Highlights

► Phytoremediated marine were used as peat-free growing media for growing red robin photinia plants

► Plants grown on sediments were compared with those grown on common peat-based growing media

► Environmental impact related to the use of sediments- common peat-based growing were compared by LCA

► Plants grown on fertilized sediments were comparable to those grown on peat-based growing media

► The LCA showed a lower C footprint of plants grown on sediment- than peat-based growing media

Phytoremediated marine sediments as suitable peat-free growing media for production of Red Robin photinia (*Photinia x fraseri*)

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Abstract

Phytoremediated marine sediments were used as peat-free growing media for the red robin photinia (*Photinia* x *fraseri* L.). Plants were grown on growing media containing sediment only (S), sediment mixed with composted pruning residues (S+PR), sediment fertilized with controlled release fertilizers (S+F) and traditional peat-based growing media, considered as control treatment (C). Plant elongation, plant dry weight, leaf chlorophyll, concentration of malondialdehyde (MDA), macronutrients and heavy metals were determined at the end of one growing season. The environmental impact related to the use of phytoremediated sediment-based as compared to peat-based growing media was evaluated by the Life Cycle Analysis (LCA). The sediment-based growing media presented significantly higher bulk density, pH and electrical conductivity values, lower C and N contents, and significantly higher total and available P. The red robin photinia grown on S+F growing media showed morphological and chemical parameters similar to those of control plants (C), whereas plants grown on S and S+PR showed lower growth. Leaf concentration of nutrients and heavy metals varied depending on the considered element and growing media, but were all within the common values for ornamental plants, whereas the highest MDA concentrations were found in leaves grown on peat-based growing media. The LCA indicated the use of sediments as growing media could reduce the C footprint of ornamental plant production and the relative contribute of growing media to the environmental impact per produced plant. We concluded that sediments phytoremediation and use in plant nursery is a practical alternative re-use option for dredged sediments.

Keywords: Dredged sediments; Phytoremediation; Ornamental Plant; Peat; LCA; Sustainable plant production

Introduction

High grade ornamental plant production in containers requires growing media that generally contain peat and palm fiber and coir pith, mixed with pumice or perlite to improve porosity and stability, and fertilized to reach adequate levels of nutrients. It was estimated that in the European Union (EU) about 40 million m^3 of growing media are produced every year (Altmann et al., 2008), and peat is currently still the prime raw material for professional growing media (Schmilewski 2009; Ceglie et al., 2015). Palm coir fiber and pith are by-products of the coconut processing that are increasingly used as ingredients of growing media thank to its suitable pH value (between 5 and 7), good physical stability and water retention properties, and is widely avaialble on the market. In recent years increasing conflicts of peat extraction and use with EU environmental Directives such as Environmental Impact Assessment Directive (92/43/EC), Habitats Directive (Natura 2000), Birds Directive (Directive 2009/147/EC), are emerging. This urge the plant nursery sector to search for alternative peat-free growing media and soil improvers. Also pumice and perlite, other key ingredient of peat-based growing media, are non-renewable resource and high impact materials, respectively, and their use must be progressively reduced in the future. Palm coir fiber- and pith-based growing media also have high environmental impact related to high initial salinity and transportation, as it is produced mainly along the South-East India and Sri-Lanka coasts, and requires long shipment distances for EU producers.

Regardless of the large research efforts to reduce peat in growing media (e.g. Abad et al., 2001; Garcia Gomez et al., 2002), by replacing them with various plant residues and organic wastes (Garcia Gomez et al., 2002; Hernandez Apaolaza et al., 2005), the materials tested so far have shown limited potentials mainly due to variability of the original materials, adverse physico-chemical properties and sanitary problems, particularly in the use of composted biosolids (Abad et al., 2001; De Lucia et al., 2013).

Sediments from the coastal, riverine and lacustrine environments of developed Countries are regularly dredged to guarantee the free navigation and docking activities, to prevent flooding events, and control water contamination caused by the release of pollutant accumulated into bottom sediments. Management of dredged sediments is a major environmental issue in worldwide, as they are generally considered as waste materials, although the major international Conventions (e.g. Barcelona Convention, 1995) have suggested to reuse the dredged sediments to the maximum extent. The amount of dredged sediments in Western Europe is in the order of 250 million tonnes per year, 200 million tonnes of sea origin and 50 million tonnes from inland water bodies. In Europe, currently none of the EU environmental Directives deal specifically with dredged material, but three main Directives have a direct or indirect impact on sediment management (Figure 1): the Water Framework Directive (2000/60/EC), the Waste Framework Directive (75/442/EEC, 91/156/EEC), and the Habitat Directive (92/43/EEC). The recent changes in the EU and national legislation on sediment management, have progressively supported the re-use of unpolluted or remediation and re-use of dredged sediments. In fact, Europe must face large-scale remediation of sediments in many river basins impacted by historical contamination, and there is growing concern to fulfill the European Water Framework Directive (SedNet, 2003).

Ornamental plant production is among the most remunerative agricultural sectors, with an estimate annual gross production in the EU of ca. 20 millions of Euros, and a slightly increasing demand in the last 20 years (European Commission, 2015). Most ornamental plants are produced in containers, and demand for growing media will also likely increase in the future. Therefore, the use of alternative peat-free growing media, constituted by locally available low impact materials, is an interesting option to prevent limitations and losses of value for the production of ornamental plants. In a previous study, we showed that phytoremediation could be a technique for reclaiming dredged marine sediments and allow them for a safe use as growing media for several ornamental plants (Mattei et al., 2017). We hypothesized that phytoremediated sediments could be optimized to allow the production of ornamental plants of comparable grade as plants grown on traditional peat-based growing media, and reduce the environmental impact of plant nursery production. We tested our hypothesis growing ‘Red Robin’ photinia plants (*Photinia* x *Fraseri*), a plant of prime interest for the Italian ornamental plant market, on either phytoremediated sediments or traditional peat-based growing media. The environmental impact of the photinia production on sediment- or peat-based growing media was evaluated by the Life Cycle Analysis (LCA). The LCA is a widely accepted procedure for assessing the impact of productive process involving various activities, and is considered a key decision support tool, increasingly used for assessing the environmental performances of products throughout their whole life cycle, identifying differences among different systems in terms of resource consumption and environmental impacts (Cellura et al., 2012). Recent applications of the LCA to the plant nursery sector has allowed to assess the relatively high impact of peat-based growing media on the production process of ornamental plants (Lazzerini et al., 2016).

Materials and methods

2.1. Sediment properties and experimental set up

The used dredged sediments were phytoremediated in a confined facility of the port of Livorno (Central Italy, 43_3302500 N, 10_1703900 E), as described by Masciandaro et al. (2014). The phytoremediated sediments presented relatively low residual concentrations of heavy metals and total petroleum hydrocarbons (Table 1).

In March 2012, 100 kg of remediated sediments were transported to the Center for Experimental Plants Nursery (Ce.Spe.Vi.) in Pistoia (Tuscany, Central Italy), manually homogenized, and used for growing one-year-old vegetatively propagated plants of the evergreen shrub red robin photinia (*Photinia* x *fraseri*). Plantlets were transplanted into 2-L pots containing remediated sediment only (S), remediated sediment and composted pruning residues (S+PR) mixed at 1:1 v:v, remediated sediment added with a controlled release fertilizer (S+F) (Osmocote, Everris) at rate of 4.5 g per plant (corresponding to 0.7 g of N), or peat and pumice mixture mixed at 1:1 fertilized with Osmocote at the same rate as above, representing the control treatment (C). Plants were manually watered and nursery managed for the whole growth period. On September 2012, the plants were transplanted into 2l pots, 8 replicates for each type of substrate. Therefore, the experimental set-up shared a total of 32 plants, arranged in a completely randomized design, and was The experiment was carried out in the Center for Experimental Nursery (CeSpeVi), Pistoia (Tuscany). From September until the end of October 2012, the plants grew in plain-air, irrigated twice per day for 20 minutes by a sprinkler irrigation system. At the end of October 2012, all plants were transferred into not-heated glass greenhouse, where they were manually watered until March 2013.

2.2. Sediments physico-chemical properties

Sediment texture of 39% sand, 45% silt, and 16% 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 pHmeter (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.

2.3 Measurement of plant growth and stress, chlorophyll content and element concentration

Plant growth parameters were determined at the beginning and at the end of the growth period. Plant biomass was determined at the end of the experiment by the difference between the plants fresh weight and weight of plants after drying at 60°C. Chlorophyll A and B concentration was quantified analyzing 2 leaves from each plant per substrate type according to (Jeffrey e Humphrey, 1975). Leaves were manually grinded in a mortar in the presence of 10 ml of 90% acetone, and the extract was collected in polypropilene tubes and stored in the fridge for 24 h. Afterward, the extracts were centrifuged for 5 min a 4000 x *g* and 1ml of supernatant was analyzed using a spectrophotometer (Lambda 35 PerkinElmer) at 664 and 647 nm (Taiti et al., 2016). Absorbance at and 750 nm was also measured to correct the values for eventual turbidity. Absorbance values were used for quantification of chlorophyll A and B, respectively, according to (Jeffrey e Humphrey, 1975). Concentration of malondialdheyde (MDA) was determined by the reaction with 2-thiobarbituric acid (TBA), and the concentration of the MDA-TBA was measured by spectrophotometry at 532 nm (Pignattelli et al., 2012).

Concentration of Cd, Cr, Cu, Ni, Pb, Zn, Mg and Ca in plants were determined on 8 leaves for each plant and type og growing media. Leaves were dried and milled, and 100 mg were transferred in 25 ml becker for mineralization with 65% HNO_3 and 60% $HClO_4$, and subjected to temperature increase from 100 to 300°C. After mineralization, all extracts were diluted to 10 ml with deionized water and elemental concentrations were quantified by atomic absorption spectrophotometry (AAnalyst 200, PerkinElmer).

2.4 LCA analysis

The system boundary was defined by the carbon footprint emissions associated with the production of photinia plants using a ‘cradle to farm-gate’ approach (Shine et al., 2005). The system included emissions associated with the following processes: phytoremediation and transport of marine sediments (1), production and transportation of plastic and peat yearly used (2), production and application of fertilizers (3), production of crop protection chemicals (4), electricity and fuel used for nursery operations such as fertilizer application, irrigation, plants transport within the nursery) (5). The complete system diagram of an LCA analysis of sediment is reported in Figure 1. The LCA was mainly focused on the impact of the materials used for the growing media. Impact associated to the farm infrastructure (e.g. buildings, greenhouses, irrigation and fertigation systems) and to sediment dredging were not considered, because the plants were all grown in the same farm and the sediment dredging was conducted independently from it subsequent use of as growing media. The Global Warming Potential (GWP) expressed as kg of CO_2 equivalents (kg CO_2 eq.) was used as impact category, defined as the cumulative radiative forcing effect between the present moment and a selected time interval caused by a unit mass of gas emitted in the present time. The Kg CO_2 eq. values were calculated per m^3 of growing media and per produced plant using the GaBi software (PE-International, http://www.gabi-software.com/), supported by the Ecoinvent 3.3 database.

2.5. Data analysis

Results are presented as mean of eight independent replicates plants for each type of growing media. Significance of differences between mean values of plant elongation and dry biomass of growing media parameters were assessed by the analysis of variance (ANOVA) followed by the Fischer PLSD test, with $P < 0.05$ as significance threshold value.

Results

The main physicochemical characteristics of the different growing media are reported in Table 1. The bulk density was significantly lower in the peat-based growing media (C), whereas followed by S+PR, S and S+F growing media (Table 1). The pH value of the peat-based growing media was acidic whereas the sediment-based growing media had all similar alkaline pH value (Table 1). The EC value was significantly higher in the sediment-based growing media than in the peat-based growing media, with the highest value found for the S growing media (Table 1). Total and organic C contents were significantly higher in the peat-based than in sediment-based growing media, whereas the total N content was significantly higher in the C and S+F than in the S and S+PR growing media (Table 1). Total and available P were was significantly higher in the S+F, followed by the S and S+PR growing media, whereas the lowest total and available P concentrations were observed in the C growing media (Table 1).

3.2 Plant growth, leaf chlorophyll content, and plant stress indication.

Plant elongation at the end of the growth period showed similar trends for all types of growing media, with similar values for S+F and C treatments and significantly lower values for S and S+PR growing media (Figure 1). Biomass was significantly higher for plants grown on C and S+F growing media as compared to plants grown on S and S+PR growing media, either for roots and shoots (Figure 1). The leaf dry weight showed no significant differences between plants regardless of the growing media (Figure 1). Content of chlorophyll a was significantly higher in plants grown on C and S+F growing media, content of chlorophyll b was higher in plants grown on C and S growing media (Figure 1). As a result, total chlorophyll content was significantly higher in plants grown on C and S+F growing media (Figure 1). Malondialdheyde (MDA) concentration was significantly higher values in leaves of plants grown on C, followed by plants grown on S and S+PR, whereas the significantly lower value was detected in leaves of plants grown on S+F growing media (Figure 1).

3.3 Heavy metal and macronutrient concentrations in plant roots and leaves

Among heavy metals, Cu and Ni concentrations showed significantly higher concentrations in leaves of plans grown on S+F, followed by plants grown on S+PR for Cu and grown on S+Pr and S for Ni (Figure 2). Significantly higher concentrations of Pb and Zn were found in leaves of plants grown on peat-based growing media (C), followed by plants grown on S+Pr and S+F for both elements (Figure 2). The lowest Pb and Zn concentrations were detected in leaves of plants grown on the S+Pr growing media (Figure 2). Calcium and Mg concentrations showed the following ranking orders: C > S+F > S+PR = S for Ca, and S+PR > S = C > S+F for Mg (Figure 2).

3.4 LCA analysis

The LCA results showed a positive environmental effect of the use sediment in growing media, as it resulted in values of 12.5 kg CO_2 eq per m^3 of phytoremediated sediment and 70.0 kg CO_2 eq per m^3 of peat. Calculation of the relative impact of individual plants grown on sediment-based growing media expressed as % of the GWP impact of the plants produced on peat-based growing media (the standard practice), showed that the use of all sediment-based growing media reduced the C footprint (Table 2). In particular, a reduction of C footprint of 24% was obtained using the S+F, of 26% using the S and of 10% using the S+PR growing media, as compared to peat-based growing media. The differences between the various sediment-based growing media were due to the fertilization for the S+F and the use of composted pruning residues for the S+PR growing media (Table 2). The LCA also showed that the growing plants on reclaimed sediment also reduced the incidence of the growing media on the overall GWP per produced plant from 22% for peat-based growing media to 9%, 4% and 8% for the S, S+PR and S+F growing media (Table 2).

Discussion

The results of our work showed that marine sediments, reclaimed by phytoremediation could be used for growing ornamental plants. The sediment-based growing media presented pH and EC values and bulk density out of the typical range for commercially available growing media (Abad et al., 2001), except for the bulk density and the EC value of the S+PR growing media, due to the incorporation of pruning residues into sediments. Although the growing media physico-chemical parameters are generally considered fundamental for optimal growing media (Schmilewski, 2009), the red-robin photinia plants grew on all sediment-based growing media. However, it was also observed that fertilization was the key factor for obtain plants of comparable size and form comparable to those grown on the peat-based growing media (Stratton et al., 2001). Fertilization is particularly important for plants grown in containers because of the limited amount of substrate available for the roots, which can cause plant deficiency (Huett, 1997; Abad et al., 2001). The lower growth of plants observed on S+PR growing media was also likely due to the lower nutrient content of this growing media, particularly P, as compared to the other sediment-based growing media (Table 1). In fact, the pruning residues, mainly consisting of lingo-cellulosic moiety, did not contribute to the plant mineral nutrition and led to stunted growth (Figure 3). These results are in agreement with pervious finding by Benito et al. (2005) who reported good growth of various ornamental plants on composted pruning residues only when they were mixed with other fertile ingredients in growing media. Possibly, a combination of pruning residues and fertilization may lead to the constitution of suitable growing media.

Overall, these results showed that a standard fertilization with a slow-release NPK fertilizer was sufficient to improve the plant growth on the phytoremediated sediment to comparable levels as the peat-based growing media. This was indicated by the similar chlorophyll content in leaves of sediment- and peat-based growing media. Chlorophyll a and b are the main photosynthetic pigments, providing the chemical energy responsible for the biomass production (Filella et al., 1995), and chlorophyll content is generally reduced under nutrient deficiency and plant stress (Merzlyak et al., 1999; Moran et al., 2000). Chlorophyll content is also responsible for the plant chroma, which is an important parameter for grading the ornamental plants. Improvement growth and aspects of ornamental plants in relation to N availability have been reported both for (Mills and Jones, 1996; Hernandez Apaolaza et al., 2005).

Leaf concentrations of Cu, Ni, Pb and Zn were relatively low and comparable with those measured in 1 year old leaves of red robin photinia grown on contaminated a soil (Giorgioni and Quitadamo, 2013). The undetectable Cd and Cr concentrations in leaves of all plants could be explained by the low Cd and Cr concentrations in the peat-based growing media and by the alkaline pH value of the sediment-based growing media that could have reduced their phytoavailability by precipitation with carbonates of sediments (Renella et al., 2004). indicated that were not taken up or not translocated to the aerial part of plants grown on both sediments and peat.

The significantly higher MDA concentration in leaves of photinia plants grown on the peat-based as compared to sediment-based growing media was unexpected, as MDA concentration in plant increase in response to oxidative stress, and generally indicates the onset of a plant stress phase (Posmyk et al., 2005). The MDA is one of the end products of polyunsaturated fatty acids peroxidation (Upadhyaya and Panda, 2004), induced by an imbalance between oxidative and reductive reactions in favor of the oxidative processes, leading to the production of oxygen radical species, such as superoxide anion (O^{2-}), hydrogen peroxide (H_2O_2) and the hydroxyl- radical ($OH^{\cdot}$) (Sies, 1991). Increased MDA content in plants has been observed under stress induced by light, temperature, drought, hypoxia and exposure to heavy metals (Mishra and Singhal, 1992; Blokhina et al., 2003; de Carvalho, 2008). Bennicelli et al. (1998), studied that the time relationship of TBA-MDA and the superoxide dismutase (SOD) foliar concentration in function of substrate aeration, and reported that plants grown on oxygen deficient growing media produced higher SOD activity and had a lower TBA-MDA concentrations, whereas plants on more aerated growing media had a lower SOD and higher MDA concentrations. It can not be excluded that plants grown on sediment-based growing media adapted to hypoxic conditions by inactivation of active forms of oxygen (Vergara et al., 2012), therefore reducing the peroxidation products. However, it has been reported that the increase of MDA content may be specifically related to oxidative stress (Bennicelli et al., 1998). Non specific reactions of TBA with other non-lipid metabolites (e.g. cellular carbohydrates) or fatty peroxide-derived decomposition products present in plants grown on peat-based growing media can not be excluded (Janero, 1990; Valenzuela, 1991). Phenylpropanoid-type pigments can also contribute to the overestimation of the MDA content in leaves (Stafford, 1994).

The LCA showed that the sediment re-cycle as ingredient of growing media for plant nursery can also improve the C footprint of plant production as compared to the use of the traditional peat-based growing media. The reduction of the C footprint related to the use of sediments in growing media was similar between the S and S+F, with the only difference due to the use of the controlled release fertilizer. Differently, plants grown on S+PR growing media had a less positive result (90% compared the control plants), due to the environmental impact associated to the pruning residue composting process. The LCA also confirmed that the growing media contribute less to the GWP of nursery plant nursery production which are predominated by the cultivation practice (Lazzerini et al., 2016), but the use of sediment-based growing media can further reduce its relative contribution (Table 2). Overall, by considering the results of the LCA and the volumes of growing media used in the EU plant nursery districts, the sediment re-use in plant nursery is an option may significantly alleviate the problems of sediment inland management and disposal (Bert et al., 2009). The benefit for the dredging industrial sector may be even larger by reducing that the sediment re-use in the plant nursery further reduce the high environmental impact associated to the sediment storage in confined facilities (Puccini et al., 2013; Bates et al., 2015).

In conclusion, our results demonstrated that phytoremediated marine sediments can be used for growing high grade ornamental plants in container. Standard fertilization is sufficient to produce plants with a comparable plant grade as those grown on traditional peat-based growing media, whereas the mixing of sediments with composted pruning residues improved the bulk density and EC value of the growing media but resulted in lower plant growth and needs further improvement. The re-use of growing media based on phytoremediated sediments reduced the C footprint of plant production offering practical management alternatives to both plant nursery and dredging industries), particularly by setting short supply chains of sediment dredging, remediation and use.

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References

Abad, M., Noguera, P., Bures, S. 2001. National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. Bioresource Technology, 77, 197-200.

Altmann, M. 2008. Socio-Economic Impact of the Peat and Growing Media Industry on Horticulture in the EU. Available at http://www.epagma.eu/sites/default/files/growing%20media/socio_economic_study2008.pdf (accessed on December 2017).

Barcelona Convention 1995. Dumping protocol. Available at http://wedocs.unep.org/bitstream/id/53220/consolidated_dumping_eng.pdf (accessed on December 2017).

Bates, M.E., Fox-Lent, C., Seymour, L., Wender, B.A., Linkov, I. 2015. Life cycle assessment for dredged sediment placement strategies. Science of the Total Environment 11,309-318. doi: 10.1016/j.scitotenv.2014.11.003. Epub 2014 Dec 29.

Benito, M., Masaguer, A., Antonio, R. D., Moliner, A. 2005. Use of pruning waste compost as a component in soilless growing media. Bioresource Thecnology, 96, 597-603.

Bennicelli, R.P., Stepniewski, W., Zakrzhevsky, D.A., Balakhnina, T.I., Stepniewska, Z., Lipiec, J. 1998. The effect of soil aeration on superoxide dismutase activity, malondialdehyde level, pigment content and stomatal diffusive resistance in maize seedlings. Environmental and Experimental Botany 39, 203-211.

Bert, V., Seuntjens, P., Dejonghe, W., Lacherez, S., Thuy, H.T., Vandecasteele, B. 2009. Phytoremediation as a management option for contaminated sediments in tidal marshes, flood control areas and dredged sediment landfill sites. Environmental Science and Pollution Research International, 16, 745-64

Blokhina, O., Virolainen, E., Fagerstedt, K.V. 2003. Antioxidants, oxidative damage and oxygen deprivation stress: a review. Annals of Botany 91, 179-194.

Ceglie, F.G., Bustamante, M.A., Ben Amara, M., Tittarelli, F. 2015. The challenge of peat substitution in organic seedling production: Optimization of growing media formulation through mixture design and response surface analysis. PLoS ONE10(6), e0128600. https://doi.org/10.1371/journal.pone.0128600.

Cellura, M., Longo, S., Mistretta, M. 2012. Life Cycle Assessment (LCA) of protected crops: an Italian case study. Journal of cleaner production, 28, 56-62.

Cruz de Carvalho, M. H. 2008. Drought stress and reactive oxygen species. Plant Signaling and Behavior 3:3, 156-165.

De Lucia, B., Cristiano, G., Vecchietti, L., Rea, E., Russo, G. 2013. Nursery growing media: agronomic and environmental quality assessment of sewage sludge-based compost. Applied and Environmental Soil Science, Volume 2013, article id 565139, http://dx.doi.org/10.1155/2013/565139.

European Commission, 2015. European Commission, DG Agriculture and Rural Development, Civil Dialogue Group, Horticultural Products, Flowes and Ornamental Plants, Working Document 02/10/2015. Available at https://ec.europa.eu/agriculture/sites/agriculture/files/fruit-and-vegetables/product-reports/flowers/statistics-2015_en.pdf (accessed on December 2017).

Unit C.2. Olive oil, horticultural products Filella, I., Serrano, I., Serra, J., Peñuelas, J. 1995. Evaluating wheat nitrogen status with canopy relfectance indices and discriminant analysis. Crop Science 35, 1400–1405

Garcia-Gomez, A., Bernal, M.P., Roig, A. 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bioresource Technology, 83, 81-87.

Giorgioni, M.E., Quitadamo, L. 2013. Ornamental Shrub capacity for absorption and accumulation of heavy metals form urban polluted soils. Acta Horticolture 990, 501-508.

Hernandez Apaolaza, L., Gasco, A. M., Gasco, J. M., Guerrero, F. 2005. Reuse of waste materials as growing media for ornamental plants. Bioresource Technology, 96, 125 -131.

Huett, D.O. 1997. Fertiliser use efficiency by containerised nursery plants 2. Nutrient leaching. Australian Journal of Agricultural Research, 48, 259-265.

ISO, International Standard Organization (2006). ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines.

Janero, D.R. 1990. Malondialdehyde and thiobarbituric acid-reactivity as diagnostic indices of lipid peroxidation and peroxidative tissue injury. Free Rad Biol Med 9, 515-540.

Jeffrey, S.W., Humphrey, G.F. 1975. New spectrophotometric equations for determining chlorophyll a, b c1 and c2 in higher plants, algae and natural phytoplankton. Biochemie und Physiologie Pflanzen 167, 191-194.

Lazzerini, G., Lucchetti, S., Nicese, F.P. 2016. Green House Gases(GHG) emissions from the ornamental plant nursery industry: a Life Cycle Assessment(LCA) approach in a nursery district in central Italy. Journal of Cleaner Production 112, 4022-4030.

Masciandaro, G., Di Biase, A., Macci, C., Peruzzi, E., Iannelli, R., Doni, S. 2014. Phytoremediation of dredged marine sediment: Monitoring of chemical and biochemical processes contributing to sediment reclamation. Journal of Environmental Management 134, 166-174.

Mattei, P., D’Acqui, L.P., Nicese, F.P., Lazzerini, G., Masciandaro, G., Macci, C., Doni, S., Sarteschi, F., Giagnoni, L., Renella, G. 2017. Use of phytoremediated sediments dredged in maritime port as plant nursery growing media. Journal of Environmental Management 186, 225-232.

Merzlyak, M.N., Gitelson, A.A., Chivkunova, O.B., Rakitin, V.Y. 1999. Nondestructive optical detection of leaf senescence and fruit ripening. Physiologia Plantarum 106, 135–141.

Mills, H.A., Jones, J.B. 1996. Plant analysis handbook II. A practical sampling, preparation, analysis, and interpretation guide. MicroMacro Publishing Inc., Athens, GA, USA, pp. 422.

Mishra, R.K., Singhal, G.S. 1992. Function of Photosynthetic Apparatus of Intact Wheat Leaves under High Light and Heat Stress and Its Relationship with Peroxidation of Thylakoid Lipids. Plant Physiology 98, 1-6.

Moran, J.A., Mitchell, A.K., Goodmanson, G., Stockburger, K.A. 2000. Differentiation among effects of nitrogen fertilization treatments on conifer seedlings by foliar reflectance: a comparison of methods. Tree Physiology 20, 1113–1120.

Pignattelli, S., Colzi, I., Buccianti, A., Cecchi, L., Arnetoli, M., Monnanni, R., Gabbrielli, R., Gonnelli, C. 2012. Exploring element accumulation patterns of a metal excluder plant naturally colonizing a highly contaminated soil. Journal of Hazardous Materials 227, 362-369.

Posmyk, M.M., Bailly, C., Szafranska, K., Janas, K.M., Corbineau, F. 2005. Antioxidant enzymes and isoflavonoids in chilled soybean (*Glycine max* (L.) Merr.) seedlings. Journal of Plant Physiology 162, 403-412.

Puccini, M., Seggiani, M, Vitolo, S, Iannelli, R. 2013. Life cycle assessment of remediation alternatives for dredged sediments. Chemical Engineering Transactions 35, 781-786.

Renella, G., Adamo, P., Bianco, M.R., Landi, L., Violante, P., Nannipieri, P. 2004. Availability and speciation of cadmium added to a calcareous soil under various managements. European Journal of Soil Science 55, 123-133.

Santi, C.A., Certini, G., D’Acqui, L.P. 2006. Direct determination of organic carbon by dry combustion in soils with carbonates. Communications in Soil Science and Plant Analysis 37, 155-162.

Schmilewski, G. 2009. Growing medium constituents used in the EU. Acta Horticulture 819, 33-46.

PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.

SedNet (European Sediment Research Network) 2003. The SedNet strategy paper: The opinion of SedNet on environmentally, socially, and economically viable sediment management. Available at www.sednet.org (accessed on December 2017).

Shine, K.P., Fuglestvedt, J.S., Hailemariam, K., Stuber, N. 2005. Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. Climatic Change 68, 281-302.

Sies, H. 1991. Oxidative stress, oxidants and antioxidants. Experimental Physiology 82, 291-295.

Stafford H. 1994. Anthocyanins and betalains: evolution of mutually exclusive pathways. Plant Science, 101, 91-98.

Stratton, M. L., Good, G. L., Barker, A.V. 2001. The effects of nitrogen source and concentration on the growth and mineral composition of privet. Journal of Plant Nutrition, 24, 1745-1772.

Taiti, C., Giorni, E., Colzi, I., Pignattelli, S., Bazihizina, N., Buccianti, A., Luti, S., Pazzagli, L., Mancuso, S., Gonnelli, C. 2016. Under fungal attack on a metalliferous soil: ROS or not ROS? Insights from *Silene paradoxa* L. growing under copper stress Environmental Pollution 210, 282-292

Upadhyaya, H., Panda, S.K. 2004. Responses of *Camellia senensis* to drought and rehydration. Biologia Plantarum 48, 597-600.

Valenzuela, A. 1991. The biological significance of malondialdehyde determination in the assessment of tissue oxidative stress. Life Sciences 48, 301-309.

Vergara, R., Parada, F., Rubio, S., Perez, F.J. 2012. Hypoxia induces H_2O_2 production and activates antioxidant defence system in grapevine buds through mediation of H_2O_2 and ethylene. Journal of Experimental Botany 63, 4123-4131.

Abstract

Phytoremediated marine sediments were used as peat-free growing media for the red robin photinia (*Photinia* x *fraseri* L.). Plants were grown on growing media containing sediment only (S), sediment mixed with composted pruning residues (S+PR), sediment fertilized with controlled release fertilizers (S+F) and traditional peat-based growing media, considered as control treatment (C). Plant elongation, plant dry weight, leaf chlorophyll, concentration of malondialdehyde (MDA), macronutrients and heavy metals were determined at the end of one growing season. The environmental impact related to the use of phytoremediated sediment-based as compared to peat-based growing media was evaluated by the Life Cycle Analysis (LCA). The sediment-based growing media presented significantly higher bulk density, pH and electrical conductivity values, lower C and N contents, and significantly higher total and available P. The red robin photinia grown on S+F growing media showed morphological and chemical parameters similar to those of control plants (C), whereas plants grown on S and S+PR showed lower growth. Leaf concentration of nutrients and heavy metals varied depending on the considered element and growing media, but were all within the common values for ornamental plants, whereas the highest MDA concentrations were found in leaves grown on peat-based growing media. The LCA indicated the use of sediments as growing media could reduce the C footprint of ornamental plant production and the relative contribute of growing media to the environmental impact per produced plant. We concluded that sediments phytoremediation and use in plant nursery is a practical alternative re-use option for dredged sediments.

Figure 1. LCA system diagram of the considered materials and processes in for the experiment of the Red Robin photinia production on sediment- and peat-based growing media.

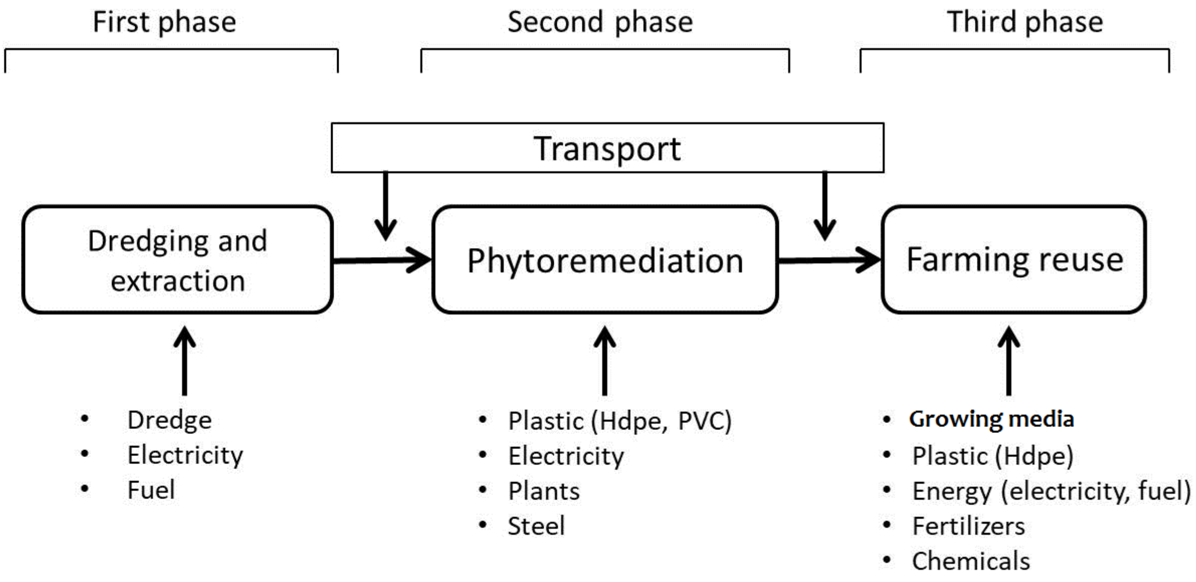

Figure 2. Red robin photinia pant elongation, biomass, leaf dry weight, chlorophyll content and malondialdehyde concentration after growth on sediment- and peat-based growing media. Different superscripts indicate significant differences (*P* < 0.05) among mean values for plant parameters grown on different growing media.

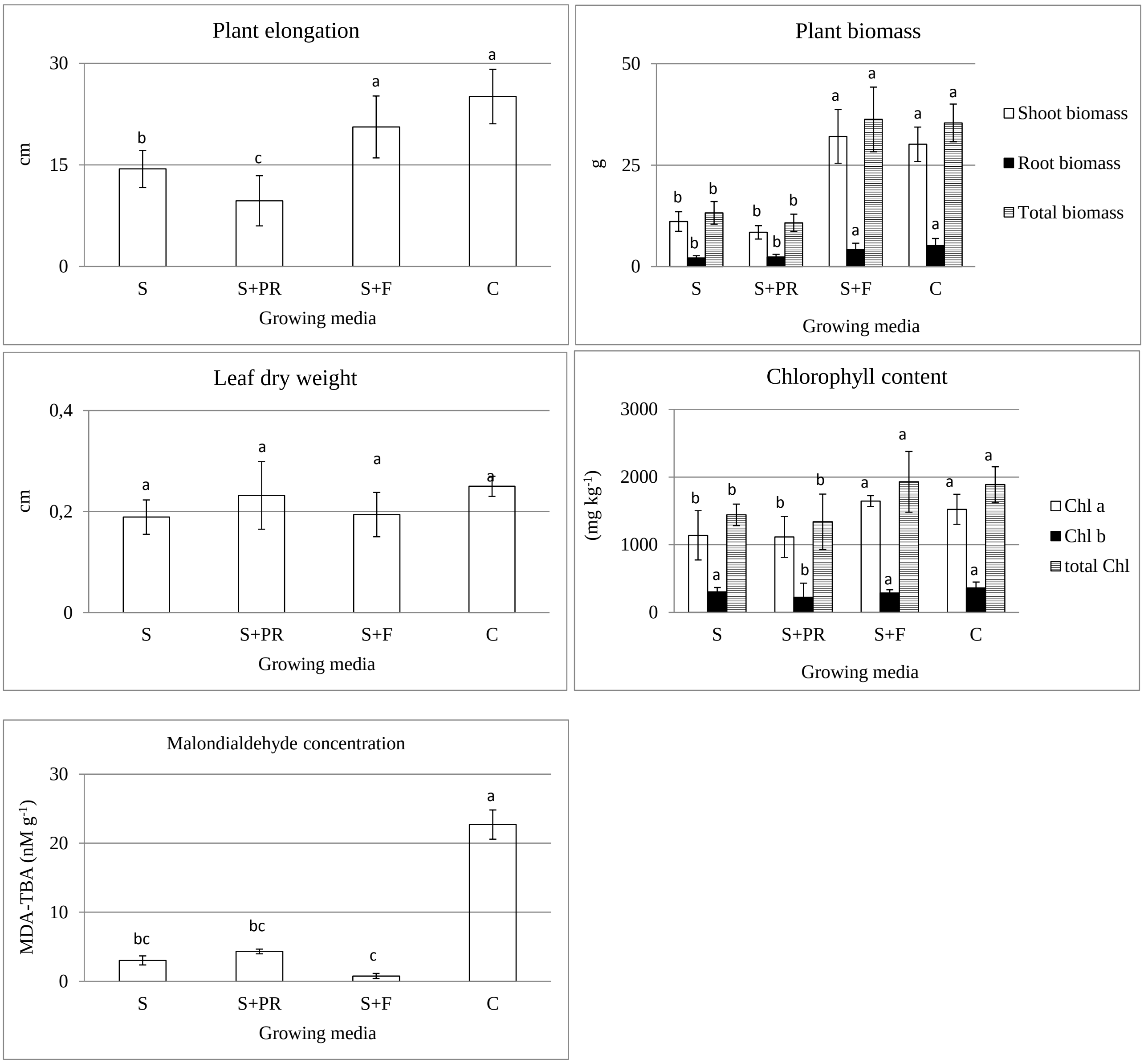

Figure 3. Concentration of heavy metals and macronutrients in the red robin photinia leaves at the end of the plant growth period. Different superscripts indicate significant differences ($P < 0.05$) among mean values for leaves of plants grown on different growing media.

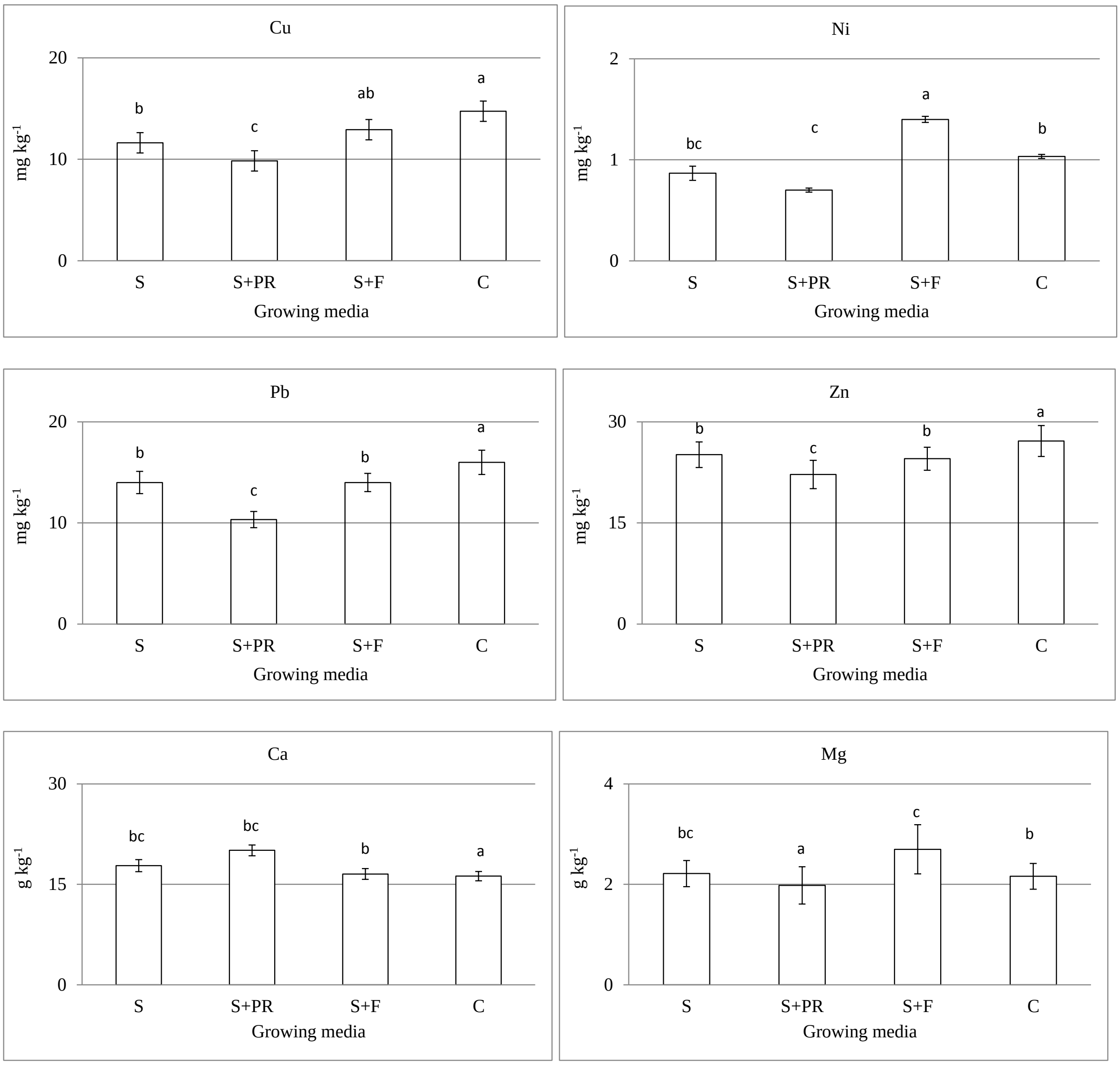

Table 1. Main physico-chemical parameters of the sediment- and peat-based growing media. Different superscripts indicate significant differences ($P < 0.05$) among mean values (n = 8).

	Growing media			
Physico-chemical parameters	S	S+PR	S+F	C
Bulk density (kg m^{3})	1012 ± 74^{c}	684 ± 59^{b}	982 ± 68^{c}	238 ± 26^{a}
$pH_{(H2O)}$	7.88 ± 0.03^{b}	7.69 ± 0.04^{b}	7.78 ± 0.02^{b}	4.55 ± 0.08^{a}
EC (mS cm^{-1})	1.08 ± 0.09^{a}	0.87 ± 0.12^{c}	0.92 ± 0.07^{c}	0.38 ± 0.06^{c}
Total C (g kg^{-1})	27.3 ± 2.4^{c}	40.8 ± 4.9^{b}	26.2 ± 2.7^{c}	893 ± 24.9^{a}
Organic C (g kg^{-1})	17.3 ± 2.3^{c}	31.4 ± 2.8^{b}	16.1 ± 1.3^{c}	524.9 ± 2.2^{a}
Inorganic C (g kg^{-1})	11.9 ± 2.0^{b}	13.4 ± 1.8^{b}	9.17 ± 0.33^{a}	ND*
Total N (g kg^{-1})	1.22 ± 0.11^{b}	1.53 ± 0.31^{b}	2.67 ± 0.33^{a}	2.50 ± 0.24^{a}
Total P (g kg^{-1})	51.3 ± 3.78^{a}	33.6 ± 2.5^{b}	57.4 ± 13.1^{a}	7.96 ± 1.30^{d}
Available P (mg kg^{-1})	2.43 ± 0.15^{b}	1.57 ± 0.10^{c}	3.22 ± 0.27^{a}	0.46 ± 0.06^{d}
Ca (g kg^{-1})	27.3 ± 3.1^{a}	16.5 ± 2.1^{b}	22.9 ± 1.83^{a}	0.43 ± 0.05^{c}
Mg (g kg^{-1})	16.2 ± 1.5^{a}	10.6 ± 1.9^{b}	17.0 ± 2.09^{a}	0.50 ± 0.14^{c}
Cd (mg kg^{-1})	1.52 ± 0.27^{a}	0.72 ± 0.10^{b}	1.37 ± 0.21^{a}	0.49 ± 0.09^{c}
Cr (mg kg^{-1})	59.3 ± 5.5^{a}	35.7 ± 2.5^{b}	61.6 ± 3.5^{a}	34.1 ± 17^{b}
Cu (mg kg^{-1})	82.1 ± 5.6^{b}	59.0 ± 6.0^{c}	82.7 ± 4.1^{b}	126.6 ± 20^{a}
Ni (mg kg^{-1})	67.1 ± 4.0^{a}	40.6 ± 4.05^{b}	65.8 ± 5.1^{a}	2.24 ± 0.79^{c}
Pb (mg kg^{-1})	65.1 ± 2.9^{a}	39.6 ± 3.5^{b}	64.8 ± 4.5^{a}	9.14 ± 1.3^{c}
Zn (mg kg^{-1})	284.6 ± 24^{a}	256.9 ± 50^{a}	286.1 ± 29^{a}	9.15 ± 1.9^{b}

*ND indicates values not determined.

Table 2. GWP values expressed as CO_2 equivalent (CO_2 eq.) of red robin photinia plants produced on sediment-based compared to the same plants produced on peat-based growing media, and GWP values of the tested growing media. Values in the ‘Variation’ column indicate the percentage of reduction of CO_2 eq. as compared to the plants grown on the different growing media. Values in the ‘Incidence’ indicate the relative contribution of growing media to the CO_2 eq. for the plants grown on the different growing media.

	GWP (Kg CO_2 eq.)			
Growing media	Per plant	Growing media	Variation (%)	Incidence (%)
S	0.232	0.02	-25.7	9
S+PR	0.282	0.01	-9.6	4
S+F	0.236	0.02	-24.4	8
C	0.312	0.07	-	22