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

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 Med-iterranean 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 land-scape 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).

Keywords:
Perennial crops
Environmental impact assessment
Environmental impacts
Bioenergy
Sustainability
Marginal land

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

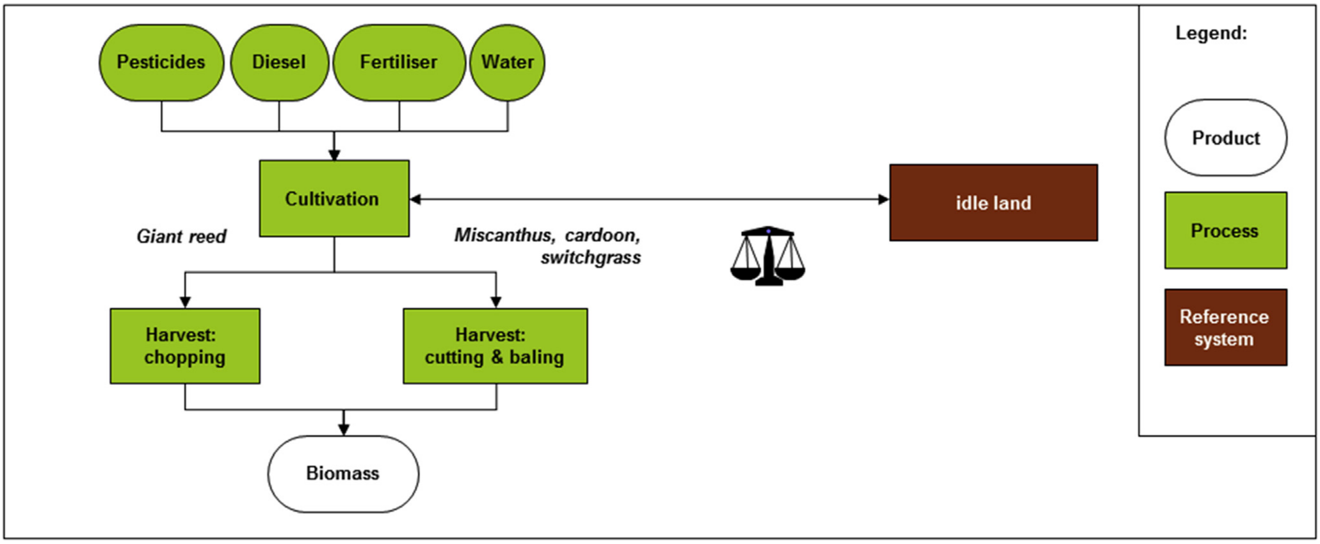

Fig. 1. Overview of the investigated system "Cultivation and harvest of perennial crops on marginal Mediterranean land".

Table 1
Input data for the cultivation of perennial crops (and wheat) on marginal land.

Parameter	Unit	Giant reed	Miscanthus	Switchgrass	Cardoon	Wheat
Biomass removal from field - dry matter	Mg ha^{-1} y^{-1}	18	14	9	10	1.5 (seed); 1.8 (straw)
Irrigation	m^3 ha^{-1} y^{-1}	6000	6000	4000	2000	rainfed
N fertilisation, N	kg ha^{-1} y^{-1}	111	38	63	85	81
P fertilisation, P_2O_5	kg ha^{-1} y^{-1}	60	16	16	21	11
K fertilisation, K_2O	kg ha^{-1} y^{-1}	385	102	22	196	29
Pesticides, active ingredient	kg ha^{-1} y^{-1}	0.15	0.15	0.15	0.35	1.2
N content in removed biomass, dry matter basis	g kg^{-1}	5	2.5	6	7	24 (seed); 6 (straw)
P content in removed biomass, as P_2O_5, dry matter basis	g kg^{-1}	3.4	1.1	1.8	2.1	10 (seed); 1.8 (straw)
K content in removed biomass, as K_2O, dry matter basis	g kg^{-1}	28	9	3.0	23	6 (seed); 12 (straw)

Perennial crops: all data represent averages over the plantation period of 15 years.

rates applied. Fertilizer rates presented for the different crops reflect also the combination of data provided by the field trials in OPTIMA with the inputs needed to cover the N, P and K being removed by the crops, which are, in the case of giant reed, particularly high due to the high yields.

Data for wheat are from the Mediterranean region and were collected from national and international organizations such as Food and Agriculture Organization (FAO) and Eurostat, and reflect data from marginal soils.

2.2. Assessment of local environmental impacts

The assessment of local environmental impacts was conducted based on the following methodological definitions and settings.

The functional unit, *i.e.*, the "utility" or "function" of a given production system varies from scenario to scenario, depending on the use option. With agricultural land becoming increasingly scarce and land-use competition between food/feed production and non-food applications aggravating, land-use efficiency is becoming a very relevant parameter. Therefore, all results are presented based on a "10 ha unit of land used for the cultivation of perennial crops". By choosing this unit, the "utility" of the production system is being conveyed, since this is the average area basis being exploited by farmers in marginal Mediterranean soils.

The year of reference for the entire assessment is 2020 and the Mediterranean region is the geographical unit all parameters and reference processes refer to.

Since respective methodological improvements are still under development, standard LCA methodology currently lacks elements to cover local and site-specific impacts on environmental factors like biodiversity, landscape, water and soil resources. Therefore, these subjects were assessed using elements borrowed from Environmental Impact Assessment (EIA).

To determine the local environmental impact of the cultivation of perennial crops on marginal land, different categories were studied: fertilizers and pesticides related emissions, impact on soil and water resources and biological and landscape diversity, following the methodology developed by Ref. [38], and adjusted by Ref. [25]. Each of these categories comprises different indicators (Table 2). The ReCiPe 2008 methodology [39] and the CML methodology ([40]) were also used for some of the indicators studied (Table 2 with details in ([41]). A qualitative scoring was used on biodiversity, landscape, effects on hydrology and soil properties evaluation, to fulfill the shortage of quantitative data. In this qualitative assessment, each crop was scored for a set of pertinent parameters, through expert judgment and literature review (Table 2). The remaining indicators were evaluated in a quantitative manner. In this study, water erosion was assessed by crossing the potential damage caused by rainfall with the soil cover characteristics of the crops during their cultivation cycles [25,38]. Wind, soil organic matter (SOM) and soil structure, were not reflected in the assessment although erosion might be also influenced by those elements. In the assessment, it was defined a P-value of 0.8 for the Mediterranean Region (the P-value from a region with no erosion control is 1). This reflects the initiatives, prevention studies and programs carried out in the Mediterranean basin [42,43]. Precipitation data

Table 2
Environmental impact assessment methodological steps for each impact category.

Category	Indicator	Assessment steps
Emissions to soil, air and water	Fertilizer-related emissions	N-Fertilizer-related emissions i Quantification of nitrogen (N) fertilizer applied (kg per year). ii Estimation of N emissions [29] (kg per year).
	Pesticide-related emissions	i Quantification of active substances (A.S.) applied (kg per year). ii Toxicity evaluation of each A.S. according to its effects on the environment, fauna and human health [28,30]. iii Aggregation of *(i)* and *(ii)* in a pesticide score (kg per year): $Pesticide\ score = \sum(amount_{A.S.\ (kg)} \times toxicity_{A.S.})$ The *Pesticide score* is accounted as "Pesticide-related emissions".
Impact on soil	Nutrient status	i Quantification of N, phosphorus (P) and potassium (K) fertilizers applied (input) (kg per year). ii Quantification of crop N, P and K uptakes and of N, P emissions (kg per year). iii Calculation of nutrient status in the soil as: $Balance\ (kg\ per\ year) = input - uptake - emissions\ (for\ N)$ Note 1 N surpluses may contribute to eutrophication of aquatic ecosystems; and this is accounted in the indicator "Fertilizer related emissions". Note 2 K surpluses may contribute to eutrophication of terrestrial ecosystems; and this is accounted in the indicator "Fertilizer related emissions". Note 3 P surpluses may contribute to eutrophication of aquatic ecosystems; and this is accounted in the indicator "Fertilizer related emissions".
	Erosion	i Division of crop cultivation in development phases from start of growth (A), to closure of crop (B), to start of senescence (C) and harvest (D). ii Estimation of a soil uncovered ratio (C-value) and of a regional amount of rainfall in each phase (R-value, mm). iii Application of the erosion control factor (P-value), which reflect the intensity of erosion control in the Mediterranean (0.8 [28]). iv Calculation of the harmful rainfall (mm per year): $\text{Total harmful rainfall} = \sum (C \times R)_{\text{stage}} \times P$
	Soil quality	Literature survey of the negative and/or positive impacts of each crop on structure, organic matter, pH, remediation potential, generation of impactful wastes.
Impact on water resources	Water resources depletion	i Quantification of crop water requirement (mm per year). ii Quantification of rainfall available to the crop during its permanence on soil (mm per year). iii Calculation of soil water balance: $Water\ resources\ depletion\ (mm\ per\ year) = water\ requirement - rainfall$ iv Comparison between water resources depletion and irrigation to evaluate the balance.
	Effects on hydrology	Effects on water flow and run-off and on refill of aquifers as influenced by crop permanence on soil, crop water needs, crop root system.
Biodiversity	Literature review and evaluation of generic effects of crops regarding: i biodiversity disturbance as related to management practices and intensity; ii aggressiveness, nativeness and allelopathy; iii reported increase or decrease of abundance and diversity of floral and faunal species.	
Landscape	Evaluation of the variation of crop scene in terms of structure (height, density, heterogeneity and openness) and color. Variation was considered to be a benefit when gains in structure and/or color were noticed. Variation implying loss of structure and/or color debited the landscape values.	

was supplied by Joint Research Centre [44] and the definition of growth stages and C-values for each crop were assembled through own field experience and previous work [45]. The collection of data represents both literature review and own experience which includes published and unpublished data associated with the OPTIMA project.

Impacts of cultivation and harvest of perennial crops (and wheat) on marginal Mediterranean land were compared with idle land (the reference system). In this assessment, analysis of the cultivation/reference system interaction with its environment and management practices was executed.

The quantitative and qualitative values measured on different scales were subjected to a normalization procedure. Indicator results were scaled from 0 (lower impact) to 10 (higher impact) against idle land (scoring 5, in the middle of the range). For each indicator, the most extreme result obtained among crops was scored "0" or "10".

In order to obtain a final score for each crop, the normalized results were followed by a weighting formula (equation (1)).

$$Score_{crop} = \frac{\sum(score_{indicator} \times weight_{indicator})}{\sum weight_{indicator}} \tag{1}$$

The definition of weighting factors brings ambiguity and subjectivity to the study at hand. However, when applied, weighting should reflect the relative importance of the impact categories in the context of the study [46]. Therefore, the weighting factors were assembled according to the environmental challenges of the European Union related to land use in marginal agricultural areas: halting biodiversity loss, stimulate favorable practices, increase profitability without intensifying, restoration of degraded ecosystems [47]. Increased weight was also specified to erosion and water resources as both are of great concern in the Mediterranean regions [42,47,48]. Different weighting systems (WS) were applied to the final results in order to assess its influence on the global classification (Table 3):

- WS1: all indicators have the same weight;
- WS2: greater emphasis on soil degradation drivers, namely K-fertilizer related emissions and soil properties [47,49], once the focus of the work is the cultivation of perennial crops on

Table 3
Weighting systems applied.

Category	Indicator	WS1	WS2	WS3
Emissions to soil, air and water	N-related emissions	1	1	1
	K-related emissions	1	1.5	1
	Pesticide-related emissions	1	1	1
Impact on soil	N-Nutrient status	1	0.5	0.5
	P-Nutrient status	1	0.5	0.5
	K-Nutrient status	1	0.5	0.5
	Erosion	1	1.5	1.5
	Soil properties	1	1.5	1
Impact on water resources	Groundwater balance	1	1.5	1.5
	Effects on hydrology	1	1	1
Biodiversity		1	1	2
Landscape		1	0.5	0.5
Total		12	12	12

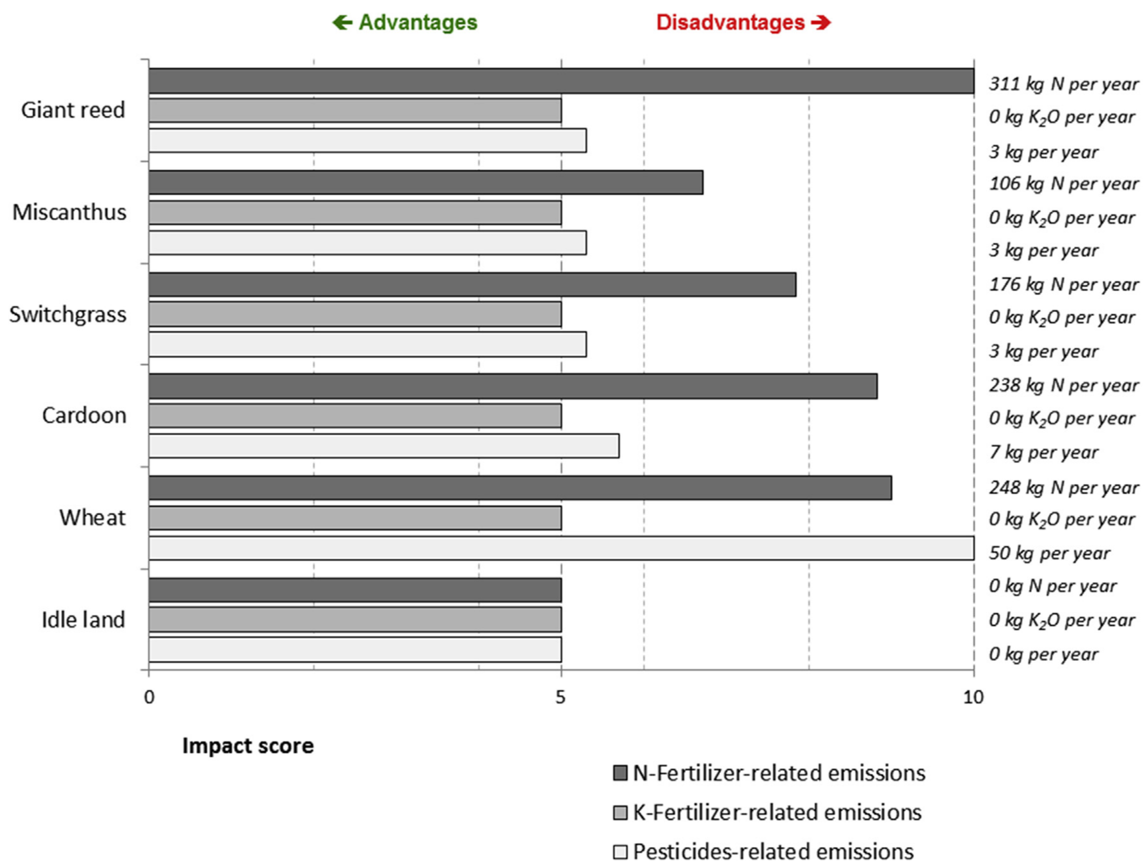

Fig. 2. Normalized scores of fertilizer-related and pesticide-related emissions impact of the perennial grasses cultivation on marginal Mediterranean land. The graph presents also the absolute values of N-fertilizer related emissions, K-fertilizer-related emissions and pesticides-related emissions for each crop and indicator, per 10 ha per year, calculated according to the methodological steps presented in Table 2. N-fertilizer-related emissions indicate the amount of N lost as N_2O, NO_3, NH_4 and NH_3.

marginal soils; emphasis also on erosion and groundwater depletion [42,47,48].

- WS3: greater emphasis on biodiversity [47]; emphasis also on erosion and groundwater depletion [42,47,48].

In WS2, it was given a higher weight to all the impacts related with soil degradation drivers, once the focus of the work is the cultivation of perennial crops on marginal soils. This is why K-fertilizer related emissions and soil properties (e.g. pH, soil organic matter) were given extra weight in this weighting system. Potassium surplus in high loads contribute to eutrophication of terrestrial ecosystems, because the salinization of the soil increases, which affects terrestrial organisms [49], and disturb a large variety of microbiologically mediated processes in soil [50].

Concerning N and P fertilizer emissions, they also represent an environmental impact, when are leached out of the soils, to ground and surface waters causing eutrophication. Therefore the impact of N and P fertilizer emissions was also acknowledged in the EIA

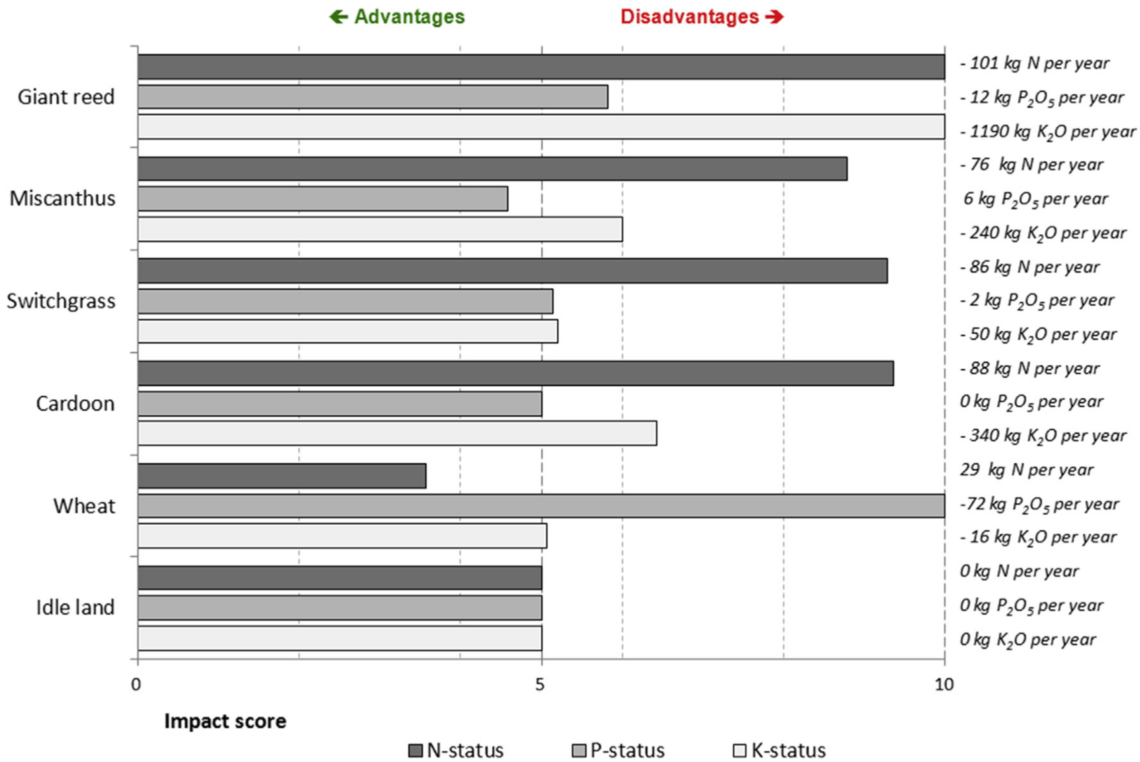

Fig. 3. Normalized scores of nutrient-status impact of the perennial grasses cultivation on marginal Mediterranean land. The graph presents also the absolute values of N, P and K-status for each crop and indicator, per 10 ha per year, calculated according to the methodological steps presented in Table 2. Negative results indicate that the application did not suffice the uptake by the crops.

(Table 2). Yet, it was decided not to give extra weight in the weighting systems applied to these indicators once the marginality of the soils was the centre of the work.

3. Results and discussion

3.1. Perennial crops cultivation impact on marginal mediterranean land

In this study four perennial crops and wheat have been analysed for their impacts on marginal Mediterranean land. In this section, results for the different categories analysed (fertilizers and pesticides related emissions, impact on soil and water resources and biological and landscape diversity) are presented and discussed to clarify the advantages and disadvantages of the different crops, as also wheat. Crops cultivated on marginal soils were compared to each other and with idle land.

3.1.1. Fertilizer and pesticides related emissions

The intensification of farming systems is increasing the losses of nutrients and pesticides from agricultural land, with detrimental effects on soil and water quality and the environment. Fig. 2 displays the impact score associated with the fertilizer-related and pesticide-related emissions derived from the cultivation of perennial crops on marginal Mediterranean land.

Concerning N fertilizer-related emissions, giant reed was the crop that showed the highest impact due to the high N input. N application is associated with acidification, greenhouse effect, ozone depletion, and ground and surface waters eutrophication [26]. Therefore, the higher the N input, the higher the risks associated with it. In contrast, Miscanthus presented a lower impact owing to low N input, followed by switchgrass and cardoon. Interestingly, giant reed, a perennial crop, showed a higher impact than the annual food crop (wheat), which diverges from the opinion that perennials show less need for fertilizers, due to less intensive soil amendment [15,26]. Nevertheless, it can be argued that the impact of giant reed cultivation will be lessened by lowering N-inputs (this will be further investigated in section 3.2). The risk associated is the yield reduction. Yet, Fagnano et al. in their work showed that giant reed gave an interesting biomass yield and gross income when grown on marginal hilly lands in a low-input cropping system [51]. Additionally, perennial crops are eligible as vegetable filters, limiting leaching due to their long growing season and the permanent and deep root system [52–54]. Taking this dynamics into account in the assessment, will reduce the burden associated with N emissions from perennials cultivation. These issues will be further evaluated in the sensitivity analysis (please see section 3.2).

Concerning K emissions, K surplus in high loads may contribute to eutrophication of terrestrial ecosystems [38]. The salinization of the soil may increase, which affects terrestrial organisms [49], and disturb a large variety of microbiologically mediated processes in soil [50]. Yet, none of the evaluated crops were hampered by K surplus (please check also the discussion in section 3.1.2), and therefore, it was attributed the same score as to idle land.

Concerning P emissions, P surplus in high loads, if leached out of the soil, may contribute to eutrophication of aquatic ecosystems [38]. Yet, leaching of P through the soil has been found to be negligible in the majority of the soils, because phosphate ions are rapidly absorbed or precipitated by soil fractions [55,56]. However, P run off from top soils, by erosion, may present some significance due to the high phosphate content [57] as well as P loss from some frozen decaying plants, as it was observed by Riddle and Bergström [58]. Soils submitted to intense cultivation conditions, that allow

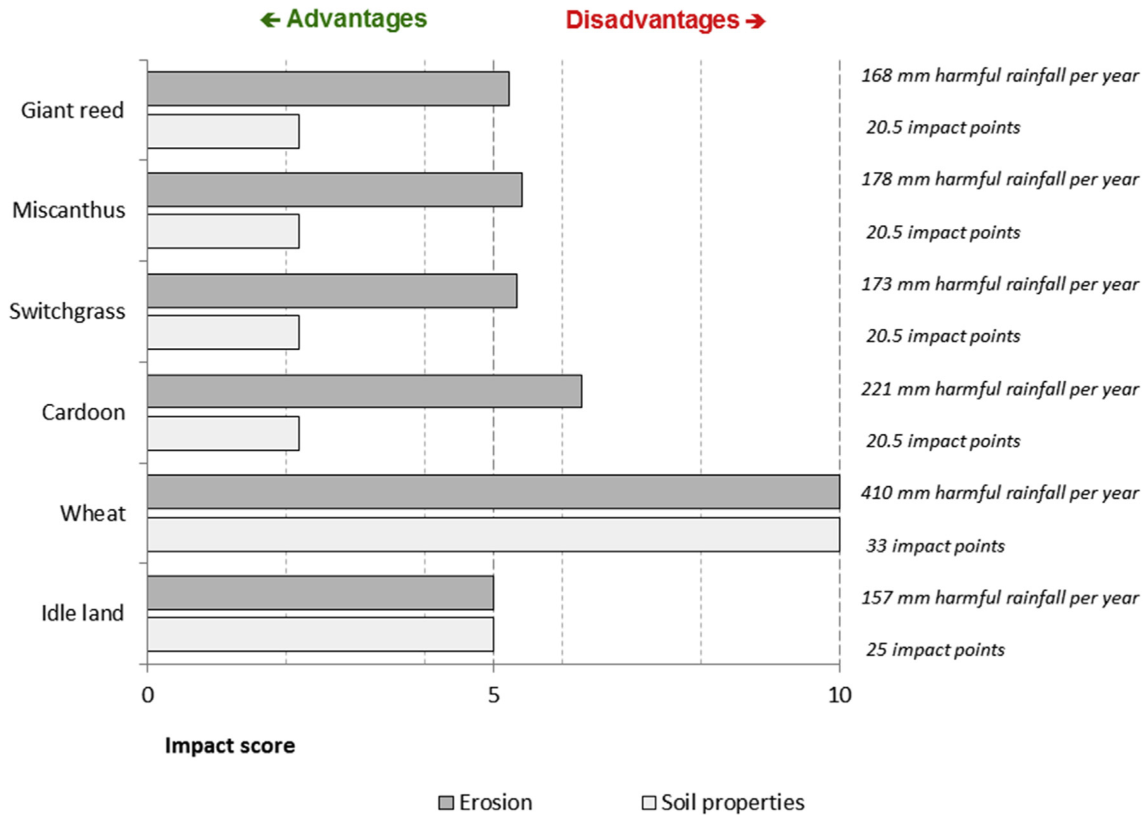

Fig. 4. Normalized scores of the impact of the perennial grasses cultivation on the erodibility and on the soil properties of marginal Mediterranean land. The graph presents also the absolute values for each crop of the total harmful rainfall used to evaluate the impacts on erosion and the score attributed to each crop regarding the soil properties, per 10 ha per year, calculated according to the methodological steps presented in Table 2.

surface water to travel directly to deeper layers of the soil, and use of manure in the fertilisation, increases the risk of P losses by leaching [57]. In fact, the use of organic amendments increases the amount of P being leached through the soil, which may result from the movement of the organically combined phosphates present in the soil solution [57]. In this work, it was only considered the application of artificial fertilizers (calcium superphosphate) and not manure. Results pointed to a balanced application of P in all the crops (please check also the discussion in section 3.1.2), and therefore, it was attributed the same score as to idle land. However, studies in the Mediterranean region [59] showed that in Miscanthus fields, in a clay soil, the resulting P surplus remained relatively inert in the soil.

In terms of pesticide-related emissions, wheat was heavily penalized due to its yearly applications. Unfavorable effects are the increased share of chemicals that seep into soil, water and air, causing noxious human health effects, damage to flora and fauna, contamination of soil and groundwater and unbalacement of pests and diseases [45]. In contrast, perennials took advantage of the use of herbicides only during planting phase of the crop, and eventually in the removal phase of the crop [60], and some crops, e.g Miscanthus and giant reed, presented no major illnesses requiring plant protection measures [61].

3.1.2. *Impact on soil*

Soil is a mixture of minerals, organic matter, gases, liquids, and countless organisms that provides a mean for aeration, water storage, supply and purification, and plays a vital role as structural and medium support for plant growth and habitat for organisms. Soil quality is affected by crop characteristics and crop management activities, which influences nutrient status, organic matter, pH, structure and erosion.

The nutrient status occurring in idle land (the reference system) was considered to be neutral, under the assumption that the uptake during vegetation growth return to the soil during senescence and decomposition (Fig. 3). Hence, when comparing with idle land, all crops, more or less, disturb the soil's nutrient status. Fertilizer application should be as balanced as possible in order to avoid excessive deficit or surplus, which can be accomplished through inputs management. Although surplus may enrich the soil nutrient pool, excessive N, P and K, will be detrimental regarding eutrophication and resources exploitation (to name a few impact categories). Reversely, excessive deficit may cause plant malnutrition and soil depletion.

Fig. 3 shows a nitrogen deficit for all perennials, indicating that nitrogen application did not suffice crop uptake and N emissions. When comparing with idle land, Miscanthus, showed the lowest impact regarding soil N reserves. Giant reed was the crop with the highest impact on the soil N reserves, followed by cardoon and switchgrass. In the case of cardoon, this negative result can be reduced if the seeds are the marketable product and the crop residues (straw) are incorporated in the field. However, for all the crops, including giant reed, the observed deficit is covered by N atmospheric deposition which accounts for 10 kg per year and per ha [41]. Cultivation of wheat showed that soil N reserves can be built up, although the surplus will be mostly lost, e.g. by leaching, impacting the ecosystems (see section 3.1.1 for additional discussion). Regarding K status, all the crops, including wheat, show that fertilizer application was unbalanced, since it is not in conformity with the crops' needs. Deeper K deficits were observed for giant

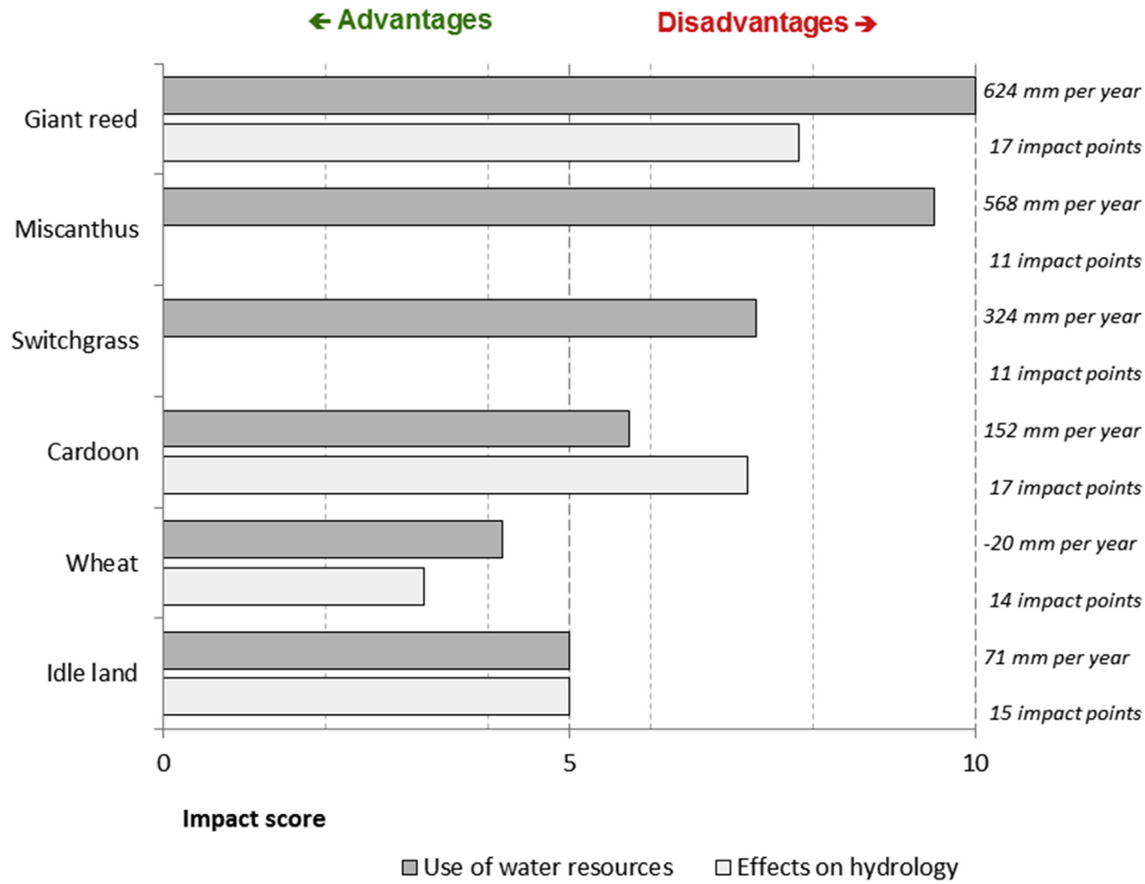

Fig. 5. Normalized scores of the impact on the water resources of the perennial grasses cultivation on marginal Mediterranean land. The graph presents also the absolute values for each crop and indicator, per 10 ha per year, calculated according to the methodological steps presented in Table 2. Concerning the use of water resources, the absolute values represent the water resources depletion of each crop. Concerning the effects on hydrology, the absolute values represent the score attributed to each crop. Negative results indicate that the crop water use was lower than the precipitation. Where bars are missing it means that the normalized score is "0".

reed. Switchgrass and wheat showed the lower deficits. Miscanthus and cardoon lie in between. However, the observed K soil depletion per year is not a matter of concern due to the abundance of this mineral in the soil (contrasting with the soil nitrogen shortage). Nevertheless, attention should be payed to avoid plant malnutrition. Concerning P status, P neutrality in the soil was verified for all the perennial crops. Regarding wheat, results showed that P-fertilizer application is unbalanced, since it was not in conformity with the crops' needs.

Soil conservation through soil erosion prevention is crucial for maintaining productivity. Erosion leads to the loss of fertile soil and structurally damage crops. Moreover, displacement of materials, such as nutrients and contaminants, through wind and water can affect nearby terrestrial and aquatic ecosystems. The highest harmfull rainfall was observed in the annual tilled crop wheat (Fig. 4). Significantly lower results were observed with perennial crops. Giant reed, Miscanthus and switchgrass showed an impact potential similar to idle land. The soil cover characteristics of cardoon influenced the higher impact score attributed to this crop. The assessment made is in line with the results presented by Cosentino et al. [24] in a sloped area of Sicily, which show that perennials reveal average lower erodibility potential and runoff due to higher rainfall capture by the deep and dense underground biomass and to a reduced exposure of the surface in a short time period.

Assessing the impact of crops on soil organic matter content, structure and pH is highly dependent on local conditions. Nonetheless, there are generic trends documented in literature that allow a comparison between perennial crops, wheat and idle land. After an extensive literature review, crops were benchmarked towards idle land and towards each other in a qualitative way (Fig. 4). The longer permanence in the field of the standing and rhizomatous biomass benefit perennial crops fields due to the accumulation of carbon which will contribute to increase the soil organic carbon stocks [62]. Evidences show that those stocks increase even below a depth that is considered sensitive to a future land use change [63]. Much less organic matter is contained in an annual plantation owing to their reduced permanence and lower inputs of residues. Perennial crops fields also promote structural integrity related to residue cover, permanence, high inputs of residues and expanded deep roots. Yet, the removal of the deep and extensive high yielding belowground biomass at the end of the crop's lifetime can also represent a burden (by releasing carbon emissions, and structurally). Opposed to this, the higher intensive soil revolving by tillage and ploughing and litter removal in annual systems maximizes the impact on soil structure [25]. In addition, the higher need for soil amendment in annual systems may alter soil pH and produce undesired waste (disposed packages). The same processes can affect herbaceous perennials systems, but the less demand for inputs and higher organic matter content curbs pH variation and waste generation [25,45]. Moreover, the recognized perennials ability for soil correction and restoration of contaminated sites granted bonuses to these crops [29–31]. Consequently, the cultivation of perennial crops (equally scored in Fig. 4) provides benefits to soil fertility, and

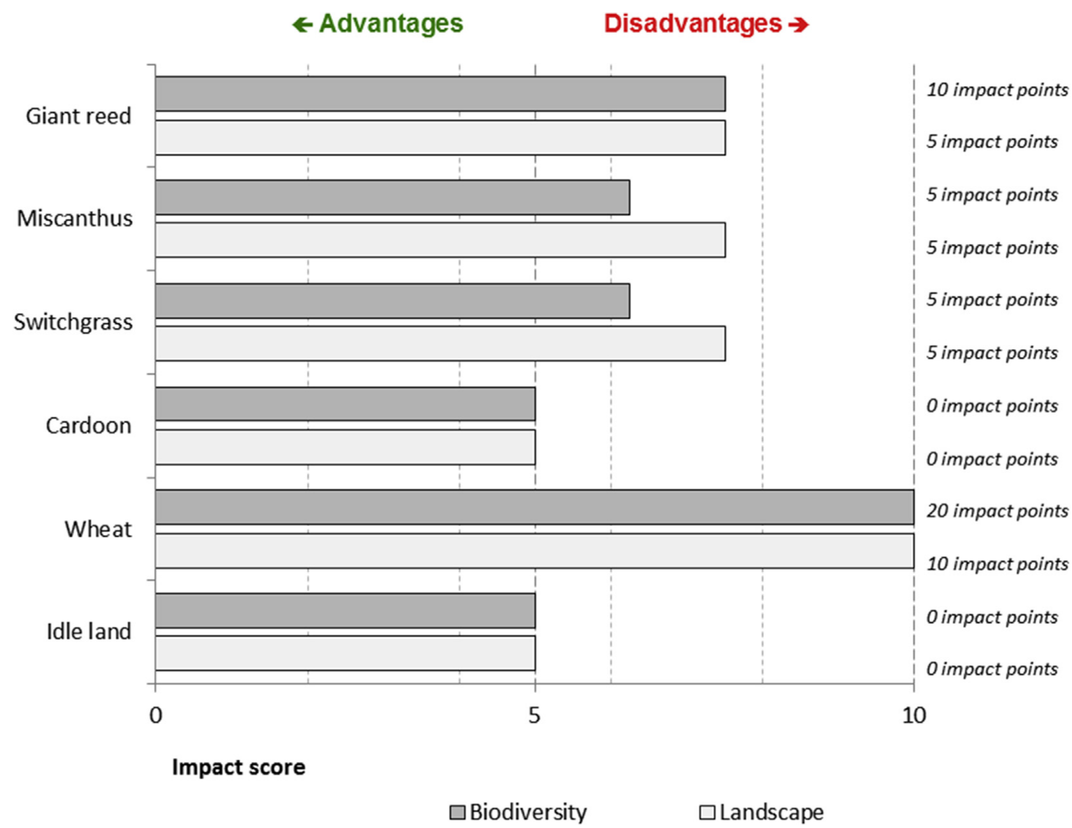

Fig. 6. Normalized scores of the impact on biodiversity and landscape of the perennial grasses cultivation on marginal Mediterranean land. The graph presents also the absolute values for each crop and indicator, per 10 ha per year. The absolute values presented for both indicators are the score calculated according to the methodological steps presented in Table 2.

therefore, compared to idle land, those crops were represented by a lower impact score. By opposition, wheat received the highest impact score.

3.1.3. *Impact on water resources*

Agriculture represents the largest share of freshwater demand in the world and also in the Mediterranean [64]. But the Mediterranean region is also facing increasing water scarcity problems [65]. Therefore, it has been suggested that stressed water resources areas should accommodate crops with low water demand [25,66]. In this respect, some perennial biomass crops perform better than annual crops used for biomass production [25,66]. Crops can either be irrigated or suppress their water needs by accessing aquifers and precipitation water. Whichever way, unless rainfall tops requirements, freshwater must be extracted from surface or groundwater, which depletes natural stocks. Hence, depletion of water resources was determined by comparing the available water provided by rainfall and the water requirements of the crop. Subtracting to water needs the available rainfall would reveal a deficit in supply or the accommodation of the requirement by the availability. According to the results presented in Fig. 5, perennials cultivation may lead to depletion of water resources, under the prevailing conditions of the Mediterranean Region. The crop with most severe average water depletion potential was giant reed, due to its highest water requirement, followed by Miscanthus and switchgrass. Cardoon among perennials was the crop with the least water depletion potential, as it presents the lowest water requirement. Interestingly, wheat cultivation is sufficed by precipitation (in typical years), scoring better than idle land that is also using water resources. When comparing the demanded water resources (presented in Fig. 5) with the applied irrigation (Table 1), the resulting figures showed a balanced approach.

Perennial crops cultivation impact on water resources can not only be judged by the water demand. The effects on hydrology should also be accounted since the utilization of water by the rooting system is dependent on local hydrological processes such as drainage and infiltration [67]. Higher soil covering, longer permanence in the soil and extensive root systems slow the travel of surface water, minimizing run-off and sediment and nutrient losses and allowing greater water infiltration. Decreased run-off allied to soil drying and increased penetration effects render perennial crops useful in flood management when cultivated in wet fields [68,69] but not annual crops, such as wheat. On the other hand, species combining higher growth rates and transpiration rates, longer seasonal growth and deeper and more complex root system (such as perennial herbaceous plants) is also disadvantageous to hydrology. Deep rooting slows down rainfall refill of aquifers, especially when associated with high evapotranspiration losses (penalizing especially giant reed, Fig. 5). The reduced irrigation on cardoon fields also penalizes this crop, once it impacts on the aquifers refill. Wheat, due to its annual character, shows an impact score lower than the permanent-aquifer-refill-barrier idle land. Miscanthus and switchgrass have overall lower impact on hydrology, mostly because the negative impacts linked with their traits are largely offset by the longer permanence in the soil and the balanced irrigation applied.

In order to reduce the impact on water resources, irrigation with wastewaters constitute a beneficial environmental alternative: water stocks will be retained and aquifers will be filled up. Moreover, perennial crops fields constitute a promising bioreactor for

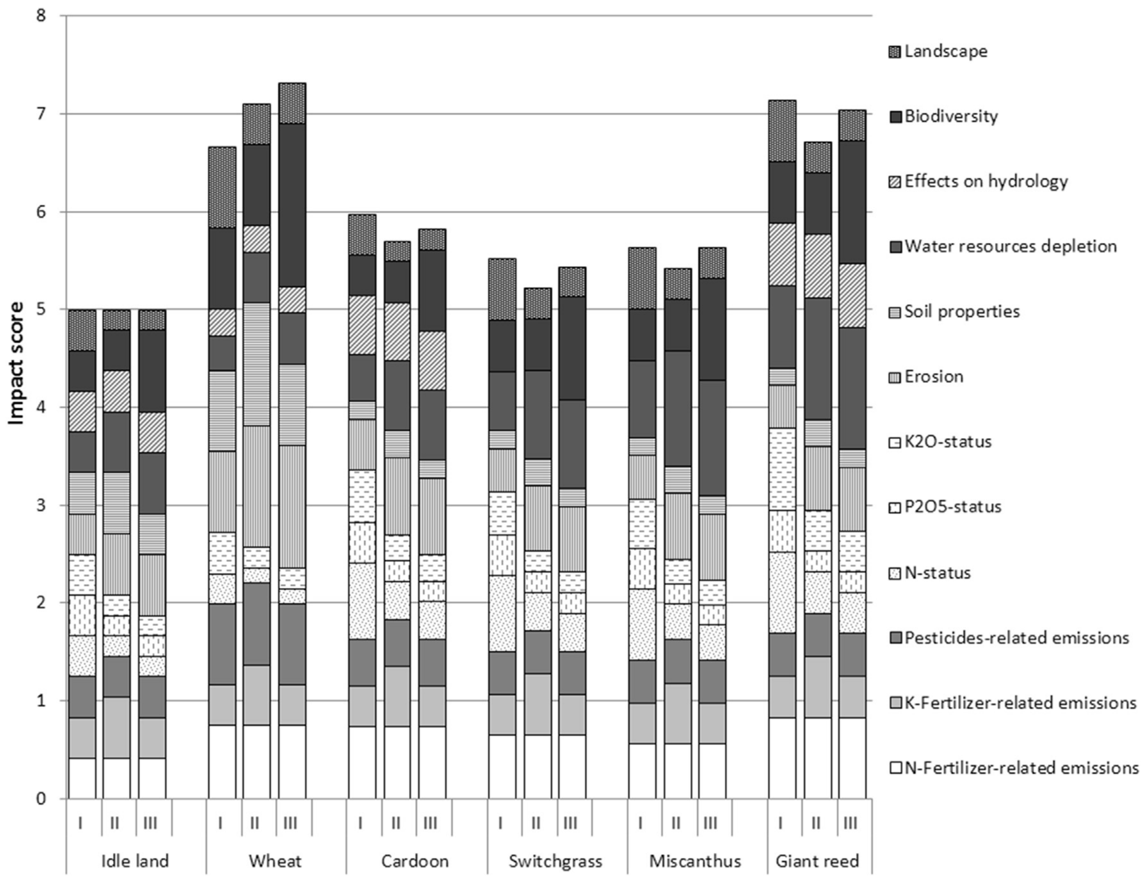

Fig. 7. Final environmental impact assessment of perennial grasses cultivation on marginal Mediterranean land (I – WS1; II – WS2: III – WS3).

the remediation of wastewaters, since excessive nutrients and pollutants will be intercepted by the extensive underground system, improving the quality characteristics of the released effluents [53,54]. As wheat takes part in the food chain, irrigation with wastewaters is not an option.

3.1.4. Biological and landscape diversity

Perennial rhizomatous crops like Miscanthus, switchgrass, giant reed and cardoon require a reduced soil tillage and use of agrochemicals (as fertilizers and pesticides). This reduced land disturbance, by comparison with annual crops, affords perennial fields with a high cover value for wildlife [70,71], supporting the enrichment in biodiversity (Fig. 6). These plants have a high above and belowground biomass, increasing the soil organic matter content due to rhizome biomass accumulation and litter deposition. These conditions favor diversity and occurrence of soil microorganisms and soil fauna, especially decomposers. Moreover, since the crops are usually harvested in the spring, the fields are used as an over-wintering sites for invertebrates and shelter for birds and small mammals [72]. Among perennials, the aggressiveness (invasive character) of giant reed [73] penalized this crop, and the native and flowering character benefited cardoon. Idle land scored as cardoon, given the complex structure and heterogeneity of the vegetation system which have a positive influence on its cover value for wildlife [74].

Landscape diversity scores followed the same pattern of the biodiversity values. The impact on landscape values in even among crops (Fig. 6). While wheat looses in homogeneity and structure, gains are verified in crops that have richer structure (perennials). But the resulting monoculture extensive farming system may be very rough for biological landscape diversity [37], compared with native conditions. The blossoming stage associated with cardoon fields granted this crop a bonus, classifying it similarly to idle land.

3.1.5. Overall results

Fig. 7 shows the overall environmental impact of the different crops studied. All the investigated crops present higher overall environmental impact than idle land, but, less impact than wheat (excepting giant reed in WS1). Therefore, the results suggest that growing perennial crops in marginal Mediterranean soils would benefit the environment (regarding the studied categories) comparing to wheat farming. Among the different perennials, switchgrass and Miscanthus presented a similar score, and the difference to idle land was narrow. Switchgrass plantations score was mostly influence by N-status. Concerning Miscanthus, N-status and water resources depletion were the indicators that contributed mostly for the impact of the crop. N fertilizer related emissions and N-status, were the indicators that mostly influenced cardoon fields' score, which showed and increased impact compared to Miscanthus and switchgrass. Giant reed was the most impactful perennial crop due especially to N and K-status, N fertilizer related emissions and water resources depletion. The high impact score attributed to wheat was given mostly by the indicators N-fertilizer and pesticides related emissions, erosion, soil properties, and biological and landscape diversity. Results show that the application of the weighting step aggravates the impact of wheat but, on the contrary, benefits all perennial crops. Emphasis on biodiversity (WS3) in detriment to soil degradation drivers (WS2) inflicts a higher impact. However, if perennial crops were to be sorted according to their performance, weighting would not significantly

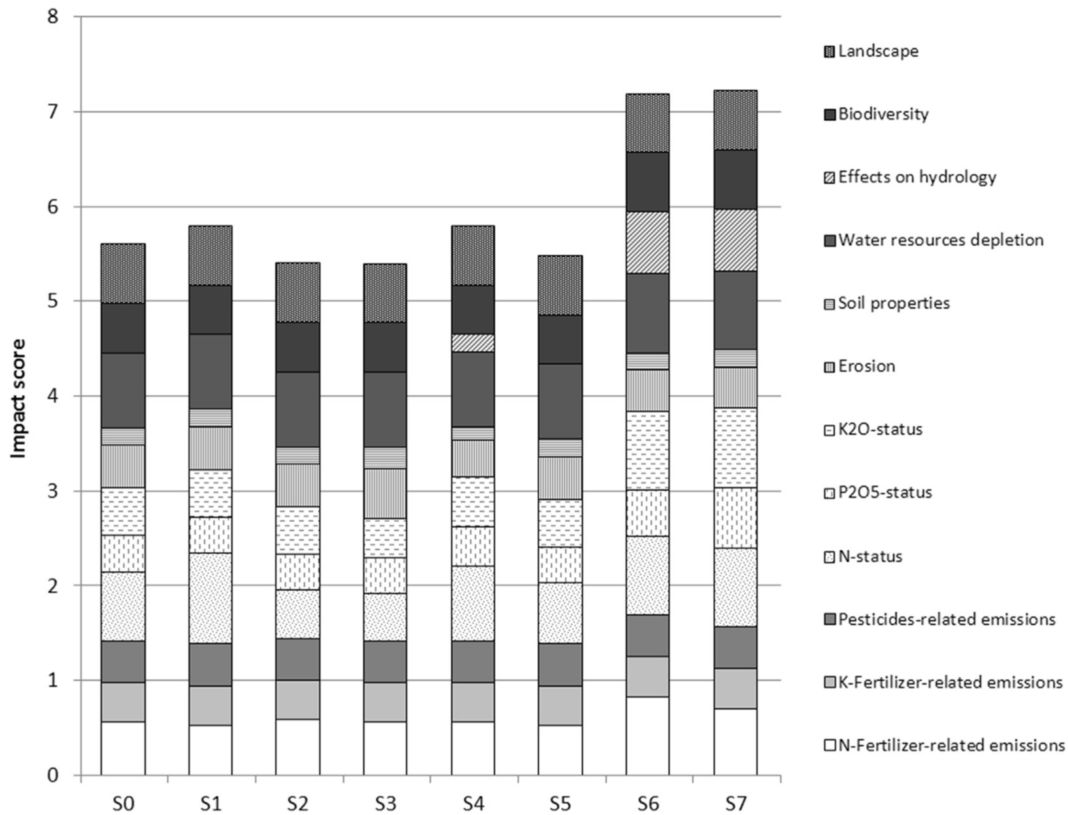

Fig. 8. Environmental impact assessment of Miscanthus cultivation on marginal Mediterranean land (S0: Miscanthus base study; S1: −20% N fertilizer, Miscanthus; S2: +20% N fertilizer, Miscanthus; S3: −30% yield, Miscanthus; S4: +30% yield, Miscanthus; S5: −20% N-fertilizer related emissions, Miscanthus; S6: Giant reed base study; S7: −30% N, P and K fertilizers, Giant reed).

influence their relative position. The only exception is giant reed which presents a better score, compared with wheat, when both weighting systems are applied.

3.2. *Sensitivity analysis*

Caution must be applied, nonetheless, when the results rely on quantified ranges dependent upon the intensity level of inputs and on the estimated yields. Therefore, it can be questioned what will it be the score of perennial crops if fertilizers are applied in a moderate manner (−20% N-fertilizer, S1 case). But production of perennial crops in marginal soils may rely also on a higher supply of artificial fertilizers (+20% N-fertilizer, S2), to overcome the soil deficiencies. And what will be the score if the marginality of the soils is so severe that yields will drop further 30%? (−30% yield, S3). It can also be quizzed if cultivating perennial crops on marginal land presents a higher environmental impact than on fertile land (+30% yield, S4). Concerning N-fertilizer related emissions, it can also be questioned if the extensive underground biomass observed in perennial crops fields will not trap the leached nitrogen (−20% N-fertilizer related emissions, S5).

Fig. 8 displays the results obtained for the investigated options (S1-S5 plus S0, the base study presented in section 3.1) based on the cultivation of Miscanthus, which was considered the best performing crop, either from the EIA results presented in this work but also from the EIA and LCA results previously obtained in the framework of the OPTIMA project [3,37]. As giant reed was the crop that presented the highest N, P and K input, it was considered to study the impact of this crop if a lower fertilizer rate was applied (30% N, P and K-fertilizers, S7 case, plus S6, the base study for giant reed). In this assessment, no weighting system was applied (WS1).

Results presented show that EIA scores do not vary significantly when the parameters tested are subjected to the changes essayed. Providing less fertilizers (S1 and S7) will reduce the impact associated with N, P and K-fertilizer related emissions, but the impact on N, P and K-surplus will be increased. In contrast, the need to increase N inputs (S2) will reduce the impact of the N-surplus but will increase the N-fertilizer related emissions. If yields will be reduced by 30% (S3), the uptake of NP and K will be lower, and the impacts related with NPK-status will be reduced. But, the lower densification of the biomass will increase the impacts associated with erosion and soil properties. Reversely, if the yields are similar to the ones in fertile soil (S4), NPK-surplus scores will be penalized and the erosion and soil properties indicators will be improved. When it was considered that the underground biomass of Miscanthus traps a higher amount of N leachates (S5), impacts associated with N-fertilizer related emissions were reduced, and N-status also, because the amount of N-trapped by the underground biomass reduced the N-deficit observed in S0 scenario.

4. Conclusions and recommendations

This study provides a generic framework on the expected environmental consequences of cultivating a set of perennial crops in marginal Mediterranean soils. Results suggest that growing perennial crops do not inflict higher impact to the environment comparing to wheat farming (regarding the studied categories). In a scale from 0 (lower impact) to 10 (higher impact), wheat and giant reed showed similar scores (6.7−7.3 and 6.7−7.1, respectively). Reversely, all the perennial crops resulted in a higher score when compared with idle land (the reference system with a score of 5), increasing in the order switchgrass (5.2–5.5), Miscanthus (5.4–5.6), cardoon (5.7–6.0), being giant reed (6.7–7.1) the most penalized crop. Globally, switchgrass and Miscanthus showed the lowest difference to the reference system because of their low nutrient demand and high biomass production.

However, looking into the different indicators studied, perennial crops cultivation provides environmental advantages in terms of soil properties and erosion (with an average score of 2.2 and 5.6, respectively), against the score of the reference system (5.0). The reduced land disturbance, the higher biomass production and the longer permanence periods contribute to this. Cardoon perform better regarding specific impacts, e.g. effect on biodiversity and landscape (scoring 5.0 like idle land) because of the flowering period and effect on water resources depletion (scoring 5.7) because of the low water need. Also, perennial crops cultivation do stand out as being beneficial in terms of K (with an average score of 5.0) and pesticide-related emissions (with an average score of 5.4) and P and K-status (with average scores of 5.0 and 6.9, respectively) (in this last indicator, the exception is giant reed). This is a consequence of the less management intensification and the need for less inputs. Less benefits derived from the N-fertilizer related emissions and N-status indicators (with average scores of 8.3 and 9.4, respectively), and from the indicators related with the impact on water resources (average score of 8.1).

Impact reduction strategies are limited to crop management options (namely inputs) which can influence emissions and nutrient status but the remaining impacts are site specific dependent, intertwined with crops traits. Therefore, the implementation of bioenergy systems derived from perennial crops cultivation should evaluate also the adequacy between crop and location. Assessing site-specific factors such as the quality of soil and groundwater, and effects on local biodiversity and landscape will give important information that can be uploaded in LCA and EIA studies, minimizing the existing gaps and strengthening the outcoming results.

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