Comparison of LCA and EFA for the environmental account of fruit production systems: a case study in Northern Italy

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ABSTRACT

Although various study cases can be found on the application of environmental indicators in agricultural activities, applications on the fruit production systems are stills rare. In the present study we apply the Life Cycle Assessment (LCA) and the Ecological Footprint Analysis (EFA) at the same commercial nectarine orchard in Piedmont (Northern Italy) in order to highlight the differences both on the results and on the methodological issues. Great care was used to choose an equal boundary setting, to consider an identical schematization of the productive processes and to utilize data referring to the same production stage. In both indicators, the calculation was conducted considering the six orchard stages highlighted by Milà i Canals (2003). The LCA was conducted in compliance with the guidelines and requirements of the ISO 14040 standard series, while EFA calculations were performed by using the methodology and the specific conversion factors implemented by the Global Footprint Network.

Keywords: Orchard management, Fruit production, Nectarine, Life cycle assessment, Ecological Footprint analysis

1. Introduction

Fruit production is considered an agricultural sector with low environmental impacts in comparison to other food sectors when considering the energy in the life cycle per kg of product (Carlsson-Kanyama et al., 2003). On the other hand the use of pesticides is an important key-issue that may increase heavily environmental impacts. As a consequence quantification of the sustainability of fruit production is required to make specific considerations and comparisons. Although a lot of aspects of the environmental accounting methodologies in the agricultural sector are already investigated, still rare are the application of an environmental indicator in fruit production (Gaillard and Nemecek, 2009).

The objectives of this work are (i) to verify the application two different environmental accounting methods to fruit production: Life Cycle Assessment and Ecological Footprint Analysis; (ii) verify the potential of each method to determine the impact of the one-year cultural practices versus the whole orchard lifetime.

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2. Methods

2.1. System description and data sources

Nectarine system and data sources are the same for both LCA and EFA, therefore they are described in one chapter. Specificity of the two different methods are described beyond.

Orchards are complex biological productive systems. In order to obtain reliable environmental assessments in orchards, instead of considered only the one-year field operations, all the impacts related to the entire lifetime of the orchard have to be accounted (Mila i Canals and Polo, 2003; Cerutti *et al.*, 2010). Therefore system boundary includes production of differentiated nectarine farming inputs and their transport to the field, fuel and electricity use during nectarine farming, nursery, orchard installation and destruction (Figure 1).

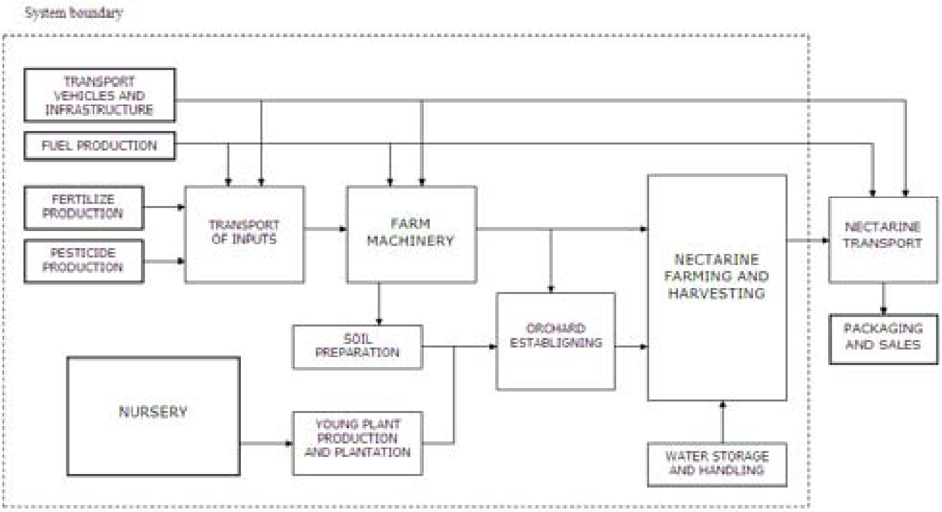

Figure 1: Reference case product system boundary for both EFA and LCA. Bold boxes indicate independent systems related to nectarine production and consumption.

The inventory was based on data from a commercial nectarine (*Prunus persica* var. *laevis* Gray) orchard in Cuneo province, Northen Italy, managed according to the Italian Integrated Fruit Production (IFP) protocol. Impacts and resources use for all of the farming operations were obtained directly on field during years 2008-2009. All other information required (e.g. nursery impacts and resources use) were collected from average agricultural practices provided by COLDIRETTI (Confederazione Nazionale Coltivatori Diretti Piemonte).

As proposed by Mila i Canals and Polo (2003) the productive system was divided in 6 stages (ST) and environmental impacts and resources use for each stage were accounted.

ST1. Nursery stage (accounted for 2 years). This stage was evaluated as the average processes and resources needed to obtain rootstocks, scions and finally young plants.

ST2. The establishment stage (occurs just one time, therefore it was accounted as 1 year). This stage was evaluated as the common practice of removing previous installation and preparing the field for the orchard. Plastic, steel, wood resources and energy for the orchard installation have been added in proportion to the lifetime of the orchard.

ST3. Low yield production due to young plants (accounted for 2 years). This stage includes all the one-year field operation (see ST4) but all impacts and resource use are proportioned to an average production on 12 t ha^{-1} due the youth of the plants.

ST4. Full production (accounted for 13 years). Following information provided from the farmer and considering local pedoclimatic conditions, agrotechniques and cultivar, the average commercial yield for 13 years as been estimated as 18 t ha^{-1}. This stage includes all the one-year field operation, particularly:

- tree management: this category comprises of operations aimed to improve orchard productivity, facilitate harvest and prevent disease proliferation (Mila i Canals and Polo, 2003).
- pest and diseases management: pesticide applications are by air-blast spraying 15 times per season using 56 kg ha-1 of active ingredients diluted in 16000 l of water per ha.
- understorey management: the management of the soil between the rows seeks to prevent competition for water or nutrients with the trees and erosion (Mila i Canals et al., 2006).
- irrigation: trees received water through drip pipe irrigation directly under the tree canopy. This system requires pumping systems that consumes electricity.
- weather damage prevention: hail prevention nets were installed, opened and closed once per season, with two field crossings by hydra-ladder.

ST5. Low yield production due to declining plants (accounted for 2 years). This stage includes all the one-year field operation (see ST4) but all impacts and resource use are proportioned to an average production on 12 t ha^{-1} due the old age of the plants.

ST6. The destruction of the orchard (occurs just one time, therefore it was accounted as 1 year). This stage was principally accounted for machinery and fuel.

2.2 Life Cycle Assessment

The functional unit for analysis is 1ton of nectarine that cross the farm gate to various commercial systems. Analysis was conducted using the software SimaPro 7, with the Eco-indicator 99 H/A (Goedkoop, & Spriensmaa, 2000) method developed by Pré Consultants of the Netherlands[1]. Various authors consider Eco-indicator 99 as one of the major environmental impact assessment method, comprehensive in nature and generating a single numerical value reflecting the composite magnitude of global impact associated with a specific product. We decided to apply the hierarchist perspective because it can be considered generalist and intermediate for most of aspects (Goedkoop, & Spriensmaa, 2000). Impact assessment is carried out to obtain a single numerical value, called Single Score, that can be easily compared to the ecological footprint of the same productive process.

2.3 Ecological Footprint Analysis

EFA is an environmental accounting system that provides an aggregate indicator that is both scientifcally robust and easy to understand by non-experts. Introduced by Rees (1992) and further developed by Wackernagel and Rees (1996), the ecological footprint quantifes the total area of the terrestrial and aquatic ecosystems necessary to supply all resources utilized and to absorb all resultant emissions involved in the production of particular products. Following the standard methodology (Global Footprint Network, 2009) all resources used for the orchard lifetime were converted into bioproductive area by using specific conversion factors available from the Global Footprint Network database (Global Footprint Network, 2006) and further updates (Ewing et al., 2009). When conversion factors were not available, embodied energy coefficients were used to convert data into the equivalent emission of CO_2. The soil occupied by structures was accounted as a built-up land component. The water consumed was accounted as the energy necessary for the irrigation and consequently, as the amount of CO_2 related to that energy.

[1] This method is still valid but just outdated. New works should use ReCiPe (Goedkoop *et al*, 2009) as the more up-to-date LCIA method.

3. Results

Main LCA results are presented figure 2.The main impact category is fossil fuels, that account for 84.91% of all the environmental impacts generated trough the production of 1 ton of nectarine. Other significant categories are respiratory inorganics (9.03%), climate change (3.61%) and acidification/eutrophication (1.02%). All other categories contribute less than 1%. Among the stages involved in peach production, ST4 (operations and resources for production high yield years) has, as expected, the highest contribution to the whole analysis: 61.96%. Characterization analysis permit to underline the amount of each impact category in each production stage. For example the impact category fossil fuel vary from 63.03% in ST1 to 93.08% in ST6; respiratory inorganics vary from 4.81% in ST6 to 22.56% in ST2; climate change vary from 1.16 in ST6 to 10.33% in ST1. Process contribution analysis (EI99 H/A, single score) show the high impact of gasoline use (70.32%), followed by electricity (6.05%), pesticide use (5.39%), N-fertilizer use (4.90%), natural gas use (4.66%). All other process contribute less than 3%.

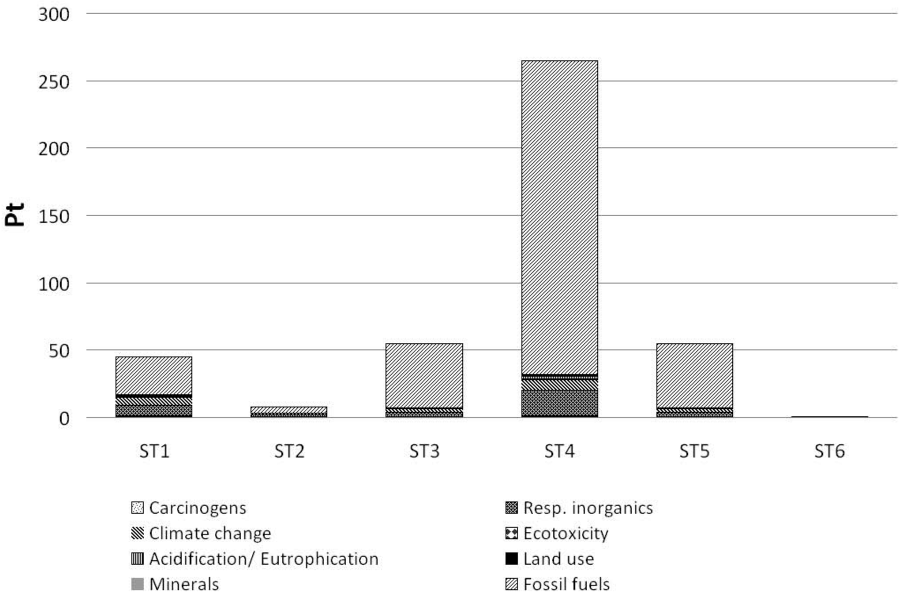

Figure 2: Impact assessment results (weighted values – Eco-indicator 99 H/A) presented in single score histogram. Impact categories that weight less than 0.1% on total pt are not shown.

Main EFA results are presented in figure 3. The total ecological footprint for the case study was 1.20 gha t^{-1} nectarines produced. The major land-component is the carbon-footprint that covers 83.27 % of the whole footprint. Lower contribution comes from the other land-components: cropland (16.37%), forest (0.32%) and built-up land (0.02%). Also in EFA, ST4 present the highest contribution: 63.89% of the overall footprint. The other stages make substantially lower contributions to the overall impact, specifically: ST1=4.83%, ST2=11.59%, ST3=ST5=9.82%, ST6=0.02%. Another interesting result is the comparison between the contribution of each resource used to the overall footprint. The main contribution came from electricity consumption (40.12%), followed by effective soil utilized for production (orchard, nursery and occupied land, 16.39%), diesel consumption (15.25%), plastic for the installations (12.82%) and fertilizers use (6.10%).

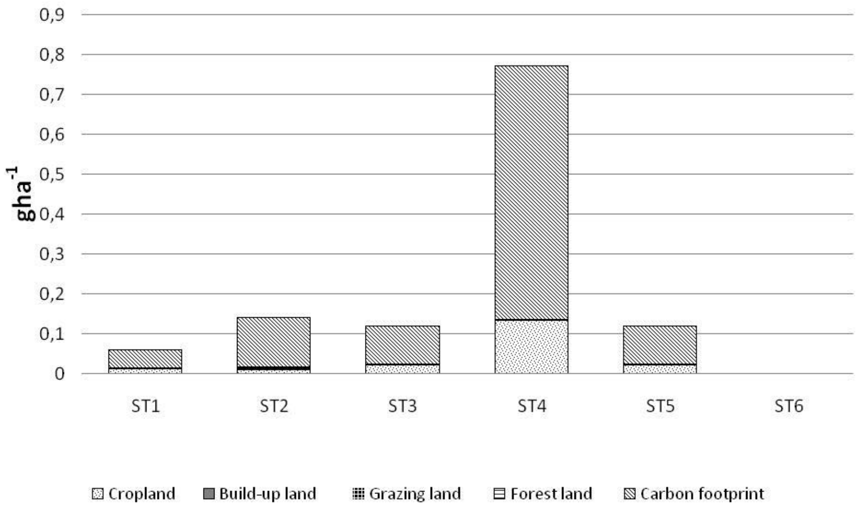

Figure 3: Ecological Footprint of the orchard system for each stage (ST1 to ST6) arranged by land categories. The footprint were accounted as the total gha of that stage divided by the total tonnage of nectarine produced from the orchard across all years.

4. Discussion

The comparison of two different assessment methodology applied to the same productive process permit to discuss both results and methodological issues. First important remark can be done observing figure 2 and figure 3. The results in single score LCA and Ecological Footprint values are strongly comparable. In both analysis ST4 (high yield field operations and resources use) make the major contribution to the environmental impacts of the productive system, particularly 61.96% according to LCA and 63.89% according EFA. Also stages ST3, ST5 and ST6 show similar results in both analysis: ST3 and ST5 contribute each for 12.76% in LCA and 9.82% in EFA, ST6 contribute for 0.16% in LCA and 0.02% in EFA.
Significant differences arise confronting ST1 and ST2. The first stage (nursery stage) is characterized by a relative low quantity of fossil fuel consumption, but a relative high quantity of fertilizers and chemicals products (fitoregulators and pesticides) compared to the orchard stages. As LCA account chemicals products, both for resource use for production and for negative effects when utilized (Van Zeijts et al., 1999; Powers, 2005), ST1 results higher in LCA (10.52%) than in EFA (4.83%). On the other hand the installation stage (ST2) can be considered principally as occupied land, energy as fuel consumption and materials applied to the field such plastics and wood. Those kinds of resources weight more in EFA than in LCA, therefore ST2 results higher in EFA (11.59%) than in LCA (1.82%). This difference in the accounting method in the other stages is balanced by a relative equilibrium of energy consumption and chemical products use, therefore results in overall percentage are strongly similar.

This study reveals that the gaps suggested by other authors (Mila i Canals and Polo, 2003) and evaluated in previous works (Cerutti *et al.*, 2010) can be significant and can be quantified both with EFA and LCA, with little differences. As orchard are not a single year production system (as can be open field crops), the application of an environmental indicator just to the full production year will probably underestimating the real ecological impact, in a variable percentage (in our study about 35% with both methods). More studies are required to verify the average gap for each fruit species; when these data are available, consideration of all stages in the application of LCA, EFA and other ecological/sustainability indicators is strongly advised.

It is interesting to compare the contribution to the total impacts that comes from specific resource used in both assessment. Fertilizers are accounted globally in EFA and divided in N, P_2O_5, K_2O component in LCA, but the total contribution is similar: 8.94% in LCA and 6.10% in EFA. These results are concordant to Mila i Canals *et al.* (2006) which identified fertilizer production and use as responsible for 5–11% of the environmental burdens of fruit production. An interesting difference can be remarked looking at the way to account the energy applied to the system. In EFA the major energetic component is electricity, that covers about 40% of total footprint, followed by diesel consumption (15.25%); but in LCA fuel consumption is responsible for about 70% (process contribution analysis) and electricity for just 6%. This difference can be explained mainly by the normalization/weighting methods of the hierarchist perspective that increase numerically the importance of the fossil fuel consumption (Goedkoop, & Spriensmaa, 2000).

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