Potentially harmful elements in soil–plant interactions

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1 Background

The collection of papers presented in this Special Issue is an outcome of the S12.07 Session “Potentially Harmful Elements in Soils” of the EUROSIL 2012 International Conference held in Bari (Italy) in April 2011, on the part of the European Confederation of Soil Science Societies (ECSSS), the International Union of Soil Sciences (IUSS) and the International Humic Substances Society (IHSS).

Soils are essential components of the environment, the basis of terrestrial ecosystems and a crossroads for biogeochemical cycles at the lithosphere–biosphere interface. The role of the pedosphere is essential for understanding soil–plant interactions, especially through the rhizosphere.

The subject of this Special Issue is of extreme importance, because of the potentially harmful effects of numerous elements on the soil–plant system. The papers in this issue cover important aspects of fundamental and applied research and provide advances in relation to existing knowledge. They deal with essential aspects of potentially harmful substances such as heavy metals, metalloids and polycyclic aromatic hydrocarbons (PAHs) with regard to the interaction of the plant system with soils and sediments.

This Special Issue contains 19 papers written by authors from 11 countries: Canada, Finland, France, India, Israel, Italy, Jordan, Pakistan, Portugal, Russia and Spain. This collection of papers is focused mainly on four topics: soil amendments, mine soils, soil total metal contents and threshold values: the biodegradation of aromatic hydrocarbons and the complexation by aliphatic ligands.

2 Research topics

2.1 Soil amendments

There are seven papers that deal with the first topic: soil amendments.

Shahid et al. (2014a, b) assessed the influence of two phosphorus (P) amendments— KH_2PO_4 and $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ —on metal speciation in rhizosphere soil and soil–plant transfer of metals. This study was performed in field and laboratory experiments with pea, tomato and mustard plants. The authors concluded that the effectiveness of in situ immobilization technique varies with the type and quantity of applied P amendment, as well as plant and metal type.

The work of Austruy et al. (2014) also deals with the role of P amendments. The authors investigated metal-phosphates formation in the rhizosphere of pea and tomato plants cultivated in polluted soils with Pb and Zn from past industrial activities. Hydroxypatite and KH_2PO_4 were used, which caused Pb and Zn immobilization in the presence of plants (mainly in the pea rhizosphere), with KH_2PO_4 and with more soil–plant contact. They concluded that metal-P complex formation in the contaminated soil depends on the type of P amendment, the period of soil plant contact, the type of plant species and the excretion of organic acids by the plant roots in the rhizosphere.

Shtangeeva et al. (2014) focused on the problems in the uptake of antimony by wheat (*Triticum aestivum* L.) seedlings grown in soil enriched with Sb amendments and the impact of soil amendments on plant growth, as well as the uptake of Sb from soils and its transfer from roots to upper plant parts. Greenhouse pot experiments were carried out. They concluded that fertilizers could be used to increase phytoextraction of Sb and its removal from contaminated soils. However, such a soil amendment should be done carefully in order to exclude or at least reduce the negative effects on plants.

Soriano-Disla et al. (2014) estimated the transfer of Cd, Cr, Cu, Ni, Pb and Zn to barley (*Hordeum vulgare* L.) grown in

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agricultural soils previously amended with sewage sludge containing different concentrations of heavy metals. Soils slightly restricted the mobility of heavy metals to roots, while plant physiology restricted the transfer of heavy metals from roots to shoots, with further restriction at higher heavy metal loadings. The transfer of Cd, Cu and Zn from soils to shoots was greater than for Cr, Ni and Pb. Sandy soils allowed greater soil–plant transfer of Cr, Cu, Pb and Zn. For Cd and Ni, soils of low pH and soil organic C posed the highest risk.

Allué et al. (2014) studied whether tannery sludge could be used for Cr biofortification of fenugreek (*Trigonella foenum-graecum* L.). Soils mixed with tannery sludge containing $6.03 \text{ g Cr}^{3+}\text{kg}^{-1}$ were potted and planted with fenugreek. Plants harvested at the initial flowering stage were analysed for total Cr, Fe, Zn and Pb. Sequential soil extraction was applied to obtain soil Cr fractions. The authors concluded that tannery sludge-amended soils containing metals within the permitted range of concentrations can increase shoot Cr in fenugreek. Only sludge with low Pb concentrations should be used for Cr biofortification of fenugreek.

Mingorance et al. (2014) investigated the use of stabilized municipal sewage sludge addition to improve acid mine soils for plant growth. A pot trial of improved soils amended with stabilized sewage sludge was carried out with tomato, rye grass and ahipa. Biomass production was improved in tomato and rye grass by sewage sludge addition, whilst ahipa growth was not affected. The authors concluded that amendments with sewage sludge of limed acid mine soils would improve soil amelioration with respect to plant establishment and development.

Rosen and Chen (2014) conducted a bioassay experiment to establish the possible relations between metal concentrations in different soil fractions and metal contents in edible plant parts and to investigate the influence of different compost loads on heavy metal availability to Chinese cabbage plants. The distribution of metals was determined by sequential extraction procedure (modified BCR protocol). The authors found that compost addition increased metal proportions in the reducible hydro/oxides of Fe and Mn associated with organic matter fractions, as well as reduced metal phytoavailability. They proposed using the water extractable, exchangeable and adsorbed, and the fraction associated with carbonates and acetic-soluble forms as a three-step sequential extraction procedure for the most phytoavailable fractions of heavy metal.

2.2 Mine soils

Eight papers in this Special Issue refer to the second topic: mine soils.

Chaturvedi et al. (2014) studied the growth and physiological response of *Tagetes patula* L. on iron (Fe) ore tailings. Pot culture experiments were used to investigate the effect of Fe

tailings, both individually, as well as in combination with soil on the growth, pigment production and the accumulation and translocation of heavy metals from the tailings. Bioaccumulation and translocation values were maximum for Fe and minimum for Ni and Cd, respectively. The authors concluded that *T. patula* L. would grow well on the tailings and survive despite an excess of heavy metals. It would also be a potential tool for phytostabilization of Fe ore tailings, and probably a source of income generation from wasteland, owing to its multiple commercial values.

Maleci et al. (2014) examined the effect of heavy metals on the morphology of dandelion (*Taraxacum officinale* Web.) growing in pots with mine soils to determine the evolution of heavy metal concentrations in leaves and roots over 3 years of cultivation and to highlight possible damage at anatomical and citological level. Plants from contaminated sites show a reduction of leaf thickness proportional to heavy metal concentration and a less organized palisade parenchyma. The parenchyma cells of the roots also displayed mitochondrial alteration. Ultimately, the histological characteristics of leaves and roots exposed a stressed state related to heavy metal content. Moreover, the presence of stress-tolerant mycorrhizal fungi could reduce metal toxicity.

Abreu et al. (2014) evaluated the biogeochemical impact of the Panasqueira (Portugal) mining activity on soils and *Arbutus unedo* L. trees, to assess the possible risks for human consumption of the fruits and brandy derived from these and to evaluate the phytostabilization potential of the arbutus tree. Soil, plant and brandy samples were analysed, and the total content (four acid digestion) of As, Cd, Cu, W and Zn were determined by inductively coupled plasma atomic emission spectroscopy (ICP). The concentrations were within the normal range for plants, except for Cd and Zn, which in some samples were above the normal values but without phytotoxic symptoms. According to the EC 466/2001 legislation, arbutus berry consumption does not constitute a health risk for humans, and arbutus trees can be used for phytostabilization in the Panasqueira area.

Santos et al. (2014) studied the effect of interpopulation variation on the accumulation and translocation of potentially harmful elements and nutrients in *Cistus ladanifer* L. from six mines in the Portuguese Iberian Pyrite Belt. *C. ladanifer* plants are able to survive in soils with heterogeneous characteristics and polymetallic contamination. Soils from Caveira, Lousal, Neves Corvo and Sao Domingos contained high total concentrations of As, Cu, Pb and Zn, but the soil-available fraction of these elements was low, irrespective of the influence of the mine. The plant species presented interpopulations and intrapopulations variations in the accumulation and translocation of potentially harmful elements and nutrients. However, all studied populations (Caveira, Chança, Lousal, Neves Corvo, Sao Domingos) except Brancanes belong to the same population cluster.

Amorós et al. (2014) reported the variations in mercury (Hg) and other trace element contents in soil and vine (*Vitis vinifera* L.) leaves from the Almadén Hg-mining district. Concentrations of Hg in soils and vine leaves were determined by an atomic absorption Lumex RA-915+ device with a pyrolysis unit (RP-91c). Hg in soil ranged from 2.376 to 0.04 mg kg⁻¹ in nonpolluted places. Maximum concentrations in leaves were detected in the proximity of the mine and/or the surrounding metallurgical areas.

Pé-Leve Santos et al. (2014) calculated the concentrations of As, Cu, Zn and W of plants and soils of mining wash sites, in order to compare the uptake of harmful elements from the contaminated soils in the different plants. The quantification was based on the fundamental parameters method for plants and on the WinAxil “compare” mode, using a standard reference material for soils. High concentrations of tungsten were found near the new wash site—and throughout the area—at concentrations many times higher than those recommended by the World Health Organization (WHO).

Rodríguez-Seijo et al. (2014) described the soils that have developed on the tailings from an abandoned Pb and Zn mine in Galicia (NW Spain) and determined the soil factors that limit revegetation. These are their low depth, high porosity and stoniness, low organic matter (OM) and cation-exchange capacity (CEC), as well as an imbalance between exchangeable cations. Moreover, the high Zn and Pb concentrations hinder revegetation. The restoration procedure recommended by the authors must overcome oxidation processes by adding organic amendments that also contribute towards fixing heavy metals or by implanting spontaneous vegetation such as common broom (*Cytisus scoparius*) or white birch (*Betula celtiberica*).

Martínez-López et al. (2014) researched As assimilation by natural vegetation of mining-influenced soils. Two mammals (a sheep and a vole) were selected to study the transfer to the trophic chain. The risk analysis was founded on the contribution of natural plants by ingestion. The As content of soil and plant materials was determined after a microwave digestion by atomic fluorescence spectrometry with flow hydride generation (HG-AES). They concluded that the levels of As in roots were higher than in shoots. The bioconcentration was very low, and the transfer factors, while slightly higher, rarely exceeded unity. When undertaken with the phytoremediation of contaminated sites, the contribution of the As level in plants to the daily diet of animals should be employed as an indicator for the screening of the vegetal species to be used.

2.3 Soil metal contents and threshold values

Two papers are concerned with the third topic: soil metal contents and threshold values.

Galán et al. (2014) proposed a robust approach for evaluating the geogenic vs. anthropogenic contribution in polluted

soils, based on three steps. Firstly, the trace element contents in potentially polluted soils and their reference and threshold values were compared. Secondly, references and threshold values for the surrounding area were calculated. Thirdly, the results of both types of area were compared.

Acosta et al. (2014) compared soil properties, especially the presence (total and DTPA extractable) and mobility of metals between soils of green areas and bare soil playgrounds in four urban parks in Murcia city (SE Spain). Grasses accumulated less metal than soils, except in roots where Cr and Zn were higher than soils by as much as 31 and 17 %, respectively. The authors concluded that grasses increased soil OM in green areas and that the soils of urban parks were able to accumulate nutrients for plants and to retain and reduce the mobility and toxicity of metals.

2.4 Biodegradation of aromatic hydrocarbons and complexation by aliphatic ligands

Two papers deal with the fourth topic: biodegradation of aromatic hydrocarbons and complexation by aliphatic ligands.

Rocha et al. (2014) investigated the biodegradation of polycyclic aromatic hydrocarbons (PAHs), acenaphthylene (Ace) and benzo[a]anthracene (BaA) by the white rot fungus *Pleurotus ostreatus*. The biodegradation of Ace and BaA (alone and in mixtures) by *P. ostreatus* was studied in a sandy soil. The results indicate that the fungal degradation of Ace and BaA was not influenced by the presence of each other's PAH in sandy soils. The bioremediation of soils contaminated with Ace and BaA using *P. ostreatus* is an interesting way of eliminating these PAHs from the polluted soils.

Shahid et al. (2014a, b) evaluated the effect of organic ligands such as EDTA and citric acid on Pb-induced oxidative stress to *Vicia faba* L. roots. They concluded that EDTA could inhibit Pb-induced toxicity to *V. faba* L. seedlings by forming stable PbEDTA complexes due to its high binding strength for Pb. However, citric acid had no effect, due to weak complexation with Pb.

3 Conclusions

All the papers described above cover important aspects of fundamental and applied research and provide advances in relation to existing knowledge.

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