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LCA application in the fruit sector: state of the art and recommendations for environmental declarations of fruit products

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ABSTRACT

Modern food production is very diverse with high levels of specialisation and complexity. These features inevitably reflect on methods in the application of LCA to food products and agro-systems. System boundaries, functional units, allocation procedures and several other aspects contribute to there being substantial differentiation in the structure of LCA applications in fruit production systems, leading to significantly different results. Indeed, although scientific literature on the topic is recent and not particularly extensive, there are already many different ways of conducting LCAs in orchards.

The aim of this paper is to propose a framework for selecting the best parameters for an LCA application in fruit production systems according to the objective of the study. This has been achieved by reviewing the scientific and technical literature on the topic. In particular papers from international journals and conference proceedings have been considered and the review has covered all main aspects for conducting an LCA in fruit production systems. The particular characteristics considered were objectives, system boundaries, the product considered, the functional unit, data origin and the environmental impact assessment method used.

A substantial part of the paper is devoted to the modelling of the orchard, as this is key to a reliable application of any impact assessment approach. Rather than merely describing the theoretical model, this paper presents concrete recommendations about how to build the orchard system for LCA application avoiding over or under-estimations of the different orchard stages.

1. Introduction

In 2010, world production of fruit was 609,213,512 t, mostly concentrated in Asia (52%) and America (22%) (FAOSTAT, 2012). In Europe, 67,254,709 t of fruit were produced, corresponding to around 11% of the fruit produced in the world, with significant contributions by Italy (25.14% of the fruit produced in Europe), Spain (22.57%) and France (12.93%). The important role played by the Asian markets is even more evident from analysing production trends over the past 10 years: while America, Europe, Africa and Oceania record fairly constant fruit production, in Asia it has increased by about 55%, making China and India the highest producers of fruit in the world, with 20.06% and 13.92% of world production respectively.

Fruit products are generally considered to have a lower environmental impact potential than most foods in western diets. For example, Carlsson-Kanyama et al. (2003) quantified the energy consumption of different diets and reported an average of 5 MJ per kg of in-season fruit (26 MJ per kg of out-of-season fruit), 15 MJ per kg of vegetables, 17 MJ per kg of bread and flour products, 33 MJ per kg of dairy products, 37 MJ per kg of meat and 75 MJ per kg of fish products. On the other hand, compared to other food products, fruit production is considered to be an intensive agricultural system in terms of inputs of pesticides and fertilisers as well as investments in capital and material (*e.g.* Mouron et al., 2006a). Indeed the embodied energy of orchard infrastructures, such as hail nets and irrigation pipes, is higher than in other cropping systems.

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Furthermore, studies examining the carbon footprint of different food choices have reported that fruit is the food category with the lowest environmental impact potential (*e.g.* Wallén et al., 2004; Berners-Lee et al., 2012). However, these studies use data from environmental assessments of generic fruit production which do not take into account specific issues within orchard systems and fruit supply chains. Indeed, different results may arise in relation to the production system (*e.g.* conventional or organic), the production site (specific soil and climate conditions affecting yield and agronomic performances) or the retailing system (long-term cold storage may dramatically influence the environmental performance of the product). Recently Mouron et al. (2012) demonstrated that the same apple cultivation in five European regions may have completely different protection requirements, leading to very different environmental impacts.

High levels of specialisation, diversification and the complexity of orchard systems inevitably affect the methods involved in applying Life Cycle Assessment (LCA) to food products and agro-ecosystems (Notarnicola et al., 2012a). It is therefore important to study the work that has already been done regarding the standardisation of methods in order to make appropriate comparisons between products.

The main aim of the paper is to describe a reference framework for choosing the best settings for LCA applications in fruit production systems. In order to achieve this goal, recommendations are collected and discussed by undertaking a review of studies assessing LCA application in fruit production systems in scientific and technical literature. Furthermore, the secondary goals of the papers are: to identify aspects of fruit production that are of environmental importance according to the studies reviewed, to discuss harmonisation projects and to give practical recommendations about how to model orchards for LCA applications. Therefore Section 2 describes state-of-the-art practice in LCA in fruit production according to a literature review procedure described in 2.1. In this section both general and critical aspects are highlighted, such as the choice of the functional unit and ways of modelling the orchard. Section 3 moves from academic studies to environmental product declarations and harmonisation initiatives as important sources for highlighting practices in LCA application in the sector. In Section 4 recommendations and best practices are presented, with Section 4.1 in particular dealing with concrete descriptions of orchard modelling and 4.2 focussing on all other LCA settings for achieving the most reliable results according to the aim of the application.

2. State-of-the-art LCA applied to fruit production

2.1. Academic literature review method

In the review of LCA application in fruit systems, only peer-reviewed papers from international journals and conference proceedings were considered. Studies that included the fruit production stage were selected by preference, while studies that considered the whole production of derivatives (*e.g.* fruit juice) were only included if they contributed to the analysis of the growth stage. The review covered all main aspects for conducting an LCA in fruit production systems. The specific characteristics considered were objectives, system boundaries, the products under consideration, functional unit, data origin and the environmental impact assessment method used.

After a preliminary study in the literature on LCA applications in the food sector, nine objectives were found to be the most common purposes of LCAs in the fruit sector. These objectives were: 1) to profile the environmental burden of a fruit product, in which a specific production system is evaluated and results are related to the case study without any intention of generalising; 2) to identify the environmental hotspots in production systems performance considering the different field operations and stages of the system; 3) to describe management strategies to improve environmental performance, a focus usually applied after objective 2 in order to give practical suggestions after the evaluations; 4) to compare the environmental burden of different food products on a common functional unit, *e.g.* a specific unit of nutrient content; 5) to compare different farming practices, *e.g.* organic and conventional; 6) to compare different environmental assessment methods such as LCA, ecological footprint analysis and water footprint in the same case study; 7) to profile the environmental burden of production in a given area by applying the LCA evaluation to a statistical database on farms in that specific area; 8) to evaluate the environmental properties of a supply chain, usually with the focus on differences in environmental impact for long and short distances between production and consumption sites; and 9) to assess a preliminary study for statistical investigations. In this case the LCA results were used with the outcomes of other indicators to develop complex indices.

2.2. General aspects

A total of 19 studies were identified: 11 articles in ISI journals and eight papers in proceedings from the LCA congress series (Table 1).

2.2.1. General aspects of the cases studied

With the exception of rare pioneering studies, it can be assumed that mainstream research on the LCA applied to fruit production systems began in around 2005. A number of papers were published in 2010 in conjunction with the 7th International Conference on LCA in the Agri-Food Sector, following the increasing trend of participation in congresses relating to LCAs of food (Notarnicola et al., 2012b). Despite the high quantity of fruit produced in Asia, most of the LCA applications published internationally focus on case studies in Europe and South America, and just one study focuses on China (Liu et al., 2010). It is therefore realistic to assume that in coming years, there will be more research on this subject on the Asian continent, both for case studies and for the environmental evaluation of fruit commercialisation.

2.2.2. Objectives

Most papers in the literature state more than one objective, with the exception of studies on the supply chain (objective 8) which usually focus on this aspect alone (*e.g.* Blanke and Burdick, 2005), even if they also investigate the field phase of the production process (*e.g.* Knudsen et al., 2011). A description of the environmental burden of the product (objective 1) is the prime objective of all studies, but it is often not the main objective, which may instead be a comparison of different methods (*e.g.* Cerutti et al., 2010). Suggestions on ways of being more sustainable (objective 3) are often associated with the evaluation of environmental hotspots (*e.g.* Cudjoe Adebah et al., 2010). The comparison of different methods is not usually applied to fruit production; it can only be found in comparisons of LCA with Ecological Footprint Analysis (Cerutti et al., 2010) and LCA with PAS 2050 (McLaren et al., 2010).

2.2.3. Data origin

Most of the studies reviewed (11 papers) are based on data collected from commercial orchards, either directly in field surveys or with questionnaires or interviews with farmers. Sometimes the approaches are a mix of these and the data collection method used for the different data in the study is not always clearly described. Four studies investigate commercial orchards and then compare the field dataset obtained with reference values. This approach allows conclusions to be drawn about specific orchards, while the

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