The effect of feeding strategy on environmental impacts of pig production depends on the context of production: evaluation through life cycle assessment

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ABSTRACT

LCA has been used in many studies to evaluate the effect of feeding strategy on the environmental impact of pig production. However, because most studies have been conducted in Europe the question of the possible interactions with the context of production is still in debate. The objective of this study was then to evaluate these effects in two contrasted geographic contexts of production, Brazil and France. The LCA considered the process of pig fattening, including production and transport of feed ingredients, feed production and transport to the farm, raising of fattening pigs, and manure storage, transport and spreading. Impacts were calculated at the farm gate and the functional unit considered was one kg of body weight gain over the fattening period. Performances of pigs were simulated for each scenario using InraPorc® population model (2000 pigs for each scenario considering between animal variability). The LCA calculations were performed for each pig according to its own performance and excretion, and the results were subjected to variance analysis. The results indicate that for some impacts there are clear interactions between effects of feeding program, origin of soybean and location of production. For climate change, the interest of phase feeding and incorporation of feed-use amino acids (FU-AA) is very limited and even counterproductive in Brazil with soybean from South, whereas it appears to be an efficient strategy with soybean from Center West, especially in Europe. Rather similar effects are observed for cumulative energy demand.. Conversely, eutrophication and acidification potential impacts are reduced by phase feeding and FU-AA addition in a rather similar way in all situations. In all situations, precision feeding, the only strategy that takes account for the between animal variability, is the most effective approach for reducing life cycle impact of pig fattening, whereas the potential of phase feeding program and FU-AA is dependent of soybean origin and geographical context of pig production, contrasting with many published results.

Keywords: pig, fattening, feeding strategy, environment, life cycle assessment

1. Introduction

The environmental impacts of pig production have come under increased debate in recent years, resulting in greater focus on identifying and mitigating the environmental degradation they may cause. The better adjustment of nutrient supply to the requirements of animals (Dourmad and Jondreville, 2007) may be a key factor in improving efficiency of nutrient retention, reducing excretion and consequently increasing the sustainability of pig production. In recent years, life cycle assessment (LCA) has been widely used in agriculture (Guinée et al., 2002) and several studies of swine production chains have been conducted (Nguyen et al., 2010, Garcia-Launay et al., 2014). Most of LCA studies about the effect of pig feeding strategies do not usually compare results in various geographical contexts and the question may be raised about possible interactions with the context of production. The differences in the human and natural resources between Brazil and France have led to the establishment of different supply chains, which may result in different environmental impacts of pig production. This offers contrasted situations in terms of raising animals, climatic conditions, diet formulation and type and origin of feed resources, which can be used to evaluate whether some feeding strategies may be environmentally friendly to one situation but not to another.

The aim of this study was thus to evaluate, using LCA, the effects of different feed formulation and feed distribution strategies on the environmental impacts of pig fattening in two contrasted contexts of pig production in South Brazil and West France.

2. Methods

System, goal and scope definition

The definition of system and subsystem boundaries was derived from Nguyen et al. (2010) and Garcia-Launay et al. (2014). The LCA considered the activity of pig fattening in two different geographical contexts (France and Brazil), including crop production, grain drying and processing, production and transport of feed ingredients, feed production at the feed factory, transport of the feed to the farm, growing to finishing pig production, and manure storage, transport and spreading. The pig production system considered was typical of conventional growing-finishing pig farms located in Brittany and South Brazil. The environmental consequences of manure utilization were evaluated using system expansion as described by Nguyen et al. (2010). Thus, manure produced was assumed to substitute a certain amount of mineral fertilizers as described by Nguyen et al. (2010).

The assessment considered the growing-finishing pig production system, with four different feeding programs: two phases (2P), four phases (4P), daily multiphase (MP) and precision feeding (PR). These strategies were combined with three formulation scenarios built with least-cost formulated feeds: (i) feeds without feed-use amino acids (FU-AA) allowed (noAA), (ii) feeds with FU-AA (withAA) and fixed crude protein content corresponding to the usual local practical recommendations, and (iii) feeds with FU-AA without any minimum crude protein constraint (lowCP). For each scenario, two types of protein sources were considered: soybean meal only (SOY) or a mix of different protein sources (MIX) including soybean meal and meat and bone meal in Brazil and soybean meal, rapeseed meal and pea in France. Two hypotheses were also considered for the soybean origin: Centre West (CW) and South (SO) Brazil, which are contrasted in terms of recent deforestation. This resulted in a total of 96 scenarios: four feeding strategies tested in 12 situations of feed formulation, in two contexts of pig production.

Performance data from experimental studies in Brazil and France were used to adjust average animal profile parameters for growth and feed intake using InraPorc® software. These profiles were used to calculate, according to InraPorc®, the average nutritional requirement curves for each sex (females and castrated males), these requirements being used for diet formulation. Because variability between animals is known to affect the response of pig populations, we used the population version of InraPorc® (Brossard et al., 2014) to evaluate the animals' response to the feeding strategies. Simulations for 2000 pigs (50% females, 50% castrated males) were performed for each feeding scenario in each country, in order to determine animal performance, nutrient balance and excretion according to InraPorc®. A total of 192 000 pigs, i.e. 96 scenarios x 2000 pigs, were simulated on a daily basis and a database was built from these simulations.

Life cycle inventory

Resource use and emissions associated with the production and delivery of inputs for crop production (fertilizers, pesticides, tractor fuel and agricultural machinery) came from the Ecoinvent database version 3 (SimaPro LCA software 8.0, PRé Consultants). Energy use in the building for light, heating and ventilation was considered, but not the emissions and resources used for the construction of buildings. Veterinary medicines and hygiene products were also not included.

It was assumed that soybean was produced in Brazil for both geographical contexts, because most of the soybean meal imported to France comes from Brazil. For Brazilian crops, LCI came from de Alvarenga et al. (2012) for maize, and from Prudêncio da Silva et al. (2010) for soybean, taking into account the effect of land-use change on carbon release due to conversion of Brazilian forest to cropland for soybean (PAS2050, 2011). For French crops, LCA came from a national database developed by French research institutes with data on the environmental impacts of all main ingredients used in animal feeds (Wilfart et al., 2015). For the feed ingredients that are co-products, i.e. soybean meal, soybean oil, rapeseed meal, rapeseed oil, and wheat bran, the resource use and emissions were economically allocated. Data for FU-AA, phytase, salt, phosphate, sodium bicarbonate and limestone used in the diet came from Wilfart et al. (2015). Meat and bone meal was assumed to come from poultry slaughter. Impacts associated with broiler production were based on Prudêncio da Silva et al. (2014) and those associated with processing were based on Wilfart et al. (2015).

Emissions to air during swine production were estimated step-by-step for NH_3, N_2O, NOx and CH_4. The CH_4 emissions from enteric fermentations were calculated according to feed digestible fiber content using equations from Rigolot et al. (2010). The CH_4 emissions from manure storage were calculated according to IPCC (2006) and Rigolot et al. (2010b) considering the average ambient temperature in each region (22°C for South Brazil and 13°C for West France). The NH_3 emissions from the building and during manure storage were calculated according to emission factors proposed by Rigolot et al. (2010), considering the effect of temperature. The N_2O and NOx emissions from slurry storage were calculated according to IPCC (2006) and Dämmgen and Hutchings (2008), respectively. The amounts of nitrogen, P, Cu, Zn, K and organic matter excreted by the pigs were obtained from InraPorc® simulations. These data were used to calculate the amount of each element available at field application. During field application, NH_3 emissions were based on Andersen et al. (2001), N_2O emissions on IPCC (2006) and NOx emissions on Nemecek and Kägi (2007). The potential of NO_3 and PO_4 leaching came from Nguyen et al. (2011).

Characterization factors and functional unit

We based our analysis on the CML 2001 (baseline) method V3.02 as implemented in Simapro software, version 8.05 (PRé Consultant, 2014) and added the following categories: land occupation from CML 2001 (all categories) version 2.04 and total cumulative energy demand version 1.8 (non-renewable fossil + nuclear). Thus, we considered the potential impacts of pig production on climate change (CC, kg CO_2-eq.), eutrophication potential (EP, g PO_4-eq.), acidification potential (AP, g SO_2-eq.), terrestrial ecotoxicity (TE, g 1,4-DCB-eq.), cumulative energy demand (CED, MJ), and land occupation (LO, m^2.year). The CC was calculated according to the 100-year global warming potential factors in kg CO_2-eq. Impacts were calculated at the farm gate and the functional unit considered was one kg of body weight gain (BWG) over the fattening period.

Calculations and statistical analyzes

The LCA calculations were performed for each pig according to its individual performance and excretion from 70 days (with 30 kg BW on average) to an average BW of 115 kg at slaughter. These calculations were performed using a calculation model developed with SAS software (SAS Inst. Inc., Cary, NC). Performance responses and environmental impacts were subjected to variance analysis using the GLM procedure (SAS Inst. Inc., Cary, NC). The statistical model included effects of country, protein source, feeding phases and amino acid inclusion. Differences were considered significant if $P < 0.05$. Means were compared using the Tukey test. For LCA data, we also performed a variance analysis taking into account the effect of interactions between country and the other factors, in order to evaluate the behavior of environmental impacts among scenarios. All analyses were performed using SAS version 9.2 (SAS Inst. Inc., Cary, NC).

3. Results

Climate change

With soybean from SO, the average values for CC ranged between the feeding programs from 2.31 to 2.45 kg CO_2-eq. per kg BWG in Brazil and from 2.28 to 2.35 kg CO_2-eq. per kg BWG in France (Fig. 1A). When soybean meal from CW was used, CC values increased up to 2.75 to 2.96 kg CO_2-eq. per kg of BWG in Brazil and up to 2.61 to 2.89 kg CO_2-eq. per kg BWG in France. Depending on the feeding program, the lowest CC impact was reached for PR, both for soybean from SO and from CW. With soybean meal from SO, the highest impacts among the AA inclusion scenarios were observed for lowCP in Brazil and for withAA in France. Conversely, with soybean meal from CW, the highest impacts were observed for noAA in both countries. Independently of soybean origin and geographical context of pig production, SOY showed higher impacts than MIX scenarios.

The variation of CC impacts among scenarios was highest for noAA, intermediate for withAA and lowest for lowCP. Scenarios based on soybean meal from CW showed higher CC impacts than scenarios based on soybean from SO (Fig. 1A). Differences between protein sources (i.e. SOY and MIX) were less pronounced for soybean from SO compared to CW and were reduced when AA inclusion increased. There was a clear interaction between the soybean origin and AA inclusion scenario, in both countries. With soybean from CW, CC impact decreased when the incorporation of AA increased, the effect being more marked for SOY than for MIX protein source, whereas no effect or even the opposite was observed with soybean from SO. The effect of the feeding program on CC was mainly affected by the soybean origin and the level of AA inclusion. With soybean from CW, increasing the number of feeding phases and precision feeding reduced CC impact in all situations; however the magnitude of the effect decreased when AA inclusion increased. Precision feeding resulted in a reduced impact in all scenarios.

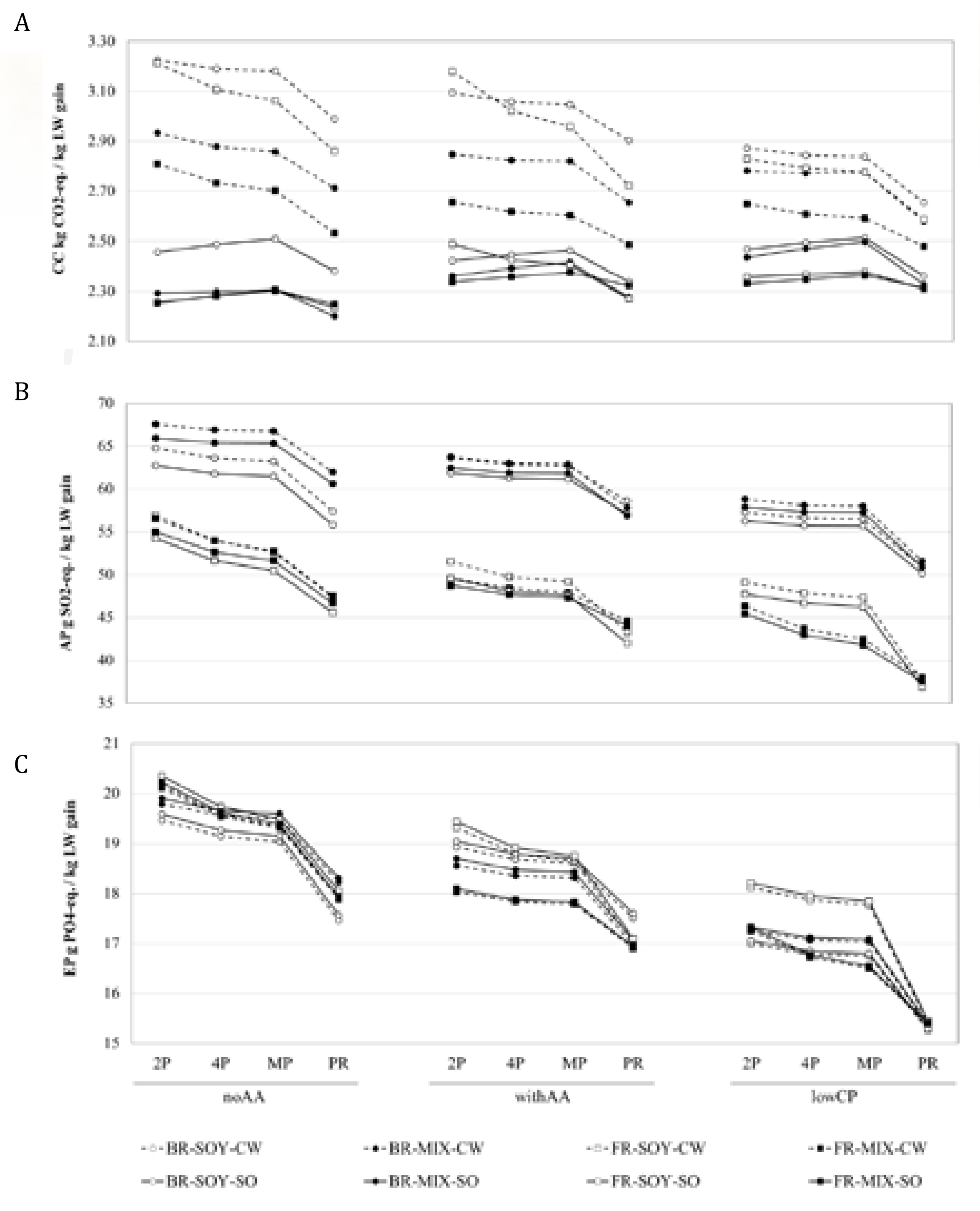

Figure 1. Interactions between effects of the feeding program, the use of amino acids and the soybean origin on environmental impact of climate change (A), acidification potential (B) and eutrophication potential (C) for Brazilian (BR) and French (FR) context of pig production. 2P, 2-phase, 4P, 4-phase, MP, multi-phase and PR, precision feeding programs. noAA, no amino acids, withAA, with amino acids, lowCP, without constraints in the crude protein content. SO, soybean from South region; CW, soybean from Centre-West Brazil. SOY, soybean meal as sole protein source, MIX, diversified protein sources.

Acidification potential

With soybean from SO, the values for AP ranged between the feeding programs from 55.3 to 61.2 g SO_2-eq. per kg BWG in Brazil and from 42.1 to 50.1 g SO_2-eq. per kg BWG in France (Fig. 1B). With soybean from CW the values were only slightly increased up to 56.4 to 62.6 g SO2-eq. per kg BWG in Brazil and up to 43.1 to 51.7 g SO_2-eq. per kg BWG in France. The lowest AP impact was reached for PR, as well for soybean from SO and CW. The highest AP impacts among the AA inclusion scenarios were observed for noAA in both countries, and the lowest for lowCP. For the French context, SOY showed 1.7% higher impacts than MIX protein source. Conversely, for the Brazilian context MIX showed 2.9% higher AP impact than SOY. The variation of AP impact among scenarios (Fig. 1B) was highest for noAA, intermediate for lowCP and lowest for withAA. In all scenarios of AA inclusion and whatever the feeding program or country, scenarios based on soybean meal from CW showed higher AP impacts than scenarios based on soybean from SO (Fig. 1B). Whatever the soybean origin, AP impact decreased when the incorporation of AA increased. The effect of the feeding program on AP was affected by the level of inclusion of AA. Increasing the number of feeding phases and precision feeding reduced the AP impact in all situations; however the magnitude of the effect decreased when AA inclusion increased. In all scenarios of feed formulation, whatever the soybean meal origin and the protein source, increasing the number of feeding phases from 2P to PR, decreased the AP impact by about 10% in Brazil and 16% in France.

Eutrophication potential

The values for EP ranged between the feeding programs from 16.3 to 18.1 g PO_4-eq. per kg BWG in Brazil and from 16.3 to 18.4 g PO_4-eq. per kg of BWG in France, with similar results for soybean from SO and CW (Fig. 1C). According to the feeding program, the lowest EP impact was obtained for PR in both countries (mean of 16.3 g PO_4-eq. per kg BWG) and the highest for 2P (mean of 18.2 g PO_4-eq. per kg BWG). The highest EP impacts among AA inclusion scenarios were observed for noAA scenarios, and the lowest for lowCP scenarios, in both countries. Independently of soybean origin, SOY showed higher EP impacts than MIX in France, whereas the opposite was found in Brazil. Differences between protein sources (i.e. SOY and MIX) increased when AA inclusion increased and were less pronounced in Brazil than in France. With both protein sources, EP impact decreased when the incorporation of AA increased, the effect being more marked for France than for Brazil. In the Brazilian context, diets based on SOY showed lower impacts than those based on MIX in noAA and lowCP scenarios, whereas the opposite was observed in the withAA scenario. Increasing the number of feeding phases and precision feeding reduced the EP impact in all situations, mainly when moving from MP to PR program. In all scenarios of feed formulation, whatever the soybean origin and the protein source, increasing the number of feeding phases, from 2P to PR, reduced the EP impact by about 8% in Brazil and 11% in France.

Cumulative energy demand

With soybean from SO, the values for CED ranged between the feeding programs from 12.8 to 13.4 MJ-eq. per kg of BWG in Brazil and from 11.7 to 12.5 MJ-eq. per kg of BWG in France (Fig. 2A). With soybean from CW, the values increased up to 15.0 to 16.1 MJ-eq. per kg BWG in Brazil and up to 12.9 to 14.4 MJ-eq. per kg of BWG in France. The lowest CED impact was reached for PR, both for soybean from SO and CW. On average, the highest CED impacts among the AA inclusion scenarios were observed for lowCP in both countries, and the lowest for noAA. On average, SOY scenarios showed higher CED impacts than MIX scenarios of protein source. In all scenarios of AA inclusion and whatever the feeding program or country, scenarios based on soybean meal from CW showed higher CED impacts than scenarios based on soybean from SO (Fig. 2A). The effect of the feeding program on CED was affected by the soybean origin and the level of AA inclusion. With soybean meal from CW, increasing the number of feeding phases and precision feeding reduced the CED impact by about 8.6% in all AA inclusions scenarios. Conversely, no effect or even a slight increase was observed with soybean from SO.

Terrestrial ecotoxicity

The values for TE ranged between the feeding programs from 8.45 to 9.19 g 1,4-DCB-eq. per kg BWG in Brazil, and from 13.1 to 14.2 g 1,4-DCB-eq per kg BWG in France (Fig 2B). According to the feeding program, the lowest TE impact was reached for PR, whereas the effect of phase feeding was very limited. In Brazil variability of TE was reduced when AA inclusion increased, without difference in mean values, whereas in France TE tended to decrease when AA inclusion increased. However the effects were rather limited. Independently of soybean origin and geographical context of pig production, SOY showed higher impacts than MIX scenarios but differences between protein sources were much higher in the French context compared to the Brazilian one.

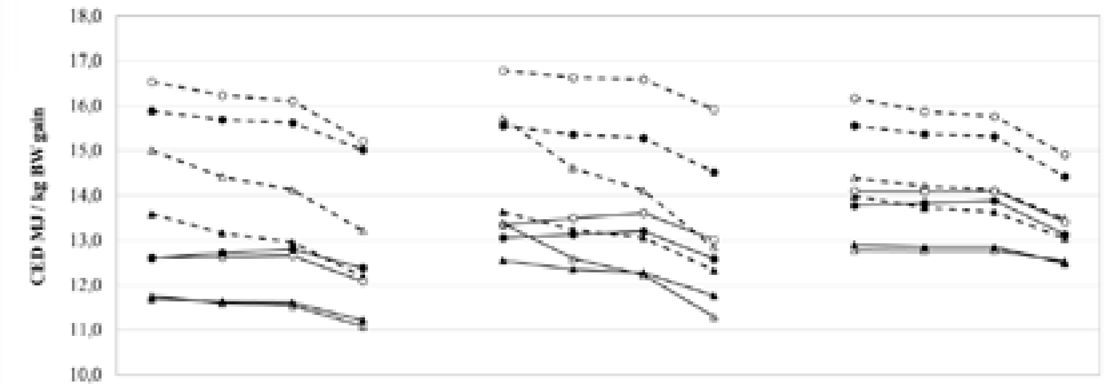

Figure 2. Interactions between effects of the feeding program, the use of amino acids and the soybean origin on environmental impact of cumulative energy demand (A), terrestrial ecotoxicity (B) and land occupation (C) for Brazilian (BR) and French (FR) context of pig production. 2P, 2-phase, 4P, 4-phase, MP, multi-phase and PR precision feeding programs. noAA, no amino acids, withAA, with amino acids, lowCP, without constraints in the crude protein content. SO, soybean from South region; CW, soybean from Centre-West Brazil. SOY, soybean meal as sole protein source, MIX, diversified protein sources.

There was a clear interaction between country and AA inclusion scenarios for TE,. In the French context, TE impact decreased by 23% when the incorporation of AA increased, whatever the soybean origin and protein source, whereas no effect or even the opposite was observed in the Brazilian context. For France, increasing the number of feeding phases and precision feeding reduced the TE impact in all AA inclusion scenarios; the magnitude of the effect decreasing when AA inclusion increased. Conversely, for Brazil, increasing the number of feeding phases tended to slightly increase the TE impact in all situations. Precision feeding resulted in a reduced TE impact in all scenarios of feed formulation, whatever the protein source and soybean origin. Compared to 2P, PR decreased the TE impact by about 21% in France and 8% in Brazil.

Land occupation

The values for LO ranged between the feeding programs from 2.33 to 2.52 m^2.year per kg BWG in Brazil and from 3.89 to 4.05 m^2.year per kg BWG in France, with similar results for both origins of oybean (Fig. 2C). According to the feeding program, the lowest LO impact was reached for PR, both for soybean from SO and from CW. The highest impacts among the AA inclusion scenarios were observed for the noAA inclusion scenario in both countries, whatever the origin of soybean meal. Independently of soybean origin and geographical context of pig production, SOY showed higher LO impacts than MIX scenarios. There was an interaction between the protein source and AA inclusion scenario in the French context. In the noAA scenario, SOY showed 2.1% lower LO impact than MIX, whereas when the incorporation of AA increased, SOY showed 5.7% higher impact than MIX, whatever the origin of the soybean meal. Precision feeding resulted in a reduced impact in all scenarios.

4. Discussion

With the hypothesis that 70% of the soybean was from CW and 30% from SO, Garcia-Launay et al. (2014) calculated lower CC impact in France for an MP program compared to a 2P feeding program. This was also the case in our study, in both countries, when soybean meal came from CW, whereas when it came from SO, the MP program resulted in a higher CC impact than 2P. This indicated that the effect of phase feeding on CC may depend on the origin of the soybean. In our study and in the studies by Eriksson et al. (2005) and Garcia-Launay et al. (2014), diets based on soybean meal only showed higher impact than diets based on more diversified protein sources. The lower CC impact obtained with these diets was related in Brazil to the use of meat and bone meal, a co-product with low CC impact. For French conditions, rapeseed meal and pea were not associated with any deforestation process, since this process occurred many centuries ago and, thus, was not taken into account in the LCA evaluation.

Variation of CC impact among scenarios was clearly reduced with the increased inclusion of FU-AA, indicating that the effect of feeding programs on CC was more pronounced when no FU-AA were included. A more pronounced effect of feeding program was also observed when soybean was from CW and especially when it was the sole protein source. In this situation, because of the high CC impact of CW soybean meal, increasing the number of feeding phases and AA inclusion was very efficient in reducing CO2-eq. emissions. This was not the case when the soybean was from SO. In Brazil with soybean from SO, CC impact tended even to rise when the number of feeding sequences increased and it decreased only in the case of precision feeding, whereas in France it always decreased. The possibility of reducing CED impact by increasing the number of feeding phases was confirmed for diets based on soybean meal from CW, but not for soybean from SO. Precision feeding only resulted in reduced CED impact in that situation.

Since both nitrogen and P contribute to eutrophication, and nitrogen contributes to acidification by ammonia emissions (Guinée et al., 2002), the AP and EP impacts were reduced in both countries by increasing the number of feeding phases and with the incorporation of FU-AA. This was not surprising because both strategies reduced nitrogen and P excretion and, consequently, also reduced the NH_3 emissions from animal housing and manure management and field application.

Feeding strategies affected TE impacts only when high impact feed ingredients were used. For this reason, the incorporation of FU-AA, the increase in the number of feeding phases and precision feeding reduced TE impact in the French context, but not in Brazil. The lower TE impact in Brazil was associated with the low TE impact of maize production, which represented more than 70% of feed composition in Brazilian formulations.

5. Conclusions

The results of this study indicate that precision feeding would be the most effective approach for reducing the life cycle impact of pig fattening, whereas the potential of multi-phase feeding programs depends on the impact considered, soybean origin and the geographical context of pig production. The interest of phase feeding and incorporation of FU-AA for reducing CC impact is limited in South America with soybean from South Brazil, whereas it appears to be an efficient strategy with soybean from Center West, especially in Europe. Conversely, potential eutrophication and acidification impacts are largely reduced by phase feeding and FU-AA addition in a rather similar way in all situations.

6. References

Dourmad, J.-Y., Jondreville C. 2007. Impact of nutrition on nitrogen, phosphorus, Cu and Zn in pig manure, and on emissions of ammonia and odours. Livest. Sci. 112:192-198.

Guinée J. B., Gorrée M., Heijungs R., Huppes G., Kleijn R., de Koning A., Oers L.V., Sleeswijk A.W., Suh S., de Haes H.A.U.. 2002. Handbook on life cycle assessment: Operational guide to the ISO standards. Kluwer Academic Publishers, Leiden, The Netherlands.

Garcia-Launay F., van der Werf H.M.G., Nguyen T.T.H., Le Tutour L., Dourmad J.-Y. 2014. Evaluation of the environmental implications of the incorporation of feed-use amino acids in pig production using Life Cycle Assessment. Livest. Sci. 161:158-175.

Nguyen,T.L.T., Hermansen J.E., Mogensen L. 2010. Fossil energy and GHG saving potentials of pig farming in the EU. Energy Policy 38:2561-2571.

Brossard L., Vautier B., van Milgen J., Salaun Y., Quiniou N. 2014. Comparison of in vivo and in silico growth performance and variability in pigs when applying a feeding strategy designed by simulation to control the variability of slaughter weight. Anim. Prod. Sci. 54: 1939-1945.

Prudêncio da Silva V., van der Werf H.M., Soares S.R., Corson M.S. 2014. Environmental impacts of French and Brazilian broiler chicken production scenarios: an LCA approach. J. Environ. Manage. 133:222-231. doi:10.1016/j.jenvman.2013.12.011

Wilfart A., Dauguet S., Tailleur A., Willmann S., Laustriat M., Magnin M., Espagnol S. 2015. LCIA results of feedstuffs for French livestock. Proc. 66th Ann. Meet. Europ. Fed. Anim. Sci., Warsaw, Poland, p. 411.

Rigolot C., Espagnol S., Robin P., Hassouna M., Beline F., Paillat J.-M., Dourmad J.-Y., 2010. Modelling of manure production by pigs and NH3, N2O and CH4 emissions. Part II: effect of animal housing, manure storage and treatment practices. Animal 4:1413-1424.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories: Emissions from Livestock and Manure Management. http://www.ipcc-nggip.iges.or.jp/public/2006gl (Accessed 10 Mars 2015.)

Dämmgen U., Hutchings N.J.. 2008. Emissions of gaseous nitrogen species from manure management - A new approach. Environ. Pollut. 154:488-497.

Nemecek T., Kägi T. 2007. Life cycle inventories of Swiss and European agricultural production systems. In: Ecoinvent V2.0 Report. Rep. No. 15a. Swiss Centre for Life Cycle Inventories, Zurich.

Eriksson, I.S., H. Elmquist, S. Stern and T. Nybrant. 2005. Environmental systems analysis of pig production – the impact of feed choice. Int. J. Life Cycle Assess. 10:143–154.

PAS2050. 2011. Specification for the assessment of the life cycle greenhouse gas emission of goods and services. British Standards Institute, London, UK.