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Environmental consequences of the conversion from traditional to energy cropping systems in a Mediterranean area

Stefania Solinas[a,*], Simone Fazio[b], Giovanna Seddaiu[a,c], Pier Paolo Roggero[a,c], Paola A. Deligios[a], Luca Doro[c], Luigi Ledda[a,c]

[a] Dipartimento di Agraria, University of Sassari,Viale Italia 39, 07100 Sassari, Italy
[b] LCA and Renewable Energy Expert (consultant), Via Suore 10/Q, 40026 Imola, BO, Italy
[c] Nucleo di Ricerca sulla Desertificazione – NRD, University of Sassari, Viale Italia 39, 07100 Sassari, Italy

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ABSTRACT

The bioenergy production greatly runs around the controversial interconnections among food, energy and environment that have noteworthy implications in various spheres. Using a cropping system approach, this study aimed at evaluating environmental impact variations associated to switching from traditional cereal, forage and horticultural systems to food/energy ones under Mediterranean conditions. The alternative scenarios included the introduction of rapeseed as dedicated energy crop in the cereal cropping systems, the valorization of artichoke residuals for energy production in the horticultural system and the shift from forage to biomass for energy production in the forage systems. A "cradle to farm gate" consequential Life Cycle Assessment approach was used that allowed to identify the environmental "hot spots" of the agricultural practices. The introduction of rapeseed into cereal crop systems and, to a lesser extent the conversion of forage systems into energy systems, showed positive effects on the environmental farming sustainability, with a variation of −32% and −8% burdens on land basis, respectively. The harvesting of artichoke residues for energy production required additional energy inputs leading to an increased impact compared to the solely edible heads harvest (+88%) on land basis.

These findings provide useful information for improving agricultural practices and designing land allocation options among crops of these Mediterranean cropping systems aiming to minimize food/energy competition and environmental burdens.

1. Introduction

The biomass from dedicated energy crops is expected to be the main source for bioenergy production in the next future (Bentsen and Felby, 2012; Krasuska et al., 2010). Several crop species are used as biomass feedstock for energy production – specifically first and second generation biofuels – although their performances strongly depend on agricultural practices management, spatial distribution and costs required in order to satisfy the industrial demand (Zegada-Lizarazu et al., 2010). A small range of food crops are currently used for first generation biofuels production because of the low biofuels productivity, the high energy input requirements and the feedstock conversion technologies that limit both the CO_2 emissions and fossil fuel consumption (López-Bellido et al., 2014). These economic and environmental constraints might be reduced through the use of perennial forage crops for second generation bioenergy production (Jaradat, 2010).

For instance, high-diversity mixture of native perennial grass species grown on degraded land and characterized by low input requirements might have lower GHG emissions than those of single dedicated crop species such in the case of maize monoculture grown on fertile soils and with high inputs (Jaradat, 2010; Tilman et al., 2006). At the same time, the dedicated energy crops are sometimes considered a strategy to guarantee bioenergy production without affecting food security and environment since they can adapt to land types that are not suitable for food production, limit CO_2 emissions and natural resources degradation and reduce the

Abbreviations: ADP, Abiotic Depletion Potential; AP, Acidification Potential; Ar, Artichoke; Ar +, Artichoke + residual; Ba, Barley; CAP, Common Agricultural Policy; CML2, Center of Environmental Science of Leiden UniversityNL; DM, dry matter; DW, Durum Wheat; EP, Eutrophication Potential; EU, European Union; GWP, Global Warming Potential; HTP, Human Toxicity Potential; iLUC, indirect Land Use Change; LCA, Life Cycle Assessment; Ma, maize; MAEP, Marine Aquatic Ecotoxicity Potential; ODP, Ozone Depletion Potential; POCP, Photochemical Ozone Creation Potential; Ra, rapeseed; Ry, ryegrass; Sub. Equiv., Substance Equivalent; TEP, Terrestrial Ecotoxicity Potential; Tr, triticale.

* Corresponding author. Fax: +39 79229394.
E-mail addresses: ssolinas@uniss.it (S. Solinas), sim.faz@libero.it (S. Fazio), gseddaiu@uniss.it (G. Seddaiu), pproggero@uniss.it (P.P. Roggero), pdeli@uniss.it (P.A. Deligios), ldoro@uniss.it (L. Doro), lledda@uniss.it (L. Ledda).

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production inputs demand (Dipti and Priyanka, 2013). However, the energy crops cultivation is not devoid from objections about the competition with food crops for land, water, fertilizers, *etc.* and their economic and environmental benefits depend on a thorough assessment of the production system efficiency as a whole (Dalla Marta et al., 2010). The bioenergy production greatly runs around the controversial interconnections among food, energy and environment that have noteworthy implications in terms of land availability and biomass potential (Popp et al., 2014; Long et al., 2013). Since biomass production for contributing to energy security exploits a finite resource which can be alternatively used for food production, land competition could be a risk for food security in a long term perspective (Fritsche et al., 2010; Rathmann et al., 2010). The changes in land uses, including the availability for biomass production, is a thorny issue which is expected to be affected by various factors such as agricultural productivity enhancements, change in diets (Johansson, 2013; Haberl et al., 2011), inputs availability and their use (*e.g.* land, water, fertilizers and pesticides), technological advancements in farming intensification (Allen et al., 2013). Nevertheless, different options could be implemented in order to mitigate the food-energy-environment conflict and, as a consequence, to guarantee the biomass production sustainability. A useful response to land conflicts might be the integration of food/feed and energy crops in cropping systems and/or an adequate land allocation among these crops (Dauber et al., 2012). Moreover, well planned crop rotations including energy crops could contribute to reduce the external input requirements and the natural resources exploitation and to improve the carbon sink and the land productivity (Zegada-Lizarazu and Monti, 2011). Technological improvements with respect to resource use efficiency, crop productivity, agricultural practices, *etc.* integrated with careful agricultural land use planning are recognized to play a significant role in energetic biomass production (Scarlat et al., 2013; Bringezu et al., 2009) even under conditions constrained by climate, water availability and soil fertility (Spiertz, 2013). However, poor attention has been put on detecting and then analysing the farmers' attitude towards a change of farming systems in favour of bioenergy production (Giannoccaro and Berbel, 2012). Nevertheless, farmers' point of view appears to affect by a variety of different and constraining socio-economic and political factors (*e.g.* educational level, off-farm job, farm typology specialization, Agricultural Policy measures, food prices and bioenergy requirement) (Giannoccaro et al., 2014; Ostwald et al., 2013).

The competition bioenergy *vs.* food/feed crops might be reduced through the exploitation of the so called "surplus" lands for energy crops cultivation (Dauber et al., 2012; RFA, 2008) which include degraded, abandoned and/or marginal lands. However, despite these surplus lands might play a noteworthy role for bioenergy crop diffusion, they are not devoid of environmental and socio-economic constraints (Spiertz, 2013; Dauber et al., 2012).

An additional valid alternative for reducing conflicts among food, energy and environment could be represented by the exploitation of crop residues for bioenergy production (Cherubini and Ulgiati, 2010; Scarlat et al., 2010), although the sustainability of this biomass source is an ongoing thorny issue (Weiser et al., 2014; Muth and Bryden, 2013; Jiang et al., 2012). The removal of agricultural residues for bioenergy production is strongly affected by several factors that should be taken into account in order to foster the environmental sustainable use of these biomass sources (Muth et al., 2013).

Various studies have tackled the environmental implications of the energy crops cultivation in the EU Mediterranean context and with respect to the main local agricultural systems (Bacenetti et al., 2014; Palmieri et al., 2014; Fazio and Monti, 2011; Fernando et al., 2010). However, to our knowledge poor attention has been put on the assessment of the environmental burdens (*i.e.* substances and energy emitted to soil, air and water by a certain product during its life cycle) variation due to the conversion from food/feed cropping systems to food/energy systems.

In this study, the environmental sustainability associated to the conversion of some traditional food or feed cropping systems into alternative systems devoted to integrally or partially produce biomass for energy purposes has been evaluated in a Mediterranean area. The LCA methodology was used to identify the environmental burdens and benefits deriving from cropping system conversions. This analysis could be a useful support for farmers' decisions toward a harmonic and sustainable balance between food and bioenergy production at farm scale. Moreover, the assessment of the environmental impacts of energy cropping systems might provide relevant suggestions for addressing policy strategies that might foster the implementation of sustainable agricultural practices and the identification of trade-offs between food and bioenergy production systems.

2. Methodology: Life Cycle Assessment

The LCA is a quantitative tool for evaluating the potential environmental impacts related to products or services aimed at identifying possible improvements in terms of environmental burdens reduction and resource management (Baumann and Tillman, 2004). It was chosen because it is a tool widely applied for evaluating environmental burdens in agricultural production systems with reference to both crops and cropping systems under different agro-ecological conditions (Goglio et al., 2012; Fazio and Monti, 2011; Brentrup et al., 2004). Although the LCA approach in agriculture is often performed on single crop basis, in this study LCA was applied at cropping system level, *i.e.* considering the whole rotation cycle and agronomic practices needed. Therefore the LCA was modeled by comparing traditional *vs* alternative cropping systems under specific agricultural contexts.

In this study, the LCA was performed according to the ISO standardization guidelines (ISO, 2006) and through the Simapro 7.3.3 software (Goedkoop et al., 2010a,b).

2.1. Goal and scope definition

The main goal of this study was to compare the environmental sustainability of some traditional *vs* alternative cropping systems (*i.e.* for energy or integrated energy and food purposes) in the context of irrigated and rainfed Mediterranean cropping systems. Specifically, this paper aimed to: (i) assess the environmental impacts of different energy and food crops; (ii) evaluate the environmental sustainability variation due to the introduction of energy crops within cropping systems traditionally focused on food and/or feed production. The study was carried out considering three traditional cropping systems (Fig. 1) in Sardinia (Italy) that are the most predominant in the island (INEA, 2014) as well as representative of relevant agricultural systems in the Mediterranean Basin: rainfed winter cereal cropping systems, irrigated forage systems for dairy cattle and horticultural system based on globe artichoke growing. The alternative scenarios (Fig. 1) were selected among those that are deemed representative of the most probable opportunity for the socio-economic development of the Mediterranean areas and consequently to mitigate the recent difficulties of the agricultural sector (Floris et al., 2013; Deligios et al., 2011; Solinas et al., 2011).

The Sardinia region can be considered a suitable territory for cropping systems development based on energy crops since the economic crisis that the industrial, agricultural and livestock sectors are facing in this island is leading to land abandonment or conversion of arable land into grasslands even in areas served by irrigation infrastructures (Cocco et al., 2014; Ledda et al., 2013;