

# Methodological developments for LCI of French annual crops in the framework of AGRIBALYSE®

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## ABSTRACT

In the framework of the French research program AGRIBALYSE®, Life Cycle Inventories of 12 annual crops have been worked out. Specific developments were required to establish the LCI of these crops. Firstly, as cropping management and environmental conditions vary both in space and time, emissions modelling at a national scale is a complex task and induced methodological challenges. Secondly, environmental assessment of a single crop requires taking into account the whole cropping rotation, in particular to assess nitrate leaching emission and allocate nutrient burdens between crops. Hence, a specific work, based on statistical data, was done to develop a nitrate model and to take into consideration fertilization practices into whole rotations. These developments provide a framework to assess emissions at a national scale in consistency with average agricultural practices and field observations. Availability of data can be a limiting factor and determine choices made for agricultural LCA-making. The nitrate model and the allocation method developed for AGRIBALYSE® are two examples of structured and simplified methods based on and parameterized with national statistical data and provide consistent results.

Keywords: annual crops, allocation, LCI, nitrate, rotation

## 1. Introduction

AGRIBALYSE is a French research program (2010-2013) launched by ADEME and aimed to produce public Life Cycle Inventories (LCI) of agricultural products. It pursues two purposes: i) build an LCI database to provide data for the environmental labeling of food products and ii) share the data to enable the agricultural and food industries to assess the production chain and reduce environmental impacts (Colomb et al., 2014; Koch P.; Salou T., 2013). In the framework of this program, Life Cycle Inventories (LCI) of 25 product groups have been produced, whereof 12 are referring to annual crops, as cereals, leguminous, oleaginous and industrial crops,. A common methodological framework has been established for all the plant production inventories to ensure a homogeneous database. But at the same time, the crop diversity (annual / perennial, field / greenhouse, French / tropical crops) required specific choices to model at the best the different productions. LCA of crops induce different challenges:

- (1) *Data collection*: for French cereals, leguminous, oleaginous and industrial crops, detailed and representative statistical production related data are available by crop for the main production systems from national administration or technical institutes. However, this is not the case for organic production. Moreover, few data on soil and climate conditions are available in these surveys.
- (2) *Allocation of inputs and direct emissions between crops*: emissions depend on practices managed on the whole crop rotation and not only on one crop. For instance, fertilization to one crop may benefit following crops too. Moreover, the emissions of some environmental flows vary in function of the management and features of one crop but also of the preceding or following crops. In particular, nitrate leaching due to the nitrogen fertilization of one crop depends on the quantity applied but also on the intercrop management and on the following crop. Hence, environmental assessment on single crops requires taking into account the whole crop rotation. But statistical data are rarely available on a crop rotation level.
- (3) *Calculation of direct emissions*: the estimation of an average value for some emissions, as nitrate, for a given crop at the national scale is difficult as the emissions greatly vary depending on agricultural practices, type of soil and climatic conditions.

The main methodological choices and the database as well as a result analysis for annual crops are described in two other contributions to the LCA Food 2014 (Colomb et al., 2014, Willmann et al. 2014). This article describes the main specific choices and methodological developments that have undertaken to cope the features of

French annual crops and agronomic specificities. The first part discusses the modelling framework. Specific developments for nitrate leaching assessment and nutrients burdens allocations are presented in the two following parts.

## 2. Modelling framework

For a complete and detailed information on methodological choices, we here refer to the AGRIBALYSE methodological report (Koch and Salou, 2014). For a general description about the modelling framework, system boundaries and the quality control, see Colomb et al. (2014).

### 2.1. Main methodological framework

LCI for 12 cereals, leguminous, oleaginous and industrial crops have been established. Several production systems for the same product have been described to distinguish different productions in function of their quality or of the mode of production (Table 1). The system boundaries considered in AGRIBALYSE are from cradle to field gate.

Table 1. AGRIBALYSE inventories for cereals, leguminous and oleaginous and main sources for description of production systems

Product groups	Inventories	Main source for description of production systems
Barley	Barley, conventional, malting quality, national average	[1]
	Forage barley, conventional, national average	[1]
Durum wheat	Durum wheat grain, conventional, national average	[1]
Soft wheat	3 Soft wheat grain, conventional LCI: breadmaking quality, 15% moisture / protein improved quality, 15% moisture / national average	[1]
	2 Soft wheat grain, organic (model type), Central Region LCI: after Alfalfa / after fava beans	[2]
Triticale	Triticale grain, conventional, national average	[5]
	Triticale grain, organic (model type), Central region	[2]
Grain maize	Grain maize, conventional, 28% moisture, national average	[1]
Silage maize	Silage maize, conventional, national average	[1]
Rapeseed	Rapeseed, conventional, 9% moisture, national average	[3]
Sunflowers	Sunflower, conventional, 9% moisture, national average	[3]
Faba beans	Faba beans, conventional, national average	[5]
	Spring faba beans, conventional, reduced protection	[5]
	Faba beans, organic (model type), Central Region	[2]
Peas	Winter pea, conventional, 15% moisture	[1]
	Spring pea, conventional, 15% moisture	[1]
Potatoes	4 ware potato, conventional LCI: for industrial use / for fresh market, firm flesh varieties / for fresh market, other varieties / variety mix, national average	[1]
	Starch potato, conventional, national average	[1]
Sugar beet	Sugar beet roots, conventional, national average	[4]

[1] survey on agricultural practices of the French agricultural administration managed in 2006 (2006 SSP farming practices survey), [2] RotAB: project for organic arable crop systems without livestock (<http://www.itab.asso.fr>), [3] survey of CETIOM, [4] survey of ITB, [5] according to expert opinion

As for most of the production systems, detailed and representative statistical data about agricultural practices are globally available by crop from surveys of national administration or technical institutes, these data were used by preference (Table 1). With the exception of organic production and of some conventional produced crops (faba beans, triticale), those provide detailed information about the different crop operations and applied inputs from the harvest of the preceding crop to the harvest of the surveyed crops and the harvest. If necessary,

these data were completed by expert opinions in particular to distinguish agricultural practices in function of their quality and to adjust data to be representative for the period 2005-2009. On the other hand, no data on soil and climate conditions were available in these surveys. In the absence of representative statistical data, study cases from the project RotAB have been used to establish LCI for organic productions. So, the aim of these inventories is not to represent the French organic production but to provide an order of magnitude for one example of organic arable system production without livestock.

Emissions associated with inputs are based on existing data, mainly from the database Ecoinvent® V2.2. Some input references have been adapted to French specificity when possible as for example fuel consumption by tractors during field work, transport of inputs and fertilizer product.

## 2.2. Identification of models for the calculation of the direct emissions

The substances quantified have been selected following international standard recommendations, knowledge about the contribution of the substance emitted by agricultural activities on environmental impacts and the existence of valid models. Each flow was calculated with a specific model chosen as the most suitable according to the objectives and limits of the program. Such models should not require input data that are too difficult to collect, and should be validated for France and recognized internationally. We also considered whether models simulate the effect of agricultural practices on emissions.

For some flows, different models used for LCA, national inventories, agronomical research or development have been identified in particular for  $\text{NO}_3^-$ ,  $\text{N}_2\text{O}$  or  $\text{NH}_3$  emission assessment. Mechanistic models allow the assessment of evolving changes in farmer practices but are often applied to a relatively small geographical region, assuming a homogeneous environment with respect to soil and climate. Their application at a larger scale is difficult as input data to models, including cropping management and environmental conditions, can vary both in space and time. In the meantime, no or few data on soil and climate conditions were available in the surveys on farming practices. Hence, models used to assess  $\text{N}_2\text{O}$  or  $\text{NH}_3$  emission for national inventories (IPCC 2006b Tier 1; EMEP/EEA 2006, 2009 Tier 2) were finally chosen. For  $\text{NO}_3^-$  emission, a specific empirical model has been developed based on a risk analysis approach (see 3. Nitrate leaching modelling).

Only one model meeting AGRIBALYSE requirements was identified for some flows as phosphorus (SALCA-P), heavy metals (SALCA-ETM) or eroded soils (RUSLE). The application of these models for AGRIBALYSE required some adaptations, in particular taking into account French production conditions and using them at a national scale, while they have been established for applications at field scale. Hence, some parameters have been adapted when possible. For instance, average soil and climate parameters at regional scale have been assessed basing on INRA soil and metrological database to implement RUSLE. However, as data were missing, it appeared that the adaptation of SALCA-P to the French context was not possible. Some parameters related to plots, as slope, have been assessed by expert judgment. To assess the relevance of this model on French situation, a specific work was done to compare results to experimental data (Willmann et al., 2014).

Some flows were not assessed as no valid model has been identified. It is the case of particulate emissions other than ammonia, as the data currently available in France and Europe was considered to be insufficient to take satisfactory account of these emissions. Among the various  $\text{NO}_x$  gases only  $\text{NO}$  was considered for direct flows, owing to the lack of appropriate models for the other gases.

## 3. Nitrate leaching modelling

### 3.1. The aim of the model

Different mechanistic field-models have been identified to assess either only  $\text{NO}_3^-$  emission (eg: the model DEAC, described in Cariolle 2002 and Cohan et al., 2011; or SALCA- $\text{NO}_3$ , described in Richner et al. 2006), or  $\text{NO}_3^-$ ,  $\text{NH}_3$  and  $\text{N}_2\text{O}$  emissions (the model STICS, described in Brisson et al. 1998 and Syst'N, being published). In the meantime, their application at region scale is difficult. Schnebelen et al. (2004) developed and assessed an upscaling approach of STICS to model nitrate leaching at regional scale. This approach has been proven effective at the scale of a small agricultural area (i.e; 526 km<sup>2</sup>) but is likely to introduce additional errors, as it is based on assumption of homogeneous crop and soil parameters on simulation units. Moreover, the application of this approach at the French national scale is a lengthy and data-intensive process.

Very simple models that estimate nitrate leaching as a fraction of applied fertilizer (IPCC 2007; Miller et al. 2006; Powers 2007) are too crude to compare production systems or assess effects of changes in farmers' practices. Bentrup et al. (2000) estimated nitrate leaching on the basis of estimated post-harvest soil mineral nitrogen content, but some input data for the model (nitrogen mineralization and immobilization in the soil) are difficult to quantify at large scales. Basset Mens et al. (2006) developed a method combining a risk analysis approach, based on the risk analysis proposed by Cattin et al. (2002), with regional leaching data. In this study, a model was specifically designed to assess some production systems in the Brittany region in western France, and the method therefore is not valid outside this region. However, this approach has been proven efficient at providing an average estimation of nitrate leaching for a specific region and it is based on easily available data regarding farmers' practices and soil parameters. This method could therefore be applied at a national scale after specific development.

### 3.2. General principles of the model

The COMIFER model proposed by Cattin et al. (2002) is a qualitative simplified approach that is applicable at a plot scale to qualify the risk of leaching. It takes account a "crop risk" and an "environment risk" (depending on the quantity of water percolating through the soil and the mineralization conditions).

Concerning the "crop risk", the COMIFER model classifies conditions according to the following criteria, in order of importance.

1. Period without presence of vegetation able to absorb nitrogen (depending on the following crop and the sowing of an intermediate crop)
2. Capacity of the following crop to absorb nitrogen in the fall (depending on the following crop)
3. Application of organic fertilizer in the fall (C:N ratio < 8)
4. Quantity of nitrogen provided by crop residues (depending on the crop studied and the management of residues)

The COMIFER model defines the "environment risk" by the combination of two criteria: i) the soil drainage index and ii) the organic matter content of the mineralizing soil layer.

Then, it classifies the risk according to various "crop risk" x "environment risk" combinations.

### 3.3. Specific developments

ARVALIS managed different developments based on this model for its implementation in AGRIBALYSE:

1. A weighting system for the different classification criteria was drawn up by expert opinion on the basis of the model to estimate the risks for crop conditions not covered in the COMIFER classification.
2. The COMIFER provides a risk classification according to the crop and environment risks. Each level has been associated with a nitrate leaching amount, based on expert opinion.

Table 2. Nitrate leaching amount (kg N-NO<sub>3</sub><sup>-</sup>/ha) according to the crop and environment risks.

		« crop risk »				
		1	2	3	4	5
« soil risk »	1	5	10	20	25	30
	2	10	15	25	30	40
	3	15	20	30	40	50
	4	20	30	40	55	60
	5	30	40	40	60	80

3. The balance between nitrogen supply and the crop requirements is not a parameter used in the COMIFER model. This was based on the assumption that there was no excessive nitrogen fertilization on the previous crop which could generate an excessive increase in the nitrogen content of residues. On the one hand, many studies (Chaney, 1990; Richards et al., 1996; Machet et al., 1997) have shown that when N inputs are lower than the crop requirement, the N application has a very little effect on the nitrate amount that is available after harvest

and potentially leachable. On the other hand, excessive N inputs can potentially increase the amounts of N leached. These depends on cropping practices, soil type and climate conditions (Lacroix et al., 2006).

First, the effect of the excessive N inputs (N inputs minus crop N requirements) on the residual soil mineral nitrogen content (SMN) after harvest has been assessed from the relationship established by the COMIFER (1997), based on 400 measures. Then, the surplus amount of nitrate leaching was assessed, based on the supplementary SMN and parameters on leaching fraction. As the effect of excessive N-fertilization was merely assessed on the experimental sites, these fractioning parameters have been established for each “environment risk” by expert opinion (Table 3).

Table 3. Fractioning parameters to assess the effect of excessive N-fertilization from the increase of SMN and nitrate leaching results for an excess of 50 kg N/ha

		Soil risk				
		1	2	3	4	5
<b>% of the supplementary SMN that is leached</b>		0.5	0.6	0.7	0.8	0.9
<b>Supplementary nitrate leaching (kg N-NO<sub>3</sub>)</b>	<b>cereals and oilseed rape</b>	7	8	9	11	12
	<b>maize and sugarbeet</b>	12	14	17	19	22

The “crop risk” weighting system and assignment of leaching quantities to each “environment risk” x “crop risk” combination were validated by measures on 5 sites for three to fourteen years on contrasting situations. Some simulations have also been made with the DEAC model (Cariolle 2002) in order to obtain references for a very low « soil risk ». The validity of the model at plot scale was also confirmed by a work being published. This work aims to compare three different models applied on two different study cases.

### 3.4. Implementation of the model for the AGRIBALYSE program

As no statistical data cover both agricultural practices and soil-climate data, different databases have been used (Table 4). It was not possible to localize precisely the agricultural plots from the public survey on agricultural practices but the sampling of this survey was built to provide representativeness at the scale of administrative regions. Hence, nitrate leaching was assessed at the scale of administrative regions, although these regions do not correspond to homogeneous agronomical units.

The crop risk was estimated for the 1,000 plots covered by the SSP for the 2006 farming practices. For each crop and each administrative region, the average risks were estimated for each “crop – following crop” combinations. The average risks for each crop and each administrative region were obtained from these risks for crop combinations weighted by the frequency of these combinations, also estimated with the farming practices survey.

The geographic French soil database managed by the INRA Soil Science Unit, Orleans, was used to estimate the environment risks. It describes a set of soil typology units, characterizing distinct types of soil. The soil typology units are described using attributes defining the nature and properties of the soils (eg: texture, water system, soil parent material, etc.).The environment risk was estimated for each soil typology unit based on soil water retention capacity and climatic data from the Arvalis database covering 84 weather stations over the last 30 years. The areas corresponding to each risk category in each administrative region were then characterized to estimate the average risk.

Average nitrate leaching amount for each crop was estimated at administrative region scale from the average crop risk in the administrative region and the average environment risk of the administrative region. However, for the plots of the farming practices survey, available data were insufficient to estimate a N recommendation and to compare it with the N inputs in order to take into account the effect of excessive inputs. Hence, we managed a sensitivity analysis, considering the frequency of excessive N fertilization from 5 to 20% and N inputs exceeding by 50 kg N/ha the crop requirement.

Table 4. Data sources for the implementation of the model for the AGRIBALYSE program

Input data	Source data
Volume of production of the crop per region	statistic of the French agricultural administration for 2005-2009
Following crop	2006 SSP farming practices survey
Intercrop following the crop studied	
Application of organic fertilizer in the fall	
Residue management	
Excess amount of N inputs	Expert opinion
Soil-climate data: water properties of the soil (characteristic humidity, root depth of crops), meteorological data (rain, potential evapotranspiration), organic matter content	geographic French soil database managed by the INRA Soil Science Unit, Orleans meteorological: Arvalis database

### 3.5. Results

We can identify 4 groups of crops.

- 1) The lowest emissions are observed for sugar beet because of the low soil nitrate nitrogen after its harvest.
- 2) Sunflower and potato harvested in autumn are mainly followed by soft winter wheat. As the intercrop duration is short, emissions are low.
- 3) Nitrate leaching amounts are in the same range for pea, oilseed rape, cereals and grain maize. Emissions for barley are lower than those of soft winter wheat as 40% of barley plots are followed by oilseed rape, instead of 14% for soft winter wheat. As oilseed rape has a high capacity of N absorption, this explains this difference.
- 4) Finally, forage maize emissions are higher because of low residues restitution. As the C/N ratio of maize residues is high, those induce a net organization of soil nitrogen during the following intercrop and then reduce the risk of nitrate leaching.

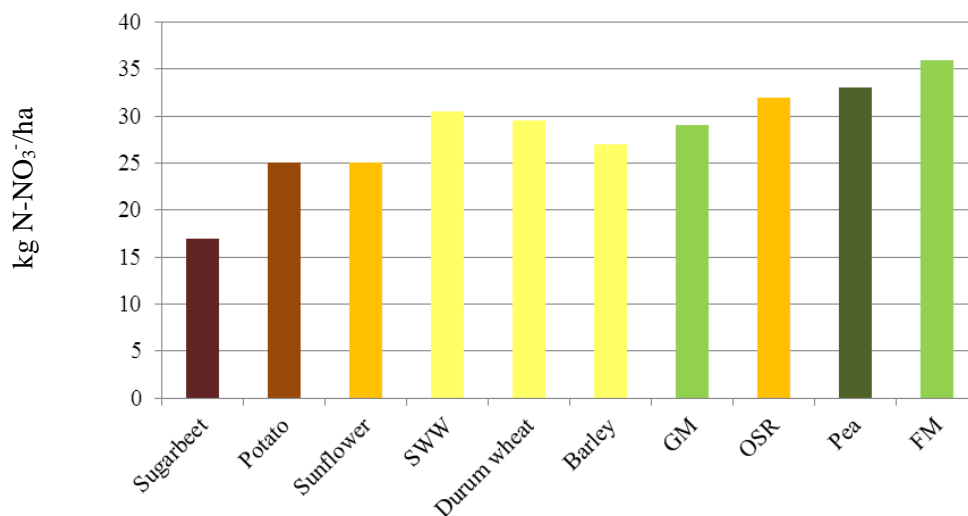


Figure 1. Average nitrate leaching amount for each crop at national scale. SWW: soft winter wheat; GM: grain maize, OSR: oilseed rape, FM: forage maize

As this model only concerns annual crops, its results can be compared to results from the literature at the regional scale for regions with a low proportion of area occupied by meadows and perennial crops. Using these results and the crop frequencies in each region, average nitrate leaching amounts per region were estimated and compared to literature results at the watershed scale (Table 5). The estimation of among 30 kg N-NO<sub>3</sub><sup>-</sup> leaching under root-zone is confirmed by these published results.

Table 5. Comparison of results at regional scale using the AGRIBALYSE methodology scale with bibliographic references

Watershed	Source	Years	Flow kg N/ha/an	Description	AGRIBALYSE results for the concerned regions, kg N/ha/an
Seine	Ducharne et al. 2007	1990-2000	30	NO <sub>3</sub> <sup>-</sup> leaching amount under root-zone estimated by STICS	26-30
Marne	Ledoux et al. 2007	1995-2000	20-33	NO <sub>3</sub> <sup>-</sup> leaching amount under root-zone estimated by STICS-MODCOU	34

The validation by experimental results shows that the model is relevant to estimate nitrate leaching at plot scale from easily available data. The application at administrative region hides a wide diversity of situations but provides consistent results for average nitrate leaching amount at regional scale.

#### 4. Allocation of nutrient burden between crops

##### 4.1. Principles and allocations for cropping sequences in the AGRIBALYSE database

It is difficult to allocate the impacts of a production system to each crop in a cropping sequence because certain practices may involve several crops in the rotation system and certain emissions depend on the practices and characteristics associated with a crop as well as on the practices and characteristics associated with previous or following crops.

The ILCD Handbook (JRC and IES 2010) recommends taking account of the nutrients remaining in the system after a crop has been harvested as a co-product of this crop and continues by extending the system or by allocation. Different allocation rules have been identified in bibliography (Audsley et al. 2003; Blonk 2010; Gac et al. 2006; Van Zeijts et al. 1999). However, these references rarely lead to common accepted rules in term of methodology or their suggestions are not always easy to apply because of data availability (Gueudet et al., 2012).

It is the case for allocation of Phosphorus (P) and potassium (K) inputs. For instance, in some studies, they are allocated in function of the nutrients exports (Gac et al. 2006; Van Zeijts et al. 1999) or of the recommended quantities (Audsley et al. 2003; Blonk 2010). We chose to allocate them in function of crop exports as the allocation based on recommended quantities require data that are not easily available at the national scale (PK soil content, PK input during the past few years).

Concerning the allocation of nitrate, Powers (2007) develops a method to allocate the flux between the different crops in function of the fluxes measured on fields cultivated on single crop. However, this is not applicable for every situation as some crops cannot be cultivated as single crop. Audsley et al. (2003) prefer to allocate these fluxes half to preceding crop and half to the following crop. William et al. (2006) allocate the total leaching fluxes at the rotation scale to the different crops in function of the post-harvest N surplus. These two options require data on precise practices data on the whole rotation that were not available at the national scale. Hence, in this study, we chose to allocate the estimated leaching flux to the crop 1.

Table 6. Allocation rules used for cropping sequences

Element	Comments	Allocation rule
Phosphorus (P) and potassium (K) inputs	These are immobile in the soil. Some farmers use residual nutrients by applying P and K fertilizers to one crop only in quantities sufficient to supply the needs of following crops. P and K inputs remaining as crop residues were considered as available for the following crops.	The impacts associated with the production of these inputs and emissions (P, PO <sub>4</sub> , ETM) related to their application are allocated to each crop proportionally to their nutrients exports, assessed from the harvested yield and PK contents of harvest. Sources: COMIFER farming practices survey and tables of crop exports
Phosphorus (P) loss	Main of phosphorus loss is induced by soil erosion. Soil erosion by crop was assessed by RUSLE, which takes into account occupation time and agricultural practices on each crop.	No allocation was managed on soil erosion and P loss.
Organic nitrogen	Only a fraction is directly available to the crop to which the organic nitrogen is applied. The rest contributes to a stock of organic matter, which could benefit all crops in the rotation.	The nitrogen available for the crop to which the fertilizer is applied (PAN) is allocated to that crop. The rest is allocated to all the crops in the rotation. Sources: Farming practices and the mineralization dynamics of organic fertilizers from the CASDAR project "Sustainable soil management"
Mineral nitrogen	The amounts of nitrogen applied in mineral form are directly available for the crop to which the fertilizer is applied.	The impact of production and the emissions of the nitrogen applied to a crop in mineral form are allocated in full to this crop.
Intercrop-nitrate	Residual nitrates remain in a soil after a crop has been harvested. These may be used by the following crop but a fraction may also be leached.	The impact of nitrate production and emissions between crops are allocated to the previous crop.
Nitrogen from crop residues	Crop residues may constitute a source of nitrogen for the following crop(s). They may also produce N <sub>2</sub> O emissions evaluated using the methodology of IPCC Tier 1.	The impact of nitrogen contained in crop residues and the N <sub>2</sub> O emissions from these residues are allocated to the crop which produced these residues.

#### 4.2. Allocation of organic N, P and K inputs on the basis of the 2006 SSP farming practices survey

Organic N, P and K inputs were allocated to all crops in a cropping sequence according to the rules outlined in table 7. This type of allocation required a detailed knowledge of the fertilizers applied and the yield for each crop in the rotation system. There was little statistical data for cropping sequences and the information that was available did not cover the production of all the crops studied in AGRIBALYSE. The 2006 SSP farming practices survey covered crops and not cropping sequences. However, it had the advantage of covering most of the main production regions for about ten major crops. It also gave information on the history for each plot and in particular details about previous crops. The year 2006 was considered representative of fertilizer applications during the reference period 2005-2009.

The succession of crops grown in the 14,000 plots studied was known for the period 2001 to 2005. An analysis of this data showed nearly 4,000 different cropping sequences. This diversity and the size of the samples did not make it possible to reconstitute fertilization practices for each type of cropping sequence. To take account of this diversity, these rotation systems were grouped together as "cropping sequence groups" using appropriate statistical optimal matching methods (Gabadinho et al., 2011). The 4,000 rotation systems were grouped into 34 major cropping sequence groups, depending on the dominant crops and production region (Jouy and Wissocq, 2011; see

Table 7 for example). This made it possible to take account of the differences in the application of fertilizers for a given crop depending on the rotation system and region, based on SSP 2006 data. After allocation according to the rules in Table 6 for each crop within the cropping sequence groups, a French average input of organic N, P and K was calculated for each crop.



Table 7. Example of cropping sequences identified in the Northern region

Region	Cropping sequences	Area in 2006 (ha)
Northern	Sugarbeet (18%), winter wheat (50%), potato (8%)	719 000
	Silage maize (24%), temporary grassland (10%), winter wheat (39%), barley (13%)	561 000
	Oilseed rape (23%), winter wheat (44%), barley (23%)	551 000
	Winter wheat (43%), barley (13%), leguminous	254 000
...		

### 4.3. Results

The allocation rules modify significantly the nutrient amount attributed to each crop (Table 8). For instance, organic manure is spread by preference on silage maize as this crop uses efficiently organic nitrogen. In the meantime, only a fraction is available for silage maize. Hence, organic N amount allocated to silage maize is much less than the spread amount. High amount of K<sub>2</sub>O is applied on potato in particular as this crop requires amount superior to this exportation. A fraction of this amount is allocated to the other crop as this K<sub>2</sub>O “excess” remains available for the following crops.

Table 8. Nutrient attributed by crop before (B) and after (A) allocation, example on a few crops

	kg organic N / ha		kg mineral P <sub>2</sub> O <sub>5</sub> / ha		kg organic P <sub>2</sub> O <sub>5</sub> / ha		kg mineral K <sub>2</sub> O / ha		
	B	A	B	A	B	A	B	A	
Silage maize		166	114	24	33	73	46	14	4
Soft winter wheat		11	18	25	39	7	19	42	10
Spring pea		-	9	29	22	-	7	46	19
Starch potato		55	41	47	25	21	12	202	161

Their effect was particularly significant on three indicators (Figure 2):

- the global warming (IPCC 2007) in particular on maize (variation of 10%) as N<sub>2</sub>O emission is function of the applied organic N amount and NH<sub>3</sub> and NO emissions,
- the freshwater eutrophication potential (ReCiPe 1.05H). Field emissions do not significantly vary with allocations as SALCA-P was only sensitive to P<sub>2</sub>O<sub>5</sub> spread as liquid manure and as mineral or solid manure. In the meantime, mineral P<sub>2</sub>O<sub>5</sub> production contributes from 30 to 50% of the freshwater eutrophication potential, this explains the significant effect of allocations on this indicator (variation from 10 to 20%),
- the cumulative fossil and nuclear energy demand (CED1.8) of potato (variation of 7%).

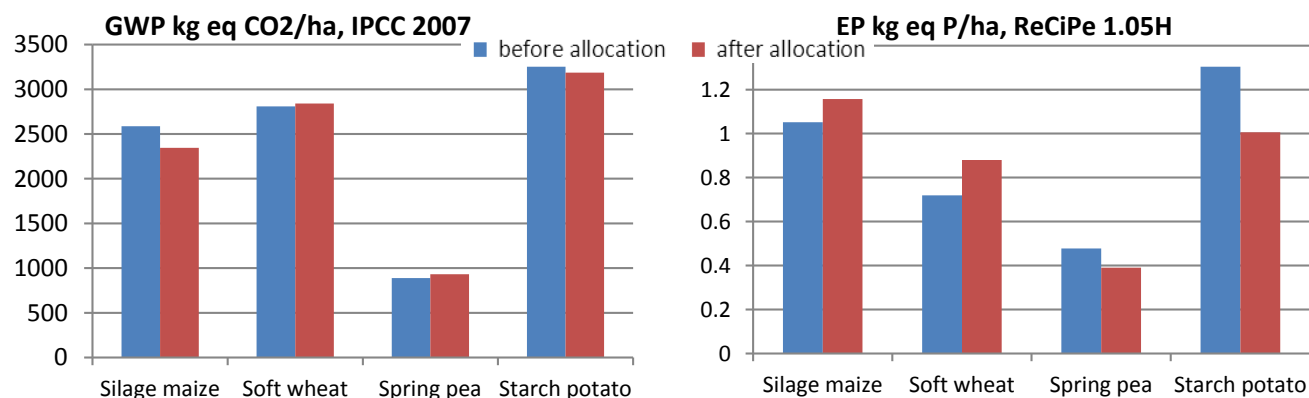


Figure 2: allocations effects on LCA indicators, example of global warming potential (GWP) and eutrophication potential (EP)

## 5. Conclusions

Substantial work and developments have been carried out within AGRIBALYSE program in order to produce consistent references relative to real agricultural practices and field observations in France. The implemented methods should evolve with improved knowledge.

In France, statistical databases on agricultural practices or on the soil are valuable sources of information for the LCAs of crops. Thanks to their exploitation and crossed with the expertise in the field, AGRIBALYSE was able to establish average references. Further work on typology of production systems would enhance the understanding of the variability of impacts due to the agricultural practices and the natural conditions. However, for some sectors (eg organic production), the statistics are lacking and should therefore be completed. The actual LCIs for these products have a lower representativeness than for other products.

Moreover, the estimation of some flows (eg N<sub>2</sub>O emissions, carbon storage in the soil) may be improved soon. Further to AGRIBALYSE program, the project ECOALIM, funded by ADEME and CASDAR, aims to optimize feeding to reduce environmental impacts of livestock. Important work is carried out within this framework to estimate fluxes of nitrogen in water and air and allocate impacts in the crop rotation. But we must not stop there. Other flows (eg phosphorus, pesticides and trace elements) are estimated with a high uncertainty because the available models are not robust enough or due to insufficient data for adapting the models to the French context regarding phosphorus. They must be also subject of works.

Finally, some impacts, such as water and biodiversity, were not covered within AGRIBALYSE, due to a lack of adequate methods or of available data. Both are major issues and will be the subject of research efforts in the future.

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