Implications of Uncertainty and Variability in the Life Cycle Assessment of Pig Farming Systems

C. Basset-Mens, H.M.G. van der Werf, P. Durand, Ph. Leterme

INRA, UMR Sol Agronomie Spatialisation de Rennes-Quimper, 65, rue de Saint Brieuc CS 84215, 35 042 Rennes Cedex, France. Tel. +33 2 23 48 52 22; fax +33 2 23 48 54 30; email : basset@roazhon.inra.fr

Abstract: In a case study of pig production systems we propose a simple quantification of the uncertainty of LCA results (intra-system variability) and we explored inter-system variability in order to produce more robust LCA outcomes. Our quantification of the uncertainty took into account the variability of technical performance (crop yield, feed efficiency) and of emission factors (for NH_3, N_2O and NO_3) and the influence of the functional unit (FU) (kg of pig versus hectare used). For farming systems, the inter-system variability was investigated through differentiating by the production mode (conventional, quality label, organic (AB)), and farmer practices (Good Agricultural Practice (GAP) versus Current practice (CP)) while for natural systems, variability due to physical and climatic characteristics of catchments expected to modify nitrate fate was explored. For the eutrophication impact category, the variability of field emissions contributed more to uncertainty than the variability of building emissions, crop yield and feed efficiency. The influence of the FU on eutrophication results was very important when comparing systems with different degrees of intensification such as GAP and AB. Concerning inter-system variability, differences in farmer practices had a larger effect on eutrophication than differences between production modes. Finally, the physical characteristics of the catchment and the climate strongly affected the eutrophication result.

Keywords: uncertainty, variability, Life Cycle Assessment, pig production, eutrophication.

1. INTRODUCTION

The uncertainty of LCA outcomes stems from our attempt to convert the variability of the real world into LCA results through parameters, models and choices (Huijbregts, 1998). Treating uncertainty of LCA results represents a challenge at different levels. Currently, the analysis of the uncertainty in LCA studies, even if crucial, is rarely done (Ross, 2002), because of the lack of simple methods allowing its quantification. However, when data and knowledge are available, integrating a major part of the variability of both human and natural systems can reduce the uncertainty of LCA results. Concerning natural systems variability, the choice of the model used to convert emissions into regional impact such as aquatic eutrophication will strongly affect the result of assessments of the environmental performance of farming systems.

In a case study of pig production, we proposed an approach based on one reference LCA result, (i) to produce a simple quantification of its uncertainty, (ii) to explore the variability due to production systems (farmer practice and production mode) and due to nitrate transfer in the natural system (physical and climatic characteristics of catchments).

2. MATERIALS AND METHODS

2.1. Production systems

2.1.1. Production modes

This study dealt with the processes up to and including the production of pigs on the farm. Three contrasting production systems were defined. The Good Agricultural Practice (GAP) scenario corresponds to current intensive production (or “conventional” production), optimised in particular with respect to fertilisation practices, as specified in the French “Agriculture Raisonnée” standards (Rosenberg and Gallot, 2002). In the GAP scenario, pigs are raised at high density in a slatted-floor confinement building. The Agriculture Biologique (AB) scenario corresponds to organic agriculture according to the French version of the European rules for organic animal production (Ministère de l’Agriculture et de la Pêche, 2000) and the European rules for organic crop production (CEE, 1991). The Label Rouge

(LR) scenario corresponds to the Porc Fermier Label Rouge quality label (Groupements des fermiers d'Argoat, 2000). In the AB and LR scenarios pigs are born and raised outdoors until weaning, and in an open-front straw-litter building at low animal density after weaning.

Table 1. Characteristics of the animal production stage for the Good Agricultural Practice (GAP), Current Practice (CP), Label Rouge (LR) and Agriculture Biologique (AB) scenarios

	GAP/CP	LR	AB
Piglet production			
Weaned piglet/ sow/year	25.5	22.6	20.3
Weaning age, days	25.7	28	42
Feed per sow (boar included), kg/year	1313	1490	1695
Weaning to slaughtering			
Surface per pig, m^2	0.85	2.6	2.3
Feed to gain ratio	2.7	2.9	3.2
Slaughter age, days	175	190	195
Slaughter weight, kg	113	115	120
Feed consumed, kg	275	312	340

Data concerning resource use and emissions associated with the production and delivery of inputs for crop production (fertilisers, pesticides, tractor fuel and machines) were derived according to Nemecek and Heil (2001). Data for energy carriers for road and sea transport were from the BUWAL 250 database (BUWAL, 1996). Data concerning resource use and emissions associated with buildings (production and delivery of materials, construction) were from Kanyarushoki (2001). Data on crop production, transport distances, feed composition and system performance were based on statistics, estimates from experts and data from producers' associations.

For all crops, production corresponded to good agricultural practice, i.e. fertilisation according to anticipated crop needs and integrated pest management for GAP and LR. For the three scenarios, we assumed that pig manure (liquid manure for GAP, solid manure for LR, composted solid manure for AB) was used to fertilise Brittany-grown crops used as feed ingredients. For LR and GAP, yield levels were averages for 1996 – 2000 (AGRESTE, 2001; FAO, 2002). The yield levels of AB crops were according to experts from the region of production. For the processes concerning the transformation of crop products into feed ingredients and the production of feed, the inventory of resources used and emissions to the environment was limited to resources and emissions associated with the use of non-renewable energy. For ingredients resulting from processes yielding more than one product (e.g. soy cake, wheat gluten), resource use and emissions were allocated according to the economic value. Data for feed production (involving, amongst others: grinding, heating, mixing, pelleting) were from Sanders (2000).

For GAP, data on technical performance of the animal production stages (Table 1) were according to published statistics (ITP, 2001). For LR, data concerning piglet production (PP) were from ITP (2001), data concerning weaning to slaughtering production (WS) were averages supplied by the LR producers' association. For AB, data on technical performance were based on an optimised model of organic pig production (Berger, 2000) adjusted according to expert judgement. For GAP and LR, manure was stored, while for AB, manure was composted. Overall, GAP was more intensive than AB: higher feed efficiency, younger age at slaughter and less surface per pig. LR was intermediate between GAP and AB.

Ammonia emissions due to the application of ammonium nitrate fertiliser were estimated according to ECETOC (1994) and ammonia emissions following application of slurry were according to Morvan and Leterme (2001). Ammonia and nitrous oxide emissions from slurry in pig buildings were from IPCC (1996) and UNECE (1999). Methane emissions due to enteric fermentation and housing type were from IPCC (1996). For LR and AB, data on the production of excreta, emissions from buildings, during storage, during composting and from crops and paddocks, were chiefly obtained with the support of an expert panel from the Institut National de la Recherche Agronomique. The panel comprised: J. Y. Dourmad, Th. Morvan, J.M. Paillat, P. Robin and F. Vertès. The panel based its expertise on their experiments, simulation models and on their interpretation of the available literature.

For the four production scenarios, the contributions of the major emissions to eutrophication, acidification and climate change are summarised in Table 2.

Table 2. Contributions of the major emissions to eutrophication, acidification and climate change for GAP, CP, LR and AB scenarios and corresponding characterisation factors. Emissions are expressed in the unit indicated for each impact category.

Impact category (unit)	GAP	CP	LR	AB	Characterisation factors
Eutrophication (g PO_4 -eq /kg pig)					
NO_3	11	19.1	11.4	12.5	0.1
NH_3	8.3	8.5	3.6	6.1	0.35
NO_x (as NO_2)	0.95	0.94	0.95	1.71	0.13
PO_4	0.42	0.48	0.41	1.11	1
Total	20.8	29.3	16.6	21.6	
Acidification (g SO_2 -eq /kg pig)					
NH_3	37.8	38.7	16.4	27.9	1.6
NO_x (as NO_2)	3.65	3.61	3.67	6.57	0.5
SO_2	1.47	1.66	1.61	2.13	1.2
Total	43.5	44.9	22.6	37.2	
Climate change (g CO_2 -eq /kg pig)					
N_2O	964	1440	2150	2320	310
CO_2	882	950	1120	1390	1
CH_4	458	460	187	256	21
Total	2300	2850	3460	3970	

2.1.2. Farmer practice

In order to explore the influence of the farmer practice on the final result, a Current Practice scenario (CP) was defined with current fertilisation practice: fertilisation exceeded crop needs (Houben and Plet, 1997) for four of the major crops used as feed ingredients, leading to a three to four-fold increase of nitrate losses for these crops.

2.1.3. Uncertainty analysis

In order to explore the robustness of the GAP results, an uncertainty analysis was conducted. Crop yields, WS feed to gain ratio, field emissions (NH_3, N_2O and NO_3) and emissions of NH_3 and N_2O from buildings and manure storage were identified as important issues for the variability of results. For the parameters concerning these issues, a high and a low value reflecting what we coined “realistic” rather than overall variability were defined in addition to the default reference value. The “realistic” uncertainty interval thus defined contains about two thirds of the overall variability for the parameter concerned. In order to assess the relative importance of each of the four issues, we constructed for each issue favourable and unfavourable variants by combining on the one hand all favourable values and on the other hand all unfavourable values. The summation of the uncertainty sources quantified is proposed as an indicator of the uncertainty of the GAP results. Finally, in order to assess the influence of the choice of functional unit, impacts were expressed by two functional units corresponding to the two main functions of agricultural production systems. Kg of pig produced (live weight at slaughter) reflects its function as a producer of market goods, whereas ha of land used reflects its function as a producer of non-market goods (e.g. environmental services).

2.2. Natural systems

The natural context was considered for the transfer of nitrate in catchments through hydrological behaviour and rainfall. Three contrasting catchment types were selected (Table 3).

Table 3. Characteristics of the catchment types

	Geology	Wetlands (% of total surface)	Seasonal cycle
Type P	Granite	High (25%)	Reversed*
Type K	Schist	Middle (10%)	Normal*
Type S	Granite	Low (5%)	Normal*

*: Normal cycles present high nitrate concentration in winter and low in summer and conversely for reversed cycles.

Three levels of effective rainfall (resulting runoff of the rain falling on a catchment) were selected : 300, 435 and 700 mm. Thus, nine catchment scenarios were obtained by combining the three catchment types and the three levels of effective rainfall.

2.3. Evaluation methodology

2.3.1. Current LCA

The current LCA methodology was applied for seven impact categories. Only eutrophication, climate change and acidification are presented in this article. As recommended by Guinée et al. (2002), Eutrophication Potential (EP) was calculated using the generic EP factors in kg PO_4-eq., Global Warming Potential for a 100 year time horizon (GWP_{100}) was calculated according to the GWP_{100} factors by IPCC (Houghton et al., 1996) in kg CO_2-eq. and Acidification Potential (AP) was calculated using the average European AP factors by Huijbregts (1999) in kg SO_2-eq. (Table 2).

2.3.2. Eutrophication

Assessing the fate factor for nitrate in catchments (ratio between annual fluxes of N export from the catchment in the river and annual fluxes of N input in the catchment, namely leachable nitrate) require the quantification of the N retention capacity of the catchment, which is generally thought to be due to heterotrophic denitrification in the upper horizon of bottom land (Sebilo et al., 2003). This was done using the hydrology and biogeochemistry model INCA (Integrated Nitrogen in Catchments) (Whitehead et al., 1998). INCA is a semi-distributed and process-based model simulating the nitrogen fate through terrestrial systems and rivers. The model was calibrated against flow and chemistry data from the selected catchments. For the simulation of nitrate transport and the calculation of fate factors, estimated values for leachable nitrate based on historical fertilisation data were used. Leachable nitrate increased from 3.7 kg/ha (1965) to 93 kg/ha (2003), and it remained stable afterwards. This stabilisation of the nitrogen load allowed to reach an equilibrium state and to estimate the real fate factor for nitrate, eliminating the long term storage or release effect. The N retention capacity of the catchments was a function primarily of the percent of wetlands and secondly of the effective rainfall. The fate factors obtained ranged thus from 0.9 for the scenario crossing catchment type S and highest effective rainfall to 0.35 for the scenario crossing catchment type P and lowest effective rainfall. These fate factors were used to assess the eutrophication impact of the GAP scenario by multiplying with the generic EP factors.

2.4. Reference result

All the results were referred to one reference LCA result obtained by combining one production mode (conventional production mode), one level of farmer practice (good agricultural practice = GAP scenario), with average values for key parameters and the standard evaluation methodology, included aquatic eutrophication (fate factor for nitrate = 1).

3. RESULTS

Per kg of pig, the eutrophication result for GAP was: 0.0208 kg PO_4-eq while per ha it was 38.3 kg PO_4-eq. Both per kg and per ha, uncertainty was large (around ± 50%) and was mainly due to field emissions (around ± 35%) (Fig. 1). Both per kg and per ha, eutrophication was lower for LR (-20% and -30%, respectively). For AB, the result was very dependent on the choice of the FU: eutrophication was similar per kg but 40% less per ha. Eutrophication was 40% higher for CP than for GAP. Finally, when the fate factor was 0.9 or 0.35 instead of 1, the eutrophication result was reduced by 5 to 35% (Fig. 1).

The reference result for climate change was 2.30 kg CO_2-eq per kg of pig and 4236 kg CO_2-eq per ha. Both per kg and per ha, uncertainty intervals were very large and were mainly due to field emissions. Both per kg and per ha, climate change was higher for LR (+ 50% and +30%, respectively.). As for eutrophication, the climate change result for AB was very dependent on the FU: climate change was 70% higher per kg but was similar per ha. Finally, CP resulted in an increase of more than 20% of the climate change impact relative to the reference result. Per kg of pig, the reference result for acidification was 0.0435 kg SO_2-eq, while per ha it was 80.1 kg SO_2-eq. Both on a per kg and a per ha basis, uncertainty intervals for acidification were smaller than for eutrophication and climate change (± 30% and ± 20%, respectively).

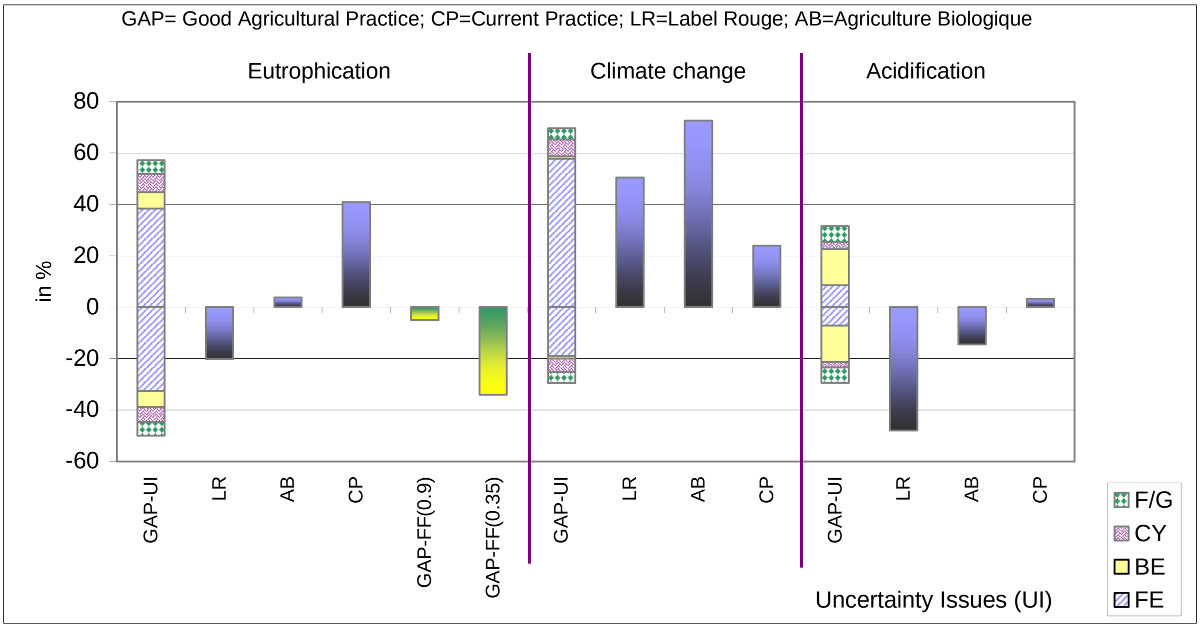

Fig 1. Uncertainty of LCA results (per kg of pig) for eutrophication, climate change and acidification. GAP-UI: Contribution of feed to gain ratio (F/G), crop yield (CY), building and manure emissions (BE) and field emissions (FE) to uncertainty for the GAP reference scenario. Other bars indicate differences for the LR, AB and CP scenarios and for 0.9 and 0.35 fate factors relative to the GAP reference scenario.

Uncertainty of the reference result was mainly due to building emissions and secondarily to field emissions. Both per kg and per ha, acidification was much smaller for LR: 48% less per kg and 55% less per ha. The difference between the reference result and AB depended on the FU once more: acidification results were close when expressed per kg (15% less for AB) (Fig. 1), while when expressed per ha, acidification was 53% less for AB. Finally, the CP scenario was similar to the reference result for acidification.

4. DISCUSSION AND CONCLUSION

Uncertainty for GAP (the reference) was large and originated primarily from the estimation of emission factors at the inventory stage. For eutrophication and climate change, field emissions were the main source of uncertainty while for acidification it was building emissions. The uncertainty of the results can reflect the real variability of the processes involved: for instance nitrate leaching is a function of soil characteristics and climate, but uncertainty can also arise from a lack of knowledge about these processes. Namely, for the emission of N_2O in the field due to nitrogen input we used the emission factor and the uncertainty interval proposed by Mosier et al. (1998), which are based on a literature review of field studies conducted in temperate regions of the world, with different fertiliser types, soils and climates. The large uncertainty range reflects the contrasting background conditions of the measurements. An approach is required, for instance the use of a suitable simulation model, which allows a more reliable estimation of emission factors (for N_2O, but also for NO_3 and NH_3) by assigning this variation to its controlling variables in order to produce an estimate that takes into account both environmental conditions (climate, soil…), farmer practices and technology used.

A practical methodology was defined to analyse the uncertainty of the reference scenario results. It could also be interesting to perform this uncertainty analysis using Monte Carlo simulation.

We explored the inter-system variability. The difference between LR and CP on the one hand and GAP on the other did not depend much on the FU used, because these systems present similar degrees of intensification whereas the difference between AB and GAP was very dependent on the FU.

For eutrophication, the difference between GAP and CP was larger than the difference between GAP and the other two systems (LR and AB). This result illustrates that farmer practices may affect the final result more than production modes.

LR and AB scenarios did better than or similar to GAP for eutrophication and acidification but they did worse for climate change. Eutrophication and acidification are considered as hot spots for the GAP scenario and even more for the CP scenario. However, this study reveals climate change as a hot spot for LR and AB. Basset-Mens and van der Werf (submitted) have demonstrated that the straw litter housing system was the main responsible for this hot spot, but also that this production stage seems to present important margins of improvement in this respect.

For eutrophication, the consequence of integrating the different catchment types in the analysis has been considered. Contrasting fate factors for nitrate were obtained by simulating nitrate transfer in nine catchment scenarios with the INCA simulation model. These fate factors ranged from 0.35 to 0.9 revealing potentially diverse and important N retention capacities for the catchments depending on their hydrology, the effective rainfall and the wetland surface. The reference result was reduced of 5% with a fate factor of 0.9 up to 35% with a fate factor of 0.35. These first simulations illustrate the importance of taking into account the environment where the pollutants are transfered in assessing aquatic eutrophication. These results complete the work of Huijbregts and Seppälä (2000; 2001) and demonstrate the need for further research on the simulation of the fate of pollutants in LCA models.

5. ACKNOWLEDGEMENT

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