Using of the LCA methodological framework in perennial crops: Comparison of two contrasted European apple orchards

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ABSTRACT

Life Cycle Assessment (LCA) is a helpful approach for a better understanding of the environmental impacts of apple orchard cropping systems. The application of LCA to perennial cropping systems raises methodological questions such as the consideration of non-productive stages. Two recent reviews give recommendations (Cerruti et al., 2011) and a methodological framework to deal with perennial crop cycles (Bessou et al., 2012). The objectives of our study were to test these recommendations and framework by comparing two contrasted apple fruit production systems (intensive and semi-extensive) and to assess the weight of the non-productive stages in the orchard life cycle impacts. Unproductive stages weighted up to 21% and 28% of the studied impact categories, in the semi-extensive and intensive orchard respectively, with little contribution of the nursery stage. The consideration of the unproductive stages is discussed and the necessity to explicit the approach used to account for the duration of perennial cropping systems is also outlined.

Keywords: LCA methodology, perennial crop, apple production, orchard conservative design, orchard management

1. Introduction

Life cycle assessment (LCA) is a comprehensive methodology, which considers the whole life cycle of the cropping systems. In the case of perennial crops such as orchards, unproductive then productive stages characterize the cropping system. This aspect raises methodological questions about the way to account for all orchard stages in the total impact assessment. Two recent reviews (Cerutti et al., 2011; Bessou et al., 2012) recommend integrating those non-productive stages in the impact assessment. Moreover Bessou et al. (2012) propose practical guidelines for perennial cropping systems according to data availability to describe and account for those stages in a LCA study. These guidelines propose to encompass every stage of the perennial cropping cycle, as well as different approaches to model it. Our main goal was to test the methodological recommendations of these authors, by analyzing the contribution of each life cycle stage in the total environmental impact of two contrasted apple orchard systems: one intensive and one semi-extensive. Intensive systems refer to orchards managed to maximize fruit production, usually including several of the following design traits and management practices: dense planting of short-lived trees on dwarfing rootstocks, high chemical inputs, intensive pruning to shape the trees in a restricted form, and frequent mowing the orchard groundcover (Dart, 2008). In contrast, orchards that are managed extensively request less use of pesticides and fertilizers with relatively long-lived trees that could reach the veteran stage. We expected these two orchard systems to affect the relative importance of the non-productive stages in the LCA and therefore, to be good case studies to use with this newly developed guidelines.

2. Methods

Two existing and contrasted apple orchards were compared following the methodological guidelines proposed by Bessou et al. (2012) and Cerutti et al. (2011) to analyze perennial cropping systems with LCA. To comply with current methodological frameworks for perennial crop LCA, the different stages of the orchard life cycle including non-productive stages, were accounted for. The non-productive stages included nursery, orchard creation (planting), orchard establishment and destruction.

2.1. The studied apple cropping systems and their modelling

The two studied orchard systems were described and modelled from on-farm surveys. The geographical origin, namely Northern (Picardy) and Southern (Rhone Valley) France, for the intensive and semi-extensive systems respectively, ensured the data consistency of each modelled apple production system (Bessou et al., 2012). The main characteristics of the studied orchards are summarized in Table 1. The two studied orchards differed in their lifetime, orchard height and associated machinery use, irrigation management (in relation with the climatic context) and planting distances. Moreover, the intensive orchard establishment stage lasted two years compared to one year in the semi-extensive orchard. Indeed, the semi-extensive orchard was harvested as soon as the annual production reaches around 3 to 4 tons/ha, i.e. in its second year after planting. In the intensive orchard, fruits were harvested only once the production has reached a yield of 20 tons/ha (namely in the 3rd year), in order to optimize the costs.

Table 1. Main characteristics of the two studied production systems.

Characteristics	Intensive orchard	Semi-extensive orchard
Cultivar	Jonagold	Golden
Planting density (number of trees/ha)	2500	1100
Tree height (m)	2.5	4.5
Pruning	Mechanical	Manual
Between-row management	Mowing and mulching	Mowing and mulching
Irrigation system	No irrigation	Buried irrigation system with localized drippers
Weed, pest and disease control	Mainly chemical	Mainly chemical
Harvest method	Manual	Manual with elevator
Lifespan (years):	15	26
- Orchard establishment	Year 1 and 2 (2 years)	Year 1 (1 year)
- Productive stage (commercialized apples)	Year 3 to 15 (13 years)	Year 2 to 26 (25 years)
Annual average yield over the productive stage (t/ha/year)	55.4	37.8
Cumulated commercialized yield over orchard whole life time (t/ha)	720	944.7

For both orchards, all cultural practices related to fertilization, plant protection, between-row management, tree training, fruit load management as well as harvest were collected. As recommended by the two reviews, the modelling of each orchard stage, namely the unproductive stages (i.e., nursery, orchard creation, establishment and destruction) and the productive stage (i.e., years with apple commercialization) was included in the analysis. During the nursery stage, grafted trees were produced, which were considered as inputs in the orchard creation stage. The orchard creation stage corresponded to the soil preparation before planting, planting and installation of orchard infrastructure such as poles, wires and the irrigation system if the orchard is watered. During the orchard establishment stage, fertilizer doses corresponded to one third of those of the full production years. The inputs of an average production year are listed in Table 2. The two studied orchards differed mainly in the fertilizer and pesticide doses, which were higher in the intensive orchard. The last stage of orchard destruction entailed the removal of trees and infrastructure.

Table 2. Input list for one average productive year for the two production systems, with N: Nitrogen and a.i.: active ingredient.

Input	Intensive orchard	Semi-extensive orchard
N fertilizer rate (kg N/ha)	114	47.3
Pesticide, active ingredient (kg a.i./ha)	74	28.5
Including copper and sulfur (kg a.i./ha)	44	15
Fuel consumption (L/ha), including harvest	289	234
Including self-driven elevator fuel consumption (L/ha)	-	67
Pesticide and fertilizer and growth regulator applications (runs/ha)	47.4	41
Other mechanical practices (pruning, mowing, mulching) (runs/ha)	5.7	4

Following Bessou et al. (2012), the data available for the two orchards implied to use two different approaches to describe the studied orchards during their whole lifetime. Indeed, a modular approach, with each stage independently modeled, was used for the intensive system: data were recorded for the different stages from one single year. A chronological approach, which consists in describing all the historical course of the crop development, was used for the first eight years of the semi-extensive system, while neighbor orchards were the basis to estimate the characteristics of the following seventeen years.

2.2. System boundaries and functional units

The two studied systems encompassed life cycle phases from cradle (namely the production of the inputs of all the modelled stages), to the gate of the apple storage place. To compare the two studied systems and follow the recommendations of Cerutti et al. (2011), two functional units (FU) were used. The mass-based FU was calculated for 1 ton of apples for the cumulated yield over the whole orchard lifetime. The area-related FU was 1 $ha^{-1}.year^{-1}$ of land used to produce apples over the whole orchard lifetime.

2.3. Inventory and characterization methods

The inventories needed for the manufacturing and supply of inputs and buildings were taken from Ecoinvent V2.2. Following the recommendations of Cerutti et al. (2011), a nitrogen balance based on the tree requirements was calculated for each year of the establishment and productive stage of the orchard.

Climate change, terrestrial acidification, freshwater and marine eutrophications and energy consumption were calculated with SimaPro V7.3.3 software using Recipe method (Goedkoop et al., 2009) and cumulative energy demand method V1.08 (Althaus et al., 2007). Despite the importance of pesticide applications (Table 2), emissions related to the use of sulfur- and copper-based pesticides could not be computed with the existing fate models (Villanueva-Rey et al., 2014). As a consequence, ecotoxicity and toxicity impacts were not assessed in the present study.

3. Results

3.1. Contribution of the non-productive stages to the total environmental impacts

The relative contribution of each stage (non-productive and productive) to the five calculated environmental impact categories is presented for both semi-extensive and intensive orchard systems (Figure 1). Whatever the impact category and the FU, the unproductive stages represented up to 21 % and 28 % in the semi-extensive and intensive orchards, respectively. The nursery itself accounted at maximum for 1% and 2.6% of the orchard whole life impact in the intensive and the semi-extensive orchards, respectively.

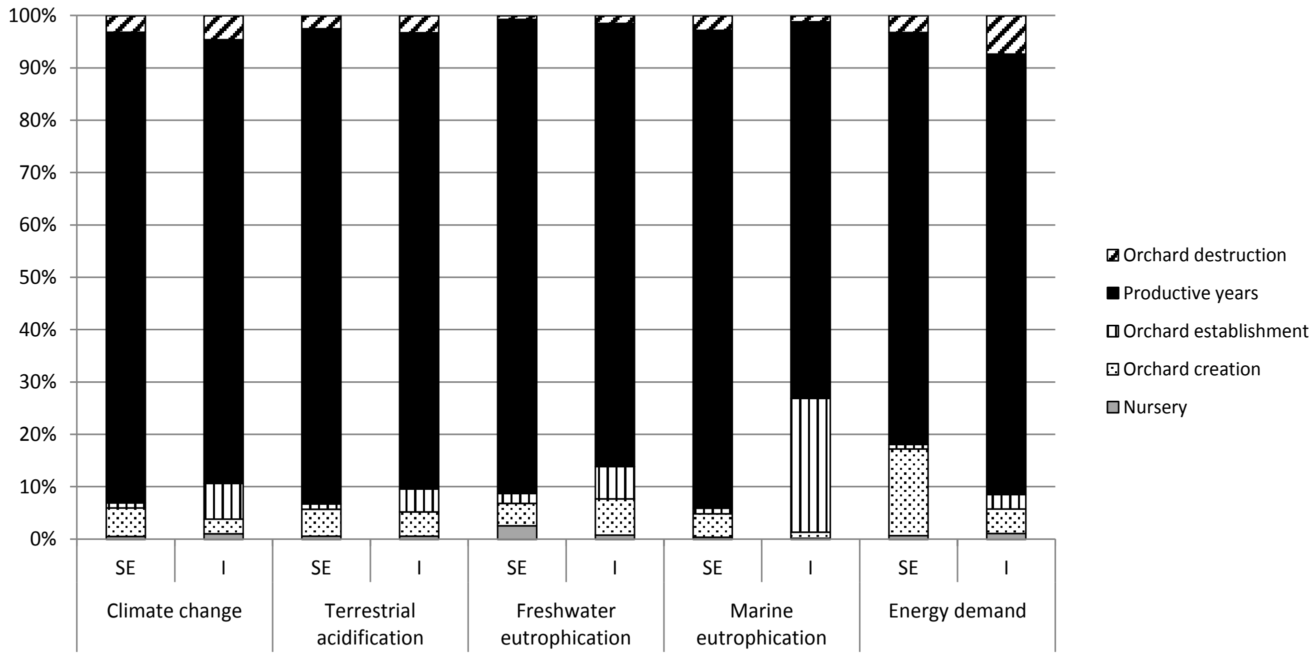

Figure 1. Relative contribution of each stage (productive years and non-productive stages) to five environmental impact categories in the semi-extensive (SE) and the intensive (I) orchard systems.

In the intensive orchard, the main contributor to climate change, terrestrial acidification, freshwater and marine eutrophication impacts among non-productive stages was the 'orchard establishment', while the 'orchard creation' stage accounted for 3% to 7% for climate change, terrestrial acidification and freshwater eutrophication impacts. In the semi-extensive orchard system, the main contributor to all calculated impact categories among the unproductive stages was the 'orchard creation' (i.e. soil preparation, planting and orchard infrastructure creation).

These differences among orchards can be explained by the duration of the 'orchard establishment' stage and the climatic constraint. Indeed, the establishment phase of the intensive orchard entailed two unproductive years, versus one in the semi-extensive orchard. Besides, as there was no irrigation system in the intensive orchard due to sufficient rainfall to fulfill the crop requirements, the relative weight of the creation stage was lowered.

The contribution of the non-productive stages to the total impacts was lower in the semi-extensive orchard compared to the intensive orchard for all the studied impact categories, except for energy demand with similar or higher value according to the FU. This result could be related to the energy consumption occurring during the 'orchard creation' in the semi-extensive orchard. Indeed, planting was mechanized and required heavy equipment, whereas it was manual in the intensive system. Moreover, the semi-extensive system was irrigated with a buried irrigation system, which also required heavy machinery use to install it. The energy demand for the non-productive stages mainly corresponded to the tree removal (orchard destruction) in the intensive orchard.

3.2. Environmental impact of the two orchard systems

The impact per (ha.year) of the intensive orchard was 1.5 to 11 times higher than the one of the semi-extensive orchard for climate change, terrestrial acidification, freshwater and marine eutrophication, except for energy demand with similar values. For the mass-based FU, the differences were less important, or opposite for freshwater eutrophication and energy demand (Table 3). Indeed the cumulated yield for both orchard types is relatively similar with 720 tons for the intensive orchard and 945 tons for the semi-extensive orchard, even though their lifetimes are different with 15 years for the intensive and 26 years for the semi-extensive orchard.

Table 3. Environmental impacts of the orchard systems as expressed per ton of fresh fruits and per (ha.year).

	ton^{-1}	**(ha.year)$^{-1}$**

Impact categories	Unit	Semi-extensive	Intensive	Semi-extensive	Intensive
Climate change	kg CO_2 eq	75.24	89.79	2733.71	4309.94
Terrestrial acidification	kg SO_2 eq	0.710	0.985	25.789	47.269
Freshwater eutrophication	kg P eq	0.033	0.024	1.22	2.000
Marine eutrophication	kg N eq	0.037	0.155	1.33	15.005
Energy demand	MJ	1160	880	42143	42243

The higher environmental impact observed for most impact categories (except energy demand) in the intensive orchard was mainly related to fertilization, among which nitrogen applications. Indeed the production and in-field emissions of fertilizer inputs contributed to 55% and 28% of the climate change in the intensive and semi-extensive orchards, respectively. Terrestrial acidification and marine eutrophication were mainly explained by nitrogen fertilization in the intensive orchard (70 to 86% of the impact), whereas it was related to both fertilizers and pesticides production and use (50% of the total impact) in the semi-extensive orchard.

Regarding the energy demand, the mean annual fuel consumption during the productive years was lower in the semi-extensive than in the intensive orchard, but it was balanced by the mechanization of the semi-extensive system, which was higher over the whole orchard life cycle compared to the intensive orchard. Indeed, the machinery and the infrastructures used to plant and irrigate the orchard were more important and more energy-consuming in the semi-extensive than in the intensive orchard. Moreover, due to the tree height in the semi-extensive orchard, a self-driven elevator was used for each manual operation (pruning, thinning and harvest).

4. Discussion and conclusion

The present study confirms the environmental burden of unproductive stages with up to 28% of the total impact, although the nursery itself was of little importance (1 to 2.2% of the orchard whole life impact).

It is noticeable that the present comprehensive results about climate change impact and energy demand are similar to those published by Mouron et al. (2006) for the area-related FU, while they are two to threefold higher than those published by Milà i Canals et al. (2006) and Alaphilippe et al. (2013) on similar semi-extensive orchards. Only Mouron et al. (2006) included the unproductive and establishment stages in its calculation, which explain that the results are comparable to the present study. The use in the present work of a chronological approach, with the consideration of several years of full production, with annual adjustment in crop operations and alternate fruit bearing also contributes to explain the differences among studies.

Our work outlines the necessity of standardization to model the perennial crop life cycle and attests that the methodological frameworks proposed by Bessou et al. (2012), and Cerutti et al. (2011) are relevant to assess global environmental impacts in orchards.

In conclusion, aside from marine eutrophication and cumulative energy demand, the weight of the unproductive stages in all impact categories was only slightly changed between our two contrasted orchard designs and managements. An intensive establishment stage and a semi-extensive creation stage may noticeably contribute to marine eutrophication and cumulative energy demand, depending on their durations and intensification levels. So, based on our results, we recommend that, when identifying the hotspots of apple production systems, LCA has to focus on and privilege an accurate representation of the field stages, including the orchard establishment and the orchard creation.

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