

Enhanced Heavy Metal Phytoextraction from Marine Dredged Sediments Comparing Conventional Chelating Agents (Citric Acid and EDTA) with Humic Substances

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Abstract Laboratory experiments were carried out to examine the effects of chelating agents on heavy metal extraction from slightly contaminated dredged sediments from the port of Livorno (Italy). Ethylene diamine tetraacetate (EDTA), citric acid (CA) and humic substances (HS) were tested in two different concentrations each: 120 and 480, 500 and 2,000, 500 and 1,000 mg/l, respectively. Solubilisation of heavy metals (Cu and Zn) was observed for both EDTA and HS in the extraction kinetic experiments: 58% of the total Cu and 50% of the total Zn in the sediment were mobilised from the solid matrix using EDTA (480 mg/l) and 32% of the total Cu and 5% of the total Zn, using HS (1,000 mg/l). It was observed that solubilized metal levels were positively related to the chelating agent concentration. HS performance in the heavy metals mobilisation and phyto-toxicity tests was considered promising. HS represent an innovation in enhanced phytoextraction techniques: they can

be considered an environmentally non-impacting bio-agronomic amendment. CA induced no significant effects on heavy metal mobilisation and it also negatively affects seed germination (Germination Index < 40%). Laboratory experiments with plants showed that none of the treatments significantly affected the biomass production and a trend could only be detected for the heavy metal uptake into shoots of *Paspalum vaginatum* sp. Transplantation of seashore paspalum is useful as a pre-treatment of contaminated dredged sediments, since it is a salt-tolerant species and it can be easily adaptable on a nutrient poor and fine textured medium.

Keywords Phytoextraction · Marine sediments · Humic substances · Vermicomposting · EDTA · *Paspalum vaginatum* sp.

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1 Introduction

The effectiveness of phytoremediation has been proven for the treatment of many classes of contaminants, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAH), chlorinated solvents, pesticides and heavy metals (Aprill and Sims 1990; Anderson et al. 1994; Newman et al. 1997; Salt et al. 1997; Chang and Corapcioglu 1998; EPA 2000;

Nedunuri et al. 2000; Pivetz 2001; Schnoor 2002). When the contamination level of the soil is low, phytoremediation could be the most economical and effective reclamation strategy (Jones 1991), particularly feasible as a long term solution to the problem.

Phytoextraction is one of the phytoremediation techniques that uses plants able to accumulate concentrations of metals from contaminated soil in their biomass, distinguishing between hyperaccumulating species (Kumar et al. 1995; Blaylock et al. 1997) and species with a high biomass production (Bregante et al. 2001).

Phytoextraction could also be an effective solution for the treatment of dredged sediments. The contamination of sediments from the dredging of rivers or coastal harbours represents a problem that has assumed a notable importance in terms of the number of cases and the quantitative and economic extent of the necessary activities of restoration (Mulligan et al. 2001; Lors et al. 2004; Meers et al. 2005). Due to the high quantities of sediments to be treated every year and the high costs of traditional reclamation techniques, the conventional treatments of the sediments are not in most cases economically sustainable (Meers et al. 2003) and phytoremediation techniques could play an important role in these situations. Nevertheless, sediments, and particularly marine sediments, have poor hydraulic and agronomic characteristics, so that mixing with selected materials is probably the only way to make phytoextraction an effective remediation technique.

In this study sediments slightly contaminated with heavy metals from the port of Livorno (Italy) were analyzed. According to a preliminary laboratory study, these sediments resulted inadequate (low permeability and low nutrient content) for a direct phytoextraction technique (Iannelli et al. 2006).

Furthermore, the high salinity of the sediments obliged the use of a salt-tolerant species. *Paspalum vaginatum* was selected, as it was already used in phytoremediation techniques applied to marine sediments (Hue et al. 2002).

Besides the choice of the best plant and cultivation technique, in most cases, the key to successful phytoextraction is a reasoned choice of chelators. Literature reports a great number of chelating agents that have been used for enhanced phytoextraction (EDTA, CDTA, DTPA, EGTA, EDDHA, malic acid). However, these chelators present potential risks to groundwater con-

tamination in real scale application (Huang et al. 1997; Blaylock et al. 1997; Huang and Cunningham 1996; Wu et al. 1999; Tandy et al. 2004; Luo et al. 2006). Other studies have focused on biodegradable chelating agents, but they were found to be unsuitable for efficient phytoextraction (Vandevivere et al. 2001; Tandy et al. 2004; Meers et al. 2005; Luo et al. 2005; Luo et al. 2006).

The aim of this study was to compare a natural chelating agent (humic substances from vermicompost) and a biological chelating agent (citric acid), with a synthetic and widely used chelating agent (EDTA) for the phytoextraction of Cu and Zn from slightly contaminated sediments.

Vermicompost is the end-product of the metabolism of organic matter by some species of earthworms (*Eisenia foetida* Savigny). Humic substances from vermicomposting (HS) have already been studied for agronomic purposes (Benitez et al. 2005; Arancon et al. 2006). To the best of our knowledge, the use of HS extracted from vermicomposting as chelators for phytoextraction application, could be considered an innovation in this field.

HS are persistent polymeric compounds with a complex chemical structure. This structural heterogeneity and complexity led us to suppose that it had a strong capacity of metal complexation and ion sequestration from a substrate. Tipping's book (2002) focuses on the important binding properties of these compounds which regulate the chemical reactivity and bioavailability of hydrogen and metal ions in the natural environment. Furthermore, their use as chelating agents poses no environmental risk, since they are constitutive organic compounds in soil.

Since the first step in the phytoextraction process is represented by solubilisation of metals (then followed by uptake into the roots and transport to the shoots), in our work particular attention was devoted to study of the extraction kinetics with different chelators.

In addition, the function of *Paspalum vaginatum* sp. in phytoextraction applied to marine sediments was globally evaluated. Some studies have shown that *Paspalum vaginatum* sp. has high metal tolerance and is useful in the revegetation of metal contaminated lands (Shu et al. 2002). It has also been reported to be very effective in up taking sodium (Na) from soil or sediments, thereby reducing salinity and making the medium more amenable to diversified plants and microbes present in the rhizosphere (Hue et al. 2002).

2 Materials and Methods

2.1 Sediment Characterization

Samples of polluted marine sediments were dredged from the port of Livorno (Central Italy). These sediments were structured by mixing with 20% weight of uncontaminated soil prepared from building excavation material. The main sediment characteristics and the preliminary feasibility experiments were described by Iannelli et al. (2006). Main chemical and physical properties of the resulting mixture are reported in Table 1.

Electrical conductivity (EC) and pH were measured in 1/10 (*w/v*) aqueous solution. Particle size distribution ($<700\ \mu\text{m}$) was performed using the laser light diffraction device X100 (Microtrac Inc., U.S.A.). The analysis was carried out on wet samples treated with sodium hexametaphosphate (5%) to prevent grain coagulation. The organic carbon (C_{org}) was determined by oxidation using a RC-412 MULTI-PHASE CARBON (Leco, U.S.A.), total nitrogen (N_{tot}) was determined by flash combustion using a FP-528 PROTEIN/NITROGEN DETERMINATOR (Leco, U.S.A.) and total phosphorus by using the method reported by Olsen and Sommers (1982), which is based on chemical digestion with the spectrophotometrical detection of the product (P as phosphate) at 720 nm. The total heavy metals and the exchangeable heavy metals (solubilised with Diethylene triamine pentaacetic acid (DTPA) 0.005 M and $\text{CH}_3\text{COONH}_4$ 1 M, pH 6.4; SISS 2000) were determined by means of a Flame Atomic Absorption Spectrometer (Perkin-Elmer 3030).

2.2 Extraction Kinetics with Chelators

Three different chelators were tested in two different concentrations each, starting from dosages found in the literature (Luo et al. 2006; Meers et al. 2005): EDTA at 120 and 480 mg/l (corresponding to 5 and 13 mmol kg^{-1} soil), citric acid (CA) at 500 and 2,000 mg/l (corresponding to 26 and 104 mmol kg^{-1} soil) and humic substances (HS) at 500 and 1,000 mg/l.

HS were extracted from vermicompost (lignocellulose waste mixed with municipal biosolids), to obtain an active biochemical carbon fraction bound to the extracellular enzymes of the soil (Masciandaro et al. 1997). The vermicompost was dried and pounded. Afterwards it was put in a 1.5 l polyethylene bottle with a neutral sodium pyrophosphate extracting solution ($\text{Na-PP}_i/\text{H}_3\text{PO}_4$) 0.1 M, pH 7, at 1:4 *w/v*. Then the bottle was shaken in a thermostatic bath (Doubnoff) at 37°C for 24 h. At the end of the incubation, the extract was transferred into plastic tubes and centrifuged at 9,000 rpm for 15 min. The supernatant was filtered using a 2.5 μm filter paper (Whatman No. 42). The extract was then dialyzed through specific dialysis tubes (CelluSep T1, MWCO 3500 Dalton), in order to eliminate the salts in the sample (such as the sodium pyrophosphate) and obtain a purified sample. The carbon content in the humic substances was determined using potassium dichromate in the presence of sulphuric acid digestion. The amount of HS expressed as humic-carbon in the extract was determined using a spectrophotometer at a wavelength of 590 nm. Some HS characteristics are reported in Table 1. Using plastic tubes, 2 g of dried and pound sample and 20 ml of each different solution of chelating agents (corre-

Table 1 Physicochemical parameters of the mixture and HS used

Parameters	Mixture (sediment: soil as 5:1 <i>w/w</i>)	Humic substances (HS)
pH	9	7.2
EC (dS m^{-1})	3	1.8
Clay (%)	13	—
Silt (%)	68	—
Sand (%)	19	—
N_{tot} (%)	0.2	—
P_{tot} (%)	0.04	—
C_{org} (%)	3.8	—
Humic-carbon (mg/l)	—	1,800
Organic matter (%)	6.5	—
Cu (mg kg^{-1})	84	3.6
Zn (mg kg^{-1})	140	14.2

sponding to 13 and 3 mmol kg⁻¹ soil for EDTA, and 104 and 26 mmol kg⁻¹ for CA), were shaken for 1/2, 1, 2, 4, 7, 9, 11, 14 days at room temperature (25°C). Then the samples were centrifuged for 15 minutes. The supernatant was filtered using a 2.5 µm filter paper (Whatman No. 42) and transferred into a polyethylene jar. The determination of the extracted metals in the chelated solution was performed through atomic adsorption. Acidified (HNO₃ and HClO₄) water (MilliQ Academic A10 (Millipore)), without sample, was used as blank.

2.3 Phytotoxicity Test

In order to evaluate the phytotoxicity of chelated solutions on seed germination, the Germination Index (GI) was calculated for each chelating agent and concentration, at 1, 7 and 14 days after treatment, following Zucconi's procedure (Zucconi et al. 1981). Twenty seeds of *Lepidium sativum* sp. were put in a Petri dish submerged by the 2 ml solution of chelating agent, kept at room temperature and in the dark for 72 h. Water was used as the control thesis. GI was calculated as $G \cdot L_m / L_c$, where G represents the number of germinated seeds in each thesis versus the control thesis, L_m is the average of root lengths in each thesis and L_c is the average of root lengths in the control thesis.

2.4 Determination of Heavy Metal Speciation Forms

A three-step sequential extraction procedure was used to determine the concentration of heavy metal speciation forms in the mixture (Möcko and Waclawek 2004; Rauret et al. 1998). The heavy metals taken into consideration were Zn and Cu. The three-step sequential extraction procedure was carried out step-by-step:

Step I – 40 cm³ of 0.11 mol dm⁻³ CH₃COOH per 1 g of dry sediment sample was shaken overnight on mechanical shaker at temperature of 25°C (released of the exchangeable, water- and acid- soluble fraction); Step II – 40 cm³ of 0.1 mol dm⁻³ NH₂OH.HCl (adjusted to pH=2 with HNO₃) was added to residue and extracted overnight at 25°C (released of the reducible species); Step III – 10 cm³ of 8.8 mol dm⁻³ H₂O₂ was added to residue and digested first for 1 h at 25°C, and then for 1 h at 85°C in a water bath with a second volume of hydrogen peroxide. After cooling, the residue was extracted overnight with 50 cm³ of

1.0 mol dm⁻³ CH₃COONH₄ (adjusted to pH=2 with HNO₃), at a temperature of 25°C (released of the oxidisable species).

The first fraction (acid-soluble) is the most mobile and potentially toxic fraction for plants. This group of elements is bound in a sorption complex and strictly associated with carbonates. The second fraction includes metals adsorbed and occluded in Mn–Fe oxides. The third fraction is correlated with the sediment organic matter. Metals are incorporated into the stable high molecular weight organic substances, which release small amounts of heavy metals slowly. The last fraction (residual and non-extractable) is formed by heavy metals retained within the crystal lattice of minerals and in well-crystallised oxides.

To determine the binding forms of heavy metals in soil, chemical extraction procedures were designed, referring to the three-stage sequential protocol (Standards, Measurements and Testing Programme of the Commission of European Communities – BCR; Quevauviller et al. 1999).

2.5 Plant Analysis

Samples of 140 g of dry mixture each (sediment: soil as 5:1 w/w, 350 g of fresh weight, relative humidity $H=60\%$) were placed in plastic pots (12 cm i.d.×12 cm height) and 20 g of green compost was applied to the pots' surface as the plants' substrate of growth. The moisture was maintained at near field water capacity by adding deionised water on a daily basis for 30 days. Two plants of *Paspalum vaginatum* sp. were planted in each pot. The treatments were: **CA** (concentration of 500 mg/l, 20 ml per pot, in triplicate); **HS** (concentration of 500 and 1,000 mg/l, 20 ml per pot, in triplicate); **EDTA** (concentration of 120 mg/l, 20 ml per pot, in triplicate); water (as control, in triplicate). Chelators were applied with a syringe to the surface in a singular application, after two weeks from the plantation, instead of the daily water supply. All experiments were conducted in the laboratory under natural light. The experimentation was carried out for 14 days. The shoots and the roots were analysed for heavy metals detection after they were washed with tap water and rinsed with deionised water, then dried at 70°C.

Samples (200 mg) of shoot and root dry matter were digested using a solution of HNO₃ and HClO₄ (5:1 volume ratio) and the heavy metals were determined by atomic adsorption.

To consider the heavy metal translocation from roots to shoots of *P. vaginatum*, a shoot-to-root quotient was calculated as a ratio of metal concentrations in the two parts, after two weeks of treatment.

2.6 Statistical Analysis

Statistical analyses of the experimental data were performed using the STATISTICA 6.0 (StatSoft, Italia) software package. All reported results are the means of three replicates. Two-factors analysis of variance (factorial ANOVA) was used to check the statistical significance of observed data differences. The significant levels reported ($p < 0.05$) are based on Student's distribution. The means were compared by using least significant difference values calculated at $p < 0.05$ (Tukey's test, HSD procedure).

3 Results and Discussion

3.1 Effects of Chelators on Metal Solubilisation and on Phyto-toxicity

Extraction kinetics of Cu and Zn are shown in Fig. 1. Significant results were found using EDTA (120–480 mg/l) both for Cu and Zn. HS 1,000 mg/l also led to satisfactory results for Cu. Slight effects of HS 500 mg/l were recorded for Cu and of HS 1000 mg/l for Zn. A slight effect of CA was reported only for the highest concentration (2,000 mg/l) for Cu, while the other CA concentration did not significantly differ from the control.

The extraction efficiency was positively related to concentration of chelating agents. In fact, at the end of the experiment, the highest yields of extraction were found for EDTA 480 mg/l (extraction of 58% Cu and 50% Zn), HS 1000 mg/l (extraction of 32% Cu and 5% Zn) and CA 2000 mg/l (extraction of 32% Cu).

The dynamics of solubilisation greatly differed according to the chelators: HS were able to solubilise heavy metals at the maximum level only 1 day after treatment; while solubilisation by EDTA continued to increase with time, without reaching the plateau, after 14 days of experimentation. It can be deduced that more metal could be mobilised by prolonging the exposure time of treatment (more than 14 days), with an EDTA treatment. Data reported in Meers et al. (2005), showed that an exposure time of 40 days

could be considered sufficient to reach the plateau. HS potential efficiency of heavy metal mobilisation could change according to the properties of the substrate from which the vermicompost is obtained (Vaughan and MacDonald 1976; Burns et al. 1986; Ceccanti et al. 1996).

The use of CA (500 mg/l) and EDTA (120–480 mg/l) showed a germination index (GI) between 40–60% (Fig. 1). This means a toxicity level that could significantly affect plant germination (Barbero et al. 2005). On the contrary, in the plant experiments (Section 3.3), no treatments negatively affected the dry mass yield of *P. vaginatum* and this is probably due to the buffer effect of the mixture and to the strong resistance of the *Paspalum* species. The application of higher concentrations of CA (2000 mg/l) indicated a high toxicity level for germination (GI < 40%). The highest GI (120–140%) was for HS (500–1,000 mg/l), as already found in other studies (Dixit and Kishore 1967; Burns et al. 1986). Referring to each treatment, the same GI values found for each extraction time ($p > 0.05$) indicated that the presence of Cu and Zn did not influence seed germination.

3.2 Heavy Metal Speciation in the Sediment

The four different fractions of Cu and Zn present in the sediment are shown in Fig. 2. The data obtained showed that Zn was predominant in the exchangeable and reducible fraction (39% and 23%), while Cu was predominant in the fraction bound to organic matter (77%). The residual fraction did not exceed 10% of the total content for both examined metals. Comparing these results with the extraction kinetics (Section 3.1), it appeared that the whole exchangeable fraction of Cu and the whole fraction bound to reducible species (e.g. Fe–Mn hydroxides) were completely mobilised with EDTA 480 mg/l and HS 1000 mg/l. As regards Zn distribution, the water- and acid-soluble fraction was completely mobilised only using EDTA (120 and 480 mg/l), while HS 1,000 mg/l was able to remove only a fifth part of it (8% of mobilisation). CA overall performance was considered unsatisfactory.

3.3 Effects of Chelators on *Paspalum vaginatum* sp. Growth, Metal Distribution and Phytoextraction

The dry mass yields of *P. vaginatum* are shown in Fig. 3. Statistically there were no differences between

Fig. 1 Effects of the application of chelators (CA 500–2,000 mg/l, EDTA 120–480 mg/l and HS 500–1,000 mg/l) on metal mobilisation and on seed germination. pH=7–8 for each concentration. Values are means \pm SD ($n=3$)

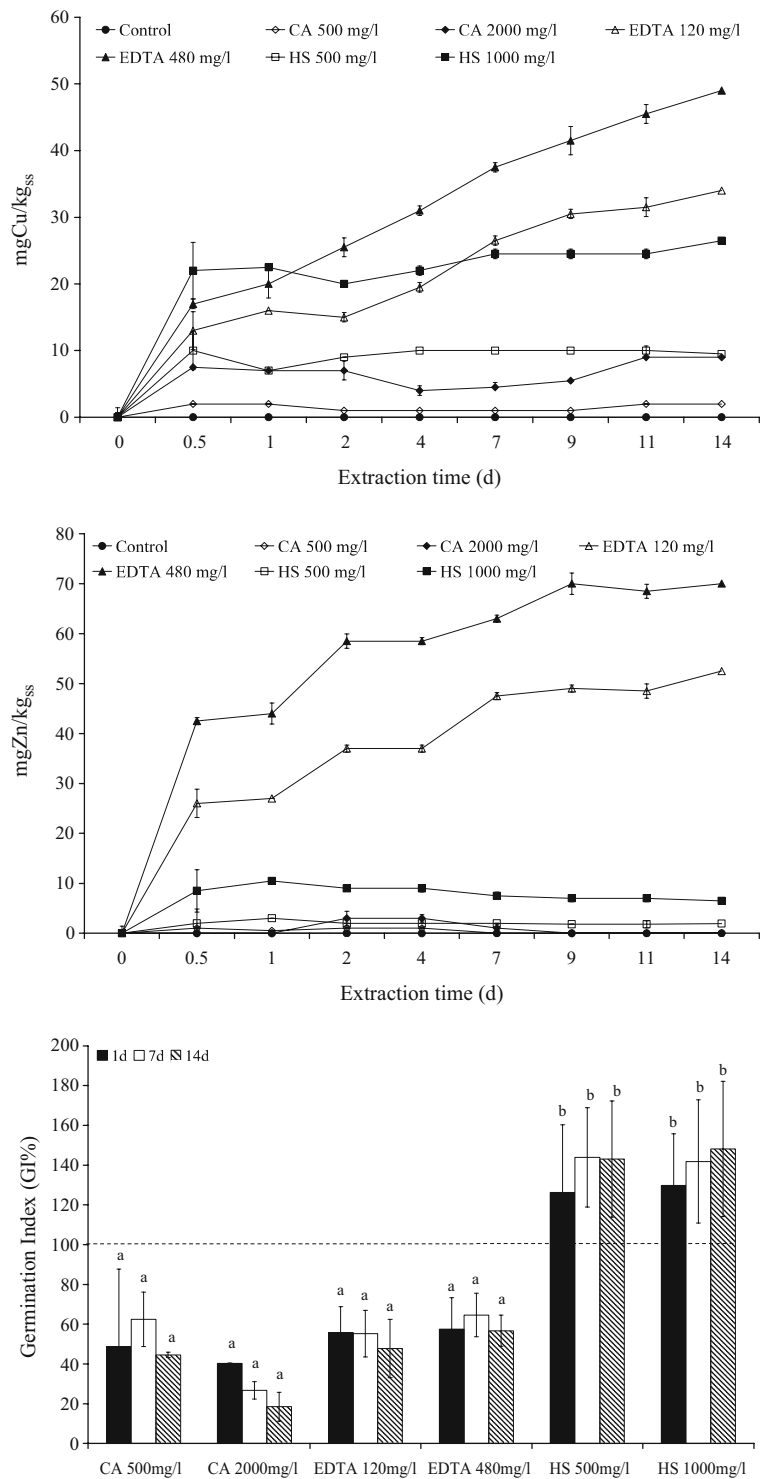
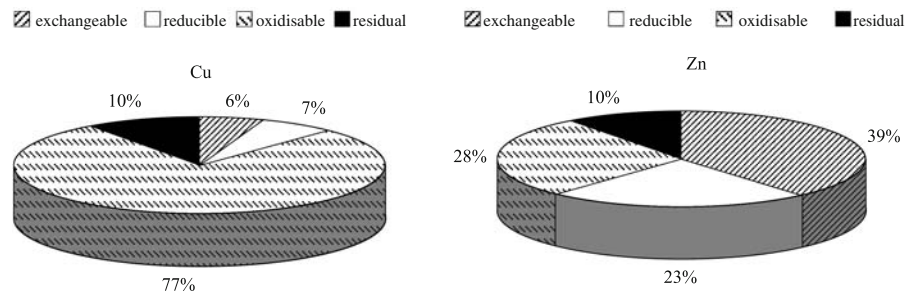


Fig. 2 Heavy metal (Cu and Zn) speciation

tested theses. However, some tendencies could be highlighted for shoot dry mass.

Treatments with HS (500–1,000 mg/l) enhanced shoot growth. Humic substances could be considered an efficient agronomic bio-amendment. Plants with treatment of CA (500 mg/l) and EDTA (120 mg/l) showed a slight decrease in shoot biomass compared with the control ($p < 0.05$).

Observed concentrations of Cu and Zn, in shoots and roots, following the treatment with HS (500–1,000 mg/l), EDTA (120 mg/l) and CA (500 mg/l) are shown in Fig. 3. Compared with the control, the application of chelating agents did not significantly increase the concentrations of Cu and Zn either in the shoots or in the roots and there were no significant differences in the concentrations even comparing the different chelators. Exceptions have been found using EDTA 120 mg/l and HS 500 mg/l for the Cu and CA 500 mg/l for the Zn. The highest Cu concentration was found in the roots, while for the Zn there was no significant difference between root and shoot concentration ($p > 0.05$). The low level of uptake found in our experiment was probably due to the short time span between soil treatment and harvest (14 days). Longer periods may be required.

Luo et al. (2005) showed that the percentage of Cu phytoextracted by corn, using biodegradable chelators (EDDS 5 mmol/kg) was 0.6% of the total Cu in the soil. In this study, the effects of the application of chelating agent on the uptake of Cu in the shoots of *Paspalum vaginatum* sp. in the pots treated with the maximum concentration of HS (1,000 mg/l) was of one order less (0.05%). The same percentages were obtained referring to the other treatments. To justify these low values, note that the phytoextraction

technique was applied to a low level of polluted sediment, characterized by a silt–clay matrix and a high salinity level. Some changes in sediment conditions, such as pH, may effect this in a different and unknown way the chelating efficiency of chelating agents in comparison to a soil (Meers et al. 2005).

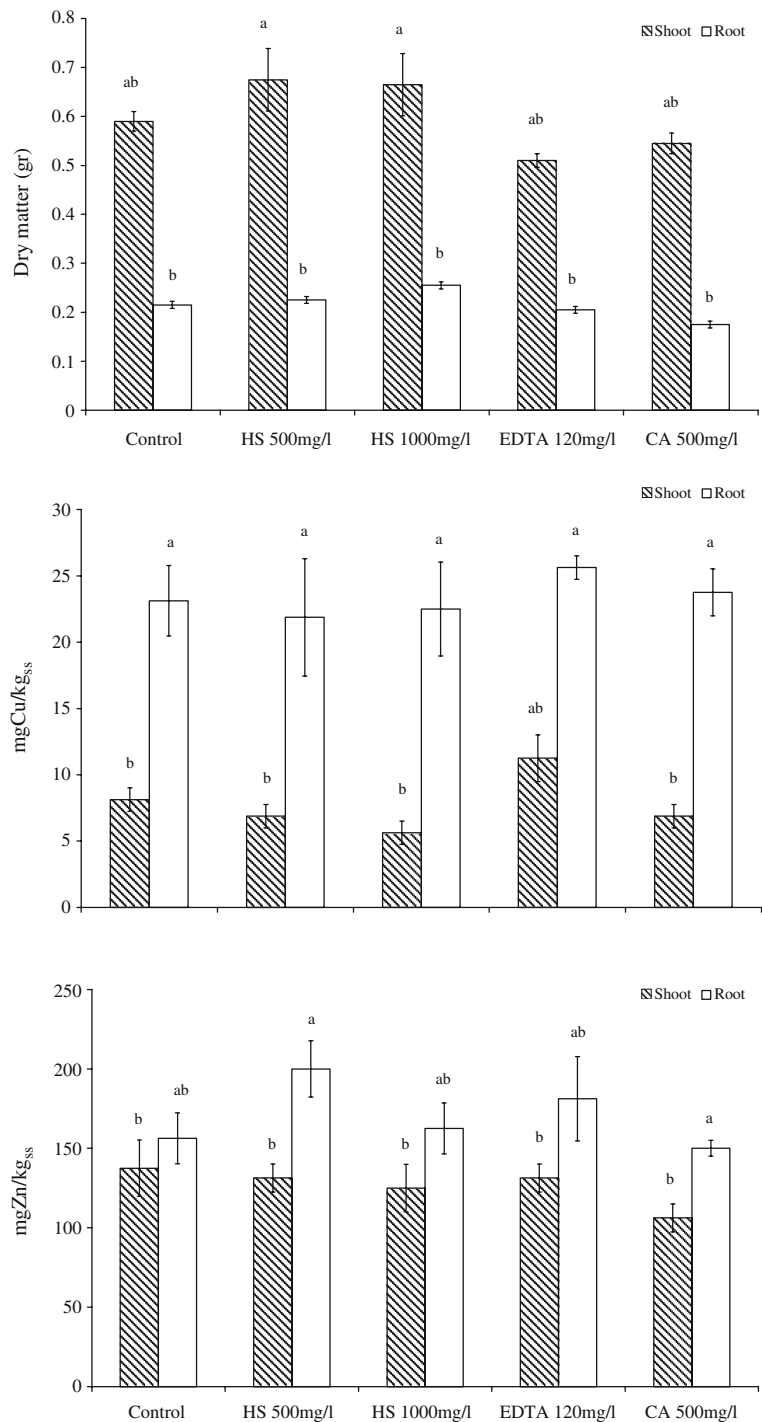
The medium concentration (considering all treatments) of Zn and Cu found in the shoots of *P. vaginatum*, was of 100–120 mg Zn/kg ss and 7–10 mg Cu/kg ss and it was practically the same found in the untreated pots. The low observed phytoextraction effect of *P. vaginatum* was probably related to the nature of the substrate (marine sediment), the presence of sodium and the levels of organic and inorganic pollutants, which could negatively interact with the plant metabolism and compromise the functionality and efficiency of plants in the enhanced phytoextraction process.

Furthermore, *P. vaginatum* sp. showed a low capacity to uptake metal into the roots and to transfer metal to the shoots, even in the pots treated with chelators. The root concentration factor (RCF, Mattina et al. 2003) was 0.05% for Cu (mean value for all the treatments) and 0.1% for Zn.

Considering the dry matter yield of the plants, the total mass of the heavy metals was in the shoots, especially for the Zn. Despite the low rates of uptake both for Cu and Zn, it seemed from our results that the leaf cells of *Paspalum* sp. were able to accumulate more Zn than Cu.

Metal distribution in the plants did not seem significantly affected by the application of chelators (Table 2). The shoot-to-root ratio of the concentrations of Zn was higher than the ratio referred to Cu. The same result was observed referring to the total

Fig. 3 Effects of the application of chelators on the dry matter yields of shoots and roots and on the concentrations of Cu and Zn in *Paspalum vaginatum* sp. Values are means \pm SD ($n=3$). Different letters indicate statistically different values at $p<0.05$



phytoextraction, both considering the total metal and the exchangeable fraction (Table 2). The extraction values obtained suggested that only the mobilised fraction of the metals was effectively absorbed by the

plants and subsequently translocated to the shoots, even if with low values.

To estimate the actually absorbed fraction of mobilised metals, the maximum mobilised mass levels ob-

Table 2 Effects of chelating agent treatments on the translocation of Cu and Zn

Parameters	Control	HS 500 mg/l	HS 1000 mg/l	EDTA 120 mg/l	CA 500 mg/l
Shoot-to-root quotient for metal concentration					
Cu	0.4±0.08 ^a	0.3±0.1 ^a	0.3±0.01 ^a	0.4±0.05 ^a	0.3±0.05 ^a
Zn	0.9±0.03 ^b	0.7±0.1 ^b	0.8±0.1 ^b	0.7±0.05 ^b	0.7±0.05 ^b
Metal absorbed by shoots/total metal in the sediment (%)					
Cu	0.05±0.03 ^c	0.04±0.08 ^c	0.04±0.02 ^c	n.r.	n.r.
Zn	0.3±0.1 ^d	0.3±0.2 ^d	0.3±0.2 ^d	0.2±0.1 ^d	n.r.
Metal absorbed by shoots/exchangeable metal fraction in the sediment (%)					
Cu	0.7±0.1 ^e	0.7±0.2 ^e	0.6±0.1 ^e	0.9±0.2 ^f	0.6±0.1 ^e
Zn	1.1±0.8 ^f	1.2±0.9 ^f	n.r.	n.r.	n.r.

Values are means±SD ($n=3$). Values with the same letter are not significantly different ($p>0.05$).

n.r. Non-representative data

served in the sediment solution experiment (Section 3.1) were compared to the mass extracted per plant in pots receiving identical doses of chelating agents. For example, in the treatment with the highest observed total metal extraction with natural chelating agents (HS 1,000 mg/l), only 7% of mobilised Cu and 0.2% of mobilised Zn were recovered in the shoots of *P. vaginatum*. Very similar results were obtained considering the highest observed total metal extraction with synthetic chelators (EDTA 120 mg/l). Only 6% of mobilised Cu and 0.7% of mobilised Zn were recovered in the shoots of the plants.

Despite the low observed phytoextraction potential denoted by our experiments, this study confirmed the previously mentioned positive features of *P. vaginatum* species for the revegetation of contaminated sediments. This is based on its well known tolerance to salinity, metal concentrations and capability of growing in poor agronomic substrate, thus contributing to their amelioration.

4 Conclusion

Enhanced phytoextraction of slightly contaminated dredged sediments from Livorno Harbour (Italy) was evaluated, using synthetic (EDTA), natural (HS) and biological (CA) chelating agents. Mobilisation of Cu and Zn was observed for EDTA 120–480 mg/l and HS 1,000 mg/l in the extraction kinetic experiments. CA performance was considered unsatisfactory.

HS performance in the mobilisation of metals from the solid matrix of the sediment represents an innovation in enhanced phytoextraction techniques,

because it could be also used as an agronomic amendment and it does not impact on the environment.

Plant experiments showed that none of the treatments significantly affected the biomass production of *Paspalum vaginatum* sp. and phytoextraction of Cu and Zn, even if different tendencies were observed for EDTA and HS treatments. These low effects might be attributed to the short duration of the experiment and/or to the poor properties of the medium in which seashore paspalum (*Paspalum vaginatum* sp.) was planted.

However, the transplantation of seashore paspalum could be useful as a pre-treatment of contaminated dredged sediments (previously mixed with a soil rich in nutrients and organic matter for the physical-chemical amelioration), since it was confirmed to be a salt-tolerant species and to make the medium more amenable to diversified microbes and other plants.

Finally, even if the results of the pot study were not particularly encouraging, the combination of *P. vaginatum*, microorganisms in the rhizosphere and organic substances, seems to be a viable option to promote a chemical-physical and nutritional amelioration of this poor growth medium, particularly feasible for the land agronomic reuse of marine dredged sediments.

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