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Effect of an organic amendment on availability and bio-accessibility of some metals in soils of urban recreational areas

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Metal-containing amendments can deteriorate the environmental quality of soils of urban recreational areas.

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ABSTRACT

A composted biosolid from wastewater treatment was added to soils of two public parks of Sevilla, and successive samples were taken during one year. In one of the parks, a second addition of biosolid was carried out after the first year. The soil contents in metals (pseudo-total) and their plant-available and oral bio-accessible fractions were significantly altered when the soils were amended with biosolid. Increase of the bio-accessible metal contents represents a deterioration of the environmental quality of recreational areas, where hand-to-mouth transfer of pollutants to children is likely to occur, although part of the metals added might be leached by rainfall or irrigation. The limits established in several countries for metal contents of soils in recreational areas are often exceeded after application of the biosolid. A careful study of the metal contents of recycled wastes is thus recommended before being used for green area maintenance.

1. Introduction

Waste recycling is nowadays considered very important to minimize undesirable impacts on the environment. This becomes of utmost importance in urban environments, as high population densities cause the production of large amounts of various wastes. Application of composts of several origins as amendments to agricultural soils has been a common waste management practice for many years, although the possible input of metals and other pollutants present in the amendments has to be carefully considered (McBride, 2003; Singh and Agrawal, 2008). Despite the suggestions of some authors (e.g. Viljoen et al., 2005) aiming at a sustainable future of cities including agricultural activities close to or immersed into urban life, with few exceptions (e.g. communal activities in Sevilla, Madrid et al., 2008; or in some US cities, Brown, 2009; Goldstein, 2009), green areas of large industrialized cities are very rarely used in agricultural activities for production of food, so that addition of amendments obtained from various wastes to soils of such areas is often considered a good practice for maintenance of the grass cover, with no especial care about possible significant contents of some potentially toxic metals in the amendments. In contrast with international efforts to preserve natural, relatively untouched ecosystems, less scientific or political attention has been traditionally paid to that type of nature close to where people live and work, such as green areas in cities (Chiesura, 2004), although a significant increase is observed in the number of studies on urban soils published in the last few years in scientific journals. In fact, although some countries have specific regulations for maximum metal contents of urban soils, such limits are generally higher than those for agricultural soils (Madrid et al., 2006). However, it is often forgotten that in playgrounds and other recreational areas, hand-to-mouth is a very likely way of transfer of metals from soils to humans, especially children (Abrahams, 2002). Some authors consider soil ingestion as a main source of Pb ingested by children (De Miguel et al., 2007; Johnson and Bretsch, 2002), and responsible for a high blood Pb level of children in some areas (Filippelli and Laidlaw, 2010). It is then important to know, not only the possible effects of amendments likely to be used in such areas on the total (or pseudo-total) contents, but also on the availability and bio-accessibility of soil pollutants, estimated by various extracting solutions (Kim et al., 2002; Quevauviller et al., 1997; Santos et al., 2010; Sialelli et al., 2010). In the work described here, field experiments were carried out in grass-covered areas of two public parks of Sevilla to know the effect of a composted biosolid often used as organic amendment by the Parks & Gardens Service of the local government on availability of several metals. In fact, recycling of

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Table 1
Descriptive data of the soil samples and the biosolid.

	Miraflores	Príncipes	Biosolid
pH $CaCl_2$ 0.01 M (1:2.5)	7.9	7.8	6.4
EC (1:5)/μS cm^{-1} [a]	123	151	7950
CCE/g kg^{-1} [b]	184	208	140
Sand/g kg^{-1}	628	402	
Silt/g kg^{-1}	242	411	
Clay/g kg^{-1}	130	187	
Organic C/g kg^{-1}	21.1	34.0	270
Pseudo-total (aqua-regia)			
Cu/mg kg^{-1}	20.5	54.2	325
Pb/mg kg^{-1}	36.9	117	184
Zn/mg kg^{-1}	58.9	160	563
Available (EDTA)			
Cu/mg kg^{-1}	3.9	12.2	
Pb/mg kg^{-1}	15.2	57.2	
Zn/mg kg^{-1}	12.2	30.9	
Bio-accessible (SBET)			
Cu/mg kg^{-1}	9.4	12.9	
Pb/mg kg^{-1}	34.9	100	
Zn/mg kg^{-1}	27.7	84.5	

[a] Electrical conductivity.
[b] Calcium carbonate equivalent.

biosolid from wastewater treatment is a common problem for any large city in developed countries. Actually, since 2006 every European city of population above 2000 inhabitants must have a wastewater treatment system (EU Directive 91/271/EEC). The metals chosen were Cu, Pb and Zn, as they are often considered as those most affected by anthropogenic activities in urban soils (Madrid et al., 2004). Although pollution with other potentially toxic elements and/or persistent organic pollutants can occur in specific cases related with the use of composted biosolids, the metals chosen here have been shown to behave differently from other metals in urban soils of several cities including Sevilla (Ajmone-Marsan et al., 2008).

2. Materials and methods

A composted biosolid obtained from the wastewater treatment plant of Sevilla local government was chosen for the study. This material is often used as organic amendment for the local parks managed by the Parks & Gardens Service, and is also commercialized for similar uses. Some relevant properties of the material are given in Table 1. The metal concentrations are comparable to those reported for similar materials (e.g. Fuentes et al., 2008), and clearly below the limits established by European regulations for such materials that can be applied to soils (Directive 86/278/EEC), 1000, 750 and 2500 mg kg^{-1} for Cu, Pb and Zn respectively.

Areas of about 5 × 5 m covered with grass (*Cynodon dactylon*, "grama") were allocated for the field experiments of this study in two public parks of Sevilla, Miraflores and Príncipes, respectively located on the NE and SW of the city. Both parks have been used in other previous studies (Madrid et al., 2008), and relevant properties of both soils are also given in Table 1. The surrounding areas are in both cases densely populated, and both parks are thus extensively used as recreational sites by the abundant nearby population, with hundreds of visitors every day, including collective educational activities of children from nearby schools.

In each allocated area, nine 1 × 1-m plots were arranged in a latin-square design of three files and three columns, so that no treatment was repeated within each file or column, 30-cm wide lanes were left between adjoining plots, and samples were taken to estimate the initial characteristics of each soil. The size of the plots was chosen due to the lack of feasibility of using a larger area of a public park for the experiment. The allocated area and the nine plots of each park were conveniently marked with stakes and coloured ribbon to avoid interference from the park users. It must be stressed that when experiments of this kind have to be carried out in public urban parks, the possibility of human interference is often unavoidable, and cooperation of the Parks Service personnel is necessary. Grass was uprooted as much as possible in the nine 1-m^2 plots of each park, and three doses of biosolid were added (0, 2 and 8 kg m^{-2}, equivalent to 0, 20 000 and 80 000 kg ha^{-1}), and mixed as thoroughly as possible with the soil in the 0–10 cm surface layer. Samples of about 1 kg were taken from each plot 1, 3, 6 and 9 months after the addition of the amendment. Despite the precautions, in several occasions the stakes and ribbons marking the plots in Miraflores park had to be replaced due to damages probably caused by human intervention, and therefore the effect of a second addition of the biosolid after 13 months was tested only in Príncipes park, where no human interference was observed. Grass was not so densely grown as it was at the beginning of the assay, so it was not uprooted for this second addition. The biosolid of the second addition was from the same batch as the first, which was kept in the dark at 4 °C between additions. Samples were again taken just before the second addition and 5 and 11 months after the second application of biosolid.

General descriptive properties were estimated in every sample by standard procedures (Madrid et al., 2004): particle size distribution was determined by the hydrometer method, pH in 1:2.5 water extract, electrical conductivity (EC) in 1:5 extract, calcium carbonate equivalent (CCE) by a manometric method, and organic C (OC) by $K_2Cr_2O_7$ oxidation. Analysis of pseudo-total metal contents (Gupta et al., 1996) was carried out by microwave-assisted (Ethos 900, Milestone, Italy) aqua-regia digestion (Kingston and Haswell, 1997) and determined by Induced Coupled Plasma Optical Emission Spectrometry (ICP-OES Iris Advantage, Thermo Scientific, USA).

The possible variation of availability or solubility of Cu, Pb and Zn during the experiment was estimated by extraction with 0.05 M EDTA at pH 7 (2.5 g/25 ml) (Quevauviller et al., 1997) or 0.4 M glycine at pH 1.5 (0.3 g/30 ml) (Simple

Table 2
Maximum acceptable limits (in mg kg^{-1}) established in various countries or regions for the metals studied here in soils of residential/recreational areas (unless otherwise mentioned).

Country/Region	Pb	Zn	Cu	References
Québec	500	500	100	Ministère de l'Environnement du Québec, 2002
Canada	140	200	63	Canadian Council of Ministers of the Environment, 2007
Italy	100	150	120	Ministero dell'Ambiente, 2006
Sweden [a]	80	350	100	Swedish Environmental Protection Agency, 1997
Netherlands [b], [c]	85/530	140/720	36/190	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 2000
Slovenia [b], [d]	85/100/530	200/300/720	60/100/300	Anonymous, 1997
Portugal [b], [e]	300/450	300/450	100/200	Ministerios da Agricultura, Desenvolvimento Rural e das Pescas e do Ambiente, 1996
Euskad [i]	450	–	–	Sociedad Pública de Gestión Ambiental, 2002
Andalucía [b], [e], [f]	250–350/400–500	300–600/500–1000	150–300/300–500	Aguilar et al., 1999
UK (pre-2002) [g]	500 [h], 2000 [i]	300 [j]	130 [j]	Department of the Environment, 1987
UK [k]	450	–	–	Department of the Environment, Food and Rural Affairs, 2002

[a] "KM", land with sensitive use (residential areas, kindergarten, agricultural, etc.).
[b] No distinction is made for any particular land use.
[c] "Target" and "intervention" values.
[d] "Limit", "warning" and "critical" values.
[e] Different values are given for pH below and above 7.
[f] "Research required" values. Ranges instead of single values are given.
[g] ICRCL (Interdepartmental Committee on the Redevelopment of Contaminated Land) "threshold" trigger values.
[h] Domestic gardens and allotments.
[i] Parks, playing fields and open spaces.
[j] Any uses where plants grow.
[k] Typical CLEA (Contaminated Land Exposure Assessment) Soil Guideline Values, residential without plant uptake.