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ABSTRACT

The French project ECOALIM aims to improve the environmental impacts of husbandries by optimizing their feed. This project defines the environmental impacts of the production of raw materials for animal feeding and optimizes the formulation of feed compounds with environmental constraints in order to improve environmental footprint of animal products. The project covers different farming systems and production areas in France and is based on life cycle assessment (LCA). The objective of this study was to develop a dataset of environmental impacts of feed ingredients, while taking into account agricultural practices and processing.

The LCA results obtained for rapeseed grown in France, with different agricultural practices, at the field gate, are discussed here, while similar results are also available for other crops (wheat, barley, maize, sunflower, pea…). Several life cycle inventories (LCI) were carried out: national average data representative of France (average French rapeseed) and LCIs with different crop managements based on case studies, in different regions of France, with different crop rotations (rapeseed in crop rotation with introduction of intermediate crops, or with introduction of legumes, or with organic fertilization, or rapeseed cultivated with an associated crop). The LCA methodology was applied, considering environmental burdens at the rotation system scale. Focus is made this paper on five impact indicators (Climate Change ILCD, Cumulative Energy Demand non renewable fossil+nuclear, ACidification ILCD, EUtrophication CML, Consumption of Phosphorus).

For the rapeseed LCIs presented, the main contributor to selected environmental impacts was field emissions. The assessment of practices such as organic fertilization, the introduction of intermediate crops, the introduction of legumes in the rotation or an associated crop within rapeseed crop showed some improvements on impacts. But results were very variable between the different case studies.

Keywords: rotation, rapeseed, organic fertilization, intermediate crop, associated crop

1. Introduction

Animal feeding contributes very significantly (up to 80 %) to the overall environmental impact of animal products (meat, milk) assessed by Life Cycle Assessment (LCA). But, the current feed formulation only takes into account economical and nutritional constraints. The French project ECOALIM aims to improve the environmental impacts of husbandries by optimizing their feed. This will lead to select different feedstuffs in the formulation, or to change their ways of production (crop managements, transformation processes). To perform such optimization, LCA data concerning the feedstuffs are needed. It should be then integrated to advice tools for stakeholders to help them in reducing the environmental impact of feed while still taking into account economic and social aspects.

A previous study highlighted the need for homogeneously developed data on environmental impacts of feed ingredients to formulate low-impact feeds and investigate mitigation options (Nguyen et al., 2012). The database constructed within the project ECOALIM gathers the most accurate and representative data on Life Cycle Inventories (LCI) to date for French feed ingredients, with 149 average feed ingredients (non-processed and processed ingredients, several perimeters: field gate, storage agency gate, plant gate and harbor gate) and 16 feed ingredients from specific crop itineraries (Wilfart et al., 2016).

In this paper, we focused on five LCIs concerning rapeseed at the field gate: the inventory for average French rapeseed obtained from statistical data, and four inventories constructed with different agricultural practices in order to evaluate their ability to reduce the environmental impacts of that crop. The studied agricultural practices were implemented at two different levels:

- at the level of the rapeseed crop : "associated crop" which means that winter oilseed rape is grown with an intercropping frost-sensitive crop (preferentially legume crop). This agroecological solution impacts directly the rapeseed crop management,
- at the level of the crop rotation: rapeseed crop is included in a cropping system and some agricultural practices implemented at this level may have an effect on the environmental

impact of each crop in that system. The three studied agricultural practices at this level were: organic fertilization (OF), systematic introduction of cover crop (SCC), introduction of protein crops in the rotation (legume crops as pea or soybean or faba bean, PC).

Similar LCA results, with the effect of agricultural practices, are available for other crops (wheat, barley, maize, sunflower …) in the ECOALIM database. Other LCA perimeter where also, used, at the mill gate for instance, for rapeseed meal, with five different rapeseed meal LCIs coming from the five different rapeseed LCIs at the field gate (national average + 4 agricultural practices). Yet the LCA results obtained for rapeseed grown in France, at the field gate, with different agricultural practices, are discussed here.

2. Methods

The Life cycle inventory for French rapeseed at national level was based on the similar inventory included in the Agribalyse® database (French national database of the main agricultural products; Koch and Salou, 2015), with updated emission factors for ammonia (EMEP/EEA, 2013). Within this ECOALIM project, one major methodological difference compared to Agribalyse® was the distribution of the phosphorus fertilizer inputs and nitrate emissions among the different crops involved in the same crop rotation (according to crop requirements and removal for phosphorus, and equally among crops for nitrate leaching).

The LCA perimeter used for rapeseed at the field gate starts from "craddle" which takes into consideration the production of the inputs needed to produce the feed ingredient (seeds, fertilizers, energy, materials, …), and it ends at field gate. The functional unit for data collection was 1 ha, while the functional unit for LCIA was 1 kg. Data were collected over the period 2006-2012. The background data (electricity, transport) came from the Ecoinvent V3.1 database. All produced data were checked and validated by an LCA expert committee.

Focus is made this paper on five impact indicators: Climate Change ILCD (kg CO_2 eq), Cumulative Energy Demand non renewable fossil+nuclear (MJ), ACidification ILCD (mol H^+ eq), EUtrophication CML (kg PO_4^{3-} eq), and Consumption of Phosphorus (kg P).

3. Life Cycle Inventory

For the French rapeseed crop (**RS-Fr**), the national average inventory was obtained from statistical data adjusted with expert judgments. This inventory data were based on the period 2006-2010, but data were not collected each year (most data were calculated as the mean of three Terres Inovia's surveys respectively conducted in 2008, 2009 and 2010).

For the "associated crop" rapeseed (**RS-AC**), the inventory was based on the RS-Fr inventory, with modifications related the intercropping frost-sensitive legume crop: additional seeds (faba bean seeds), decrease of the nitrogen fertilizer amount (- 30 kg N/ha), and less herbicide treatments (- 33% herbicide active substances and - 1 tractor with plant protection sprayer). These inventory data are presented in table 1, and were supported by experiments (Cadoux et al., 2015).

Table 1: Main inputs used and yield for average French rapeseed and "associated crop" rapeseed

Crop	**Yield (9% H2O)**	**N mineral**	**N manure**	**P2O5**	**K2O**	**Seeds**	**Pesticide** active ingredient	**Diesel**	**Agricultural machinery**
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
RS-Fr	3243	161.6	17	48	28	2.5	1.98	78.3	8.2
RS-AC	3243	131.6	17	48	28	2.5 rapeseed + 50 faba bean	1.43	77.4	8.1

For the other three rapeseed LCIs, with agricultural practices introduced at the crop rotation level, introduction of systematic cover crop (**RS-SCC**), organic fertilization (**RS-OF**), introduction of protein crop (**RS-PC**), the method was quite different, and not based on statistical data. Hence, different LCI for soft winter wheat, barley, grain maize, oilseed rape and sunflower were carried out based on 12 case studies, representative of different farming systems (characterized by different pedoclimatic conditions, yield potential, choice of the crops in the rotation), distributed in different regions of France. These case studies have been defined at the rotation scale by regional agronomists to be representative of the main farming systems in each main production region. Among these case studies, seven ones included rapeseed and were located in the East of France (rotation rapeseed-wheat-barley), in the North of France (with one short rotation rapeseed-wheat-barley, and another longer rotation rapeseed-wheat-sugar beet-wheat-barley), in the Centre of France (rotation rapeseed-wheat-barley), in the West of France (rotation rapeseed-durum wheat- soft wheat-sunflower-soft wheat-barley), in North-West of France (rotation rapeseed-soft wheat-sugar beet-soft wheat) and in the South of France (rotation rapeseed- soft wheat-sunflower- durum wheat). The implementation of the scenarios (SCC, OF, PC) was consistently adapted to each case study, depending on the regional agronomic possibilities, with regional expert judgments. The choices and aftermath on the LCI, concerning each scenario introduced into the case studies were:

- Introduction of systematic cover crop: letting volunteer rapeseed plants after rapeseed harvest was considered as a cover crop; sowing a combination of cruciferous and legume seeds between a cereal harvest and a spring crop sowing was another intermediate cover crop. This agricultural practice led to a decrease of nitrate leaching (-50% nitrate leaching after rapeseed harvest when there are volunteer rapeseed plants) and to a reduction of the amount of nitrogen fertilizer applied on the following crop. Seeds for intermediate crops and destroying the cover crop residues (with shredder or herbicide) were included in the inventory. The reduction of nitrate leaching was shared between all the crops in the rotation.

- Organic fertilization: the amounts, the choice of the organic fertilizer types (manure, slurry…) and their transport depended on each case study, and were adapted to the regional context. A rule, limiting the organic fertilizer inputs, was set up in order to avoid excessive phosphorus inputs at the rotation scale. This agricultural practice led to a reduction in mineral nitrogen fertilizer inputs, and to different results in the calculation of ammonia and nitrogen oxides emissions.

- Introduction of legume crop in the rotation: the choice of protein crop was adapted to the regional context. We considered spring pea in the case studies with rapeseed (other cases without rapeseed introduced soybean crop). This agricultural practice had a positive effect on the following crop (mainly cereal), as it allowed a lower nitrogen fertilizer input.

To produce for instance the **RS-SCC** inventory, in each regional case study, we calculated the effect of this agricultural practice (systematic introduction of cover crop in the rotation) by creating an LCI with +1 kg of rapeseed with systematic cover crop in one case study and -1 kg of rapeseed from basic scenario (rapeseed in the same case study without any of the three studied agricultural practices). Then, in order to produce an average inventory of the effect of SCC at the level of France, a ponderation of the effect of SCC in individual case studies was made, according to the yield of rapeseed crop in each case, and to the surface that each case study represents in each region (Jouy and Wissocq, 2011). Finally, the RS-SCC inventory was composed by the RS-Fr inventory for 1 kg of product + 1 kg of the average effect of SCC. So, the RS-SCC, RS-OF and RS-PC inventories had the same yield 3243 kg /ha at 9% moisture than RS-Fr and RS-AC.

4. Life Cycle Impact Assessment

The LCIA results are presented in table 2, while a comparison is showed in figure 1.

Table 2: LCIA results for 5 rapeseed crop at field gate, according to various agricultural practices

Impact	unit		RS-Fr	RS-SCC	RS-OF	RS-PC	RS-AC
Climate change ILCD	kg CO_2 eq	CC	0,927	0,919	0,883	0,926	0,820
CED 1.8 non renewable fossil+nuclear	MJ	CED	5,537	5,537	4,786	5,512	4,944
Acidification ILCD	molc H^+ eq	AC	0,0210	0,0210	0,0194	0,0210	0,0190
Eutrophication CML baseline	kg PO_4^{3-} eq	EU	0,00755	0,00651	0,00746	0,00772	0,00729
Phosphore consumption	kg P	P	0,00735	0,00735	0,00143	0,00679	0,00730

The assessment of practices such as organic fertilization, the introduction of intermediate cover crops, the introduction of protein crops in the rotation and an associated crop within rapeseed crop showed some improvements on impacts (figure 1). First, Climate change (CC) and Acidification (AC) were mostly reduced with RS-AC (-12% and -10%), as it allowed a direct reduction of the amount of mineral nitrogen fertilizer in the rapeseed crop. Then, Cumulative Energy Demand non renewable fossil+nuclear (CED) was mainly reduced with RS-OF (-14%) and RS-AC (-11%) for the same reason. Eutrophication (EU) was mostly reduced with RS-SCC (-14%) as nitrate leaching was reduced in those rotations with intermediate cover crops. Finally, the consumption of phosphorus resources (kg P) was dramatically reduced down to 19% with RS-OF (-81%), as most of phosphorus supply necessary in the rotation for crop growth was brought by manure. RS-PC had a weak effect on indicators for rapeseed crop, whereas this agricultural practice mainly benefited the following crop after protein crop (always a cereal) with reduced nitrogen fertilization. So the introduction of legume crop in the rotation did not benefit directly rapeseed crop but proved to be a beneficial practice at a rotation scale (Nemecek, 2015).

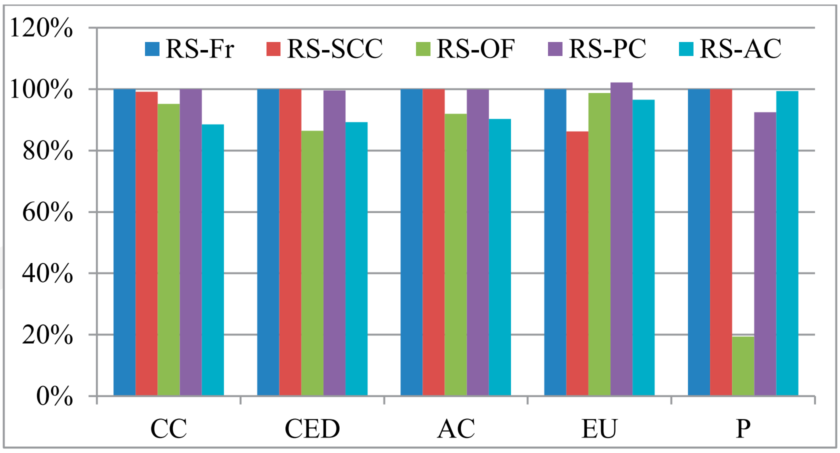

Figure 1: comparison of LCA results of rapeseed with various agricultural practices.
RS-Fr= Rapeseed, conventional, average France. RS-SCC= Rapeseed with systematic cover crop in the crop rotation. RS-OF= Rapeseed with high level of organic fertilization in the crop rotation. RS-PC= Rapeseed with insertion of a protein crop in the crop rotation. RS-AC= Rapeseed with an associated crop (frost-sensitive legume crop) with the rapeseed crop

In figure 2, only RS-Fr and RS-AC LCA results were presented, to evaluate the main contributors to the five studied impacts.

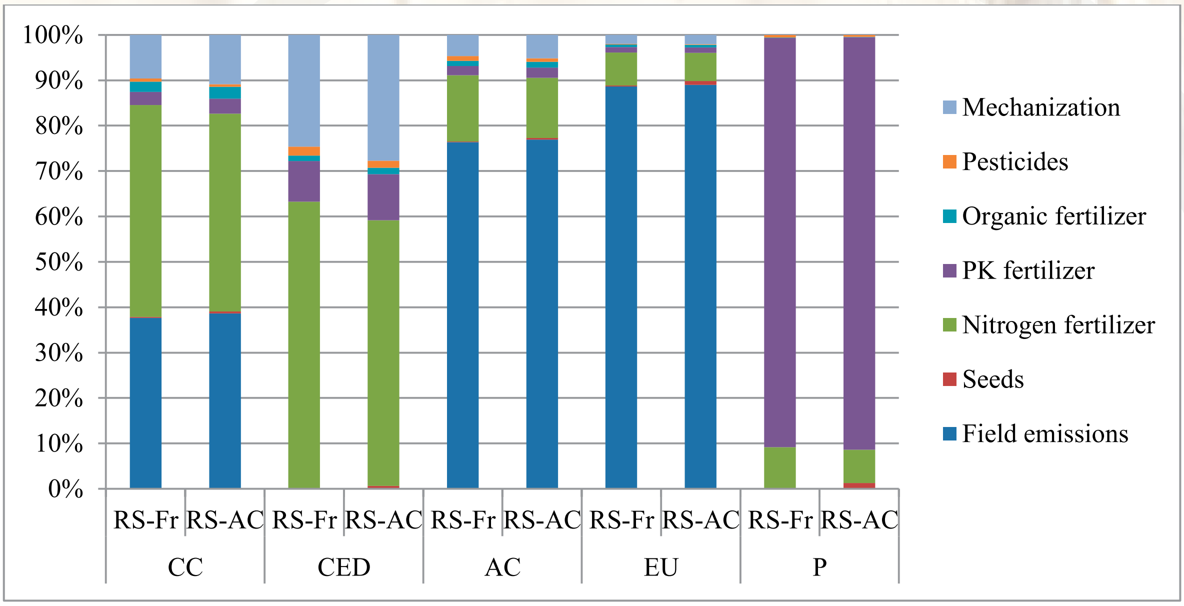

Figure 2: distribution of impacts for Average French rapeseed, and “associated crop” rapeseed

For rapeseed crop, the main contributor to acidification impact was field emissions (of which 91% ammonia and 9% nitric oxides) and to eutrophication impact too (of which 56% nitrate, 26% ammonia, 8% phosphorus, 5% nitrous oxide, 4% nitric oxides). The field emissions were also an important contributor to climate change impact, mainly due to nitrous oxide emissions, which are linked to nitrogen fertilization. For climate change, the other important contributor was the production of nitrogen fertilizer supplied to rapeseed crop. This nitrogen fertilizer is a main contributor to CED impact, as its production is energy consuming, while mechanization (including agricultural machinery, diesel production and diesel combustion) was also an important contributor. The consumption of phosphorus, as a non renewable natural resource, was due obviously to the input of mineral phosphorus fertilizer on the crop. The RS-Fr and RS-AC repartitions were almost identical.

But the results were very variable between the different case studies (figure 3), as the introduction of agricultural practices was adapted to each regional context. For instance, the organic fertilization was a stronger lever to reduce the climate change impact, in the case studies in the Centre of France and in the East. This was because, in these two regions, manure is rarely used on arable crops, so the effect is higher than for a case study like West of France where organic fertilization is already present in the basic scenario. So, the inventories for agricultural practices, based on seven case studies for rapeseed, gave highly variable LCIA results, which made comparison difficult. This is to be added to the variability of primary data.

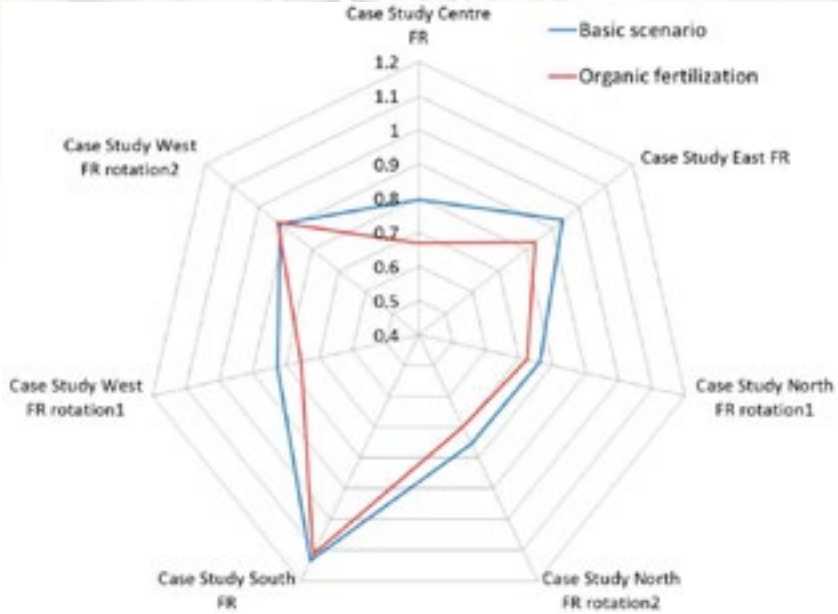

Figure 3: Climate change results of rapeseed at the field gate (g CO2-e/kg) for seven case studies (in different French regions), and two different agricultural practices (Basic scenario versus High level of organic fertilization in the crop rotation scenario).

4. Conclusions

The assessment of practices such as organic fertilization, the introduction of intermediate crops, the introduction of legumes in the rotation or an associated crop within rapeseed crop showed some improvements on impacts. The agricultural practices studied here had beneficial effects by lowering mineral nitrogen or phosphorus fertilizers, or by lowering emissions such as nitrate or nitrous oxide. A combination of several agronomic levers, adapted to each context could be a way to lower environmental impacts more efficiently. Indeed, the introduction of intermediate crop reduced the eutrophication impact, while the associated crop (intercropping frost-sensitive legume crop within rapeseed crop), and organic fertilization both reduced Energy consumption, Climate change and Acidification impact for rapeseed crop. Organic fertilization had a strong effect on consumption of natural phosphorous resources. The introduction of legumes in the rotation didn't benefit rapeseed crop directly, but proved to be an interesting practice at a rotation level. Other agricultural practices could be further studied, with a beneficial effect on impact like ecotoxicity or human toxicity.

Finally, these results represent a step forward to share with the agricultural sector in order to promote good farming practices and environmental assessment. Thus, this should encourage the first processing and the feeding industries to promote better agricultural practices.

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