Journal of Environmental Management 159 (2015) 37–47

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Effect of fresh and mature organic amendments on the phytoremediation of technosols contaminated with high concentrations of trace elements

Nour Hattab [a, b, *], Mikael Motelica-Heino [a], Olivier Faure [c], Jean-Luc Bouchardon [c]

[a] *ISTO, UMR 7327 — CNRS/Université d'Orléans, Campus Géosciences, 1A, Rue de la Férollerie, 45071 Orléans Cedex 2, France*
[b] *Université d'Orléans, UFR-Faculté des Sciences, Laboratoire de Biologie des Ligneux et des Grandes Cultures, UPRES EA 1207, Rue de Chartres, BP 6759, F-45067 Orléans Cedex 02, France*
[c] *Ecole Nationale Supérieure des Mines de Saint-Etienne, Département SPIN, Laboratoire GéoSciences & Environnement, 158 Cours Fauriel, F-42023 Saint Etienne Cedex 2, France*

ARTICLE INFO

Article history:
Received 6 April 2015
Received in revised form
7 May 2015
Accepted 10 May 2015
Available online xxx

Keywords:
Soil contamination
Phytostabilisation
Trace elements
Organic amendment
Mobility
Phytoavailability
Soil exposure intensity

ABSTRACT

Organic compounds resulting from the decomposition of organic amendments are used in the remediation of trace element (TE) contaminated soils. The mobility, phytoavailability and soil exposure intensity of molybdenum (Mo), chromium (Cr), zinc (Zn), copper (Cu), Cobalt (Co) and Arsenic (As) were evaluated in the phytoremediation of contaminated technosols after the addition of two organic matter types, fresh ramial chipped wood (RCW) and composted sewage sludge (CSS). The experiment consisted of nine main treatment blocks: (A) 3X unamended soil (NE), (B) 3X soil amended with RCW and (C) 3X soil amended with mature CSS. Total dissolved TE concentrations were determined in soil pore water (SPW) sampled by Rhizon samplers. The soil exposure intensity was assessed by standard Chelex 100 DGT (diffusive gradient in thin films) probes. TE phytoavailability was characterized by growing dwarf beans on potted soils and analyzing their foliar TE concentrations. The results of the present study indicate that the addition of fresh RCW and CSS has a positive effect on contaminated technosols. RCW decreased the mobility of all the studied TE in the SPW, whereas CSS reduced the mobility of Mo, Cr and Co, while it increased the mobility of Zn, Cu and As compared with the NE soil.

The Zn soil exposure intensity assessed by DGT was not significantly changed by the addition of RCW and CSS, while the Cr soil exposure intensity was significantly decreased after RCW addition compared with the soil treated with CSS and the NE soil. In contrast Cu and Co were non labile in the three soils. Both RCW and CSS decreased the foliar concentration and the mineral mass of Mo, Zn, Cr, As and Co in the bean leaves but increased the foliar Cu concentration.

1. Introduction

Among anthrosols, technosols and hortic, anthrosols are considered to be the most exposed to pollution (Bulgariu et al., 2007; Thornton, 1991; Florea and Munteanu, 2003; IUSS, 2006). The high concentration, distribution and migration of TE in these soils represent an important environmental problem due to the great toxicity of these elements that may cause major perturbations to soil ecosystems (Jamil et al., 2014; Alloway, 1995; Kabata-Pendias and Pendias, 1992; Ross, 1994). In fact the high concentrations of TE in the contaminated anthrosols is more problematic than for other soils because most of the properties of these types of soil may change with time, making their handling more difficult (Kelly et al., 1996). Therefore to limit the solubility and the bioavailability of metal(oid)s in contaminated anthrosol a special soil-management techniques is required. Several treatment techniques can be used to remediate TE contaminated soils. These techniques include physical and chemical remediation, and agro-ecological engineering methods such as phytoremediation (Chen et al., 1999, 2000a,b). Conventional soil reclamation technologies such as ‘dig and dump’, soil washing, and sieving are effective but destructive thus not sustainable in terms of consumption of raw materials and waste production (Raicevic et al., 2005; Dermont et al., 2008). In addition,

---

* Corresponding author. ISTO, UMR 7327 — CNRS/Université d'Orléans, Campus Géosciences, 1A, Rue de la Férollerie, 45071 Orléans Cedex 2, France.
E-mail address: nour.hattab@univ-orleans.fr (N. Hattab).

http://dx.doi.org/10.1016/j.jenvman.2015.05.012
0301-4797/

they are very expensive, particularly for large contaminated sites. Less invasive, low-cost phytotechnologies such as phytostabilization, singly and in combination with *in situ* stabilization (*i.e.* assisted phytostabilization), are potential management options to restore the physical, chemical and biological properties of TE contaminated soils (Mench et al., 2000; Bolan and Duraisamy, 2003; Perez de Mora et al., 2005; Raicevic et al., 2005; Kumpiene et al., 2006, 2008; Segura and Ramos, 2013).

Several mineral and organic amendments can improve phytostabilization and the production of plant by decreasing the solubility, leaching and bioavailability of TE (Brown et al., 2004; Basta and McGowen, 2004; Kumpiene et al., 2008; Mench et al., 2010; Angelova et al., 2013). The immobilizing effect of such amendments are thought to act through various complex processes *e.g.* adsorption onto mineral surfaces, formation of stable compounds with organic ligands, surface precipitation and ion exchange (Kumpiene et al., 2008; Ahmad et al., 2011). However, these processes are still not well understood and the choice of a particular amendment is often problematic. Thus, case studies assessing the mobility and bioavailability of TE in contaminated soils managed by assisted phytostabilization are needed to better define the pros and cons of such management options (Mench et al., 2010).

Organic matter (compost, manure or various organic wastes) additions to soil have long been considered important in maintaining the quality of both natural and managed soils, principally because of their capacity to provide nutrients to the soil's living organisms and through their influence on the soil physical properties. This influence on soil properties depends on several factors such as the quantity, type and maturation of the organic matters applied to the soil and the soil properties. Moreover organic amendments may enhance the soil fertility and microbial activity, leading to the amelioration of the soil quality as a whole. These overall modifications generally decrease the mobility and the bioavailability of TE, even if temporarily, and thus promote the reestablishment of vegetation and increase plant growth (Castaldi and Melis, 2004; Madejón et al., 2006; Branzini and Zubillaga, 2012).

Nevertheless, the effect of organic amendments on the mobility and the bioavailability of metal(loid)s depends on the nature of the organic matter itself, its microbial degradability, its effects on soil chemical and physical proprieties, as well as on the particular soil type and metal(loid)s concerned (Walker et al., 2003, 2004; Angelova et al., 2013). However very few comparative studies have been performed so far and the choice of a particular organic amendment in assisted phytostabilization strategies often remain empirical.

The main aim of this work was to assess the effect of two different organic amendments (composted sewage sludge (CSS) and fresh ramial chipped wood (RCW)) on the mobility, phytoavailability and soil exposure intensity of several TE in a metallurgical technosol remediated by assisted phytostabilization.

2. Materials and methods

2.1. Site description and experimental design

The studied site is a metallurgical landfill (Industeel-Loire; 45°32′ N; 4°38′E) near Lyon, France. It is located behind a steel and iron factory which is still in activity. Site description and experimental design were previously reported in Hattab et al., 2014a.

The main chemical and physical properties and the total metal concentrations measured in the RCW and CSS before being mixed with the technosol are given in Table 1. The main pedological characteristics of the soils studied (taken at 0–20 cm depth) are given in Table 2. Their total metal concentrations are given in Table 3. The average concentration values of metals measured in the soil were 5837 mg kg^{-1} Cr, 620 mg kg^{-1} Mo, 1464 mg kg^{-1} Zn, 444 mg kg^{-1} Cu and 80 mg kg^{-1} As (Table 3). These TE concentrations are well above the limits of TE concentrations measured in natural unpolluted French soils (Baize, 2000), which confirms the existence of a very high polymetallic contamination.

Table 1
The main physico-chemical properties and total metal concentrations measured in the RCW and CSS.

Chemical or physical property	CSS	RCW
C (%)	21.07	58.8
N (%)	2.96	1.15
C:N ratio	7.12	51
P (%)	2.23	0.11
C:P ratio	9.45	535
K (%)	0.54	0.53
Ca (%)	11.19	1.39
Mg (%)	0.5	0.12
OM (%)	30.9	78
CEC (cmol(+)kg^{-1})	–	–
pH (H_2O)	8.8	5.2
Total TE concentrations	**CSS**	**RCW**
Cr (mg kg^{-1})	91.3	13.7
Mo (mg kg^{-1})	2.3	0.5
Cu (mg kg^{-1})	161.1	14
Zn (mg kg^{-1})	360.2	97.6
As (mg kg^{-1})	16.8	2

Table 2
Main pedological characteristics of the soils studied determined four months after the plots preparation. For each treatment, data are the mean of 3 measurements.

Parameter	Treatment		
	RCW + NE	CSS + NE	NE
Texture	Sandy	Sandy	Sandy
pH	10.63 ± 0.23	10.63 ± 0.12	11.20 ± 0.17
C_{org} (g kg^{-1})	22.07 ± 5.64	42.30 ± 9.17	19.92 ± 3.00
N (g kg^{-1})	0.47 ± 0.12	2.33 ± 0.32	0.33 ± 0.06
C/N	47.70 ± 5.10	17.97 ± 0.25	60.00 ± 5.96
CEC(mEq/100 g)	5.63 ± 1.10	6.77 ± 0.15	5.77 ± 0.55
P_2O_5 (g kg^{-1})	0.03 ± 0.00	0.25 ± 0.04	0.02 ± 0.00
K_2O (g kg^{-1})	0.29 ± 0.05	0.59 ± 0.07	0.09 ± 0.07
CaO (g kg^{-1})	18.88 ± 6.71	20.70 ± 1.13	24.67 ± 2.17
MgO (g kg^{-1})	2.66 ± 0.44	1.29 ± 0.09	2.79 ± 0.44
Na_2O (g kg^{-1})	0.08 ± 0.07	0.14 ± 0.02	0.14 ± 0.03

Table 3
Total TE concentrations (hydrofluoric acid extraction) of the studied soils determined four months after plots preparation. For each treatment, data are the mean of 30 measurements (10 samples per plot, 3 plots per treatment).

1.1 Metal	2.1 Treatment		
	RCW + NE	CSS + NE	NE
Cr (mg kg^{-1})	5397 ± 962	5138 ± 1057	6286 ± 957
Mo (mg kg^{-1})	545 ± 175	654 ± 62	660 ± 141
Cu (mg kg^{-1})	418 ± 113	401 ± 56	416 ± 22
Zn (mg kg^{-1})	1314 ± 577	1102 ± 468	1218 ± 647
As (mg kg^{-1})	80 ± 19	74 ± 11	91 ± 14

2.2. Assessment of TE (phyto)availability

TE (phyto)availability in the studied soils was assessed using three different approaches: *i*/the measurement of growth inhibition and TE accumulation in *Phaseolus vulgaris*; *ii*/the measurement of metal concentration in the soil pore water; and *iii*/the diffusive gradient in thin films (DGT) method to assess the TE soil exposure intensity.