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Research paper

Environmental impact assessment of perennial crops cultivation on marginal soils in the Mediterranean Region

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ABSTRACT

Perennial crops, as energy feedstocks, offer ecological advantages over fossil fuels by contributing to the reduction of greenhouse gases and fossil energy savings. Yet, the intensity of agricultural production may increase the pressure on soil, water resources and on biological and landscape diversity. Moreover, land use competition with food crops is demanding a spatial segregation of energy producing areas to land currently marginal for agricultural production. Therefore, the objective of this work was to determine the local and site-specific environmental impacts associated with the cultivation of perennial crops in marginal soils. The study, supported by the European Union (project OPTIMA - Optimization of Perennial Grasses for Biomass Production), was developed and applied to the cultivation phase of several perennial crops, in marginal soils of the Mediterranean region, using environmental impact assessment (EIA) protocols. Investigated crops include *Miscanthus* (*Miscanthus* × *giganteus* Greef et Deu), giant reed (*Arundo donax* L.), switchgrass (*Panicum virgatum* L.) and cardoon (*Cynara cardunculus* L.). Different categories were studied: fertilizers and pesticides related emissions, impact on soil and water resources and biological and landscape diversity. Results suggest that growing perennial crops in marginal Mediterranean soils do not inflict a higher impact to the environment than wheat farming (the current land use). At a scale from 0 (lower impact) to 10 (higher impact), against idle land (the reference system with a score of 5), wheat and giant reed showed the highest scores (6.7–7.3 and 6.7–7.1, respectively). Impact scores of the remaining perennials decreased in the order cardoon (5.7–6.0), Miscanthus (5.4–5.6), and switchgrass (5.2–5.5), the last one showing the lowest difference to the reference system. Overall results suggest that perennial crops provide benefits regarding soil properties and erodibility (with an average score of 2.2 and 5.6, respectively). Cardoon also showed benefits related with the biological and landscape diversity, scoring 5.0, like the reference system. On average, perennial crops showed a score of 6.3 and 6.9 towards the same categories. Impacts associated with water resources and N-fertilizer related emissions were high (with average scores of 8.1 and 8.3, respectively) but impacts associated with pesticide related emissions were low (average score of 5.4).

1. Introduction

Biomass is a renewable and sustainable feedstock for energy and materials, associated with energy supply diversification, non-renewable resources and greenhouse gas savings and mitigation of problems related with materials biodegradability [1–4]. However, the increasing demand for biomass, associated with the technological development and the mandatory renewable energy targets, increases the competition for land, threatening food security [5–7]. Consequently, cultivation of industrial crops on marginal, degraded or abandoned land is repeatedly suggested as an

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approach to minimize land use competition with food crops and land use change controversies [5,8–11].

Marginal land can be defined as land where cost-effective production, under given environmental conditions, cultivation techniques, agriculture policies as well as macro-economic and legal conditions results in low profit margins [5,11]. The term denotes land currently marginal for agricultural production due to natural constraints (low grade soils, adverse climatic conditions or steep slope) [12]. Therefore, to grow industrial crop cultivars on marginal land, while generating technical and economic benefits and limiting environmental impacts, still represents a challenge. The productivity loss in marginal conditions, the effects on the biomass characteristics and the need for higher inputs (fertilizers, fuel, water) may hinder the economic viability of the crop and weaken its environmental performance [5,13]. Additionally, the higher land area needed to meet the demand for feedstock may result in conflicts with pasture lands and lands of high nature value, rich in biodiversity [5,14]. Nonetheless, production of industrial crops in marginal areas is considering a promising option to sustain and improve rural development, especially in areas threatened by abandonment [5]. Under this topic, the EC-funded project OPTIMA (Optimization of Perennial Grasses for Biomass Production, www.optimafp7.eu) aimed to explore the potentialities of perennial crops on underutilized or abandoned marginal lands in the Mediterranean region. In the framework of the project, one of the objectives was to evaluate the environmental impacts associated with the perennial crops production chains, in marginal land allocated to the Mediterranean region.

Perennial crops, such as *Miscanthus* x *giganteus* Greef et Deu. or *Arundo donax* L., are high yielding lignocellulosic crops with great potential for the production of biofuels and biobased products [15]. Perennial crops cultivation offers several environmental advantages and provides a wide range of ecosystem services. These crops show high nutrient and water use efficiencies due to their extensive rooting system which holds on fertilizers and water [16–18]. The deep roots and ground cover, associated with its lengthy permanence [19], stabilize the soil and store carbon [20–23], reducing erosion [24] and the need for pesticides [25–27]. Consequently, it has been argued that cultivation of perennial crops in marginal soils have the potential to restore soil properties (fertility, structure, organic matter) [28], halting degradation and desertification [29–32]. This is particularly important in the Mediterranean, where the steep slopes and extensive dissection, and the long history of human intervention in the natural ecosystems have resulted in the highest rates of soil erosion in Europe [33]. Moreover, the majority of Europe's abandoned agricultural land and saline soils lies in the Mediterranean (along with Eastern Europe) [32,33]. However, cultivation of perennial crops in marginal soils may represent also a threat to biodiversity, due to the monoculture system, or to the water resources, once in the Mediterranean irrigation is usually needed to cover the water requirements of those crops. Yet, the research into the environmental impact of perennial crops cultivation on marginal land is limited [34–36] and the information on marginal Mediterranean land even less [3,10,37].

The environmental studies developed under the OPTIMA project concluded that the cultivation of perennial crops on marginal land in the Mediterranean region and their use for stationary heat and power generation can achieve substantial greenhouse gas emission and non-renewable energy savings, and if appropriately managed will have relatively few environmental side effects [3,37]. Yet, those studies compared the entire life cycles of bioenergy and bio-based products to equivalent conventional products. Considering the rural development, detailed and more comprehensive information on the local and site-specific environmental impacts (which means related to a particular place, such as biodiversity, soil and water resources) of the agricultural phase of perennial crops cultivation on marginal Mediterranean land still need to be critically assessed. Environmental Impact Assessment (EIA) is an evaluation method focused on local environmental effects, used to explore the possible environmental effects of a proposed project. It examines the anticipated environmental effects and determines the importance of these effects, on both the short and the long term. A previous study on 15 energy crops was made using EIA methodologies with the aim to evaluate the local and site specific effects of their cultivation in Europe [25]. However, the study focused on the cultivation of those crops in standard soils. Therefore, the current study, intends to assess the environmental consequences derived from lower yields and degraded soils, when perennial crops are cultivated in marginal soils in the Mediterranean region, following the application of the same methodology.

On this basis, this study aimed to provide answers to the following questions:

- Which local and site-specific environmental impacts are related to the cultivation of perennial crops on marginal land in the Mediterranean region?
- Which of the assessed crops perform best in terms of local and site-specific environmental impacts?
- Which parameters are of particular relevance and which options for improvement exist?

2. Methodological approach

The basis for assessment of local environmental impacts is outlined in section 2.1 entitled “System Description.” Section 2.2 outlines the specific methods used for the assessment.

2.1. System description

Fig. 1 gives an overview on the investigated system. The system includes cultivation and harvest of perennial crops on marginal Mediterranean land. The reference system was “idle land”, land currently not used for agricultural purposes, lying idle with a sparse vegetation cover, due to insufficient profit margins for the farmer under the prevailing regulatory framework conditions. Thus, no displacement of current land use to other areas or indirect land use change (iLUC) effects was taken into account. Investigated crops include *Miscanthus* (*Miscanthus* × *giganteus* Greef et Deu), giant reed (*Arundo donax* L.), switchgrass (*Panicum virgatum* L.) and cardoon (*Cynara cardunculus* L.), due to their favorable characteristics, including yield, nutrient demand, water use efficiency, adaptability to competitive environmental conditions, etc. Cardoon, in contrast to the other investigated crops is not a perennial grass but a thistle-like perennial herb, and it was assessed because it is native to the Mediterranean region, where it is particularly adapted. Besides the perennial crops, wheat was also analysed. As this is a traditional crop in the Mediterranean, even in the marginal areas, its performance will serve for comparison with the studied crops. Table 1 summarizes several important input data for the investigated crops. Data presented in Table 1 resulted from the harmonization of field data obtained from trials conducted by OPTIMA partners. Those trials were located in Aliartos (Greece), Bologna and Catania (Italy) and Madrid (Spain). Each location tested two or three crops.

It was considered the cultivation on marginal Mediterranean land as a main scenario, and a range of cultivation conditions and achievable yield levels was assessed, which is reflected by the comparatively low yields listed in the Table 1, the relatively high amount of irrigation needed and the different N, P and K fertilizer

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