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Can the Life Cycle Assessment methodology be adopted to support a single farm on its environmental impacts forecast evaluation between conventional and organic production? An Italian case study

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ABSTRACT

The role of the life cycle assessment (LCA) in the agrifood sector is widely recognised as an important tool that supports environmental decision-making. The main difference between agricultural and industrial studies is the need to evaluate output data from the natural processes that result from farming practices, especially fertilisation and pesticide treatments. Many LCA studies in the agrifood sector have been conducted on a large geographical scale (regional or national) and have considered data from multiple production years.

The main goal of this research is to understand whether a study based on the LCA approach can support a single farm's comparative forecast evaluation of conventional and organic production based on primary data relative to a short time period and considering site-specific climate conditions. For this purpose, two operative steps were implemented: (i) a comparative environmental assessment of conventional and organic production within a simulated three-year cycle that tested the results through an uncertainty analysis and (ii) a sensitivity analysis to assess the influence of the geoclimatic factors on the impact assessment results.

Primary data that reference a specific production year from an Italian farm situated in the Polesine area were considered. A "from cradle to farm gate" comparative LCA was performed, considering the conventional and organic production of barley and soybean. The influence of the spring rainfall index on the environmental assessment results was analysed with a sensitivity analysis by modelling 18 different scenarios.

This research suggests that the annual variation in agricultural production must be considered when comparing organic and conventional farming. The spring rainfall index significantly influenced yields and, therefore, the comparative results, thus shifting the preference from one farming system to the other.

This study confirms the usefulness of the methodological LCA approach, even for a single farm using historical data that related to a short period of time (e.g., one year). The results can be considered for provisional assumptions about the environmental impact assessment of different agricultural cycles (conventional or organic).

1. Introduction

Recently, great attention has been paid to conventional and organic production, which, at the EU level, is regulated by the Council Regulation (EC) No. 834/2007 (EC, 2007). The EC establishes the essential elements of organic crop production, including fertility management, choice of species and varieties, multiannual crop rotation, recycling of organic materials and cultivation.

Many studies have been conducted in these areas using the life cycle assessment (LCA) methodology to evaluate the environmental impacts of organic and conventional agrifood productions (Notarnicola, 2011; Notarnicola et al., 2012; Zimmermann et al., 2011). Because of the significant differences between agricultural and industrial systems, the LCA application in the agrifood sector requires methodological modifications and adaptations (Audsley et al., 1997; Bessou et al., 2013; Mila i Canals et al., 2006; Roy et al., 2009).

In agricultural production, the LCA methodology is usually applied to compare different alternative production scenarios, for

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both the production and tillage levels, and some applications are focussed on the comparison between organic and conventional practices (Dalgaard et al., 2001; De Backer et al., 2009; Meier et al., 2012; Meisterling et al., 2009; Refsgaard et al., 1998; Salomone and Ioppolo, 2012). Several common elements have emerged from LCA studies that compare conventional and organic farming. Whereas organic farming improves the soil quality and biodiversity (Mader et al., 2002; Tuomisto et al., 2012) and reduces the use of pesticides (Meisterling et al., 2009; Roy et al., 2009), conventional farming typically has higher yields than organic farming (de Ponti et al., 2012; Salomone and Ioppolo, 2012; Seufert et al., 2012) and, consequently, requires less land than organic production (Van der Werf et al., 2009; Williams et al., 2010) to achieve the same quantity of product.

Furthermore, for these types of LCA studies, specific farm site features such as climate, soil properties and crop management are all important factors that may have a significant influence on the product (Kim et al., 2009). Pacini et al. (2003) underlined the reliance between regional pedoclimatic factors and the environmental performance of the cultivations, and several LCA studies have provided detailed descriptions of the local factors related to this case (Martinez-Blanco et al., 2011; Mila i Canals, 2006). These indices can influence, for example, the balance of soil nutrients such as nitrogen (N), phosphorus (P) and potassium (K), the growth of insect pests and weeds and, consequently, crop yields.

Currently, most LCA studies in the agrifood sector have been conducted on a regional or national scale and have considered historical data on a large temporal scale (4 years or more) (Blengini et al., 2011; Cellura et al., 2012; Kim et al., 2009; Roer et al., 2012). However, a single farm cannot base its business and strategic choices on studies that are not case-specific. Additionally, a small- to medium-sized farm rarely has the available data related to a large period of time, and average data from a database could be very different from real, case-specific data (see also Abeliotis et al., 2013; Notarnicola et al., 2013). Particular geoclimatic and site-specific conditions could have relevant influences on the LCA results in the agrifood sector (Martìnez-Blanco et al., 2011; Pacini et al., 2003).

The main goal of this research is to understand whether an environmental assessment based on the recognised LCA methodological approach can support a single farm's comparative forecast evaluation of conventional and organic farming based on primary data relative to a short time period (one year) and considering site-specific climate conditions (in particular rainfall conditions).

For this purpose, we focussed on two actions: (i) a comparative environmental impact assessment to evaluate the potential environmental impacts of soybean and barley production in conventional and organic farming systems within a simulated three-year cycle that tests the results through an uncertainty analysis and (ii) a sensitivity analysis on the impact assessment results in modelling all of the possible scenarios to assess the influence of the spring rainfall index as an important geoclimatic factor.

2. Materials and methods

2.1. Comparative environmental impact assessment of conventional and organic simulated cycles

To evaluate the differences in the environmental impacts of two simulated agricultural cycles and to analyse the influence of the spring rainfall index as a geoclimatic parameter, we performed a comparative assessment of soybean and barley production with conventional or organic farming following the approach suggested for an LCA study. Unlike other studies in the literature (Fukushima and Chen, 2009; Knudesen et al., 2010; Mohammadi et al., 2013), the inventory data elaborated in this study are derived from activity data for a specific farm located in the Polesine area in the eastern part of the Po Valley region in the Rovigo Province (Italy). For this simulation, we have considered activity data from a specific annual agricultural production where standard conditions, in terms of climate conditions and therefore yields, were verified. These data have been combined for the simulation of a three-year cycle, in particular soybean–barley–soybean, for both conventional and organic cycles. We assumed an agricultural cycle because the multiannual crop rotation is mandatory for organic production in accordance with Art. 12 of the Council Regulation's crop production rules (EC, 2007) and because it is considered a good agricultural practice for conventional agriculture. Cultivation methodology can increase soil quality and reduce the nitrogen fertiliser requirements for crop production (Meisterling et al., 2009).

In accordance with the requirements of the international standard for LCA studies (ISO, 2006a,b), we have defined the goals and the system boundaries for our study and collected inventory data to calculate the final results by means of a life cycle impact assessment.

2.1.1. Goal and scope definition and system boundaries

For the comparative impact assessment of two simulated agricultural cycles (conventional versus organic), we first analysed four different crop systems: conventional and organic barley and conventional and organic soybeans. The three-year cycles compared were identified as soybeans-barley-soybeans.

The focus of this specific study was on the agricultural stage, and the product system included all of the agricultural processes that were required for the production of soybeans and barley as well as the auxiliary processes such as the transport of seeds and fertiliser and the maintenance of farm vehicles, as suggested by Mila i Canals et al. (2006).

A mass-based functional unit is adequate when analysing only the agricultural stages of the life cycle of an agricultural product (Audsley et al., 1997; Mila i Canals et al., 2006; Hayashi, 2013). In accordance with the scope of the study, the functional unit (FU) was 1 kg of harvested seeds in the three years, composed of 1/3 kg of soybeans from the first production year, 1/3 kg of barley from the second year and 1/3 kg of soybeans from the third year.

Because the focus of the study was crop production rather than product transformation, storage or consumption, the system boundaries included all of the life cycle stages "from cradle to the farm gate" (see also Abeliotis et al., 2013; Nemecek et al., 2011; Roer et al., 2012), excluding the distribution, processing and consumption of products (see also Mila i Canals et al., 2006; Zimmermann et al., 2011). The system boundaries include the soybean and barley production processes from ploughing to harvesting and the manufacturing processes of chemical and organic fertilisers, herbicides, pesticides and fuels. The cut-off criteria for the initial inclusion of inputs and outputs were based on 1% mass: the mass input and output that cumulatively contribute more than 99% to the mass input and output of the product system are included in our analysis (see also Abeliotis et al., 2013).

Fig. 1 represents the system boundaries of the four annual cultivations studied: a) conventional soybeans, b) conventional barley, c) organic soybeans and d) organic barley. All the specific agricultural steps are reported as well as all the inputs and outputs considered for each product system.

Although some studies suggest that machine production is relevant when assessing the environmental impact of agriculture (Mila i Canals, 2006), in this case, considering the comparative nature of the environmental assessment study, agricultural machinery and equipment (i.e., tractors, ploughs, and harvesters) were