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EVALUATION OF THE ENVIRONMENTAL IMPACTS OF FRUIT PRODUCTION USING LIFE CYCLE ASSESSMENT (LCA) (REVIEW)

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Abstract

One important tool for the evaluation of the environmental impacts of fruit production is Life Cycle Assessment (LCA). More than 150 papers published in peer-reviewed scientific journals were selected and reviewed to provide an integrated perspective. In-depth analyses of the methods used were presented according to the specific topics. Conventional and organic technologies were compared for different fruit species highlighting the environmental impacts of their components such as the carbon footprint. Specific topics were reserved for horticultural inputs (fertilizers, phytosanitary protection products) and also for seedlings respectively planting material. The Life Cycle Assessment proved to be a suitable tool to visualize the effects of a decision on the environmental system during the entire life cycle of a horticultural product.

Key words*: carbon footprint; organic technology; horticultural product life cycle.*

INTRODUCTION

Life cycle assessment (LCA) is the comprehensive analysis of a product's entire life cycle in terms of sustainability (Golsteijn, 2020). Hunt & Franklin (1996) mentioned in their study, regarding the origin of LCA in the USA, that the idea of environmental life cycle assessments (LCA) was conceived in the late 1960s and early 1970s, in the same period as in Europe. Harry E. Teasley, Jr., in 1969, elaborated the first formal analytical scheme that was to become LCA, while he was managing the packaging function for the Coca-Cola Company. He presented a study in which the energy, material, and environmental consequences of the entire life cycle of a package from the extraction of raw materials to disposal were quantified. The term LCA was used since 1990 in the U.S.A., the historical term for these environmental life cycle studies being resource and environmental profile analysis (REPA).

Volkwein & Klöpffer (1996) presented the general principles of LCA beginning with the most general basis for evaluation criteria deduced from human rights. The most important human right is the right to life, guaranteed to every person through a series of international regulations. Their thesis stated that the protection of individuals against operations of a third person is indirectly existent because a state cannot tolerate the threat of the life of a person by environmental pollution caused by a third person. This human right is the benchmark of a comprehensive environmental policy.

According to the right to life, the precautionary principle has to be considered by the definition of environmental goals and the valuation of the ecological importance of the impact categories.

The concept of sustainable development including the precautionary approach is found in all the documents since the "Earth Summit" in Rio 1992: Agenda 21 (UN 1992), Rio Declaration (UN 1992), Statement of Forest Principles (UN 1992), Convention on Climate Change (UNEP/WMO, 1992), and Convention on Biological Diversity (UNEP 1992), but also in the most of the documents issued after, like Sustainable Development Goals of Agenda 2030, European Green deal, European Bioeconomy Strategy, European Food and Nutrition Security Strategy - Food 2030, New

DG Agri strategy on Agricultural Research and Innovation, The Common Agricultural Policy (CAP) and CAP 2020+, The European Union Climate and energy package action, European Biodiversity Strategy.
The task of the evaluation procedure in LCA follows the general principles. Each impact can be judged by a set of criteria explicitly or implicitly answering questions regarding the impact on the right of family and private life, the right to the enjoyment of the highest attainable level of health of the population, or the impact on the future generation. There is also an evaluation of the level of danger of the impact or the request of the priority of the use of renewable resources.

Purposes and use cases of LCA. Life cycle thinking aims to increase the sustainability of a product or system along its entire value chain by reducing environmental impacts and at the same time increasing socio-economic performances (UNEP 2020). LCA primarily focuses on environmental impacts alone (ISO 14,040/14,044), assessing quantitatively the environmental impacts of products and services along their value chains. Environmental impacts in the LCA context refer to adverse impacts on the areas of concern such as ecosystem, human health, and natural resources (Peña et al., 2021; Viere et al., 2020; Muralikrishna & Manickam, 2017; Lee & Inaba, 2004).
The leading standards for Life Cycle Assessment are (Finkbeiner, 2013; Klöpffer, 2012; Lee & Inaba, 2004; www.iso.org/standard):
➢ ISO 14040:2006. Environmental management - LCA - Principles and framework with AMD 1:2020;
➢ ISO 14044:2006. Environmental management - LCA - Requirements and guidelines with AMD 1:2017 and AMD 2: 2020;
➢ ISO/TR 14047:2012. Environmental management - Life cycle assessment - Illustrative examples on how to apply ISO 14044 to impact assessment situations
➢ ISO/TS 14048:2002. Environmental management - Life cycle assessment - Data documentation format;
➢ ISO/TR 14049:2012. Environmental management - LCA- Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis.
Muralikrishna & Manickam (2017) presented life cycle phases and processes according to ISO ISO 14,040/44 framework (Figure 1):

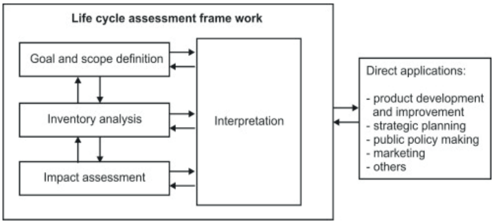

Figure 1. Life cycle phases and process according to ISO ISO 14,040/44 framework (Muralikrishna & Manickam, 2017)

Goal and Scope definition. The goal for LCA has to respond to what are the objectives of performing the LCA study, what are the application areas of the LCA results, and who are the potential audience.
The scope has to present clear descriptions, including the product system, the function of the product system, the product system boundaries, and data category (Lee & Innaba, 2004; Klüppel, 1997; ISO 14040:2006).
The life cycle inventory analysis scheme is presented in Figure 2 (Lee & Innaba, 2004), this stage being focused on data collection and aggregation (Reap et al., 2008; Klüppel, 1997; Neitzel, 1996; Owens, 1996).

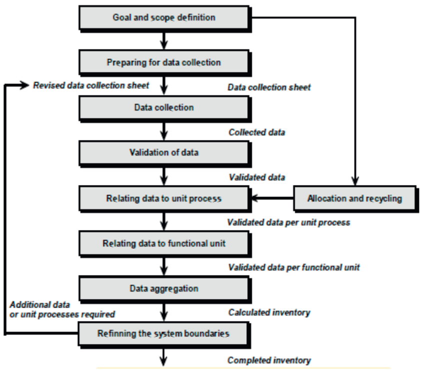

Figure 2. Life cycle inventory analysis (Lee & Innaba, 2004)

The life cycle impact assessment scheme is presented in Figure 3 according to Lee & Innaba (2004).

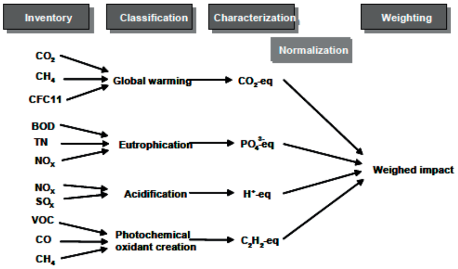

Figure 3. Life cycle impact assessment (Lee & Innaba, 2004)

Life cycle interpretation contains three key elements as defined by ISO 14044: (1) the identification of key issues, (2) the evaluation (including checking completeness, sensitivity, and consistency), (3) development of conclusions together with recommendations (Lee & Innaba, 2004; ISO 14044:2006).

LCA involves a complex analysis beginning with data collection, processing, and analysis. Viere et al. (2020) presented a comprehensive scheme with the software used in LCA (Figure 4).

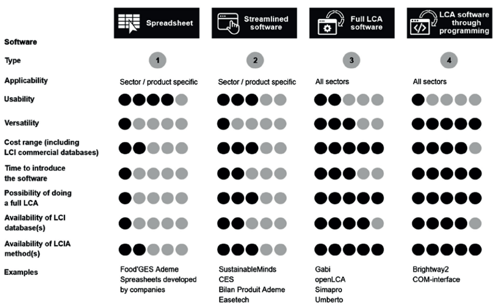

Figure 4. Software used in LCA (Viere et al., 2020)

The objective of this review was to present the evaluation of the environmental impacts of fruit production using LCA through published articles inventory.

ENVIRONMENTAL IMPACTS OF FRUIT PRODUCTION USING LIFE CYCLE ASSESSMENT

There were several topics analysed, components of the evaluation of the environmental impacts of fruit production using Life Cycle Assessment: (A) agricultural ecosystem, land use, crop species choice, specific methodology; (B) pesticide and fertilizers evaluation; (C) fruit species crop cultivation and (D) fruit residues.

For the first topic, a selection of articles focused on the agricultural ecosystem, production, evaluation of agro-food products, details regarding the nutritional function of food, land use impact with some soil quality indicators in the context of life cycle assessment was made (Table 1).

Table 1. Studies on environmental impacts of agricultural ecosystems (mainly fruit production) using life cycle assessment

A. agricultural ecosystem, land use, crop species choice, the specific methodology	
agricultural production	Cowell & Clift, 1996; Li et al., 2019
urban agriculture	Peña and Rovira-Val, 2020
fruit and vegetable production and evaluation of impact mitigation practices, Spain	Martin-Gorriz et al., 2020
products from agro-based companies	Mfitumukiza et al., 2019
agri-food, Portugal	Morais et al., 2016
field emissions in the carbon footprint of agricultural products	Peter et al., 2016
nutritional functional units in commodity-level life of agri-food system	McAuliffe et al., 2020
nutrition function of foods	Weidema & Stylianou, 2020
food consumption and nutrition	Nemecek et al., 2016
consequences of diet	Carlsson-Kanyama et al., 2003
review, environmental product declarations	Schau & Fet, 2008
transport	Sim et al., 2007
agricultural strategic development planning	Tsangas et al., 2020
Agri-food process and circular economy	Stillitano et al., 2021
land-use through kiwifruit production	Coelho & Michelsen, 2014
land use impacts on the natural environment	Cowell & Lindeijer, 1999; Koellner & Scholz, 2008; Milà i Canals et al., 2007; Müller-Wenk & Brandão, 2010; Koellner et al., 2013
soil compactation indicator	Garrigues et al., 2013
soil acidification and nutrient management	Peters et al., 2011

In the second topic (pesticide and fertilizers evaluation), are highlighted researches regarding pesticide-related toxicity impacts of crops, comparing nutritional value and yield as functional units in the environmental assessment of horticultural production with organic or mineral fertilization; distribution, and budget of nutrients in a commercial apple orchard; environmental and agronomical assessment of three fertilization treatments applied in horticultural open field crops; horticulture and orchards as new markets for manure valorisation with less environmental impacts; fertilizers production and human health impacts of more pesticides (Table 2).

Table 2. Studies on environmental impacts of pesticide and fertilizers in fruit production

B. Pesticide and fertilizers evaluation	
pesticide emissions for LCA of agricultural products	Hauschild, 1999
organic waste treatments yielding the most relevant organic amendments and fertilizers, France	Avadí, 2000
human health impacts	Fantke & Jolliet, 2016
pesticide assessment	Hellweg & Geisler, 2003; Rosenbaum et al., 2015
production	Gaidajis & Kakanis, 2021; Wu et al., 2021; Muñoz et al., 2018a,b
manure for orchards and horticulture	Fangueiro et al., 2021

In the third topic, more studies regarding the evaluation of fruit crop impact on the environment using LCA are listed.

Production systems, semi-intensive and intensive, extensive and intensive production, determining cropping patterns with emphasis on optimal energy consumption, organic conversion, organic farming is also presented.

For different species like almond, apricot, apple, blueberry, peach, pear, pomegranate, raspberry, strawberry, walnut, the impact of their cultivation technology was evaluated. Several studies focused on different fruit species evaluation, comparing apples with oranges; pistachio, almond, and apple production in Greece; pistachio, nectarine, peach, and apple in Iran; apple, banana, orange, peach, pear in China. In the end, two studies on the assessment of fruit residues are listed (Table 3)

Table 3. Studies on environmental impacts of fruit production using life cycle assessment

C. Fruit species crop cultivation	
Almond	
almond production, California, USA	Marvinney & Kendall, 2021
Apricot	
comparison orchard systems, Italy	Pergola et al., 2017
Apple	
apple-growing, Switzerland	Mouron et al., 2006a, b
apple production, New Zeeland	Milà i Canals et al., 2015
conventional and organic apple production in Nova Scotia, Canada	Keyes et al., 2015
intensive versus semi-extensive apple orchards, France	Alaphilippe et al., 2016
conventional and organic apple production, China	Zhu et al., 2018
organic and low-input apple production, France	Alaphilippe et al., 2013
comparison between ancient apple and Golden delicious production, Italy	Cerutti et al., 2013
comparing domestic versus imported apples, Europe	Milà i Canals et al., 2007
the carbon footprint of southern hemisphere fruit exported to Europe (apple from Chile to the UK)	Iriarte et al., 2021
mulch using in apple orchards, Canada	Bamber et al., 2020; Bamber et al., 2021
drying methods for the production of apple powder, Italy	Marco et al., 2015
apple consumption in Belgium	Goossens et al., 2019
Blueberry	
the carbon footprint of organic blueberry production, Chile	Cordes et al., 2016
organic blueberries, Chile	Rebolledo-Leiva et al., 2016
Citrus	
Comparison between organic and conventional, Spain	Ribal et al., 2017
Peach	
overview of environmental and economic assessments in the fruit sector; red peach production system, Sicily	Ingrao et al., 2015
potential pollutant-induced, China	Wang & Zhao, 2019
packaging, transportation, Japan	Sasaki et al., 2021
production, Portugal	Pires Gaspar et al., 2018

Pear	
the environmental burdens of pear production systems; environmental mitigation; further mitigate environmental impacts by improved nutrient management	Wang et al., 2020
fossil energy use and greenhouse gas emissions in pear production, China	Liu et al., 2010
fertilizer application	Vatsanidou et al., 2020
Pomegranate	
production, Peru	Vázquez-Rowe et al., 2017
Raspberry	
fruit production, Chile	Vásquez-Ibarra et al., 2021
Strawberry	
production, Spain	Romero-Gámez & Suárez-Rey, 2020
protected strawberry productions, Italy	Ilari et al., 2021
Walnut	
seedlings production	Cambria & Pierangeli, 2011.
Comparative studies on fruit species	
pistachio, almond, and apple production, Greece	Bartzas et al., 2017
pistachio, nectarine, peach, and apple, Iran	Ordikhani et al., 2021
review on the farm stage	Bessou et al., 2013; Cerutti et al., 2014; Cerutti et al., 2011
oil palm fruits from Indonesia, and small citrus from Morocco	Bessou et al., 2016
apple and orange, Netherlands	Tyszler et al., 2014
apple, banana, orange, peach and pear, China	Yan et al., 2016
D. Residues	
fruit waste utilization	Srivastava et al., 2021; Tedesco et al., 2019

CONCLUSIONS

Life Cycle Assessment is a relatively new instrument in evaluating the environmental impacts of the product or service from the very first to the very last or from cradle to grave.
Although in the beginning, there were few studies regarding the impact of fruit growing on the environment, our study highlighted the extension of these researches, both specific to a fruit species and on different technology details. Being an efficient instrument for environmental product declarations, connecting the LCA results and the socio-economical needs of producers is important for acceptance by the agricultural sector. Producers can operate with LCA as a tool for increasing their competitiveness.
Further actions are needed to communicate in the form of improvement opportunities, that can be a useful addition to changing producer behaviour and reducing environmental emissions.

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