Life Cycle Assessment on the role of Specialty Feed Ingredients on livestock production's environmental sustainability

Summary – North America

IFIF - International Feed Industry Federation

and

FEFANA – EU Association of Specialty Feed Ingredients and their Mixtures

2015

Table of Contents

Companies and Associations members of the SFIS[1] Technical Board:

Associations

IFIF – International Feed Industry Federation

FEFANA – European Union Association of Specialty Feed Ingredients and their Mixtures

AFIA – American Feed Industry Association

JFMA – Japanese Feed Manufacturers Association

Sindirações - Brazilian Feed Industry Association

Full members

Adisseo France SAS

ADM

Ajinomoto

BASF SE

DSM Nutritional Products Ltd.

Evonik Nutrition and Care GmbH

Novus Europe S.A./N.V.

AB Vista

Dupont Industrial Biosciences

Observers

Alltech

Nutreco

Taminco

InVivo

[1] SFIS: Specialty Feed Ingredients Sustainability project (led by International Feed Industry Federation and FEFANA)

Glossary

AA: Amino Acids

AP: Acidification Potential

BFI: Base Feed Ingredients

EP: Eutrophication Potential

FCR: Feed Conversion Ratio

FU: Functional Unit

GHG: GreenHouse Gases

GWP: Global Warming Potential

LCA: Life Cycle Assessment

LUC: Land Use Change

N: Nitrogen

P. Phosphorus

PCR: Product Category Rules

Phy: Phytases

SFI: Specialty Feed Ingredients

Definitions

Feed ingredient: any ingredient, whether processed, semi-processed or raw, which are intended to be fed directly to food-producing animals (adapted from (Good practices for the feed industry, FAO and IFIF, 2010).

Based Feed Ingredient: feed ingredient which aim at covering the nutritional requirements, particularly in terms of energy, protein, fibers and macro minerals.

Specialty Feed Ingredient: are feed ingredient which are intentionally added to the feed to provide a specific functions, such as technological, nutritional (micronutrients and amino acid), sensory or zootechnical (e.g. phytase).

Livestock: in this document, livestock means pig and broiler

Basic Feed: in this document, the feed that does neither contain AA nor Phy

Table of Figures

Introduction:

Livestock production is recognized as a significant source of emissions in the environment in a liquid, gaseous or solid form. This environmental impact can be mitigated by adopting feeding management measures. The use of Specialty Feed Ingredients (SFI) in animal nutrition is a valuable contribution to mitigate the environmental impact of animal production, by e.g. reducing the excretion of certain nutrients (nitrogen (N), phosphorus (P)), improving the performance of the animals, reducing the feed consumption or allowing the use of locally based or unusual feed ingredients such as co-products from food production or food processing.

The goal of this study was to conduct a Life Cycle Assessment (LCA) in conformity with the ISO 14040/44 standards in order to analyze the cradle-to-farm exit gate environmental performance of pig and broiler production systems in three representative regions worldwide[2] (Europe, North America and South America) with and without SFI supplementation. It is also aimed at providing credible scientific evidence for informed decision making in areas related to the environmental impact of animal production. The supplementation of compound feeds with SFI such as amino acids and enzymes like phytase is the state of the art technology in modern livestock production to fulfil the nutritional requirements of animals and close the nutrient gap in the most precise way.

The study was conducted respecting the effects of SFI on animal performance as well as on environmental impacts in different regions of the world.

The LCA was completed to increase the knowledge of the application and use of SFI on the environmental impacts of livestock production systems, to identify areas with high potential for improvement of environmental sustainability performance, to provide information and data for future investigations in the feed to food chain and to identify research gaps and uncertainties. It also provides a credible basis for policy makers to take into account different ways of mitigating the environmental impact of livestock production.

The outcome of the present study is also intended to contribute to the public debate on sustainable meat production and in assisting to set science-based benchmarks towards a sustainable animal production sector.

The study has been done as a joint effort between member companies of the IFIF and FEFANA under the technical support of Thinkstep®[3].

The critical review was done by an independent review panel of 3 international experts on standards and animal nutrition.

Specialty Feed Ingredients (SFI):

To investigate the key role of SFI on the environmental impact of animal production, four amino acids (lysine, methionine, threonine and tryptophan) and phytases have been selected as representative products to demonstrate the positive effect of adding SFI in the animal diets, in the different regions tested.

[2] In this summary, only the results obtained in North America are provided.
[3] Stuttgart; Germany (formerly PE International)

Methodology:

LCA is a standardized scientific method for systematic analysis of flows (e.g. mass and energy) associated with the life cycle of a specific product, technology, service or manufacturing process system to assess its environmental impacts. The scope of the present study is a "cradle-to-farm exit gate" LCA. The Functional Unit (FU) chosen is the live weight of animals (pig and broiler), when leaving the farm. The study encompasses three regions (Europe, North America and South America). Due to the broad range of animal products after processing, the use and end-of-life of these final products are not part of this study. The results of this study can be used in product specific studies to reflect the complete life cycle.

The study provides a comparison of the environmental profile of livestock productions systems, when diets include SFI or not. Three (3) diets[4] have been tested for pigs:

- The Basic Feed formulated according to local practices in the different regions, without the addition of AA and Phy
- A feed (Feed + AA) providing the same level of nutrients as the Basic Feed, formulated with the use of AA
- A feed (Feed + AA + Phy) providing the same level of nutrients as the Basic Feed, formulated with the combined use of AA and Phy

A similar approach has been taken for the broilers' diets. However, due to the formulation constraint on the energy content of the Basic Feed, the Feed Conversion Ratio (FCR) was increased in the broiler production system fed with the basic feed (1.81 with the Basic Feed compared with 1.70 in the feeds with AA and with AA and Phy)

A set of environmental impacts (Global Warming Potential - GWP; Acidification Potential – AP and Eutrophication Potential - EP) is used. It provides a useful perspective for different stakeholder groups, such as the SFI producing Industry and the feed and meat (food) industry in general, livestock farmers, government agencies, non-governmental organizations, scientific bodies, LCA practitioners and the media.

A sensitivity analysis to evaluate the impact of FCR on the environmental footprint of livestock production has been developed. It consists in:

- Increasing the FCR by about 9 % and 10.5 % for pigs and broilers production systems respectively compared to the Basis Feed scenario
- Reducing the FCR by about 9 % and 12 % for pigs and broilers production systems respectively compared with the scenario with the feed + AA + Phy

Based on the present methodological approach by defining the FU, setting the system boundaries and establishing allocation rules, the outcome of the study can also be used for other LCAs of SFI, not only for amino acids and phytases. Stimulated by the outcomes of the study, the so-called "product category rules (PCR)" will be developed generally for all the other SFI. Within the framework of LCA investigations to continuously improve and complete the environmental impact of animal production, the principles used in the present study may be also tested for other SFI, with a view to validate the PCR.

[4] In this summary, only the results of the Basic Feed and the Feed + AA + Phy are reported.

System boundaries:

This study is limited to the system boundaries described in the Figure 1 regarding its results and the interpretation of its findings. It is therefore stated that it is only applicable to the specific conditions described in this report. The results of this assessment are to be used according to the defined goal and scope only.

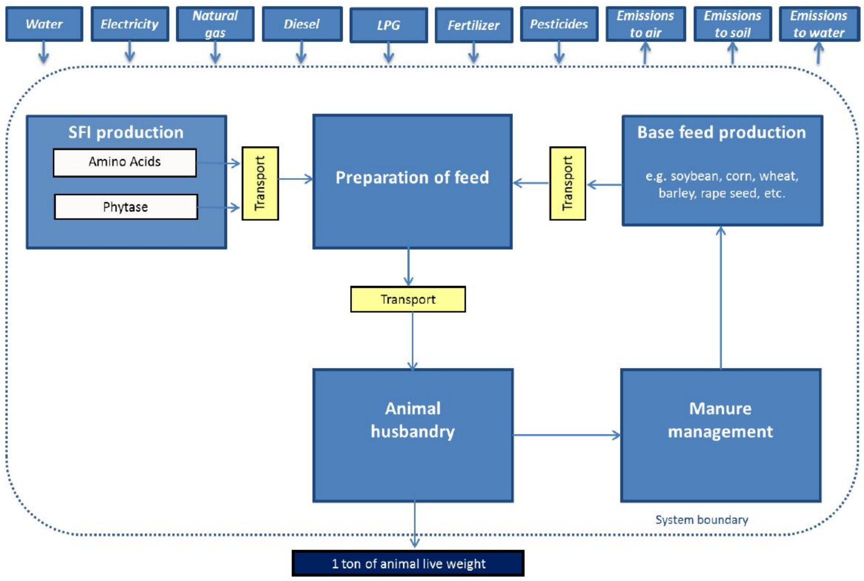

Figure 1 - Overview of the system (including the subsystems production of base feed ingredients (BFI), SFI, feed mill processes, animal husbandry and manure management).

Production of Base Feed Ingredients (BFI)

One basic function of feed - for both, pigs and broilers - is to cover the energy requirements of the animals, as it is needed for all metabolic processes. Carbohydrates such as starch and sugar deliver a high energy level. Also fat and protein components increase the energy content of the feed, whereas fibers reduce the energy content (Spiekers et al, 2011) Cereals such as wheat, barley or corn serve as major sources of energy in pig and broiler feed (Eriksson et al, 2005; Mosnier et al, 2011;Van der Werf et al, 2005; Wenk et al, 2006). On the other hand, proteins in feed are important to deliver amino acids, which are the essential building blocks for most tissues of the body (PIC, 2005). Major sources for crude protein in diets are soybeans, other oil meal crops and legumes (Eriksson et al, 2005; Mosnier et al, 2011; PIC, 2005; Van der Werf et al, 2005). Cereals, which are often the main component of feed, contain low levels of proteins (Sharpley et al, 2003).

Cereals and protein sources contain P but with low bioavailability, as P is strongly bound with phytic acid, to form phytate. The other main P source is mineral phosphate with a much higher bioavailability (Bomans et al, 2005). In some regions meat and bone meal can also contribute to P supplies, but not in the European Union where its use is forbidden.

The composition of the feeds is different for the two livestock production systems and for the different regions, therefore different BFI are used. In addition, the sourcing of BFI varies according to the investigated region. This was taken into consideration when setting up representative feed compositions for the three regions by the specific nutritional experts of the Technical Board (SFIS Technical Board), which were validated by the Scientific Council (Scientific Council) of the project.

Production of SFI

Amino Acids

Amino acids are simple organic molecules, in which an amino group and a side chain are attached to a carboxyl function. There are approximately 20 amino acids, which form the essential building blocks for all proteins. While plants are able to synthesize all amino acids, essential amino acids need to be provided via the feed to animals. The supplementation with industrially produced amino acids complements and/or replaces agriculturally produced proteins, which show generally an imbalanced amino acid profile. Consequently, this supplementation reduces the crude protein content of the feed, which ensures a balance for the animal and at the same time leads to lower N excretions (Aarnink et al, 2007; Binder et al, 2011; IFEU, 2004; Lammers et al, 2010; Mosnier et al, 2011; Osada et al, 2011; Portejoie et al, 2004; UBA, 2003).

More than 100 years ago Justus von Liebig, a German scientist, identified that some amino acids are only available in small amounts in natural BFI, but are of major importance for animal health and productivity (Tokach et al, 2012). Based on his principle of the limiting minimum, displayed with a barrel in which water overflows at the lowest plank, these amino acids are limiting overall growth of animals if missing (Figure 2). Surplus feedings can be avoided if the limiting amino acids are added to the feed.

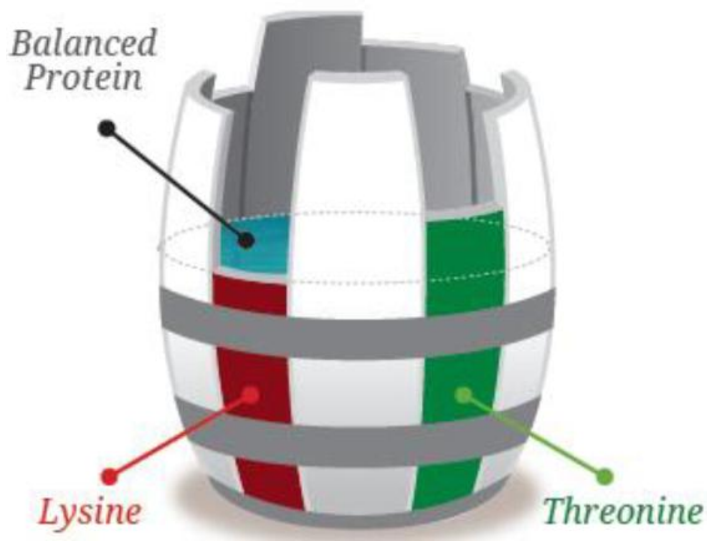

Figure 2 - Amino acid supplementation facilitates improved balance of amino acids in feed (Tokach et al, 2012)

The first limiting amino acids for pigs are:

- Lysine
- Threonine
- Methionine
- Tryptophan

The first limiting amino acids for broilers are

- Methionine
- Lysine
- Threonine

Supplementation with the free form of these amino acids is considered in the supplemented feeding regimes of this study.

The main possibilities to produce amino acids are the chemical synthesis or the microbial production through fermentation with overproducing microbial strains. Microorganisms, mostly bacteria, are transformed through classical breeding or genetic modification to produce a higher quantity of amino acids than the original strain. Microbial synthesis takes place in fermentation processes with sucrose and/or glucose as carbon source.

Depending on the desired amino acid, different production routes have to be chosen due to the structure of the amino acids and the required precursors.

Lysine, threonine and tryptophan are mainly produced through fermentation. Fermentation processes take place in stirred-tank reactors, which provide the optimum conditions for the metabolism of the microorganisms through stirring and aeration (Drauz et al. 2007).

Methionine for feed use is generally chemically synthesized from ammonia. Methionine is recovered by crystallization (Drauz et al. 2007). Some other methionine sources are produced as a liquid without crystallization (FEFANA, 2014).

Phytase

Enzymes are proteins, which act as catalysts for all kind of metabolic processes (Nielsen et al, 2007a). Digestion is a process which is operated by enzymes in the digestive tract. Phytases are enzymes which hydrolyze phytate to release free P. Phytases can be found in plants, microorganisms and animals (Herbots et al, 2008). The phytase production by animals is often considered as negligible. It is mainly produced by bacteria, e.g. in the rumen of ruminants, which contributes to the higher digestibility of P in this species, and in the hindgut of pigs but without interesting effects on P supplies because P absorption occurs only in the small intestine.

P is a key dietary element and plays an important role in numerous metabolic reactions. It is also the basic component for the formation of the bone tissue. Approximately two thirds of P in animal feed is present in the form of phytate. Monogastric animals have only limited ability to utilize phytate bound P (Herbots et al, 2008).

Phytase is naturally found in some cereals especially wheat, triticale and rye, but not produced by pigs and poultry. As phytase from plant origin is heat sensitive and unstable, it is usually not sufficient to degrade most of the phytate present in the feeds in modern pig and broiler production systems. Diets based on corn and soybean meal contain almost no natural phytase. Microbial phytase is added to the feed to improve plant P digestibility (Bühler et al, 2004). Through this increase of digestion efficiency of P and depending on the diet, lower or no supplementation of mineral P is needed to cover the P requirement of the animals, resulting in a reduced P excretion (Herbots et al, 2008).

Most phosphate, used to supplement feed in the absence of phytase, is derived from rock, which is a non-renewable resource, and current global reserves may be depleted in 50-100 years (Cordell et al, 2011). Maintaining P resources as global reserves has been identified as one of the greatest challenges for sustainable food production.

The supplementation of animal feed with the phytase improves the availability and digestibility of plant P which leads to a reduction in the mineral P content of the feed and to a decrease in P excretion (Augspurger et al , 2009; Nahm, 2002; Nielsen et al, 2007; Plumstead et al, 2007; Sharpley et al, 2003; Smith et al, 2004).

Enzymes can be obtained through extraction from living material or more frequently from microbiological fermentation (Chotani et al, 2012). The respective microorganisms – bacteria, yeasts or fungi – can be selected and grown through classical breeding or genetic engineering from original strains. The main part of commercially available phytase is produced with fungi, whereas bacterial and yeast production constitute a small amount (Herbots et al, 2008). The fermentation through micro-organisms takes mostly place in an aerobic stirred tank reactor (Chotani et al, 2012). The extracellular enzymes are then recovered from the biomass through centrifugation and filtration. The enzymes then need to be isolated, typically through filtration, concentration, purification and drying. The final formulation includes preservation and standardization, which can be achieved through dilution followed by drying (Nielsen et al, 2007).

Results

Main outcomes

The main study outcomes can be summarized as follows:

In general, supplementation of animal feed with SFI is significantly beneficial for the impact categories Acidification Potential (AP) and Eutrophication Potential (EP). This statement is true for pigs and broiler production systems in all studied regions. On the other hand, the contribution or improvement potential for the Global Warming Potential (GWP) is much more complex and must be analyzed more carefully.

- For broiler production systems in Europe and South America, but not in North America, there are significant environmental improvements for the GWP impact category.
- For pigs' production systems, there are no significant improvements for the GWP impact category in none of the regions if Land Use Change (LUC) emissions are not considered. Depending on the choices made for some sensitive parameters, improvements can turn into insignificant setbacks.
- LUC emissions from soybean products produced in South America, based on a qualitative evaluation and not on a quantitative basis, are a significant driver of GreenHouse Gas (GHG) emissions for Europe and South America. As the use of soybean meal products in animal diets is reduced by supplementation of SFI, the latter can contribute to reduce GHG emissions per FU.

The environmental hot spots of animal production depend on the impact category: For GWP animal feed production is the most significant contributor, for EP is the manure field application, for AP is the manure storage (for pig production systems) and manure field application (for broiler production systems).

The life cycle stages such as the preparation of the feed and animal housing showed minor contributions to the overall results. Transportation only plays a role if long distance feed imports are involved in the supply chain. Based on data from a literature study the environmental impact of the production of the amino acids and phytases appear to be of minor relevance. Nevertheless, the production data of SFI could be further improved (primary data).

Nitrogen (N) and Phosphorus (P) excretion

The use of amino acids and phytases in pigs feed has a significant impact on the amount of N (36 % reduction) and P (35 % reduction) excreted by the animals, as shown in Figure 3.

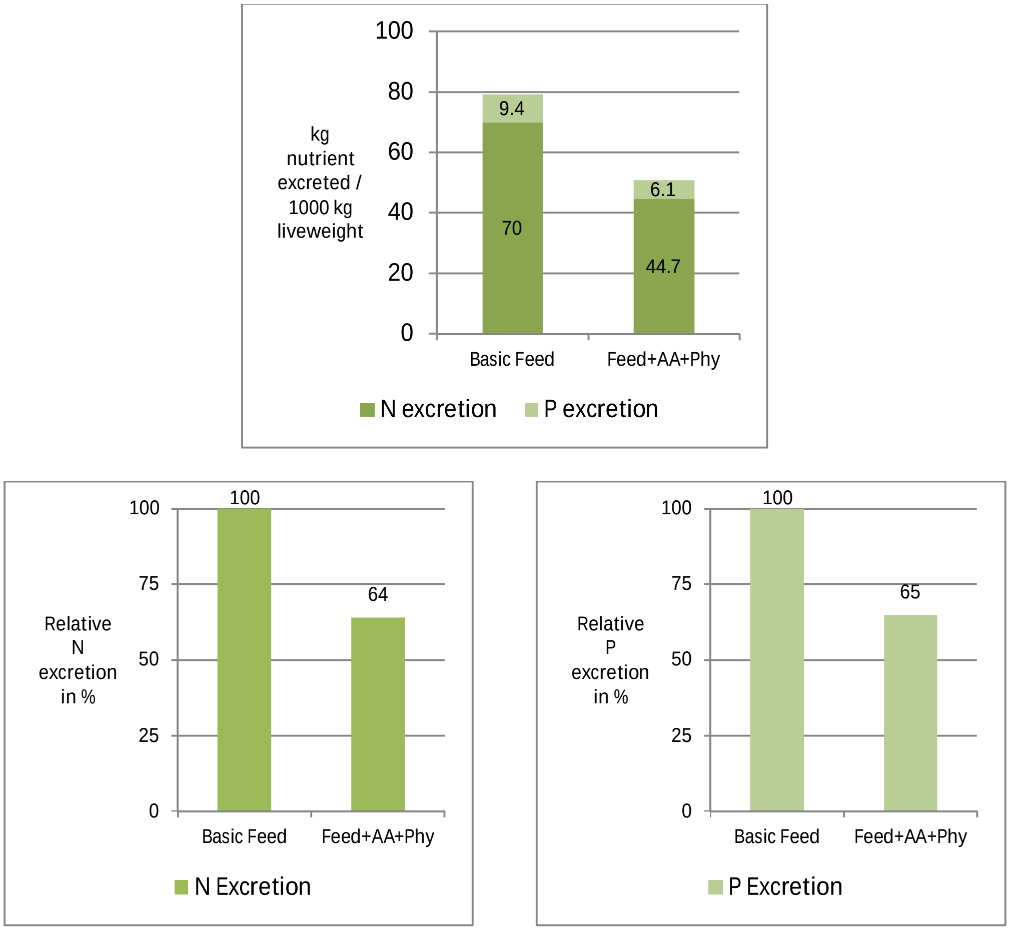

Figure 3 - The addition of amino acids and phytases significantly reduces the excretion levels of nutrients (N and P) for pigs' production system in North America

Similarly, the use of amino acids and phytases in broiler feed leads to a significant reduction of N excretion (27 % reduction), linked to the combined effect of reduction of N in feed and lower FCR. The addition of amino acids and phytases reduces the P excretion compared to the basic feed (48 % reduction) due to the lower FCR and reduction of P in the diet, as shown in Figure 4.

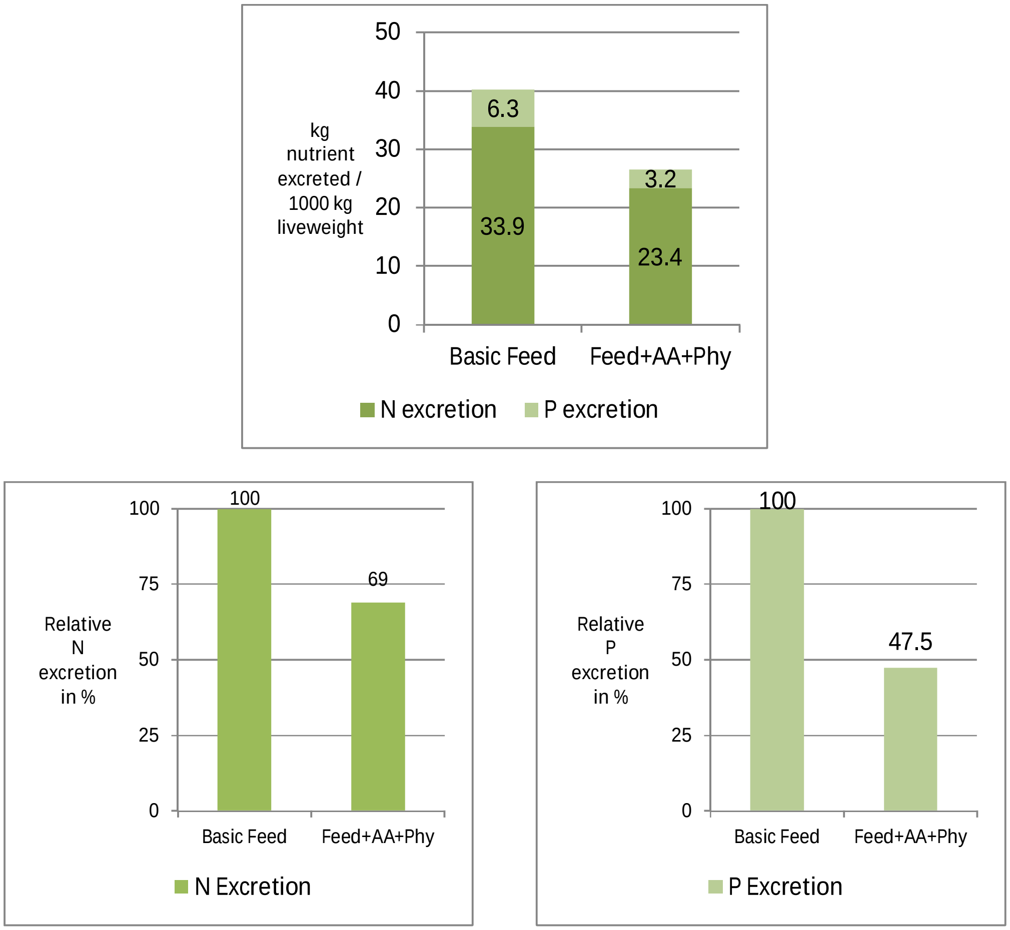

Figure 4 - The addition of amino acids and phytases significantly reduces the excretion levels of nutrients (N and P) for broiler production system in North America

The reduced excretion is the triggering element for the mitigation of the environmental impacts (AP and EP) linked to pigs and broiler production systems.

Global Warming Potential (GWP)

The Figure 5 provides the environmental hot spots for the GWP in livestock production system in relation to the use of the Basic Feed. The main hot spot in both production systems is the sourcing of feed materials.

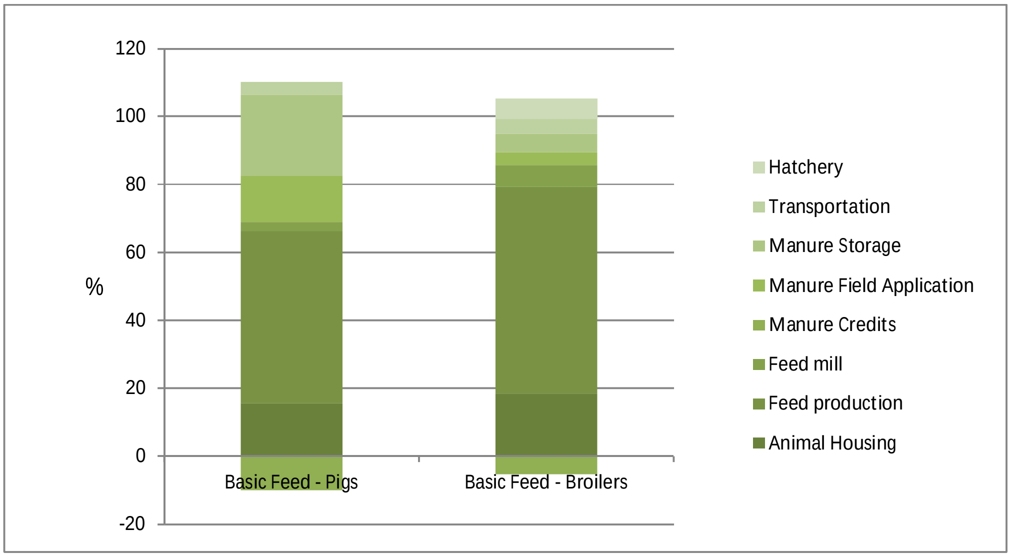

Figure 5 - Environmental hot spots for the GWP (measured in kg CO_2 equivalent / 1000 kg live weight) in livestock production systems in North America

In pigs' production system, the environmental impact (GWP) is not modified when SFI are incorporated in the diet and the hierarchy of the hotspot is unchanged. When SFI are incorporated in poultry feed, the environmental impact (GWP) of the production system is reduced to a larger extent (6 % reduction) mainly due to a reduction of the FCR. The Figure 6 provides the comparison between the different production systems.

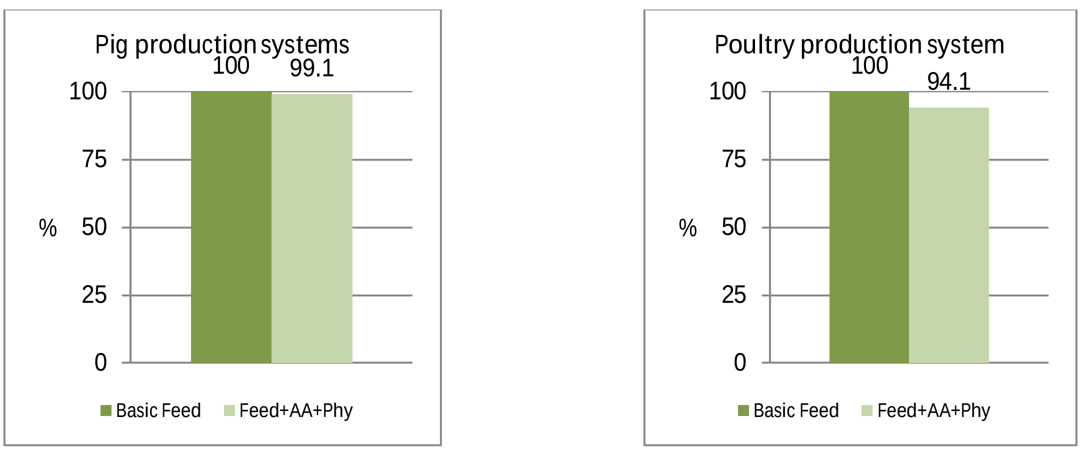

Figure 6 – The use of amino acids and phytases only slightly reduces the GWP of livestock production systems in North America

In North America, the sourcing of BFI is mainly local and does not induce direct LUC. Therefore, the modification of the environmental impact GWP with LUC (data not shown) is similar to the modification on the environmental impact GWP.

Eutrophication Potential (EP)

Figure 7 indicates the environmental hot spots for EP in livestock production systems, when the Basic Feed is fed to pigs and broilers. The main hot spot in both production systems is the manure field application.

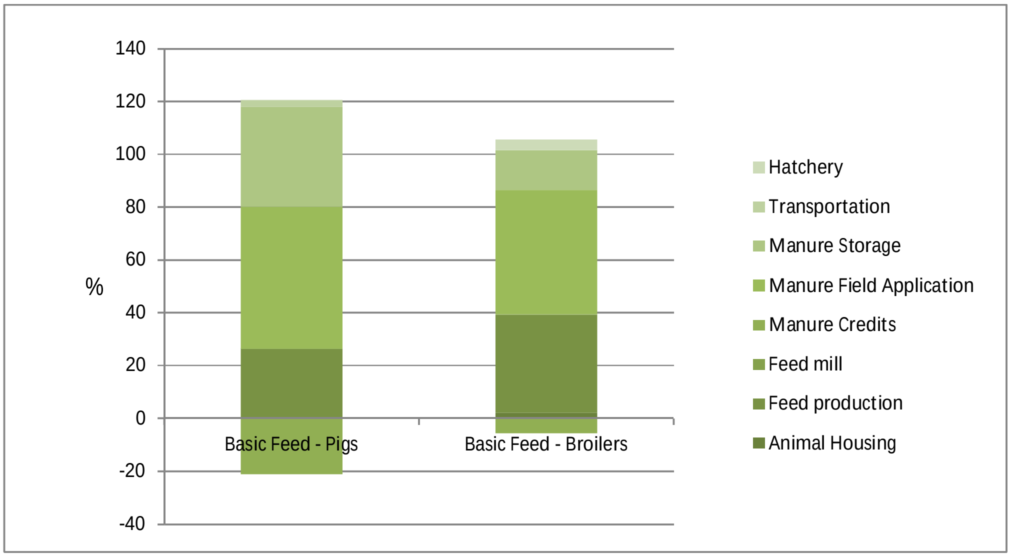

Figure 7 - Environmental hot spots for the EP (measured in kg Phosphate-equivalent / 1000 kg liveweight) in livestock production systems in North America

As shown in Figure 8, the incorporation of amino acids and phytases in feed for pigs and broilers reduces significantly the EP of livestock production systems in North America. The overall reduction of the EP is linked to a combination between a decrease of impact linked to the sourcing of feed materials and a further decrease during storage and field application of manure. Hence, the hierarchy of the hot spots is unchanged compared to the description in Figure 7.

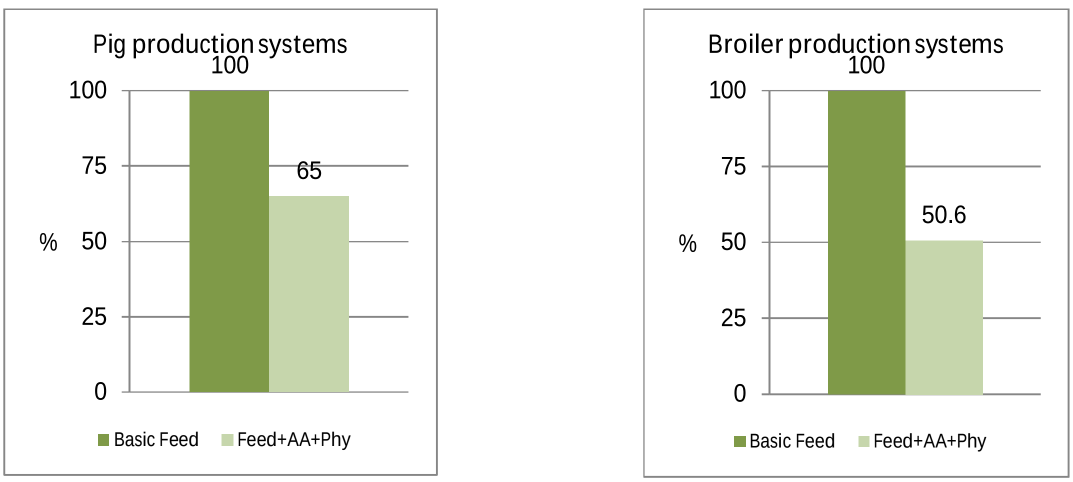

Figure 8 – The use of amino acids and phytases reduces significantly the EP of livestock productions in North America.

Acidification Potential (AP)

Figure 9 indicates the environmental hot spots for AP in livestock production systems, when the Basic Feed is fed to pigs and broilers. As indicated above, the main hot spot in pig production system is linked with the manure storage (due to ammonia emission), while in poultry production system, the main hot spot is the manure application

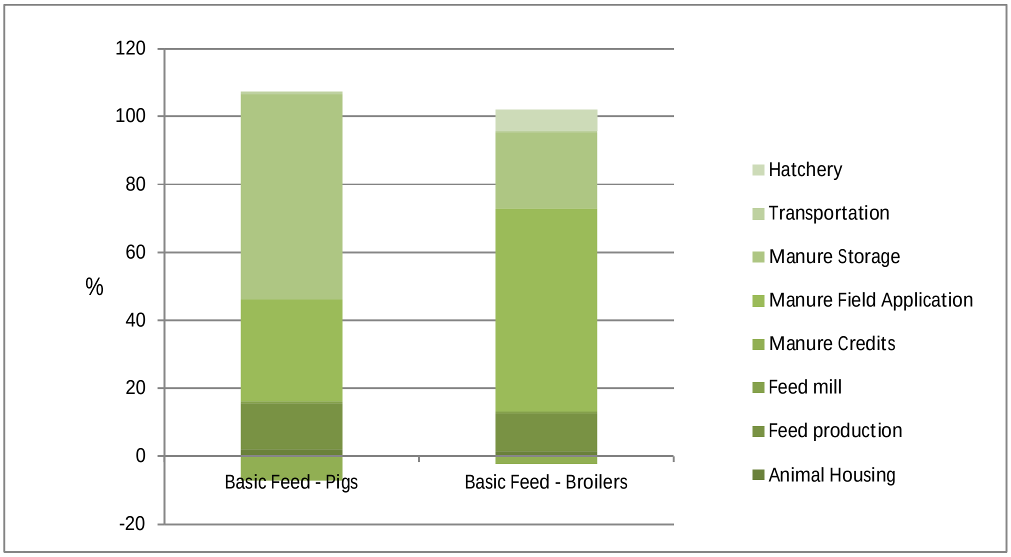

Figure 9 - Environmental hot spots for the AP (measured in kg SO_4 equivalent / 1000 kg liveweight) in livestock production systems in North America

As shown in Figure 10, the incorporation of amino acids and phytases in feed for pigs and broilers, reduce significantly the AP of livestock production systems in North America. Most of the effect is related to the use of amino acids, due to the reduction of the N concentration in feed. The overall reduction of the AP is linked to a combination between a decrease of impact linked to manure management (storage and field application). However, due the importance of these hot spots in the overall environmental footprint, the hierarchy described in Figure 9 remains valid.

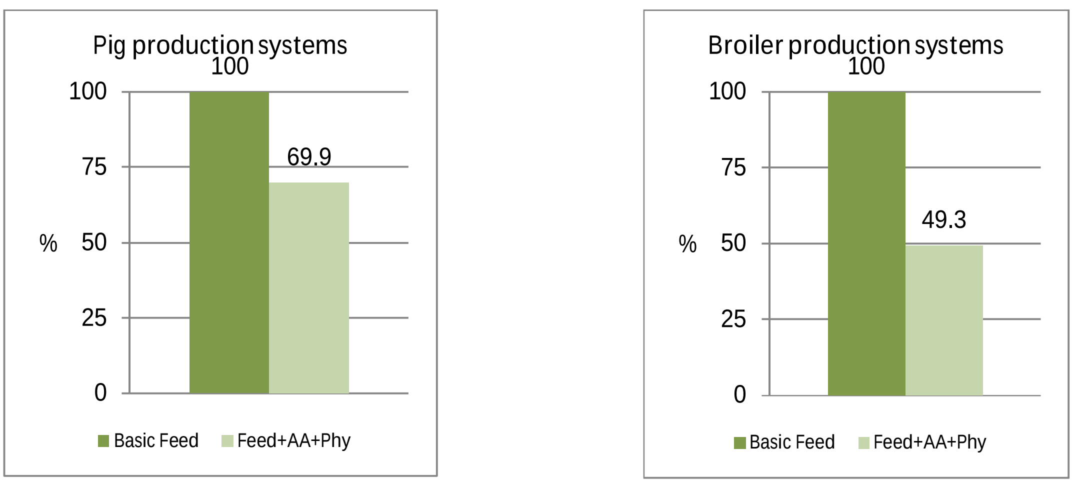

Figure 10 – The use of amino acids and phytases reduces significantly the EP of livestock productions in North America.

Sensitivity Analysis on Feed Conversion Ratio (FCR)

The results of the FCR sensitivity analysis for pigs and broilers production system, as described in Figure 11, shows that for all scenarios, the FCR improvement leads to a significant reduction of the environmental footprint of livestock production system. Hence, all stakeholders should be interested to have a low FCR and to further improve it.

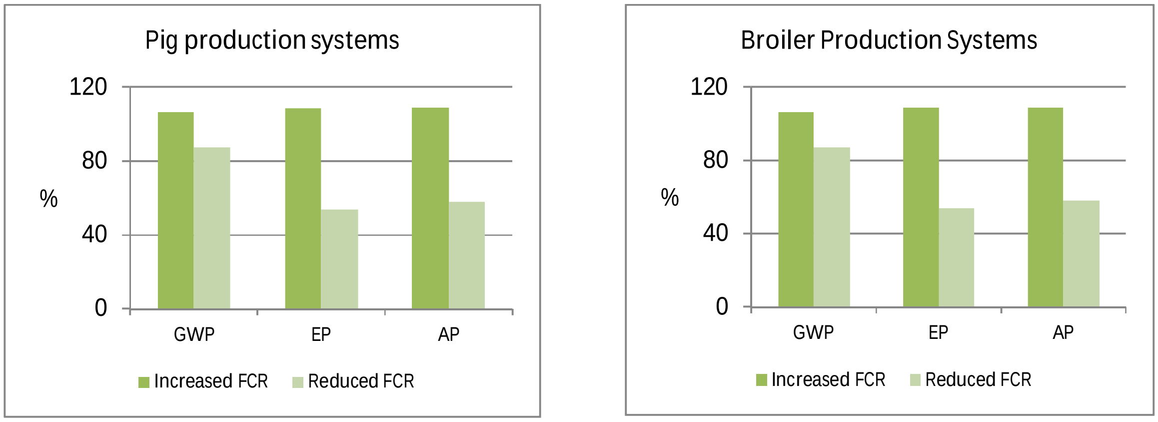

Figure 11 - Improved FCR reduces the environmental footprint, considering all the impact categories, of livestock production systems in North America

This study can be used in assisting to set benchmarks for sustainable animal production systems in different regions of the world by providing initial environmental profiles. It can serve as a starting point for LCA studies for other regions and/or other animal species than the ones tested here, and to trigger off more research to identify methodological aspects and potential data gaps.

An alignment of this study with international initiatives regarding preceding and subsequent life cycle stages of the consumer products should be further pursued and intensified.

Conclusions and Recommendations

By performing this study and analyzing its results, knowledge of the application and use of SFI on the environmental impacts of livestock production was gained and improved:

For broilers production systems, in the regions Europe and South America, but not in North America, there are significant environmental improvements for the impact category GWP, if emissions from direct LUC are not considered. For pigs' production systems, there are no significant improvements for the impact category GWP in none of the regions, if emissions from direct LUC are again not considered. Depending on the choices made for some sensitive parameters, improvements can turn into insignificant setbacks.

By supplementing SFI in animal feed, excretion of certain key nutrients (N, P) is reduced while at the same time nutrient utilization efficiency increases. Since N in manure is the major driver for emissions in manure management and manure application on the field, the SFIS supplementation is of high relevance.

Agricultural P, especially in form of manure or slurry spread as fertilizer on the fields, is regarded as a major input source for P in the ecosystem. Furthermore, P is the limiting factor for plant growth and therefore can accelerate eutrophication in many freshwater ecosystems (Sharpley et al, 2003).

Moreover, the FCR ratio has a strong overall impact into all impact categories.

Additionally, the N-modelling approach has a strong effect on the environmental profile of the different alternatives and scenarios. The approach presented here is trying to tackle methodological issues of crediting N applied on the field. This approach should be presented and discussed with an international audience.

More advanced impact assessment models - especially for eutrophication potential - have recently been developed, applying separate models for freshwater and marine water eutrophication. The SFIS Technical Board will continue to monitor the developments in this field and to update the LCA assessment according to the most advanced models, especially with regard to the methodology recommended for the Product Environmental Footprint (PEF) developed by the European Commission.

References

Aarnink et al, 2007 - Aarnink, A. J. A., M. W. A. Verstegen; 2007. “Nutrition, key factor to reduce environmental load from pig production” Livestock Science 109 194-203.

Augspurger et al , 2009 - Augspurger, N. R., J. D. Spencer, D. M. Webel, B. F. Wolter, T. S. Torrance; 2009. “An Escherichia coli-derived phytase can fully replace inorganic phosphorus in maize–soybean meal diets for growing-finishing pigs” Animal Feed Science and Technology 154 254-259.

Binder et al, 2011 - Binder, Michael, with Thomas Engenhorst and Karsten Grönke; 2011. “Comparative life cycle analysis of DL-Methionine, L-Lysine, L-Threonine and L-Tryptophan in broiler and pig production” Evonik Degussa GmbH.

Bomans et al, 2005 - Bomans, E., K. Fransen, A. Gobin, J. Mertens, P. Michiels, H. Vandendriessche, N. Vogels; 2005. “Addressing phosphorus related problems in farm practice” European Commission, DG Environment.

Bühler et al, 2004 - Bühler, M., J. Limper, A. Müller, G. Schwarz, O. Simon, M. Sommer, W. Spring; 2004. „Enzyme in der Tierernährung“ AWT (Arbeitsgemeinschaft für Wirkstoffe in der Tierernährung e. V.).

Chotani et al, 2012 - Chotani, Gopal K., Thimothy C. Dodge, Andreas Herman Terwisscha van Scheltinga, Christian Gölker, Meng H. Heng, John Kan, Todd Becker, Saburo Fukui, Atsuo Tanaka, Rainer Schmuck, Hans de Nobel, Brian Jones, Wolfgang Aehle, Rick Bott; 2012. Enzymes, 2. Discovery and Production. Ullmann’s Enzyklopedia of Industrial Chemistry.

Cordell et al, 2011 - Cordell, D., A. Rosemarin, J. J. Schröder, A. L. Smit; 2011. “Towards global phosphorus security: a systems framework for phosphorus recovery and reuse options” Chemosphere. Aug;84(6):747-58. Doi: 10.1016/j.chemosphere.2011.02.032.

Drauz et al. 2007 - Drauz, Karlheinz, with Ian Grayson, Axel Kleemann, Hans-Peter Krimmer, Wolfgang Leuchtenberger, and Christoph Weckbecker; 2007. Amino Acids. Ullmann’s Encyclopedia of Industrial Chemistry.

Eriksson et al, 2005 - Eriksson Ingrid Strid, Helena Elmquist, Susanne Stern, Thomas Nybrant; 2005. “Environmental Systems Analysis of Pig Production The Impact of Feed Choice” Int J LCA 10 (2) 143 – 154.

FEFANA, 2014 – Amino acids in animal nutrition (Ed. FEFANA)

Herbots et al, 2008 - Herbots, Ivan, Beatrix Kottwitz, Peter J. Reilly, Richard L. Antrim, Heidi Burrows, Herman B. M. Lenting, Liisa Viikari, Anna Suurnäkki, Marja-Leena Niku-Paavola, Jaakko Pere, Johanna Buchert; 2008. Enzymes, 4. Non-food Application. Ullmann’s Encyclopedia of Industrial Chemistry.

IFEU, 2004 - Ostermayer, Axel, with Sven Gärtner, Florian Knappe, Sandra Möhler, Andreas Detzel, Regine Vogt, and Jürgen Giegrich; 2004. „Ökobilanz für den Einsatz von DL-Methionin, L-Lysin und L-Threonin in der Geflügel- und Schweinemast“ ifeu-Institut für Energie- und Umweltforschung Heidelberg GmbH.

Lammers et al, 2010 - Lammers, P. J., M. D. Kenealy, J. B. Kliebenstein, J. D. Harmon, M. J. Helmers, M. S. Honeyman; 2010. “Nonsolar energy use and one-hundred-year global warming potential of Iowa swine feedstuffs and feeding strategies” J. Anim. Sci. 88(3):1204–1212.

Mosnier et al, 2011 - Mosnier, E., H. M. G. van der Werf, J. Boissy, J.-Y.Dourmad; 2011. “Evaluation of the environmental implications of the incorporation of feed-use amino acids in the manufacturing of pig and broiler feeds using Life Cycle Assessment” Animal, 5:12, pp 1972–1983.

Nahm, 2002 - Nahm, K. H.; 2002. “Efficient Feed Nutrient Utilization to Reduce Pollutants in Poultry and Swine Manure” Critical Reviews in Environmental Science and Technology, 32(1):1-16.

Nielsen et al, 2007a - Nielsen, Per H., Henrik Wenzel; 2007. ”Environmental Assessment of Ronozyme® P5000 CT Phytase as an Alternative to Inorganic Phosphate Supplementation to Pig Feed Used in Intensive Pig Production” Int J LCA 12 (7) 514–520.

Nielsen et al, 2007b - Nielsen, Per H., Karen M. Oxenbøll, Henrik Wenzel; 2007. “Cradle-to-Gate Environmental Assessment of Enzyme Products Produced Industrially in Denmark by Novozymes A/S” Int J LCA 12 (6) 432 – 438.

Osada et al, 2011 - Osada, Takashi, Ryozo Takada, Izuru Shinzato; 2011. “Potential reduction of greenhouse gas emission from swine manure by using a low-protein diet supplemented with synthetic amino acids” Animal Feed Science and Technology 166-167 562-574.

PIC, 2005 - “Kurze Fütterungsempfehlung für Ferkel, Mastschweine, Sauen und Eber“ PIC Deutschland GmbH, Ausgabe 09/05.

Plumstead et al, 2007 - Plumstead, P. W., H. Romero-Sanchez, R. O. Maguire, A. G. Gernat, J. Brake; 2007. “Effects of Phosphorus Level and Phytase in Broiler Breeder Rearing and Laying Diets on Live Performance and Phosphorus Excretion” Poultry Science Association Inc.

Portejoie et al, 2004 - Portejoie, S., J. Y. Dourmad, J. Martinze, Y. Lebreton; 2004. “Effect of lowering dietary crude protein on nitrogen excretion, manure composition and ammonia emission from fattening pigs” Livestock Production Science 91 45-55.

Sharpley et al, 2003 – Sharpley A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, R. Parry, 2003: Agricultural Phosphorus and Eutrophication (2nd ed.). United States Department of Agriculture Agricultural Research Service (USDA), ARS–149, Sep 2003

Selle et al, 2007 - Selle, Peter H., Velmurugu Ravindran; 2007. “Microbial phytase in poultry nutrition” Animal Feed Science and Technology 135 1-41.

Smith et al, 2004 - Smith, D. R., P. A. Moore, C. V. Maxwell, B. E. Haggard, T. C. Daniel; 2004. “Reducing Phosphorus Runoff from Swine Manure with Dietary Phytase and Aluminum Chloride” J. Environ. Qual. 33:1048-1054.

Spiekers et al, 2011 - Spiekers Hubert, Carsten Pohl, Walter Staudacher; 2011. „Leitfaden zur Berechnung des Energiegehaltes bei Einzel- und Mischfuttermitteln für die Schweine- und Rinderfütterung“ DLG-Arbeitskreis Futter und Fütterung.

Stein et al, 2001 - Stein, H. H., S. W. Kim, T. T. Nielsen, R. A. Easter; 2001. “Standardized ileal protein and amino acid digestibility by growing pigs and sows” J. Anim. Sci. 79:2113–2122.

Tokach et al, 2012 - Tokach, Mike, Joel DeRouchey; 2012. “Feeding swine and poultry low protein diets with feed-use amino acids and the effect on the environment” Ajinomoto Heartland Inc.

UBA, 2003 - Umweltbundesamt; 2003. “Integrierte Vermeidung und Verminderung der Umweltverschmutzung (IVU-Richtlinie) BVT-Merkblatt „Beste verfügbare Techniken der Intensivhaltung von Geflügel und Schweinen““

Van der Werf et al, 2005 - Van der Werf, Hayo M. G., Jean Petit, Joost Sanders; 2005. “The environmental impacts of the production of concentrated feed: the case of pig feed in Bretagne” Agricultural Systems 83 153–177.

Wenk et al, 2006 - Wenk, C., S. Gebert, R. Messikommer; 2006. “Environmental aspects of the use of microbial phytase in the feed for pigs and poultry” Slovak J. Anim. Sci., 39, (1-2): 59 – 62.

Annex I: Scientific Council and Review Panel

Scientific Council

Matthias Finkbeiner, Expert on ISO harmonization for LCA methodologies; expert on product LCAs

Jean-Yves Dourmad, Swine nutritionist; coordinator of the French working group CORPEN on feed formulation modulation for environment improvement

Ermias Kebreab, Expert on animal nutrition with a whole system approach to quantify GHG emissions in agriculture combined with the development of energy and nutrient utilization models in cattle, swine and poultry

John Pluske, Expert on animal nutrition and digestive physiology of pigs and other monogastric animals

Kees de Lange, Expert on nutrient metabolism and utilization especially in pigs. Aspects of his work are ingredient evaluation to minimize environmental impacts of pig production

Gustavo Lima, Latin America Nutrition Expert

Review Panel (*ISO 14044:2006)*

Matthias Finkbeiner, Expert on ISO harmonization for LCA methodologies; expert on product LCAs

Jean-Yves Dourmad, Swine nutritionist; coordinator of the French working group CORPEN on feed formulation modulation for environment improvement

Ermias Kebreab, Expert on animal nutrition with a whole system approach to quantify GHG emissions in agriculture combined with the development of energy and nutrient utilization models in cattle, swine and poultry