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Life cycle assessment of open field and greenhouse cultivation of lettuce and barley

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A B S T R A C T

In the present paper, a life cycle assessment (LCA) study regarding barley and lettuce production in Spain (Barrax and Santomera regions) and Italy (Albenga region) in both open field (OF) and standard greenhouse (GH) cultivations was performed in order to evaluate energy consumption and environmental impacts. The study examines also the impact of the use of compost produced from agricultural wastes (AW). In this context, a detailed life cycle directory was created, based on site-specific experimental data, and used for a holistic cradle-to-gate LCA analysis using the GaBi 6 software package and specific related databases. In order to reveal the importance of system boundaries, factors that are often excluded from LCA studies, such as agricultural machinery manufacture, nursery production, waste management and raw materials transportation have been considered.

According to the results of this study, the use of compost for fertilization of both crops is considered a good agronomic and ecological strategy in order to maintain productivity in terms of yield, especially in the case of greenhouse cultivation, and improve overall sustainability in the agricultural sector. Moreover, the phases of compost production, irrigation system, and greenhouse construction and operation were identified as the three main "hot-spots" with the highest environmental impact and energy contribution in all studied cases. Finally, improvements to reduce those impacts were proposed.

1. Introduction

The assessment of environmental impacts in agriculture is a fundamental task towards promoting sustainability of the sector. European Union aims to integrate environmental sustainability in economic growth, thus the use of life cycle assessment (LCA) studies is considered as a decision-support tool to evaluate different scenarios and highlight the environmental hot-spots in the life cycle of a product or a system [1–3].

LCA is a standardized methodology for the assessment of the potential environmental, human health and resource scarcity impacts associated with products and services throughout their life cycle, and includes raw material extraction, transportation, processing, product development and production, use and end-of-life treatment. LCA can identify improvements on the environmental performance of products in different life cycle stages, and assist decision-making, marketing and communication activities [4–7].

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According to the Directive 2008/98/EC [8], waste production should be reduced while recycling and re-use should be promoted in all sectors. Composting is the most widely considered treatment option for agricultural waste (AW) management, accounting for 95% of the current biological treatment operations [9]. The use of compost produced from AW for the fertilization of crops is considered as a promising alternative waste management option. However, since minimization of environmental impacts should be always taken into account, appropriate environmental indicators, including compost and soil quality or erosion degree must be also considered [10,11]. The functional structure of an LCA framework includes all life cycle stages and in addition measures and integrates typical inputs and outputs. When several impact categories (e.g. global warming, acidification, ozone depletion, and eutrophication potential) are taken into consideration, the implementation of a thorough LCA analysis becomes a quite complex process [12,13].

A cradle-to-gate LCA approach takes into account all life cycle stages, from raw materials extraction up to the distribution of the final product, while a cradle-to-grave approach takes into account all life cycle stages from raw materials extraction up to its disposal at the end of life. It is noted that cradle-to-gate boundaries can vary according to the position of the 'gate' [14]. The magnitude of environmental impacts depends on the system boundaries and the main factors considered. Regarding agricultural systems, due to their complexity, it is very important to include in LCA studies factors such as machinery manufacture, as well as pesticide and fertilizers transport, in order to obtain more reliable results [15]. Exclusion of these factors, mainly due to lack of reliable data, may often result in over- or underestimation of the impacts and thus in wrong decision making.

LCA studies were first carried out to assess the environmental impacts of industrial processes and later they included agricultural processes. Agriculture is very intensive in terms of land use, relies on natural resources, is often seasonal and is strongly related to factors such as soil characteristics, water availability, climatic conditions and presence of weeds, insect pests and pathogens. Therefore, various adaptations and assumptions regarding system boundaries, allocation methods to partition environmental loads and impacts categories should be considered in LCA studies [16–18].

For the development of a sustainable waste management model or strategy, environmental, economic and social aspects should be considered. The model can be either simple, if aims at optimization of single flows or process parameters, or complex in order to evaluate alternative waste management strategies [19]. Various LCA studies have been carried out on waste management systems and practices or for the comparison of different management options mainly related to sewage sludge and municipal solid wastes [20–25]. However, very few LCA studies have been carried out to assess impacts related to AW management and application of compost on soils [26–28].

This LCA study attempts to (i) evaluate and compare the application of AW in three different sites in Italy and Spain during the life cycle of lettuce and barley production considering two cultivation systems, open-field and greenhouse, (ii) identify the cultivation phases/sub-phases and hotspots that are energy intensive and cause most environmental impacts, and (iii) provide suggestions for improving the environmental performance of the cultivations studied.

2. Sites and methodology

2.1. *Study sites*

The sites used in the present study are located in (i) Albenga, region of Liguria, province of Savona, Italy (44°04′05.54″N–8°12′45.51″E), (ii) Finca las Tiesas, municipality of Barrax, province of Albacete, Autonomous Community of Castilla La Mancha, Spain (38°06′34.3″N–1°02′16.7″W), and (iii) Finca Tres Caminos, municipality of Santomera, autonomous community of Murcia, Spain (39°3′4,68″N–2°4′46.54″W).

2.1.1. *Albenga site*

The location of the Albenga study site is shown in Fig. 1. The site belongs to the Center for Agricultural Experimentation and Assistance (CERSAA). It is located about 1.5 km north of the town of Albenga and belongs to the geographical zone of Ligurian Alps. A big part of the study area, namely 49%, is intensively cultivated and includes fruit orchards, olive groves, horticultural crops, vineyards, maize and wheat fields. In this experimental site, cultivation of lettuce under open-field and greenhouse conditions was investigated.

In the past, the wider Albenga area was characterized by high pond density which has now been reduced as a result of human activities (urbanization, infrastructure development and intensive agriculture). The intensive use of inorganic fertilizers, mainly ammonium sulphate and ammonium nitrate, has affected groundwater quality in the study area [29]. Finally, the study area is characterized by a notable topographic contrast. The topographic relief is flat in the central and coastal parts (elevations 0–25 m above sea level (a.s.l)), whereas the south and north parts have an undulating relief with cone landforms (elevations 50–750 m a.s.l).

2.1.2. *Barrax site*

The location of Barrax study site is shown in Fig. 2. The experimental farm 'Finca Las Tiesas' belongs to the "Escuela Técnica Superior de Ingenieros Agronomos" of the University of Castilla-La Mancha. The site is about 20 km away from the capital town of the region, Albacete. The area has an elevation of 700 m a.s.l and is characterized by flat morphology. In this site, open-field cultivation of cereal (barley and soft wheat) has been investigated.

The study area is intensively cultivated and the major land uses include orchards, vineyards and cropping fields. Approximately 65% of the cultivated land is dry while the rest is irrigated. Approximately 70% of the dry land is used for the cultivation of cereals while the remaining is fallow land. The main cultivations in the irrigated land include corn 75%, barley/sunflower 15%, alfalfa 5%, onions 2.9% and other vegetables 2.1%. Over the last two decades agricultural activities impose the main pressure on water-resources availability and cause significant decrease in the piezometric level of the aquifer system.