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# Environmental impact of intensive versus semi-extensive apple orchards: use of a specific methodological framework for Life Cycle Assessments (LCA) in perennial crops

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ABSTRACT

While the management of apple orchards is intensifying through high tree density, heavy input use and short lifespan, growers in some traditional production areas keep on planting semi-extensive orchards. We assessed the environmental impacts of those two contrasted production systems using the last methodological recommendations for Life Cycle Assessments (LCA) in perennial crops. The use of such framework permitted to assess the weight of the unproductive stages in the orchard lifespan impacts, and the contribution of fertiliser direct field emissions to the total impacts.

Mainly due to fertilisation, the intensive orchard displayed the higher environmental impacts over the orchard lifespan for all calculated impact categories except energy demand. Fertilisation, including fertiliser production and application, represented half or more of the calculated impact categories in the intensive orchard, attesting to the importance of taking these field emissions into account and to include the N-tree requirements in the calculation. Methodological considerations are discussed and the necessity to explicit the approach used to account for the duration of perennial cropping systems is also outlined. Unproductive stages weighted from 9 to 21% of the studied impact categories in the semi-extensive orchard and from 13 to 28% in the intensive orchard, with little contribution of the nursery stage (from 0.2 to 2.6%). This study outlines that orchard strategies (management and design) perform differently according to the context that constrains tree water need and pest and disease control.



## 1. Introduction

In most apple producing countries, the modernisation of apple orchards leads growers to plant high tree density orchards managed with an adapted tree training (Sosna, 2004; Hampson et al., 2002; Robinson, 2008; Reginato et al., 2008). These high density systems facilitate the mechanisation and thus decrease the production costs: the evolution towards more economically competitive apple orchards therefore leads to plant intensive orchards (Robinson, 2008). Moreover, as fruit quality decreases with tree ageing (Sosna, 2004), the lifetime of orchards is shorten to 12–15 years instead of the usual 25 years to maximise first class fruit production. Intensive orchards aim at maximising fruit production, usually including several of the following design traits and management practices: dense planting of short-life trees on dwarfing rootstocks, high chemical inputs, intensive pruning to shape the trees in a restricted form, and frequent mowing of the orchard groundcover (Dart, 2008). In contrast, semi-extensive orchards display a lower tree density and request less use of pesticides and fertilisers with relatively long-life trees that could reach the veteran stage. Although these intensive orchards have proven to be economically efficient, growers in some of the main historical production areas such as the Rhone Valley (Southern France) keep on planting semi-extensive orchards with long lifespan, claiming for better environmental performances of such orchard strategies notably due to their lower input rate. However, their environmental benefit was not yet established.

Life Cycle Assessments (LCA), which is a comprehensive methodology, could bring some new arguments on the comparative environmental performances of these intensive and semi-extensive orchard strategies. To address this question, specific adjustment of the LCA methodology has to be made to evaluate the whole orchard

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strategy, including its management and design over the whole orchard lifespan (i.e. productive and unproductive stages) and its specificities.

Three recent reviews (Cerutti et al., 2011, 2014; Bessou et al., 2012) give a list of recommendations on how to integrate those unproductive stages in the impact assessment and on the needs to account for direct field emissions related to fertilisers and pesticides. These guidelines propose to encompass every stage of the perennial cropping cycle, as well as different approaches to model it. Briefly, the orchard stages to be considered are the orchard creation, establishment, productive years (several years considering the production dynamic) and destruction. Moreover, the nursery period has to be evaluated. To describe and account for these stages, Bessou et al. (2012) proposed three frames to model the perennial cropping system according to data availability: (i) the chronological approach based on data collected chronologically in a given ageing orchard; (ii) the modular approach, for which data from the different stages are collected in the same year from different neighbour plots, possibly completed by literature or prospective data for the missing stages and (iii) the spatial approach, for which data come from an area where all stages of orchards are present.

Beyond the comparison of intensive versus semi-extensive orchards with LCA, our main goal was to test the methodological recommendations of these authors, by analysing the contribution of each life cycle stage in the environmental impacts of two contrasted apple orchard systems. We expected these two orchard systems to represent contrasted cases and to affect the relative importance of the unproductive stages in the LCA and therefore, to be good case studies to use with these guidelines specific to perennial crops. Another studied aspect concerned major field emissions in the orchard. We focused on fertiliser emissions since different models were available to estimate nitrate losses: the variation in the results linked to this emission model choice is discussed.

## 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, 2014) to analyse such perennial cropping systems with LCA. To comply with current methodological frameworks for perennial crop LCA, the different stages of the orchard life cycle including unproductive stages, were accounted for. The unproductive stages included nursery, orchard creation (planting), orchard establishment (tree growth without commercial production) and destruction.

### *2.1. System boundaries and functional units of the studied apple orchards*

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 commercialised apples for the cumulated yield over the whole orchard lifetime. The area-related FU was 1 ha year of land used to produce apples over the whole orchard lifetime.

For both orchards, all cultural practices related to fertilisation, plant protection, between-row management, tree training, fruit load management as well as harvest were collected. As recommended by the three reviews, the unproductive stages (i.e., nursery, orchard creation, establishment and destruction) and the productive stage (i.e., years with apple commercialisation) were included in the analysis.

During the nursery stage, grafted trees were produced, which were considered as inputs in the orchard creation stage. Two different commercial nurseries supplied each one of the two studied orchards. In both nurseries, the plant production cycle lasted 24 months. Rootstocks were grown in field for six months before shield budding. Then the grafted trees were grown in the nursery for a second vegetative year before being transplanted in the orchard. Many operations were mechanically conducted during the nursery stage: branch pruning, soil preparation (ploughing and harrowing) and tree uprooting, while grafting of each growing tree, disbudding and detailed pruning were done manually. The main characteristics of the nursery systems and their major inputs over their whole life (2 years) are listed in Table 1. The two studied nurseries differed mainly in the quantity of young trees produced, which is lower for the nursery supplying the intensive orchard (21,250 young trees, compared to 28,000) than for the one supplying the semi-extensive orchard. The amount of inputs per tree is quite similar or slightly lower in the nursery supplying the semi-extensive orchard with trees.

The two studied orchard systems were described and modelled from on-farm surveys. Each dataset has a unique geographical origin, i.e. Northern (Picardy) and Southern (Rhone Valley) France for the intensive and semi-extensive orchards, respectively. According to Bessou et al. (2012), such data source from homogeneous production areas ensures data consistency and accuracy. The main characteristics of the studied orchards are summarised in Table 2. The two studied orchards differed in their lifetime, orchard height, and associated machinery use, irrigation management (in relation with the climatic context), trellis system and planting distances. Moreover, the intensive orchard establishment stage lasted two years instead of one year in the semi-extensive orchard. Indeed, the semi-extensive orchard was harvested as soon as the annual production reached around 3–4 tons/ha, i.e. in its second year after planting. In the intensive orchard, fruits were harvested only once the production reached a yield of 20 tons/ha (namely in the 3rd year), in order to optimise the costs.

The orchard creation stage consisted of the soil preparation before planting, planting and installation of orchard infrastructure

**Table 1**
Main characteristics of the two nurseries and their major inputs, over the whole length of the nursery stage (2 years). N: nitrogen; a.i.: active ingredient.

| Characteristics | Intensive orchard supplying nursery | Semi-extensive orchard supplying nursery |
|---|---|---|
| Young plants produced after 2 years (number of trees/ha) | 21,250 | 28,000 |
| Grafted plants (number of trees/ha) | 25,000 | 33,600 |
| Irrigation system | No irrigation | Drip irrigation |
| **Inputs** | | |
| N fertiliser rate (kg N/ha) | 150 | 141 |
| Pesticide, active ingredient (kg a.i./ha) | 100 | 45 |
| Including copper (kg a.i./ha) | 7 | 2.5 |
| Including sulphur (kg a.i./ha) | 44 | 18.8 |
| Fuel consumption (L/ha), including uprooting | 414 | 377 |