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Research article

Use of phytoremediated sediments dredged in maritime port as plant nursery growing media

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ABSTRACT

We evaluated the potential of a phytoremediated sediment (TR) dredged from maritime port as peat-free growth substrate for seven ornamental plants, in comparison with an untreated sediment (NT), in a greenhouse experiment. The studied plants were *Quercus ilex, Photinia x fraseri, Viburnum tinus, Cistus albidus, Raphiolepis indica, Westringia fruticosa* and *Teucrium fruticans*. Plant growth was monitored for ten months, and the changes in the physico-chemical properties, toxicity, microbial biomass and enzyme activities involved in the C, P and N cycles were also monitored during the plant growth period. The results showed that the studied ornamental plants could grow on both NT and TR sediments, but that the growth was higher on TR sediment. The plant growth induced changes in the sediment chemical functional groups, with clear separation between NT and TR sediments for each of the studied plant. Microbial biomass and enzyme activities significantly increased during the plant growth, more in TR than in NT sediment. Toxicity was detected in NT sediments during the plant growth whereas it was not observed in NT sediments during the whole growth period. We concluded that phytoremediation converted the dredged maritime sediments into suitable substrates for growing ornamental plants, and that the re-use by plant nursery industry can be a sustainable management and valorization for remediated sediments.

1. Introduction

Large amounts of sediments are dredged worldwide from the water bodies for keeping adequate navigation depth of harbors and waterways, and guarantee the flow capacity of rivers to prevent floods. Sediments from maritime ports are frequently contaminated by heavy metals (e.g. As, Cd, Cu, Ni, Pb, Zn) and hydrocarbons (Masciandaro et al., 2014) released by ship maintenance operations, and therefore sediment dredging is also an option to reduce the environmental risks associated to sediment contamination. Italy has a relatively high coast-to-inner land ratio, and it was estimated that about 5 M m^3 of marine sediments are dredged every year in Italy (Bortone, 2007), with limited possibilities of sea disposal due to contamination; sediment contamination also make difficult their inshore management and landfilling. Dredged sediments in Italy are classified on the base of the total concentration of heavy metals and organic pollutants, using A and B action levels for urban and industrial soils, respectively (Dlgs 152/2006, part IV, annexes D and 5). Dredged sediment can be flown back to sea or re-used when all contaminant concentrations are below the A action values, whereas for sediments with concentrations of contaminants above the action levels sediments are considered hazardous wastes and must be treated and landfilled. Although several international conventions (e.g. Oslo, 1972; London, 1972; Paris, 1974; OSPAR, 1992; Barcelona, 1995) have increasingly suggested to recycle and reuse dredged sediments, these materials often present physical and chemical properties that make them unsuitable for industrial processes (e.g. brick and cement production), and therefore dredged sediment are still underutilized and mainly stockpiled nearby the dredging areas or undergo to disposal in confined facilities.

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The plant nursery production in Europe has represented an important agricultural sector, with a gross production stable in the last years around 20 billion euros (ISMEA, 2012). Production of ornamental plants has a strong environmental impact mainly due to the large use of peat and other non renewable materials (e.g pumice) as plant substrates for container production (Lazzerini et al., 2014). In 2005 it was estimated that the plant substrates use in the EU exceeded 34 million m^3 per year, with peat representing 77.4% (26.8 million m^3) of all substrates constituents (Cattivello, 2009). Italy uses about $1.0 \cdot 10^6$ m^3 of raw peat every year, ranking in the first 5 European Countries for professional use of peat (Schmilewski, 2009). Peat for EU plant producers is mainly obtained by Baltic Countries, and although the intense exploitation of peatlands will unlikely cause an exhaustion of peat bogs, there are problems of decreasing peat quality and increasing production costs (Rea, 2005). Overall, the use of peat for growing plants is seen as no longer sustainable from both the environmental and economical point of view (Gruda, 2012; Lazzerini et al., 2016), and the question concerning a replacement for peat as a growing substrate has become increasingly important. Hence there is a pressing need to reduce or phase out peat from plant nursery production. Several amendments for plant growth media, including compost, coconut fibers have been proposed for reducing the use of peat, with variable results in terms of plant quality production (Logan and Lindsay, 1996; Abad et al., 2001; Noguera et al., 2003; Chong and Purvis, 2004; De Lucia et al., 2013). However, such materials are not always locally available, have a large variability in their physico-chemical properties and also contain plant pathogens (Landis and Morgan, 2009). It has been reported that bioenergy woody plants can be grown on dredged sediments, although variable results have been reported for plants grown on (Vervaeke et al., 2003; Hartley et al., 2011). Phytoremediation, i.e. the use of plants and associated microorganisms for restoring contaminated soils, can improve the sediment structure, and increase their nutrient content and phytoavailability (Masciandaro et al., 2014), mainly by sustaining a higher microbial biomass and activity through the release of root exudates and improving water retention (Walker et al., 2003; Renella et al., 2007). Phytoremediation, has proven to be an ecologically and economically sustainable management option for remediating dredged marine sediments (Bert et al., 2009), and it has been also shown that it leads to degradation of organic pollutants and chemical stabilization of heavy metals in dredged sediments (Doni et al., 2015).

Changes in the properties and quality of the inorganic and organic solid phases of sediments can be studied by both wet chemistry, based on soil and sediment extractions, or by mid-infrared spectroscopy coupled to multivariate analysis. The latter approach can provide an assessment of the main molecular functional groups related to chemical and physical properties and fertility of sediments (D'Acqui et al., 2010). We hypothesized that dredged marine sediments could be used as constituents of peat-free substrates for growing ornamental plants, particularly if preliminarily treated by phytoremediation to improve their physical, chemical and biological properties. We tested our hypothesis using a maritime port sediment, with pollutants concentrations exceeding the mandatory limits for their use in urban environment, which was phytoremediated and then reused to grow ornamental plants with different physiological requirements and aesthetical value. We determined the main sediment physico-chemical modifications induced by the plant growth, sediment toxicity, and microbial biomass and enzymatic activities as indicators of microbial functionality in both phytoremediated and non remediated sediments.

2. Materials and methods

2.1. Sediment properties, experimental design and growth conditions

The used sediments were obtained from the confined facility of the port of Livorno (Central Italy, 43_3302500 N, 10_1703900 E), containing sediments dredged in the period 2008–2009. Sediments were leached to reduce the initial salinity level and mixed with a 30% (w/w) of a sandy soil to reduce the initial high density. Briefly, the sediment phytoremediation was carried out in a facility designed to treat 80 m^3 of contaminated sediments. In May 2010 the sediments were phytoremediated using various plants and plant associations as described by Masciandaro et al. (2014) and for our experiments we used untreated sediments (NT) and sediment phytoremediated with *Paspalum vaginatum* (TR). After 17 month of phytoremediation the TR and NT sediments presented relatively low concentrations (mg kg^{-1}) of Cd (TR 1.24, NT 1.50), Cu (TR 53.8, NT 61.8), Cr (TR 45.1, NT 47.8), Ni (TR 65.1, NT 68.2), Pb (TR 56.1, NT 58.7), and relatively high concentrations of Zn (TR 267, NT 298). The total petroleum hydrocarbons (TPH) were present in high concentrations in both the TR (647 mg kg^{-1}) and NT (893 mg kg^{-1}) sediments. In October 2011, sediments remediated with *Paspalum vaginatum* (TR) and untreated sediments (NT) were used as substrates for growing one-year-old vegetatively propagated plants, chosen for their high added value on the local market: six evergreen shrubs (*Photinia* x *fraseri*, *Viburnum tinus*, *Cistus albidus*, *Raphiolepis indica*, *Westringia fruticosa*, *Teucrium fruticans*), and one evergreen oak species (*Quercus ilex*). The plant growth was carried out for 10 months at the Experimental Nursery Plants Center (Ce.Spe.Vi.) located in Pistoia (Tuscany, Central Italy). Hundred kg of TR and NT sediments were manually homogenized, and in November 2011 small plantlets were transplanted into 2-L pots, in 3 replicates for each species and each sediment type. Plants were manually watered for the whole growing period, and 4.5 g per plant controlled release fertilizer (Osmocote, Everris), corresponding to 0.7 g of N was supplemented to all plants at the end of February 2012, the beginning of the plant vegetative season, according to the manufacturer instructions. No further nursery care operations (e.g. pruning, pest control) were applied to prevent their potential confounding effects on the performance of the TR and NT sediments. Plant growth in terms of elongation rate were regularly checked between November 2011 and July 2012, whereas plant dry weight was determined at the end of the experiment by the difference between the plant fresh weight and after plant drying to a constant weight at 60 °C in a forced-air oven.

2.2. Sediments physico-chemical analysis

The sediment texture was determined by Bouyoucos hydrometer method (Gee and Bauder, 1986), and the initial texture of the NT sediment was 33% sand, 47% silt and 20% clay, whereas that of the TR sediment was 36% sand, 47% silt, and 17% clay. Total organic C and N in sediments were determined by dry combustion using a NA 1500 CHNS Analyzer (Carlo Erba, Milan, Italy). Inorganic C (IC) was determined as carbonate to Santi et al. (2006). The sediment pH value was measured in 1:2.5 (w:v) aqueous suspensions by pH-meter (GLP 22 CRISON, Spain), after 30 min shacking followed by 5 min settling, and the electrical conductivity (EC) was measured by a conductivity meter (COND400 Eutech Instruments, USA) on the same extracts.

Changes induced in main TR and NT sediments chemical properties after 6 and 10 months of plant growth was assessed by mid-infrared Diffuse Reflectance Infrared Fourier Transform (DRIFT) spectroscopy in combination with partial least-squares (PLS)