LCA of Starch Potato From Field To Starch Production Plant Gate

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ABSTRACT

To provide accurate agricultural LCA, the local production conditions, namely crop management techniques, weather and soil conditions, need to be taken into account. To develop adapted inventory methodology, a specific LCA study was carried out on a northern France starch potato supply area. It focused on the upstream steps and used specific crop management and logistics data. To improve inventory methods, the approach is based on process-based models simulating soil carbon dynamic and in-field pesticide emissions. The results obtained for 1 ton of potato showed the influence of soil carbon dynamic on climate change impact that resulted in carbon release between 10% and 18%. This level was mitigated by the soil carbon sequestration effect from the preceding catch crop. The soil type influence was limited due to rather homogenous pedoclimatic conditions. Nevertheless, the proposed approach enabled to account for specific cropping conditions and was designed to test various production scenarios.

Keywords: Starch potato LCA, inventory methods, emission models, Soil organic carbon, pesticide emissions

1. Introduction

Starch currently provides basic molecules for many innovative industrial applications, mainly non-food processes. Potato is the most common crop that produces starch in Northern France. To provide LCA of starch derived molecules and products with accurate and consistent data, a focus was made on the upstream processes, from potato field production to the gate of the starch processing plant. To do so, a specific LCA study was carried out on the supply area of a starch production plant located in Picardy. We were thus also able to provide local stakeholders (producers, advisers) with the environmental impacts of their production chains. There are currently scant literature references on the LCA of potato crops, moreover, most of them focus on food potato (D'Arcy et al., 2010; Williams et al., 2010), which involves crop management practices different from those used for starch potato. Hence, to provide adapted and accurate impact assessment, we used technical data from starch potato producers and specific logistics chain data. Those data were combined to in-field fluxes inventory methods using process-based models able to integrate soil and weather production conditions, and crop rotation. More precisely, two models were used to assess soil carbon dynamic and pesticide emissions. The objective of this study was thus i/ to identify the contribution of soil carbon dynamic in the global warming impact of starch potato upstream production process, and ii/ to focus on pesticide spraying which is one of the important potential environmental impacts of potato. Finally, we were also able to partly test the methodology developed for bioenergy chains (Godard et al., 2012) on another application field.

2. Methods

2.1. Studied system and functional unit definition

The studied area corresponded to the specific supply area of a starch production plant in the French Picardy region. A survey of potato growers showed that the main crop rotation including starch potato in this area was sugar beet/winter wheat/potato/winter wheat. An intermediate crop (white mustard) was sown before potato planting. The crop management technique sequence selected was the most common one described by local technicians and from producer survey (Table 1). The average distance between farm and starch production plant was considered to be 60 km, and a specific logistics chain is detailed in Figure 1.

The studied system entails all the field operations from the intermediate crop preceding potato to its harvest and transport and storage steps before starch production plant gate. All the machinery, the buildings and inputs necessary to those steps were accounted for: fuel and energy consumption, seeds, field fertilizers and pesticides, and storage treatment. The functional unit was the production of 1 t of starch potato (with a 22% dry matter content).

Table 1. Input summary of starch potato and catch crop.

Input (unit)	**Value**
Average annual yield (t fresh matter/ha)	52
Crop management (for 1 year)	
Stubble ploughing (runs)	1
Harrowing and catch crop seeding (runs)	1
Catch crop crushing (runs)	1
Ploughing (runs)	1
Harrowing (runs)	2
Sowing and ridging up (runs)	1
Haulm crushing (runs)	1
Lifting (runs)	1
Seeding rate (kg/ha)	2100
N fertilizer rate (kg N / ha)	180
K Fertilizer rate (kg K_2O /ha)	280
P Fertilizer rate (kg P_2O_5 /ha)	80
Magnesium fertilizer rate (kg MgO/ha)	30
Pesticide application (kg active ingredient/ha)	30.06

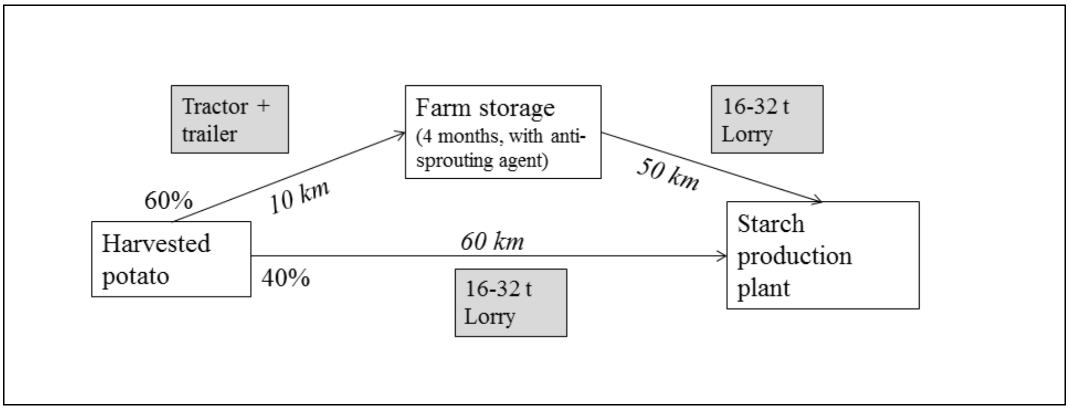

Figure 1. Logistics chain of starch potato.

2.2. Inventory methods

Life cycle inventories needed for the the manufacturing and supply of inputs and buildings were extracted from the Ecoinvent Database Version 2.2 (Swiss Center for Life Cycle Inventories, 2010).

In-field emissions of N and P were assessed using and adapting several inventory methods. Direct and indirect N_2O emissions were assessed according to the IPCC method (IPCC, 2006). NH_3 emissions to air were calculated using emission factors from Institut de l'élevage et al., 2010. The emission factor for NO_x emissions was derived from ADEME, 2010. Emissions of NO_3^- to water were estimated with a field N-balance method adapted from IFEU, 2000, and which integrates previous N fluxes (N_2O, NH_3 and NO_x). The N balance depended on crop rotation and soil type. P emissions in water by leaching, run-off and erosion were estimated according to Nemecek and Kägi, 2007. Soil erosion was estimated with the Universal Soil Loss Equation (Weischmeier and Smith, 1965).

2.3. Modelling approach for soil-carbon dynamic and pesticides emission estimates

To estimate soil C sequestration and pesticide emissions, the AMG (Saffih-Hdadi and Mary, 2008) and Pest-LCI (Birkved and Hauschild, 2006) models were used, respectively. AMG simulates the dynamics of humified organic matter, accounting for inputs from preceding and catch crop residues and their humification and mineralization rates. The main inputs of the model are crop rotation and yields, soil management and properties (texture, organic matter and $CaCO_3$ content), and annual weather conditions. The model runs on a yearly time-step, and a 20-year series of past weather data (1988-2007) was used to simulate soil carbon sequestration. The initial Soil Organic Carbon (SOC) content, to which model predictions are very sensitive, was estimated for the typical starch potato crop-rotation and soil types combinations determined from measurements of soil organic matter changes in Picardy (Duparque et al., 2011). The major soil type in the studied area was a deep clayey loam that was selected for the parameterization of AMG. The effect of soil type on the variations in soil C content over 20 years was also simulated. To do so, the next two soil types in terms of occurrence in the studied area (namely a deep loam and a clayey loam over chalk) were also input to the AMG model.

Pest-LCI simulates the fate of pesticides and their emissions during application and after-application, from soils and crop leaves. It simulates the fate of each fraction of pesticide reaching a compartment of the simulated system (air, crop, soil surface, water drainage system and groundwater). This model runs on a monthly time-step. It accounts for soil and climate conditions as well as bio-physico-chemical properties of the pesticide molecule. To ensure consistent results between pesticide emissions and soil C sequestration, the same past weather data and soil type as for the AMG simulation were used for Pest-LCI.

2.3. Impact assessment method

In order to focus on the main agricultural environmental impacts, five mid-point impact categories and corresponding reference substances were selected. Climate change (kg CO_2-eq), terrestrial acidification (kg SO_2-eq), freshwater eutrophication (kg P-eq), and marine eutrophication (kg N-eq) were calculated using Recipe method, version 1.05 (PRé Consultants, 2008). Ecotoxicity (Comparative Toxic Units – CTU) was assessed using USEtox method (Henderson et al., 2011), and energy consumption (MJ) was calculated according to the Cumulative energy demand method, version 1.08. All impact calculations were performed with SimaPro 7.3.2 software (PRé Consultants, 2011).

3. Results

3.1. Contribution analysis for starch potato

The hot spot for three impact categories out of six (Figure 2), namely climate change (CC), terrestrial acidification (TA) and marine eutrophication (ME) was nitrogen fertilization which actually compounds the production of fertilizer N and the field emissions. Its share varied from 44% to 70% of the total impacts. The CC contribution of N-fertilization mainly came from indirect greenhouse gases (GHG) emissions occurring during the production step of fertilizers, while for TA, the contribution was mostly due to the NH_3 emissions occurring after fertilizer application. The N-fertilization contribution to ME arose from nitrate leaching.

For freshwater eutrophication (FE), the most impacting stage (with 69% of the total impact) was the other fertilization step, PK fertilization, mainly due to phosphate run-off and leaching after P-fertilizer application. Ecotoxicity (E) was in turn widely dominated by the contribution of pesticides (including both production step and in-field emissions) up to 67%. Contrary to other impact categories, cumulative energy demand (CED) originated from nearly all the life cycle steps with a similar level (between 6% to 19 %), the transport phase (to the farm and to the plant) being the major contributor with 40% of the total impact. This transport phase often contributes as the second most impacting step to the other impact categories apart from CED.

One of the specific crop management techniques of potato is seeding. This step was the second after N-fertilization to ME, mainly due to the nitrate leaching occurring after N-fertilization during potato seed production step.

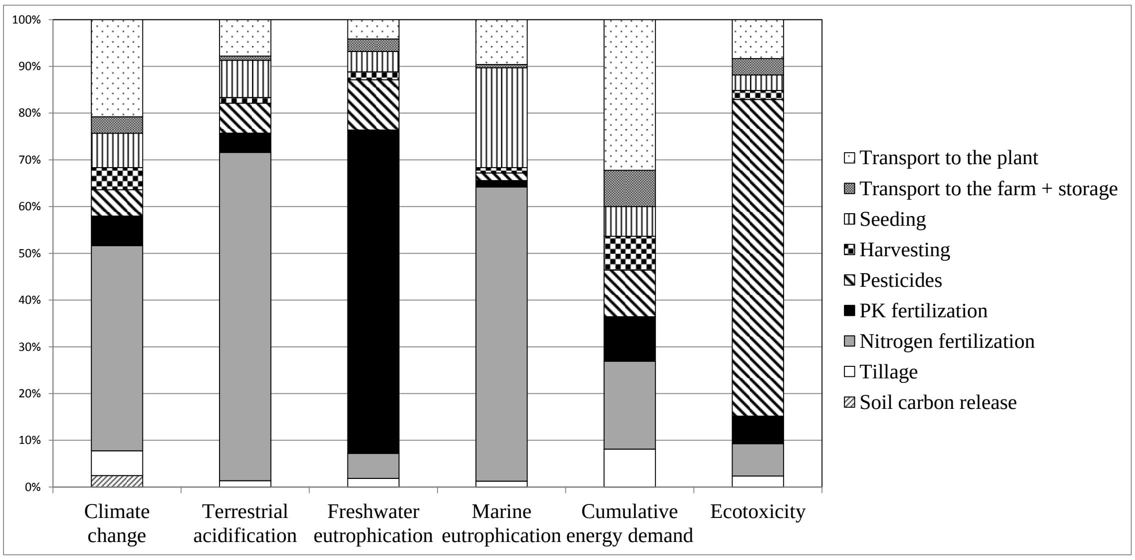

Figure 2. Contribution to the impact categories of each life cycle step from field production to starch plant gate. (CC impact includes both potato and catch crop effect on the deep clayey loam soil carbon).

3.2. Climate change impact and soil carbon dynamic: influence of soil type and intermediate crop

Soil C dynamics was influential in the CC impact, and enhanced the life-cycle GHG emissions of potato crops. Without considering the preceding intermediate crop, the latter always resulted in a release of soil C, from about 10% up to about 18% of the total GHG emissions (Table 2). Indeed all the potato haulms were exported out of field. Nevertheless, it can be noted that the catch crop preceding potato (whose impacts were allocated to the potato crop) strongly mitigated this release, with a systematic carbon sequestration reaching about 200kgC/ha/year on all the soil types. Thus the catch crop could even more than offset the soil C release of potato, and reaching, for example a C sequestration of 81 kgC/ha/year in the clayey loam over chalk.

There were few differences across the three main soil types on the CC impact. For potato crop only, the effect of the soil type on soil C dynamic was stronger than for the catch crop. Actually, the influence of soil type on soil C dynamics was limited because their properties were rather close in the AMG parameterization (texture, organic matter and $CaCO_3$ content).

Table 2. Influence of soil type and catch crop on soil carbon variations expressed per t of potato produced. (a negative value indicates a soil C release corresponding to a CC impact increase)

Soil type (ordered by their area share)	**Soil carbon dynamic contribution to climate change impact**				**Climate change impact (kg CO_2 –eq)**
	Without catch crop effect		**Including catch crop effect**		
	kg CO_2-eq	**%**	**kg CO_2-eq**	**%**	
1. deep clayey loam*	-16.7	-15.6	-2.6	-2.4	106.7
2. deep loam	-19.5	-17.8	-5.6	-5	109.5
3. clayey loam over chalk	-9.8	-9.8	5.7	5.7	99.8

* Refers to the situation represented in figure 2.

4. Discussion

4.1 Main contributing steps and comparison with other studies

The comparison with Williams' et al. study (2010) was only possible for common indicators, as the characterizing method was not the same as the one we used. The two studies showed the same order of magnitude for the CED impact (respectively 1.4 MJ/t for Williams et al., and 1.13 MJ/t in our case). Compared to the study by Williams et al., 2010, the CED proportion due to cool storage of potato is lower in our study (8% for transport+ farm storage here versus 49% for storage only for Williams et al.). This difference is certainly due to a limited storage for starch potato (40% of the harvested potato), contrary to a systematic one for food potato. In our study, the harvest step contributes to CED in the same order of magnitude as the Williams' one (7% vs 10%). D'Arcy's (2010) study showed on the contrary much higher energy consumption than in the present study (4MJ/t vs 1.13 for us). This is probably due the much lower yield they considered (28.1 t/ha in average) than the 52 t/ha we used in our case study.

4.2 Soil C dynamics integration in LCA and its effect on CC impact

We predicted the contribution of potato crop to soil C variations by simulating SOC dynamics with the AMG model. Our approach differs from Nemecek and Kägi, 2007, which is based on the C content of the biomass exported from the field, considering it a sink for atmospheric CO_2. A widespread, more practical alternative consists of considering crops as “climate-neutral”, as Schmidt et al., 2004) did in their study of flax production. The latter two approaches actually disregard the effects of crop cultivation on soil C dynamics, let alone the effects of soil type, crop rotation or climate, which play a major role in the GHG balance of agricultural crops (Ceschia et al., 2010). Using a soil C model such as AMG is a means of overcoming this limitation and accurately predicts soil C sequestration or release rates. In the present example of starch potato, these rates may mitigate or, conversely, increase the global warming impact of crops, depending on soil type and climate conditions. This modelling approach was then an alternative to the French reference from Arrouays et al., 2002, who gave a single C sequestration rate for several crops. Our estimates of C release of 0.02 Ct/DMt/year was far different from the sequestration of 0.008 Ct/DMt/year given by Arrouays et al., 2002, for French food potato. Their approach was maybe too generic to account for the specificities of starch potato growing in a particular supply area.

Moreover, the AMG model includes crop rotations in its simulations of mid to long term soil C dynamics, and in the present case, the starch potato crop rotation always sequestrated soil C, despite the potato contribution as a net C release. This raises the question of the accounting of crop rotation and the allocation of catch crops in the soil C sequestration assessment. Indeed, as we showed for starch potato, the allocation of catch crop to the following main crop can result in an opposite effect on soil C dynamics.

Beyond global warming impact assessment, another reason to use AMG is that SOC is considered a relevant indicator of soil quality for LCA (Brandão et al., 2011; Milà i Canals et al., 2007a; Milà i Canals et al., 2007b). Thus, accounting for soil quality in LCA could be facilitated by the use of SOC models such as AMG.

4.3 Modelling approaches in agricultural LCA

This study showed the relevance of using emission models instead of using default emission factors in the life-cycle inventory to account for the characteristics of a crop supply area. Indeed this approach makes it possible to integrate the diversity of cropping production systems in supply areas in agricultural LCAs. Modeling approaches have already proven to be able to integrate various biophysical and technical crop production conditions in agricultural LCA, as in the studies from Adler et al., 2007; Gabrielle and Gagnaire, 2008. We were able to integrate the specific characteristics of crop management, logistics and storage in a supply area as well as its pedo-climatic characteristics by the use of the two models AMG and Pest-LCI. Beyond soil carbon dynamics and pesticides, crop models can provide precise assessments of in-field fluxes, and particularly N-fluxes which are highly dependent on local conditions. Nevertheless their use remains unusual, since they involve numerous parameters, some which are note easily available. An alternative way to these crop models are developed balance, such as Sundial used by Williams et al., 2010, thus limiting the parameterization difficulty, and at the same time integrating crop rotation, crop management practices and pedoclimatic conditions in LCAs.

5. Conclusion

The approach proposed here has already been tested for a different context and for other crops, namely biomass feedstocks (Godard et al., 2012). It is a promising way to better account for the spatial variation of crop production conditions in agricultural LCA, by the integration of this variability range in model parameterization. This kind of approach is relevant to test new production scenarios, such as the reduction of pesticide application, or the change in a crop supply and production area. It is also a good way to better account for geographical aspects in decision making, by providing adapted and accurate LCA results to local stakeholders.

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