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Research article

A tree from waste: Decontaminated dredged sediments for growing forest tree seedlings

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ABSTRACT

The sediments dredged from a waterway and decontaminated through a phytoremediation process have been used as substrates alternatively to the traditional forest nursery substrate for pot productions of holm oak (*Quercus ilex* L.) planting stocks. The substrates, made by mixing decontaminated sediments to agricultural soil at different degrees, were tested in order to evaluate their suitability as growth substrates. The experiment was carried out at the nursery of the Department of Agricultural, Food and Forestry Systems of the University of Florence (Italy). The experimental design consisted of four randomized blocks with six pots as replicates for each of the following treatments: 100% sediments, 66% sediments, 33% sediments, 100% agronomic soil and 100% traditional peat based substrate. In each pot, one holm oak acorn was seeded. Germination and both physiological and morphological traits of the seedlings were analysed during and at the end of the first growing season. Holm oak grown in phytoremediated sediments at higher concentrations showed germination levels comparable to those in the traditional substrate, and survival capacity (especially in 66% sediments) slightly higher than in 100% soil. Physiological performance of seedlings resembled that on the traditional substrate which required the addition of fertilizer, at least for the first growing season. Seedlings grown in mixed substrates with higher sediment concentrations occasionally showed better photosynthetic capacity with improved connectivity between the units of the photosystem II. At the end of the first growing season, height as well as the number of growth flushes of the seedlings grown in sole sediment or soil-sediment substrates were similar to what generally is observed for forest nursery stock of *Quercus* spp.. Regarding the root-system articulation and growth in depth, results in the mixed substrates were comparable to those for seedlings grown in the traditional forest nursery media, and higher than seedlings grown in 100% agronomic soil. According to our results, the reclamation of dredged sediments can provide appropriate nursery substrate for germination beds for forestry species.

1. Introduction

Sediments deposited in harbours and waterways interfere with navigational activities, so that dredging is necessary to maintain a sailing depth; however, they adsorb and retain the settled contaminants (including metals) and nutrients (such as N and P), with consequent environmental impacts and socio-economic issues (Manap and Voulvoulis, 2015). In Europe, the classification of dredging spoils, defined as *the waste dredged out of canals, rivers, lakes and harbours to allow or facilitate the navigation of surface waters*, follows the list of wastes adopted with Commission

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Decision 2000/532/EC, which also bases on the list of hazard wastes of the Directive 91/689/CEE, if the concentration of pollutants is above the set thresholds. Therefore, sediments with concentration of pollutants over the European (Commission Decision 2000/532/EC) or the national law (DL 152/2006) thresholds must be dredged and then stocked in specific confined disposals and then brought to landfilling. Anyhow, in 2008, the European Commission has also introduced the principle of "recovering and recycling" (Directive 2008/98/CE), which allows a waste to cease to be waste and to become a secondary raw material, after all needed measures to ensure human health and environment safety (e.g., risk to water, air, soil, plants or animals, noise or odours, and to countryside or places of special interest).

Indeed, dredged sediments that are not contaminated can be relocated farther offshore in deep-sea conditions or even reused in civil engineering works such as filling material to restore eroded beaches. On the other hand, the transportation to landfill even of slightly polluted materials generates high management costs and it increases soil and space consumption for disposals and landfilling. SedNet consortium (Salomons and Brils, 2004) reported that in Europe about $200 \cdot 10^6\ m^3$ of sediments are produced every year, 65% of which contaminated by heavy metals and hydrocarbons. Therefore, the decontamination and transformation of such special waste into a valuable product would contribute reducing the environmental impact generated by dredging activities and creating 'new products' through the variety of treatments available nowadays (Netzband et al., 2002; Manap and Voulvoulis, 2015). For instance, previous experience on sediments dredged from a dredged canal in Tuscany (Navicelli, Pisa) demonstrated successful decontamination methodologies for the creation of agronomic substrates (Iannelli et al., 2010; Doni et al., 2013; Mattei et al., 2016, 2017). Nevertheless, the application of these decontaminated sediments in the agricultural sector remains poorly studied. Potentially, decontaminated sediments can be used in preparing planting stock for soil reclamation, functioning as initial substrate for hosting plants. Therefore, the suitability of decontaminated sediments as substrates needs to be tested in terms of plant adaptation to the physical and chemical characteristics of these substrates in varying proportions.

In agriculture, one of the most consuming and demanding sector for natural resources is plant nursery that requires large volumes of soils for in-field plantations or of light substrates for in-pot cultivations, which are currently mostly represented by peat (29 million cubic meters produced worldwide for this sector (Apodaca, 2015)). In this frame, it is recommendable the use of alternative substrates that guarantee quality products and as less as possible use of primary resources. Since the use of peat as plant growing substrate is no longer sustainable (Lazzerini et al., 2016), alternative plant growth media need to be tested, including contaminated biosolids (e.g., Sebastiani et al., 2004; Tognetti et al., 2004), in order to reduce the overexploitation of peatlands. Variable results for woody plants grown on dredged sediments were previously reported (Vervaeke et al., 2003; Hartley et al., 2011). Indeed, although soil quality was generally enhanced, the risk of trace element transfer to the wider environment is still a matter of debate. Nevertheless, the potential use of sediments in this sector is under-investigated, especially in consideration of the variety of cultivation typologies, substrate mixtures and plant stages (e.g., in containers or in field, for bare-root or rootball productions, seeding, transplanting, etc.).

Phytotechnologies were proven useful for remediating dredged marine sediments (Bert et al., 2009), and offered efficient solutions for the degradation of organic pollutants and chemical stabilization of heavy metals in dredged sediments (Doni et al., 2015). In a pilot phytoremediation experiment on silty saline sediments contaminated by heavy metals and organic compounds, Masciandaro et al. (2014) obtained positive indication on plant efficiency in remediating and ameliorating agronomic and functional sediment properties. Mattei et al. (2017) evaluated the potential of a phytoremediated sediment, dredged from maritime port, as peat-free growth substrate for ornamental plants and Cleansed Consortium (2016) tested the potential of phytoremediated sediments for growing ornamental shrubs, finding that the re-use by plant nursery industry can be a sustainable management solution for sediments dredged from a canal though operational limits due to the heterogeneous size of the clay aggregates.

In this study, we used the same decontaminated sediments previously tested in Ugolini et al. (2017), though improved in structure homogeneity by breaking mechanically big aggregates and sieving the material. The new substrates were obtained by mixing the decontaminated sediments to agricultural soil in different percentage per volume and they were compared to a traditional nursery substrate (peat:perlite, 50:50) in order to evaluate their suitability as growth substrates for forest tree species, from the germination stage. The studied species was holm oak (*Quercus ilex* L.), which is the dominant tree of many mature forest communities over large areas of the Mediterranean Basin and represents the degradation sequences of Mediterranean-type climax vegetation (Tomaselli, 1977; Le Houerou, 1993). Holm oak is of high functional value to the overall ecological complexity of Mediterranean ecosystems (Tognetti et al., 1998), to the extent that even restoration of degraded lands in such ecosystems take the species into account (Papadimitriou, 2013). In parallel, it is widely used in urban settings due to its symbolic and landscape value as well as to its ecological and genetic adaptability. Morphological and physiological traits of holm oak seedlings were monitored throughout the first growth season in nursery conditions. The hypothesis under investigation was that the adaptive traits to soil nutrients are expressed by holm oak seedlings in relation to their concentration in the substrates. The objective was to ascertain that the application of dredged sediments to the growth substrate does not impair plant development in holm oak seedlings and, thus, may be potentially used to complement traditional substrates in nursery cultivation, eventually.

2. Material and methods

2.1. Study site, seed characteristics and nursery cultivation

The experiment was carried out at the nursery of the Department of Agricultural, Food and Forestry Systems of the University of Florence (Italy, Lat. 43°48′30.53″ N; Long. 11°12′01.46″ E) during 2015 growing season. The climate is mild Mediterranean, with an annual mean temperature 14.9 °C (max 20.5 °C, min 9.3 °C) and 861 mm annual rainfall; the dry season occurs from the beginning of June to the end of July. Details on environmental conditions of the study site can be found in Cambi et al. (2017).

Weather parameters relative to the period of the experiment were taken from the closest meteorological station in Cascine (Firenze, Lat. N. 43°51′1″, Long. E. 11°14′13″, 40 m a.s.l.) equipped with a TEKNA data acquisition system (TEKNA, Firenze, IT) and sensors for the main weather parameters.

The seeds were collected in October 2014 in an autochthonous holm oak stand (according to 1999/105/CE) approved for seed production in Migliarino San Rossore Regional Park (Tuscany, Italy, Lat. 43° 43′ 10″ N, Long. 10° 18′25″ E). Seeds were stored in refrigerator at 3 °C in moist sand, during winter 2014–2015. In mid-March 2015, the acorns were placed in wet sand at 18 °C and, after a week of pre-germination, 120 randomly selected acorns with radicles <5-mm long were sowed. This procedure was carried out to