban garden (ROAD/60), as shown in Table 1. As and Hg concentrations were below detection limits (0.01 and 0.02 μg kg^{-1} of dry weight, respectively), while Cd amount was detected only in tomato leaves in ROAD/10, in which a significant increase in the amount of Cr, Ni, Sn and Zn was also recorded. In zucchini, greater accumulation of Ni, Sn and Zn was associated to ROAD/10, whereas Ba concentration was higher in ROAD/60 samples. The stock of pollutant deposition (g m^{-2} of leaf area) on the leaves of tomato and zucchini (Table 1), highlighted a significant higher amount of most pollutants (As, Ba, Cu, Pb, Sb, Sn, V, Zn) deposited on both crops grown nearby the road (ROAD/10) compared with the ones located far from it (ROAD/60), therein confirming the deposition of these elements from road traffic as well as their high bioavailability and leachibility from soils (Imperato et al. 2003; Madrid et al. 2002; Wong et al. 2006). As a matter of fact, anthropogenic metals have been reported to be both easily bio-available in soils and easily diffused into the vegetable cuticle, through the stomata (Bianchini et al. 2013).

3.2 Effect of different pollution sources on heavy metal load

By analyzing the soluble pool of pollutants deposited on leaves of ornamental trees surrounding urban gardens exposed to road (ROAD/10) and railways (RAILWAY/SOIL) a different patterns of metals was distinguished (Table 2). Significantly higher amount of pollutants was found in the deposition stock obtained from ROAD/10 as compared to RAILWAY/SOIL (Fig. 3, Vittori Antisari et al. 2012), except for As that resulted significantly higher on the surface of leaves collected from RAILWAY/SOIL (Table 2). Cd and Hg were not significantly different among samples. High deposition of particulate pollutants are intercepted by woodlands (Fowler et al. 1989) and urban trees are claimed to remove polluting particles from the air (Freer-Smith et al. 1997) absorbing atmospheric turbulence (Beckett et al. 2000; McPherson et al. 1994). Such phenomenon may be confirmed when comparing the behavior of deposition load on horticultural crops from that of ornamental tree leaves. As a consequence, the protection of the urban garden with ornamental trees resulted to be a sustainable solution to decrease the impact of both point and spread sources on the horticultural crops, therein leading to increased food safety.

3.3 Heavy metals risk in soil and soilless grown products

The investigation was performed to evaluate the differential metal accumulation between urban horticultural crops grown either on soil or in a soilless system. As shown in Fig. 2, samples from plants grown in either soilless (RAILWAY/SOILLESS) or soil systems (RAILWAY/SOIL) did not present differences in the total (expressed as sum of metals) concentrations. As, Cd and Hg concentrations were below the detection limits, while Cd and V were mainly found in soil-grown plants (data not shown). Significant differences in total accumulation were observed only in rosemary and eggplant samples (Fig. 2) as a consequence to greater Zn accumulation in soil-grown plants (data not shown). Consistently, depending on the species considered in the survey, differential heavy metal loads were confirmed, suggesting that accumulators (e.g. rosemary, Divrikli et al. 2006) should be avoided when cultivating contaminated soils (Fig. 2), in which soilless growing systems should also be preferred.

3.4 Heavy metal deposition and accumulation in rural and urban grown vegetables

The experiment simultaneously addressed the quantification of heavy metal deposition (Fig. 3A) and accumulation (Fig. 3B, C and D) in vegetable and aromatic species grown in rural and urban environments and as a consequence of the distance to pollution sources (e.g. main roads, railways). The pollutants deposited on the leaves were suddenly higher on ROAD/10, as highlighted by Fig. 3A. The highest concentration of metals observed in tomato leaf tissues (Fig. 3D) as compared to basil and lettuce (Fig. 3B and C) was related to the dramatically higher Cu concentration (300 to 1100 mg kg^{-1} DW, data not shown). The elevate amount of Cu observed in tomato leaves could be explained as the consequence of foliar copper sulphate application for crop protection from diseases. Copper sulphate is generally overused in urban gardens, being the unique allowed product according to community garden rules (Tei et al. 2010). A peak in Cd concentration in leaves from all species was found in CONTROL/RURAL (0.4-1.2 mg kg^{-1} of dry weight, data not shown). This could be the result of long-term soil fertilization (Tella et al. 2013) and Cd build-up in soils. Lettuce and basil (Fig. 3B and C) showed similar magnitudes of pollutants stored in their leaves and the maximum accumulation was detected in the urban garden nearby the road (ROAD/10, mean value 184 mg kg^{-1} of dry weight). Total metal concentration in tomato fruits was not significantly affected by washing, nor by the growing (rural or urban) environment and the distance from pollution sources (mean value 55.0±2.6 mg kg^{-1} of dry weight, data not shown). Overall, the greater content of metals in tomato leaf tissue can be due to longer persistence of the plant in the field as compared to lettuce and basil which have a shorter vegetative cycle. Similarly, great Ba concentration was detected in the rosemary plants grown in RAILWAYS/SOIL as compared to other seasonal crops (Fig. 2).

4 Conclusion

The concentration of heavy metals in urban grown vegetables is strictly related to the site in the city where plants are grown. When plants are cultivated nearby pollution sources (e.g. main roads), risks of heavy metals accumulation is increased (about 1.5 folds when vegetables are grown 10 m from the road as compared to 60 m away). Prior consumption, vegetables grown nearby roads need to be carefully washed (deposition is increased 1.5 to 4 folds respectively in zucchini and tomato grown nearby the road as compared to those cultivated 60 m away). Overall pollutant accumulation in plant tissue is comparable to values found in rural areas, where Cd, mainly as a consequence to long-term soil fertilization, is generally higher (up to 1.2 mg kg^{-1} of dry weight) than values found in urban products. Improper pest management, commonly experienced in allotment garden, resulted in excessive Cu accumulation (up to 1100 mg kg^{-1} of dry weight in tomato fruits). These results should find application in the future planning and design of urban allotment gardens by public administrations. Given their increased relevance in shaping today's cities, allotments should be placed at safety distance from main roads or other pollution sources, and possibly surrounded by tree barriers. The suitability of available soils should be confirmed by preliminary analyses and whenever soils are not adequate, the adoption of soilless systems encouraged, although deeper studies for confirming the benefits of soilless cultivation systems in reducing heavy metals risks are however required. Finally, the present study should also call the attention on the possible risks faced by current rural cultivation systems: long-term soil fertilization may result in heavy metal build-up in soils, therein leading to potential contamination risks.

References

Alexander PD, Alloway BJ, Dourado AM (2006) Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. Environ Pollut 144:736-745. **doi: 10.1016/j.envpol.2006.03.001.**

Alloway B (2004) Contamination of soils in domestic gardens and allotments: a brief overview. Land Contam Reclam 12:179-187. **doi 10.2462/09670513.658**.

Al Jassir MS, Shaker A, Kaliq MA (2005) Deposition of heavy metals on green leafy vegetables sold on roadsides of Riyadh City, Saudi Arabia. B Environ Contam Tox 75:1020-1027. **doi: 10.1007/s00128-005-0851-4.**

Bakirdere S, Yaman N (2008) Determination of lead, cadmium and copper in roadside soil and plants in Elazig, Turkey. Environ Monit Assess 136:401-410. **doi: 10.1007/s10661-007-9695-1**.

Beckett KP, Freer-Smith PH, Taylor G (2000) Effective tree species for local air quality management. J Arboric 26:12-19.

Bianchini G, Natali C, Di Giuseppe D, Beccaluva L (2012) Heavy metals in soils and sedimentary deposits of the Padanian Plain (Ferrara, Northern Italy): characterisation and biomonitoring. J Soil Sediment 12:1145-1153. **doi: 10.1007/s11368-012-0538-5.**

Bretzel F, Calderisi M (2006) Metal contamination in urban soils of coastal Tuscany (Italy). Environ Monit Assess 118:319-335. **doi: 10.1007/s10661-006-1495-5.**

Chen TB, Zheng YM, Lei M, Huang ZC, Wu HT, Chen H, Fan K-K, Yu K, Wu X, Tian QZ (2005) Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. Chemosphere, 60:542-551. **doi: 10.1016/j.chemosphere.2004.12.072.**

Divrikli U, Horzum N, Soylak M, Elci L (2006) Trace heavy metal contents of some spices and herbal plants from western Anatolia, Turkey. Int J Food Sci Tech 41:712-716. **doi: 10.1111/j.1365-2621.2005.01140.x**

EU (2009). Commission Regulation (EU) No 420/2011 of 29 April 2011 amending Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs. http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32011R0420&from=EN. Accessed 14 Jul 2014

Finster ME, Gray KA, Binns HJ (2004) Lead levels of edible grown in contaminated residential soils: a filed survey. Sci Total Environ 320:245-257. **doi:10.1016/j.scitotenv.2003.08.009.**

Fowler D, Cape JN, Unsworth MH Mayer H, Crowther JM, Jarvis PG, Gardiner B, Shuttleworth WJ (1989) Deposition of atmospheric pollutants on forests. Philos T R Soc Lond 324:247-265. **doi: 10.1098/rstb.1989.0047.**

Freer-Smith PH, Holloway S, Goodman A (1997) The uptake of particulates by an urban woodland; site description and particulate composition. Environ Pollut 95:27-35. **doi: 10.1016/S0269-7491(96)00119-4.**

Gee GW, Bauder JW (1986) Particle-size analysis. In: Klute A (ed) Methods of soil analysis, Part 1. Physical and mineralogical methods, American Society of. Agronomy, Madison, WI, pp 383-411

Gherardi M, Pontalti F, Vianello G, Vittori Antisari L (2009) Heavy metals in the soil-plant system: monitoring urban and extra-urban parks in the Emilia Romagna Region (Italy). Agrochimica 53:196-208.

Ghosh S, Vale R, Vale B (2008) Local food production in home gardens: measuring on-site sustainability potential of residential development. Int J Environ Sust Dev 7:430-451. **doi: 10.1504/IJESD.2008.022388.**

Imperato M, Adamo P, Naimo D, Arienzo M, Stanzione D, Violante P (2003) Spatial distribution of heavy metals in urban soils of Naples city (Italy). Environ Pollut 124:247-256. **doi: 10.1016/S0269-7491(02)00478-5.**

IUSS (2014) World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources No. 106. FAO, Rome www.fao.org/3/a-i3794e.pdf. Accessed 9 Mar 2015

Kachenko AG, Singh B (2006) Heavy metals contamination in vegetable grown in urban and metals smelter contaminated sites in Australia. Water Air Soil Poll 169:101-123. **doi: 10.1007/s11270-006-2027-1.**

Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG (2008) Health risk of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ Pollut 152:686-692. **doi: 10.1016/j.envpol.2007.06.056.**

Kelly J, Thornton I, Simpson PR (1996) Urban geochemistry: a study of the influence of anthropogenic activity on the heavy metal content of soils in traditionally industrial and non-industrial areas of Britain. App Geochem 11:363-370. **doi: 10.1016/0883-2927(95)00084-4.**

La Greca P, La Rosa D, Martinico F, Privitera R (2011) Agricultural and green infrastructures: The role of non-urbanised areas for eco-sustainable planning in a metropolitan region. Environ Pollut 159:2193-2202. **doi: 10.1016/j.envpol.2010.11.017.**

Lagerwerff JV, Specht AW (1970) Contamination of roadside soil and vegetation with cadmium, nickel, lead and zinc. Environ Sci Technol 4:583-586. **doi: 10.1021/es60042a001.**

Leake J, Adam-Bradford A, Rigby J (2009) Health benefits of ‘grow your own’ food in urban areas: implications for contaminated land risk assessment and risk management? Environ Health-Glob 8:S6. **doi:10.1186/1476-069X-8-S1-S6.**

Li X, Poon CS, Liu PS (2001) Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl Geochem 16:1361-1368. **doi: 10.1016/S0883-2927(01)00045-2.**

Madrid L, Díaz-Barrientos E, Madrid F (2002) Distribution of heavy metal contents of urban soils in parks of Seville. Chemosphere, 49:1301-1308. **doi: 10.1016/S0045-6535(02)00530-1.**

Mielke HW, Laidlaw MA, Gonzales CR (2011) Estimation of leaded (Pb) gasoline's continuing material and health impacts on 90 US urbanized areas. Environ Int 37:248-257. **doi: 10.1016/j.envint.2010.08.006.**

Muganu M, Balestra GM, Senni S (2010) The importance of organic method in social horticulture. Acta Hort 881:847-849.

Murray H, Thompson K, Macfie SM (2009) Species and species –specific patterns of metal bioavailability in edible plants. Botany 87:702-711. **doi: 10.1139/B09-019.**

Naszradi T, Badacsonyi A, Németh N, Tuba Z, Batič F (2004) Zinc, lead and cadmium content in meadow plants and mosses along the M3 motorway (Hungary). J Atmos Chem 49:593-603. **doi: 10.1007/s10874-004-1268-x.**

Orsini F, Kahane R, Nono-Womdim R, Gianquinto G (2013) Urban agriculture in the developing world: a review. Agron Sustain Dev 33:695-720. **doi: 10.1007/s13593-013-0143-z.**

Peris M, Micó C, Recatalá L, Sánchez R, Sánchez J (2007) Heavy metal contents in horticultural crops of a representative area of the European Mediterranean region. Sci Total Environ 387:42-48. **doi: 10.1016/j.scitotenv.2007.01.030.**

Rutter AP, Schauer JJ, Shafer MM, Creswell JE, Olson MR, Robinson M, Collins RM, Parman AM, Katzman TL, Mallek JL (2011) Dry deposition of gaseous elemental mercury to plants and soils using mercury stable isotopes in a controlled environment. Atmos Environ 45:848-855. **doi: 10.1016/j.atmosenv.2010.11.025.**

Salvagio Manta D, Angelone M, Bellanca A, Neri R, Sprovieri M (2002) Heavy metals in urban soils: a case study from the city of Palermo (Sicily), Italy. Sci Total Environ 300:229-243. **doi: 10.1016/S0048-9697(02)00273-5.**

Säumel I, Kotsyuk I, Hölscher M, Lenkereit C, Weber F, Kowarik I (2012) How healthy is urban horticulture in high traffic areas? Trace metal concentrations in vegetable crops from plantings within inner city neighborhoods in Berlin, Germany. Environ Pollut 165:124-132. **doi: 10.1016/j.envpol.2012.02.019.**

SSS (2014) Keys to Soil Taxonomy. 12th edn. USDA, NRCS, Washington, DC.

Tei F, Benincasa P, Farneselli M, Caprai M (2010) Allotment gardens for senior citizen in Italy: current status and technical proposal. Acta Hort 881:91-96.

Tella M, Doelsch E, Letourmy P, Chataing S, Cuoq F, Bravin MN, Saint Macary H (2013) Investigation of potentially toxic heavy metals in different organic wastes used to fertilize market gardens crops. Waste Manage 33:184-192. **doi: 10.1016/j.wasman.2012.07.021.**

van Veenhuizen R (2006) Cities farming for the future. Urban agriculture for sustainable cities. RUAF Foundation, IDRC and IIRR. ETC-Urban Agriculture, Leusden The Netherlands.

Vittori Antisari L., Gherardi M., Lorito S., Pontalti F., Vianello G. (2009). Bioindicators use for evaluation of heavy metal concentrations in urban parks. Acta Hort 881:567-572.

Vittori Antisari L, Carbone S, Ferronato C, Simoni A, Vianello G (2012) Leaf washing as an assessment tool to characterize dry atmospheric deposition. Int J Environ Qual 9:37-50. **doi: 10.6092/issn.2281-4485/3737-.**

Vittori Antisari L, Ventura F, Simoni A, Piana S, Rossi Pisa P, Vianello G (2013) Assesment of pollutants in wet and dry deposition in a suburban area around a wast-to-energy plants (WEP) in Norther Italy. J Environ Protect 4:16-25. **doi: 10.4236/jep.2013.45A003**.

Wong C.S., Li X, Thornton I (2006) Urban environmental geochemistry of trace metals. Environ Pollut, 142:1-16. **doi: 10.1016/j.envpol.2005.09.004.**

Zasada I (2011) Multifunctional peri-urban agriculture - A review of societal demands and the provision of goods and services by farming. Land Use Policy 28:639-648. **doi: 10.1016/j.landusepol.2011.01.008.**

Tables

Table 1. Trace elements accumulation and deposition in leaves of tomato and zucchini as affected by distance to main road (ROAD/10 and ROAD/60). Values expressed as mg kg^{-1} of dry weight (accumulation) and g m^{-2} of leaf area (deposition). BDL: Below Detection Limit; SD: Standard Deviation. ANOVA (Tukey test $p<0.05$) test was performed on tomato and zucchini separately. ns: not significant differences at $P\leq0.05$; *: significant differences at $P\leq0.05$; **: significant differences at $P\leq0.01$.

		As	**Ba**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Sb**	**Sn**	**V**	**Zn**
							Accumulation						
Tomato	**ROAD/10**	BDL	32.10	0.20	0.80	13.10	BDL	2.38	0.28	0.44	18.30	0.10	144.40
	SD		*0.40*	*0.00*	*0.30*	*0.30*		*0.02*	*0.12*	*0.04*	*0.80*	*0.00*	*0.30*
	ROAD/60	BDL	34.40	BDL	0.10	11.50	BDL	0.36	0.40	0.32	15.80	0.10	38.20
	SD		*0.50*		*0.00*	*0.10*		*0.04*	*0.00*	*0.00*	*6.40*	*0.00*	*0.40*
Significance			ns	*	*	ns		*	ns	ns	ns	ns	*
Zucchini	**ROAD/10**	BDL	20.80	BDL	0.10	14.90	BDL	0.60	0.16	0.44	17.80	0.10	140.00
	SD		*0.50*		*0.00*	*0.10*		*0.05*	*0.00*	*0.03*	*0.50*	*0.00*	*1.20*
	ROAD/60	BDL	34.00	BDL	0.10	12.30	BDL	0.16	0.16	0.53	7.80	0.10	13.50
	SD		*0.00*		*0.00*	*0.30*		*0.00*	*0.00*	*0.04*	*4.60*	*0.00*	*0.50*
Significance			*		ns	ns		*	ns	ns	*	ns	*
							Deposition						
Tomato	**ROAD/10**	0.3	18.2	0.1	0.9	68.8	BDL	3.5	3.6	0.2	0.3	0.5	100.1
	SD	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	ROAD/60	0.1	4.6	0.1	0.3	16.3	BDL	4.7	1.3	BDL	0.2	0.2	21.7
	SD	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*
Significance		*	*	ns	*	*		ns	*	*	*	*	*
Zucchini	**ROAD/10**	0.2	13.5	0.0	0.1	16.1	BDL	3.6	2.3	0.3	0.7	0.6	26.2
	SD	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	ROAD/60	0.0	2.6	0.0	0.1	3.7	BDL	3.0	0.6	0.2	0.1	0.1	31.5
	SD	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Significance		*	*	ns	ns	*		ns	*	*	*	*	*

Table 2. Trace elements deposition in leaves of ornamental trees as affected by distance to main road (ROAD/10 and ROAD/60). Values expressed as g m^{-2} of leaf area. SD: Standard Deviation. ANOVA (Tukey test $p<0.05$) test was performed comparing the average values of metals concentration. ns: not significant differences at $P \leq 0.05$; *: significant differences at $P \leq 0.05$; **: significant differences at $P \leq 0.01$.

		As	**Ba**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Sb**	**Sn**	**V**	**Zn**
RAILWAY/ SOIL	**Poplar**	0.93	11.31	0.08	1.42	34.25	0.06	3.88	0.75	0.12	1.45	0.30	84.75
	SD	*0.01*	*0.73*	*0.00*	*0.02*	*0.99*	*0.00*	*0.13*	*0.10*	*0.01*	*0.06*	*0.03*	*0.75*
	Cherry	1.21	14.04	0.04	1.72	55.05	0.06	5.45	0.91	0.24	1.67	0.44	57.52
	SD	*0.03*	*1.09*	*0.00*	*0.03*	*1.15*	*0.00*	*0.15*	*0.16*	*0.01*	*0.05*	*0.03*	*0.87*
	Peach	0.93	18.34	0.06	1.75	128.93	0.11	7.52	5.89	0.25	1.51	0.65	175.51
	SD	*0.04*	*1.24*	*0.00*	*0.04*	*1.18*	*0.00*	*0.19*	*0.11*	*0.02*	*0.01*	*0.01*	*1.25*
	Average	1.02	14.56	0.06	1.63	72.74	0.08	5.62	2.52	0.20	1.54	0.46	105.93
	SD	*0.56*	*1.60*	*0.03*	*0.08*	*2.70*	*0.05*	*0.60*	*0.80*	*0.12*	*0.07*	*0.09*	*12.80*
ROAD/10	**Poplar**	0.12	44.74	0.22	3.05	168.42	0.17	16.30	11.41	1.13	2.25	1.54	597.42
	SD	*0.00*	*1.26*	*0.01*	*0.03*	*2.15*	*0.00*	*0.26*	*0.13*	*0.03*	*0.02*	*0.03*	*0.72*
	Maple	0.30	43.35	0.24	3.39	110.11	0.14	9.50	10.90	0.91	2.51	1.62	511.06
	SD	*0.01*	*0.99*	*0.01*	*0.05*	*1.58*	*0.00*	*0.20*	*0.15*	*0.05*	*0.01*	*0.04*	*0.85*
	Lime	0.37	80.84	0.23	3.61	184.55	0.30	15.21	15.63	1.12	2.80	2.45	399.87
	SD	*0.02*	*0.75*	*0.02*	*0.04*	*1.96*	*0.00*	*0.23*	*0.20*	*0.06*	*0.01*	*0.10*	*1.14*
	Average	0.26	56.31	0.23	3.35	154.36	0.20	13.67	12.65	1.05	2.52	1.87	502.78
	SD	*0.16*	*4.30*	*0.05*	*0.08*	*3.80*	*0.12*	*0.30*	*0.70*	*0.04*	*0.60*	*0.10*	*15.60*
Significance		*	*	ns	*	*	ns	**	*	*	*	*	**

Figures

Figure 1. Sites used for sampling. Top box, localisation of the city of Bologna and the town of Medicina. *CONTROL/RURAL* samples were obtained from site (C). Bottom box, city of Bologna.

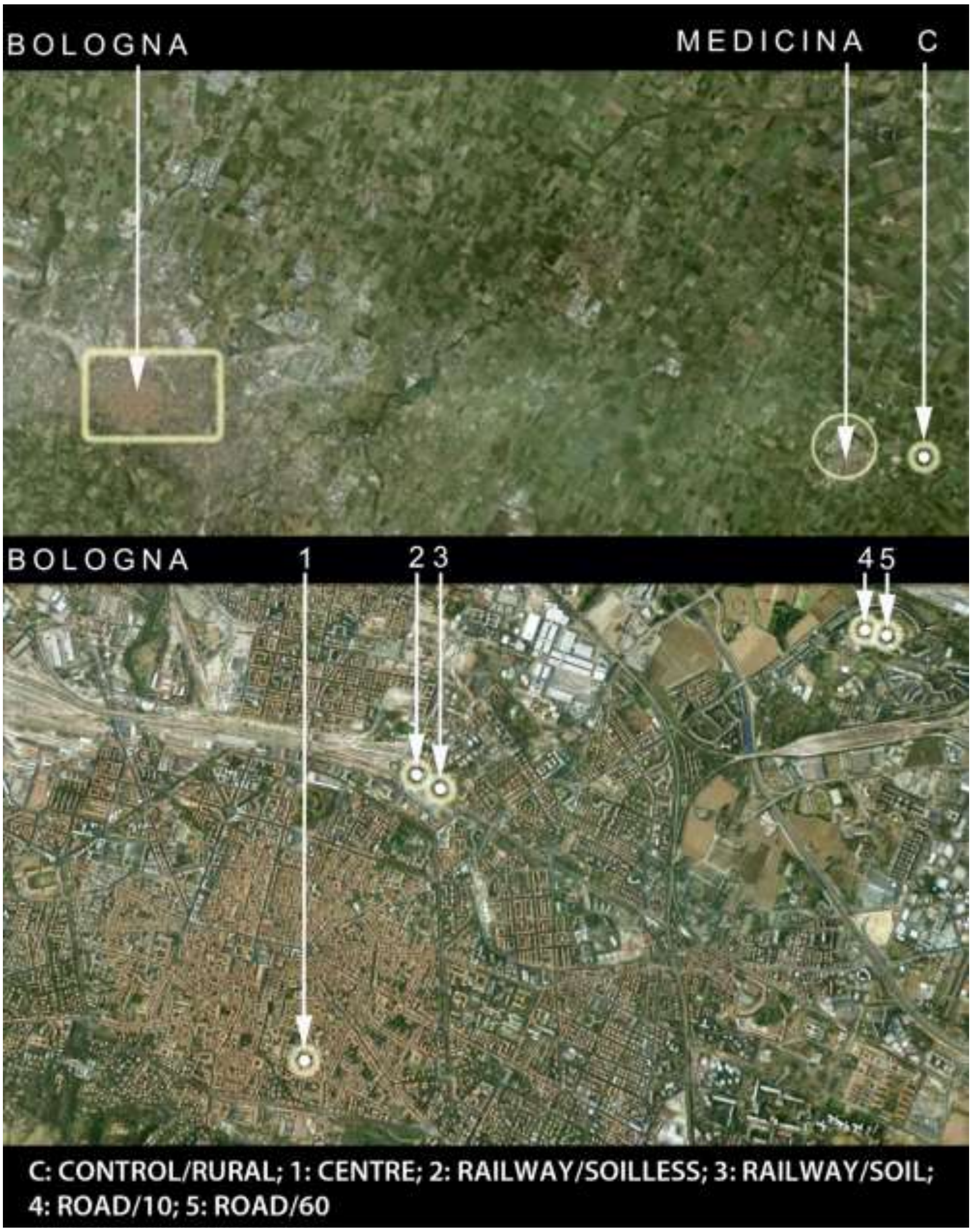

Figure 2. Cumulative concentration of selected heavy metals (As, Ba, Cd, Co, Cr, Cu, Ni, Pb, Sb, Sn, V, Zn) on leaveas of crops (tomato, sage, strawberry, pepper, rosemary, eggplant) grown on soil and soilless. Mean values, expressed as mg kg^{-1} of dry weight (DW), vertical bars represent standard deviation. ANOVA (Tukey test p≤0.05) was performed in all study sites and different lowercase letters indicate a significant difference in metals content. ns = not significant differences at P≤0.05.

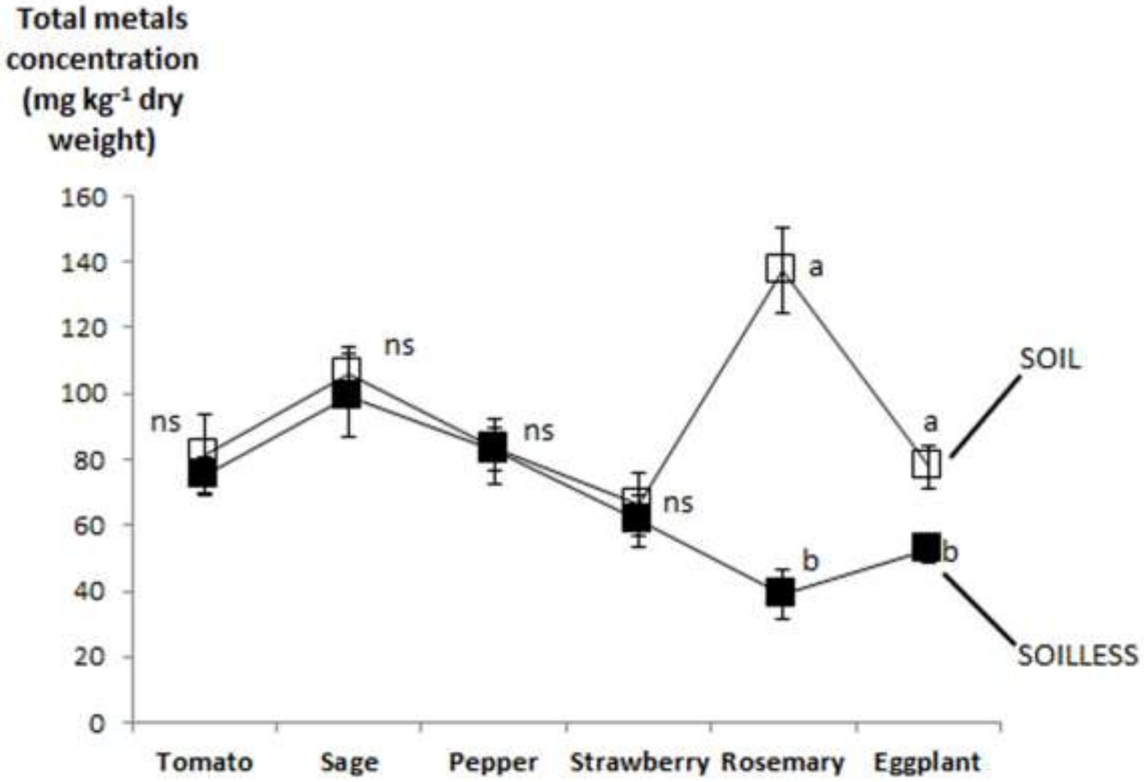

Figure 3. Cumulative pollutants (As, Ba, Cd, Co, Cr, Cu, Ni, Pb, Sb, Sn, V, Zn) deposition and tissue concentration. Deposition (A) was determined in the water after washing, as affected to garden location and growing system adopted, and expressed as g cm^{-2} of leaf area (LA). Tissue cumulative concentration, expressed as mg kg^{-1} Dry Weight (DW), on leaves of crops (basil, A; lettuce, B and tomato, C). ANOVA (Tukey test $p \leq 0.05$) was performed in all study sites and different lowercase letters indicate a significant difference in metals content.