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The potential of native species as bioenergy crops on trace-element contaminated Mediterranean lands

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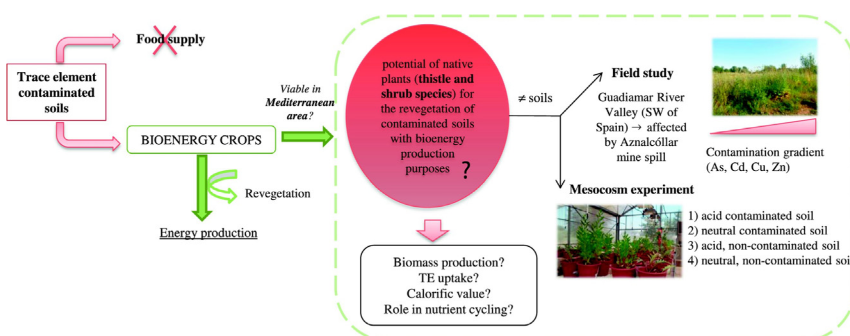
HIGHLIGHTS

- Some Mediterranean plant species were assessed as bioenergy crops for degraded lands.
- In a contaminated land *Silybum marianum* produced high biomass with a high calorific value.
- A greenhouse experiment confirmed its potential for biomass production in contaminated soils.
- *Dittrichia viscosa* also produced a high biomass with high calorific value in highly degraded soils.
- Possible problems associated to Cd accumulation into biomass must be further assessed.

GRAPHICAL ABSTRACT



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ABSTRACT

The establishment of energy crops could be an option for the management of degraded and contaminated lands, where they would not compete with food production for land use. Here, we aimed to explore the potential of certain native Mediterranean species for the revegetation of contaminated lands for energy production purposes. A field survey was conducted in a trace-element (TE) contaminated area from SW Spain, where the patterns of biomass production, TE accumulation and the calorific value of some thistle species were analyzed along a soil contamination gradient. In a greenhouse experiment the response of two thistle species (*Cynara cardunculus* and *Silybum marianum*) and the shrub *Dittrichia viscosa* to soil contamination was assessed, as well as the effects of these species on some soil microbial parameters involved in nutrient cycling (enzyme activities and arbuscular mycorrhizal colonization in roots). *Silybum marianum* was able to colonize highly contaminated soils. Its aboveground biomass accumulated Cd and had a relatively high calorific value; this value was similar in biomass obtained from both heavily and moderately contaminated soils. Greenhouse experiment confirmed that *S. marianum* biomass production and calorific value is scarcely affected by soil contamination. In addition, some soil enzyme activities were clearly enhanced in the *S. marianum* rhizosphere. *Dittrichia viscosa* is another promising species, given its capacity to produce a high biomass with appreciable calorific value in acid contaminated soils. Germination of both species was hampered in the acid contaminated soil, and therefore soil pH correction would have to be accomplished before establishing these species on extremely acid soils. Further assessment of the risk of transfer of Cd and other TE to the food chain would be needed to confirm the suitability of these species for the revegetation of contaminated lands with energy production purposes.

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1. Introduction

Soil contamination is one of the main causes of land degradation at the European level (Panagos et al., 2013). In the last decades, the concern about the extent of soil contamination by trace elements (TE) has led to high investments in technologies to address the recovery or decontamination of soils, among which phytoremediation has received special attention. This technology involves the combined use of plants and amendments, either to extract (phytoextraction) or stabilize (phytostabilization) TE in the soil-plant system, promoting the establishment of a plant cover that minimizes erosion risks and consequently the spread of pollutants to surrounding areas (Mendez and Maier, 2008; Robinson et al., 2009).

The environmental benefits of phytoremediation of a contaminated area are undeniable (Mendez and Maier, 2008). However, the accumulation of potentially toxic elements in the established vegetation often prevents an agricultural or livestock use of these areas (Madejón et al., 2009). It is therefore necessary to explore alternative uses of the vegetation in contaminated areas that do not only pose environmental, but also direct economic benefits to the social partners involved (Robinson et al., 2009; Conesa et al., 2012). The establishment of energy crops could be an option for the management of contaminated lands. Since agricultural production for food purposes is not allowed or recommended in these lands, the establishment of energy crops would not compete with food production for land use. Using these marginal lands for biofuel production would contribute to the attainment of national renewable energy targets as suggested by the European Renewable Energies Directive, which highlights the need for a sustainable production of biofuels that do not compete with food production.

In addition to the benefits derived from energy generation, the plantation of fast-growing species might also promote the sustainability of the degraded land by improving soil quality, in particular by increasing soil C stocks in the long-term (Baumert et al., 2014; Singh et al., 2006; Singh et al., 2015). At shorter time scales, the presence of the fast-growing crop species usually stimulates microbial biomass and extracellular enzyme activities in organic-matter poor or degraded soils (Cotton et al., 2013; Dou et al., 2013). Different crop species, however, might promote different changes in the soil microbial community, due to contrasted patterns of root exudation and litter quality (Mao et al., 2013).

Currently, examples of the use of fast-growing species for the revegetation of contaminated areas for energy production purposes are very limited (Ruttens et al., 2011; Witters et al., 2012; Madejón et al., 2016). Given the particularities of the Mediterranean climate (irregular rainfall, low water availability, and frequently low soil organic matter and nutrient content), many of the most common energy crops (*Miscanthus* sp., *Panicum* sp., *Jatropha* sp.) are not suitable for degraded Mediterranean areas (Robledo and Correal, 2013). Several works have shown that thistle species in the *Silybum* and *Cynara* genus could be adequate for solid fuel production in Mediterranean lands, due to their physiological adaptations to dry environments (Fernández and Curt, 2005), and their high dry matter content and calorific value (Fernández et al., 2006; Angelini et al., 2009a; Oliveira et al., 2012; Ledda et al., 2013). In addition, biodiesel can be obtained from their oily seeds, with fuel properties comparable to those of mineral diesel, and in agreement with biodiesel standards (Encinar et al., 2002; Ullah et al., 2015). *Dittrichia viscosa* (L.) Greuter has also been identified as a promising bioenergy crop species for Mediterranean lands (Robledo and Correal, 2013), because of its ability to produce a high biomass in highly degraded soils, including soils contaminated by TE (Martínez-Sánchez et al., 2012; Gómez-Ros et al., 2013).

Here, we present two studies aimed to explore the potential of some thistle species and *D. viscosa* for the revegetation of contaminated Mediterranean lands for bioenergy production purposes. In the first study, a field survey was conducted in a TE contaminated area in SW Spain (Guadiamar River Valley), where we explored the patterns of TE accumulation and the capacity for energy production through combustion (calorific value) of *D. viscosa* and some thistle species that spontaneously colonized the contaminated soils. In the second study the response of two thistle species (*Cynara cardunculus* L. and *Silybum marianum* (L.) Gaertn) and *D. viscosa* to soil contamination was analyzed under controlled conditions. Although *C. cardunculus* is a cultivated species, and does not usually colonize altered soils like *S. marianum* and *D. viscosa* do, the interest of including *C. cardunculus* in the greenhouse experiment relies on its well-known potential as bioenergy crop for Mediterranean lands (Fernández and Curt, 2005; Fernández et al., 2006; Angelini et al., 2009a; Oliveira et al., 2012). However, its tolerance to soil trace element contamination is still poorly characterized. Given that the interest of establishing these species on contaminated soils would not be limited to the production of solid fuel, but also to the improvement of soil quality in these degraded soils, the effects of the plantation of these species on some microbial parameters involved in soil nutrient cycling and C sequestration were also analyzed, namely, soil extracellular enzyme activities, which are usually used as soil quality indicators in degraded soils (Pajares et al., 2011; Paz-Ferreiro and Fu, 2016), and the degree of root colonization by arbuscular mycorrhizal (AM) fungi, which might facilitate plant establishment in degraded soils (Camprubi et al., 2015).

2. Materials and methods

2.1. Field study

2.1.1. Sampling design

Field survey was conducted in the Guadiamar River Valley (SW of Spain), an area affected by a large pollution episode in 1998, when a mining accident produced the release of ca. 6 hm^3 of TE polluted waters and sludge into the Guadiamar River (Grimalt et al., 1999; Domínguez et al., 2008). As a result, soils were polluted by several TE, in particular by As, Cu, Cd, Pb and Zn (Cabrera et al., 1999).

Nine locations were selected along a gradient of soil contamination in the Guadiamar River Valley. These locations include one site unaffected by the mining accident (site 1), seven sites affected by the accident in which remediation actions were undertaken (sludge removal, amendment addition and revegetation with woody species, sites 2–5 and 7–9), and one site affected by the accident in which no remediation activity was conducted, and therefore sludge remained on the soil surface (site 6). Details about the remediation activities conducted in the area can be found in Domínguez et al. (2008).

Biomass and soil sampling took place during May 2015, when thistle species had completely developed the floral scape and maximal biomass was reached. In each of these 9 sites 3 subplots of 10×10 m were established, and the presence of the focal species was recorded (*D. viscosa*, and thistle and related species - belonging to the Carduoideae subfamily in the Asteraceae family). The objective of this survey was to assess TE accumulation and potential energy production from biomass combustion of the focal species (thistle species and *D. viscosa*) 17 years after the pollution episode, and not to conduct a detailed analysis of the plant richness and the drivers of plant diversity in the area. Thus, data of plant richness and relative abundances of the whole plant community were not recorded. Species were identified following the nomenclature by Valdés et al. (1987). In each of these subplots three 1 m^2 square were delimited, and biomass of each of the present focal species was harvested separately. A subsample of the harvested biomass of each species was weighed immediately to determine fresh weight. Samples of surface soil (0–15 cm) were taken using a cylindrical auger from each of the 1 m^2 quadrats and combined in a composite sample for each of the three subplots delimited at each site (3 soil samples per site), except at site 1 (non-contaminated) where a single composite soil sample of the three subplots was analyzed.