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Effect of observed individual data of performance and excretion on life cycle assessment of piglets

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ABSTRACT: The objective was to evaluate the impact of producing piglets fed diets with different crude protein (CP) levels through life cycle assessment and experimental data. In Trial I (performance), 28 crossbred barrow piglets, with an initial average weight of 15.3 ± 1.15 kg were divided into a randomized block design with four treatments, seven replications and one animal per experimental unit. In Trial II (nitrogen and phosphorus balance), 20 crossbred barrow piglets with an average weight of 21.4 ± 1.62 kg were divided in a randomized block design with four treatments, five replications and one animal per experimental unit. Four experimental feeds were evaluated: HighCP, CP18, CP17 and LowCP, with 19, 18, 17 and 16 % of CP, meeting the requirements of digestible amino acids through industrial amino acid (IAA) addition. From Trial I and II data, the environmental impact was calculated for global warming potential, acidification potential, eutrophication potential, cumulative energy demand, terrestrial ecotoxicity and land occupation (LO). Total nitrogen excretion decreased by 0.226 g d^{-1} for each 1 g of reduction on daily nitrogen intake. However, there was no statistical difference ($p > 0.05$) among experimental treatments for all impact categories. For LO, there was a reduction ($p = 0.078$) of impact with CP reduction, which was 8 % lower with the LowCP diet, in comparison with HighCP. Dietary CP reduction for piglets from 15 to 30 kg, through IAA supplementation, reduced the environmental impact under LO, considering soybean meal from southern Brazil and observed individual data of performance and excretion.
Keywords: animal variability, dietary crude protein, environment, nitrogen, weaners

Introduction

The increasing awareness of climate change worldwide has pressured the livestock industry, including pig production, to deliver high quality products while reducing its environmental impact. Many past and current studies have reported that the reduction in dietary crude protein (CP), using industrial amino acids (IAA), could reduce nitrogen excretion by pigs and, consequently, mitigate the environmental burdens of pig production, as reviewed by Dourmad and Jondreville (2007). However, the pig supply chain involves a very complex system, which requires the production of fertilizers and pesticides for crop production, land transformation for crop production, a large net of transportation to and from farms, water use for animal consumption and farmyard washing, energy for light and heat and waste management (McAuliffe et al., 2016).

Life cycle assessment (LCA) evaluates the environmental impact as a whole and has been widely used recently in the swine production chain (McAuliffe et al., 2016). However, most LCA studies use average input data, adding uncertainties to the results, due to the diversity of production systems and farming practices (Basset-Mens and van der Werf, 2005; Monteiro et al., 2017a). Besides, using technical performance indicators based on the agroindustry to evaluate the effect of feeding strategies must be done carefully in an LCA study. Different researches (Brossard et al., 2009; Brossard et al., 2014) have demonstrated the effects of between-animal variability on pig performance and requirements, which could affect both performance and excretion.

This raises the question of whether this average data can be considered an adequate representation of the nutrient excretion by pigs, due to the dynamic phenomenon of dietary nutrient use, which changes over the fattening period (van Milgen et al., 2008). In addition, although several studies have been conducted on pig supply chains, to our knowledge, few studies have evaluated LCA in nutritional approaches in Brazil (Cherubini et al., 2015; Monteiro et al., 2016). Therefore, this study assessed the environmental impact of raising pigs fed with different levels of dietary CP, based on LCA methodology with observed individual data of performance and excretion.

Materials and Methods

Goal and scope definition

The definition of system and subsystem boundaries was derived from Nguyen et al. (2010) and is described in Figure 1. LCA considered the activity of piglet production, from 15 to 30 kg body weight, in four different scenarios of feed formulation (described below), including crop production, grain drying and processing, production and transport of feed ingredients, feed production at the factory, transport of the feed to the farm,

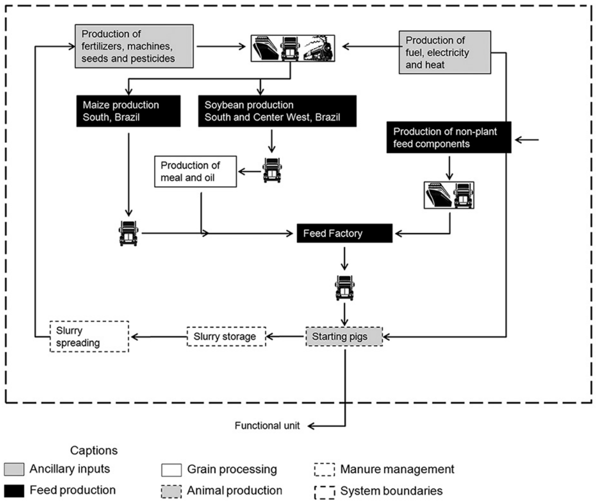

Figure 1 – System boundaries of nursery pig production in southern Brazil, from 15 to 30 kg, with main processes for the production of crop inputs, crop production, production of feed ingredients and feeds, and pig production.

starting pig production, and manure storage, transport and spreading (Figure 1). Impacts were calculated at the farm gate and the functional unit considered was 1 kg of body weight gain (BWG) over the nursery stage. The starting pig production system considered was a conventional nursery farm with indoor rearing of castrated males on partially slated floor, where manure was kept in a pit under the slats during 24 h and scraped daily (during the morning) into open slurry tanks without a natural crust cover (Cherubini et al., 2015).

Life cycle inventory (LCI)

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 emissions and resources used for the construction of buildings, nor the land occupied by the buildings. Veterinary medicines and hygiene products were also not included, as proposed by Garcia-Launay et al. (2014).

Crop production and non-plant feed components

We assumed that soybean was produced in southern Brazil, the second largest soybean producer in the country (CONAB, 2016). However, to perform the calculations for global warming potential (GWP) and cumulative energy demand (CED), the most affected categories by soybean origin (Monteiro et al., 2016), we hypothesized that 98 % of soybean comes mainly from the central-western Brazil, as proposed by Cherubini et al. (2015). Life cycle inventory for maize and soybean came from Alvarenga et al. (2012) and Silva et al. (2010), respectively. For soybean meal and soybean oil, the resource use and emissions were allocated economically (Garcia-Launay et al., 2014).

Data on salt, phosphate, sodium bicarbonate, premix and limestone used in the diet came from Wilfart et al. (2016). The antioxidant and growth promoter were assumed to have the same impacts as the premix. L-lysine HCl, DL-methionine and L-threonine inventory data came from Mosnier et al. (2011). Production of L-tryptophan, L-valine and L-isoleucine were assumed to require twice as much the amount of resources and energy as the production of L-lysine HCl (Garcia-Launay et al., 2014).

Transport specifications

The pig production system considered was located in southern Brazil, as described by Cherubini et al. (2015). This region accounts for more than 50 % of the national pig production (FIESC, 2014). For soybean from central-western Brazil, we considered 1,475 km of average distance, from grain production to feed factory, while soybean from the south was transported over 357 km of distance (Silva et al., 2010). Imported products were assumed to be transported mainly by sea followed by road (Mosnier et al., 2011).

Feed specifications

The amino acid composition of maize and soybean meal used in the diet formulation were obtained through near-infrared spectroscopy – NIRS, by Evonik Industries, and the standardized digestibility of amino acids coefficients proposed by Rostagno et al. (2011) were applied to these ingredients.

Four experimental feeds were evaluated (Table 1), with different CP contents: HighCP, CP18, CP17 and LowCP, with 19, 18, 17 and 16 % of CP, meeting the nutrient requirements proposed by Rostagno et al. (2011), adding L-lysine HCl, DL-methionine, L-threonine, L-tryptophan, L-valine and L-isoleucine to achieve the requirements for SID amino acids (Rostagno et al., 2011). Diets were formulated to have the same net energy content and, at least, 3230 kcal kg^{-1} of ME (Rostagno et al., 2011). Sodium bicarbonate was used, when necessary, to keep the same electrolyte balance among the experimental diets.

The feed production process at the factory was included to the inventory, considering that it was kept in the pig production region (Garcia-Launay et al., 2014).

Pig production

All procedures were performed in accordance to Brazilian guidelines reviewed and approved by the Ethics Committee of the State University of Maringá (protocol No. 7470031215). The Brazilian guidelines are based on Federal Law N° 11794 of 8 Oct 2008.

Two trials were carried out in an experimental farm located in southern Brazil (Iguatemi, Paraná – lati-

Table 1 – Ingredients, chemical composition and environmental impacts of diets with reduction on crude protein level.

	Experimental feeds			
	HighCP	CP18	CP17	LowCP
Ingredients, %				
Maize	64.94	67.95	71.02	74.13
Soybean meal	29.89	26.97	23.95	20.87
Soybean oil	1.445	1.093	0.711	0.315
Dicalcium phosphate	1.977	2.035	2.095	2.157
Limestone	0.455	0.439	0.422	0.405
Premix[1]	0.400	0.400	0.400	0.400
Salt	0.456	0.348	0.233	0.116
Sodium bicarbonate	-	0.158	0.327	0.499
L-Lysine HCl 78 %	0.258	0.350	0.446	0.543
DL-Methionine 99 %	0.070	0.095	0.121	0.148
L-Threonine 99 %	0.076	0.118	0.161	0.205
L-Tryptophan 98 %	-	0.011	0.028	0.044
L-Valine 100 %	-	0.004	0.057	0.111
L-Isoleucine 100 %	-	-	-	0.003
Antioxidant – BHT	0.010	0.010	0.010	0.010
Growth promoter[2]	0.020	0.020	0.020	0.020
Chemical composition, %				
Metabolizable energy (kcal kg^{-1})	3279	3263	3246	3230
Net energy (kcal kg^{-1})	2451	2451	2451	2451
SID lysine	1.093	1.093	1.093	1093
SID methionine	0.333	0.346	0.359	0.372
SID met+cys	0.612	0.612	0.612	0.612
SID threonine	0.689	0.689	0.689	0.689
SID tryptophan	0.201	0.197	0.197	0.197
SID valine	0.799	0.754	0.754	0.754
SID isoleucine	0.725	0.675	0.623	0.601
Calcium	0.768	0.768	0.768	0.768
Digestible phosphorus	0.368	0.368	0.368	0.368
Electrolytic balance (mEq kg^{-1})	190.9	190.4	190.4	190.4
Life cycle assessment, kg feed[3]				
Acidification, g SO_2-eq.	10.4	10.8	11.3	11.8
Eutrophication, g PO_4-eq.	4.30	4.30	4.32	4.33
Global warming, g CO_2-eq.	401	412	427	446
Energy demand, MJ	5.19	5.38	5.72	6.14
Ecotoxicity, g 1.4-DBC-eq.	4.95	5.03	5.16	5.32
Land occupation, m^2 × year	1.09	1.06	1.03	1.00

[1]Premix should provide at least the following nutrient amounts per kg of feed: vitamin A, 6000 IU; vitamin D3, 1800 IU; vitamin E, 30 IU; vitamin K3, 6 mg; vitamin B1, 1 mg; vitamin B2, 5.2 mg; vitamin B6, 1.5 mg; vitamin B12, 20 mg; niacin, 30 mg; pantothenic acid, 18 mg; folic acid, 0.6 mg; biotin, 0.09 mg; choline chloride, 0.32 mg; methionine, 0.1 g; lysine, 0.28 g; copper, 21 mg; iodine, 1.4 mg; iron, 0.05 g; manganese, 35 mg; selenium, 0.3 mg; zinc, 0.12 g; phytase; [2]Growth promoter: leucomycin at 30 %; [3]Calculated by using soybean meal from southern Brazil.

tude 23°25′ S; 51°57′ O, and altitude 550 m). One to determine animal performance (Trial I, from Mar to Aug 2016) and another to address nutrient excretion (Trial II, from Dec 2015 to Mar 2016).

Trial I (performance): We used 28 crossbred barrow piglets (Large White × Landrace), with initial average weight of 15.3 ± 1.15 kg and final weight of 31.6 ± 2.31 kg. Pigs were housed in a nursery masonry shed with suspended floor, covered with fiber cement tiles in a naturally ventilated room, with large windows controlled by curtains. The stalls measured 1.32 m^2, with cement floors and feeders in the front and partially slatted plastic floor with a nipple-type drinker in the back. Diets and water were provided *ad libitum* throughout the experimental period. The average daily minimum and maximum temperatures recorded in the trial period were 18.9 ± 1.95 °C and 33.7 ± 2.03 °C, respectively. The average relative air humidity of the experimental period was 69 ± 10 %.

The animals were divided into a randomized block design with four treatments, seven replications in time and one animal per experimental unit. The piglets were weighed at the beginning and end of the trial. We also weighed feed supplies and refusals. These data were used to calculate feed conversion ratio (FCR), average daily gain (ADG) and average daily feed intake (ADFI).

At the end of the trial, backfat thickness and loin muscle depth (*longissimus thoracis*) were measured from images between the 7th and 8th thoracic vertebra, using ultrasound equipment (coupled with a linear probe of 3.5 mm) and by using the Biosoft Toolbox II software for swine.

Trial II (nitrogen and phosphorus balance): Twenty crossbred barrow piglets (LW × LD) with average weight of 21.4 ± 1.62 kg were housed in metabolic cages, in a room with partially controlled environment. The average minimum and maximum temperatures recorded in the trial period were 23.2 ± 1.13 °C and 27.1 ± 0.941 °C, respectively. The average relative air humidity of the experimental period was 58 ± 21 %. The experimental design was set in a randomized block, replicated in time, totaling four treatments and five replications, and the experimental unit consisted of one piglet.

The piglets received two daily meals at 07h30 and 15h30. The total daily amount was determined according to the intake in the adaptation phase, based on metabolic weight ($BW^{0.75}$; Kleiber, 1932). To avoid waste and facilitate handling, the diets were moistened with 30 % water, and after each meal, water was supplied at the feeder at the rate of 3 mL g^{-1} of feed (considering the amount distributed), calculated for each experimental unit, to avoid excess of water consumption.

To calculate the nitrogen and phosphorus balance, total feces collection was performed for each 2 g ferric oxide (Fe_2O_3) was added to the diets to mark the beginning and end of feces collection. The total amount of feces produced was collected daily, stored in plastic bags and then kept in a freezer at -18 °C. Urine was totally collected daily in plastic buckets containing 20 mL of HCl 1:1. A 20 % sample was collected daily and frozen at -18 °C.

Analytical procedures

Representative samples of the feeds were analyzed according to Association of Official Analytical Chemists (AOAC, 2005) for dry matter (method 950.05), ash (method 942.05), crude fiber (method 962.09) and total nitrogen (method 984.13). The phosphorus, copper, zinc and potassium concentrations in feed samples were obtained by using UV-Vis spectrophotometry. Urine and feces samples were analyzed for total nitrogen and, for feces, for total phosphorus, dry matter, ash and crude fiber.

Manure management

The environmental consequences of manure use were evaluated by system expansion as described by Nguyen et al. (2010). Thus, manure produced was assumed to substitute a certain amount of mineral fertilizers, by using a mineral fertilizer equivalency (MFE, %). We assumed that the MFE was 75 % of total nitrogen in manure (Nguyen et al., 2010), with 5 % extra loss as nitrates compared to mineral fertilizers (Garcia-Launay et al., 2014), and MFE was 100 % for phosphorus (Sommer et al., 2008).

Life cycle impact assessment

Emissions from animal production

Air emissions during swine production were estimated systematically for NH_3, N_2O, NO_x and CH_4, as described by Monteiro et al. (2016). 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 room temperature. The amounts of nitrogen, phosphorus and organic matter excreted by the pigs were obtained from laboratory analyses.

Characterization factors

We based our analyses on the CML 2001 (baseline) method V3.02 as implemented in Simapro software (version 8.05) 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 GWP (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.), CED (MJ), and land occupation (LO, $m^2\ y^{-1}$). The GWP was calculated according to the 100-year global warming potential factors in kg CO_2-eq.

Calculations and statistical analyses

We calculated the average nitrogen and phosphorus retention coefficient for each diet from the balance data in Trial II (Table 2). These coefficients were then used to determine nitrogen and phosphorus excretion in Trial I, according to the actual nutrient intake of each pig (Table 2). The LCA calculations were performed for each pig according to its individual performance and excretion from 15 to 30 kg BW on average. These calculations were performed using a calculation model developed with SAS software (Statistical Analysis System, version 9.2).

Performance responses and environmental impacts were subjected to variance analysis using the GLM procedure (Statistical Analysis System, version 9.2). The statistical model included effects of CP level

Table 2 – Nitrogen and phosphorus balance of piglets fed diets with different contents in crude protein and amino acid supplementation (Trial II).

	Experimental feeds				RMSE	*p*-value
	HighCP	CP18	CP17	LowCP		
Number of pigs	5	5	5	5		
Nitrogen balance (g d^{-1})						
Intake	23.1	21.9	20.6	18.1	1.01	0.001
Excreted	8.22	6.64	6.28	5.84	0.639	0.001
Feces	2.58	2.36	2.38	2.21	0.413	0.832
Urine	5.64	4.28	3.90	3.63	0.599	0.004
Retention (% of N intake)[1]	63.4	69.5	69.5	67.7	4.18	0.104
Phosphorus balance (g d^{-1})						
Intake	4.23	4.25	3.48	3.15	0.199	0.001
Excreted	2.15	2.22	1.93	1.86	0.453	0.686
Retention (% of P intake)[1]	49.2	47.8	44.5	41.0	12.1	0.826
Regression equations[2]						R^2
As function of CP content						
Nitrogen intake (g d^{-1})	- 2.74945 + 1.38183 * CP%					0.96
N excreted in urine (g d^{-1})	- 4.90280 + 0.54024 * CP%					0.86
Total N excreted (g d^{-1})	- 4.08593 + 0.63160 * CP%					0.87
Phosphorus intake (g d^{-1})	- 2.08301 + 0.34180 * CP%					0.75
As function of N intake						
N excreted in urine (g d^{-1})	1.71057 + 0.12654 N intake g d^{-1}					0.21
Total N excreted (g d^{-1})	2.02026 + 0.22555 N intake g d^{-1}					0.47

RMSE = root-mean-square error; [1]Retention coefficients obtained from Trial II (by feed and manure analysis) were applied on nutrient intake measured in Trial I, in order to estimate nitrogen (N) and phosphorus (P) excretion in the performance essay; [2]Regressions equations adjusted for dietary crude protein (CP) content and N intake.

and block. When the dietary effect was significant, we subjected the variable to the regression analysis. The degrees of freedom from the CP level parameter were divided into polynomials. The initial body weight of the piglets was used as a covariate for the statistical analysis of ADFI, ADG, FCR, backfat thickness and loin depth. The feed intake during the trial was used as a covariate for the LCA variables. All analyses were performed using SAS version 9.2 (Statistical Analysis System, version 9.2).

The β error of LCA parameters was used to help explain *p*-values from 5 to 10 % of significance. This procedure was performed by using the power of the ANOVA test of R package.

Results

Animal performance, nitrogen and phosphorus balance

The reduction in dietary CP did not significantly affect ($p > 0.05$) the performance of piglets. The variation in ADFI and ADG was below 6 % between the experimental treatments (Table 3). Backfat thickness and loin depth were also not affected by dietary CP reduction ($p = 0.621$ and $p = 0.703$, respectively) and the estimated lean percentage was around 60 %.

Nitrogen intake ($p = 0.001$), nitrogen excreted in urine ($p = 0.004$) and total nitrogen excreted ($p = 0.001$), declined linearly with the decrease in dietary CP content (Table 2). Phosphorus intake was also reduced with the decrease in dietary CP ($p = 0.001$). Despite the lower ingestion and excretion, retention coefficients were not significantly affected ($p = 0.104$ for nitrogen and $p = 0.826$ for phosphorus) by dietary CP reduction. Nitrogen excreted in feces and phosphorus excreted were not affected ($p = 0.832$ and $p = 0.686$, respectively) by dietary CP reduction (Table 2).

Table 3 – Performance, backfat thickness and muscle depth (longissimus thoraces) of piglets fed diets with different contents in crude protein and amino acid supplementation (Trial I).

	Experimental feeds				RMSE	*p*-value
	HighCP	CP18	CP17	LowCP		
Number of pigs	7	7	7	7		
Initial BW, kg	15.0	15.1	15.5	15.7	1.128	0.461
Final BW, kg	30.6	32.6	31.0	32.1	1.35	0.701
Backfat thickness, mm	5.17	5.84	5.98	5.28	0.114	0.621
Muscle depth, mm	25.3	28.3	25.9	26.3	0.248	0.703
Lean %[1]	60.5	60.5	60.4	60.5	0.103	0.614
ADG, kg	0.717	0.754	0.712	0.738	0.062	0.665
FCR, kg kg^{-1}	1.77	1.79	1.79	1.80	0.166	0.991
ADFI, kg	1.27	1.35	1.28	1.32	0.109	0.794

BW = body weight; ADG = average daily gain; FCR = feed conversion ratio; ADFI = average daily feed intake; RMSE = root-mean-square error; [1]Lean% = 60.69798 – 0.89211 * backfat + 0.10560 * Muscle depth (Vítek et al., 2008).

The amount of nitrogen excreted in urine could be predicted as a function of nitrogen intake (in g d^{-1}): Nurine = 1.71057 + 0.12654 N intake g d^{-1}, as well as total nitrogen excreted: Nexcreted = 2.02026 + 0.22555 N intake g d^{-1} (Table 2).

Life cycle impacts

The dietary CP reduction was achieved by replacing soybean meal with maize and IAA (Table 1). For impact categories, GWP, AP, EP, CED and TE, CP reduction increased the environmental impact per kg of feed. LO was the only impact that reduced when dietary CP decreased.

Global warming potential and cumulative energy demand

No differences were found for GWP ($p = 0.831$) and CED ($p = 0.164$) among dietary treatments, regardless of the origin of soybean meal. When soybean comes from the South, the average values ranged between the experimental treatments from 1.76 to 1.77 kg CO_2-eq. per kg BWG for GWP and from 17.8 to 19.6 MJ-eq. per kg BWG for CED (Table 4). When soybean from the Central West was used, GWP values increased up to 2.45 to 2.27 kg CO_2-eq. per kg BWG, and up to 22.1 to 20.9 MJ per kg BWG for CED.

The main processes contributing to impacts were feed production (production and transport of feed ingredients, feed processing at the factory and transport to the farm), animal housing, and manure management (storage, transport and spreading; Figure 2). Manure management had the highest contribution to GWP (50 %), followed by feed production (42 %), whereas, for CED, feed production was the main contributor (54 %) followed by animal housing (48 %).

Table 4 – Potential environmental impacts, per kg of body weight gain, of piglets from 15 to 30 kg, fed diets with different contents in crude protein and amino acid supplementation.

		Experimental feeds				RMSE	*p*-value	1-β[1]
		HighCP	CP18	CP17	LowCP			
								%
Number of pigs		7	7	7	7			
GWP, kg CO_2-eq.	SO	1.76	1.76	1.77	1.77	0.138	0.831	5.15
	CW	2.45	2.39	2.34	2.27	0.182	0.139	28.8
AP, g SO_2-eq.		33.2	30.0	30.4	30.8	3.44	0.180	28.5
EP, g PO_4-eq.		11.3	10.5	10.4	10.3	1.04	0.111	31.6
CED, MJ-eq.	SO	17.8	17.6	19.3	19.6	1.49	0.164	67.6
	CW	20.0	21.1	21.5	22.5	2.89	0.618	21.6
TE, g 1,4-DCB-eq.		4.68	4.82	4.95	5.17	0.417	0.470	39.6
LO, m^2 yr^{-1}		2.06	2.00	1.96	1.89	0.150	0.078	36.0

GWP = global warming potential; AP = acidification potential; EP = eutrophication potential; CED = cumulative energy demand; TE = terrestrial ecotoxicity; LO = land occupation; SO = impact was calculated by using soybean meal from south Brazil; CW = Calculated by using soybean meal from central-western Brazil; RMSE = root-mean-square error; [1]Power of statistical test considering alpha = 5 %.

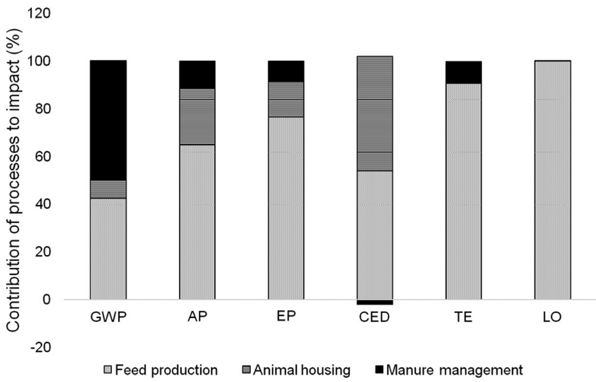

Figure 2 – Relative contribution of the different processes (%) to impacts on global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO), considering soybean meal from southern Brazil.

Potentials of acidification and eutrophication

The average values ranged from 30.0 to 33.2 g SO_2-eq. per kg BWG for AP and from 10.3 to 11.3 g PO_4-eq. per kg for BWG for EP (Table 4). Despite these variations, no significant differences were observed between the experimental feeds (p = 0.180 and p = 0.111, respectively).

For both categories, feed production had the highest contribution to impacts (65 and 77 % for AP and EP, respectively), followed by animal housing (24 and 15 % for AP and EP, respectively).

Terrestrial ecotoxicity and land occupation

Dietary CP reduction did not affect TE impact (p = 0.470); however, it reduced LO (p = 0.078) according to the power of statistical test (β = 64 %), with values ranging from 4.68 to 5.17 g 1,4-DBC-eq. per kg BWG for TE and from 1.89 to 2.06 m^2 × year per kg BWG for LO (Table 4).

Dietary CP reduction did not affect TE impact (p = 0.470), with values ranging from 4.68 to 5.17 g 1,4-DBC-eq. per kg BWG (Table 4). However, this strategy reduced LO (p = 0.078), with values ranging from 1.89 to 2.06 m^2 × year per kg BWG for LO (Table 4). Once the p-value of LO was between 5 and 10 %, we used the power of the statistical test (β = 64 %) to assume statistical difference for this parameter.

For both categories, feed production was the main contributor (91 and 100 % for TE and LO, respectively). TE was also related to manure management (9 %), but with a rather low contribution (Figure 2).

Discussion

Performance, nitrogen and phosphorus balance

Similar to the results of this study, Toledo et al. (2014) did not observe any differences in performance-related variables of piglets weighing 6-15 kg, by decreasing dietary CP levels, despite using piglets in different production stage. The amino acid imbalance may negatively influence feed intake (Park, 2006) and, consequently, performance. As this did not occur in our experiment, it can be inferred that the IAA addition was effective in keeping protein quality and performance.

Low dietary CP diets might provide the animals with less energy spent on amino acid deamination, less urea excretion in urine and lower heat production (Noblet et al., 2001), resulting in more net energy available to be deposited in the carcass as fat. However, in our study, pigs fed with low CP diets did not show increased backfat thickness, as diets were formulated to provide the same amount of net energy, exempting the effects mentioned above.

The linear reduction in nitrogen intake and excretion, with CP reduction, corroborates previous research in weaning piglets (Gloaguen et al., 2014; Toledo et al., 2014) and in growing pigs (Andretta et al., 2014; Monteiro et al., 2017b). The National Research Council (NRC, 2012) suggested that for each percentage unit of dietary CP reduction, nitrogen excretion can be expected to decrease by 8 %, due to the lower amino acid deamination and, consequently, lower urea excretion in urine. The same reduction was found in our study in which each percentage point of CP reduction (from 19 to 16 % of CP), reduced on average total nitrogen excretion by 10 %.

According to the regression equations adjusted for nitrogen intake (Table 2), nitrogen excretion in urine increased by 0.127 g d^{-1} for every 1 g increase in the daily nitrogen intake. For total nitrogen excretion, an increase of 0.226 g d^{-1} was estimated for every 1 g increase in the daily nitrogen intake. Therefore, the higher the nitrogen intake, the higher the nitrogen excretion.

Life cycle impacts

The hypothesis to reduce environmental impacts of piglet production through CP reduction was not validated by our results, as there was no statistical difference among experimental treatment for the LCA categories. These results could be attributed to the lack of difference in animal performance (Table 3), since environmental impacts are highly dependent on feed intake and final values are expressed per kg of BWG. Although there was no significant differences, some trends could be observed in agreement with results obtained in fattening pigs (Garcia-Launay et al., 2014). However, in the literature, most LCA is performed on average data without any statistical analysis.

Global warming potential and cumulative energy demand

The increase in GWP impact per kg of feed when dietary CP is reduced and soybean from southern Brazil was used (Table 1) is related to higher IAA addition and replacement of soybean meal by maize. Global warming potential associated with IAA production is higher per kg of product than for grain or soybean meal production (Ogino et al., 2013).

The benefits of the IAA addition related to the reduction of nitrogen excretion during housing and, consequently, lower nitrogen gaseous emissions, might compensate for the higher impact of low CP diet. However, this was not observed in our study, since no significant difference was observed for GWP among dietary treatments (Table 4). This could be related to the hypothesis for the soybean origin. When we assumed that 98 % of the soybean was produced in central-western Brazil with recent deforestation, the reduction in the dietary CP led to the reduction in GPW, although not significant (Table 4). Silva et al. (2010) showed that CO_2-eq. emissions due to the effect of land use change because of rainforest conversion in crop areas, increasing GWP of soybean meal. In this situation, replacing soybean meal by cereals and IAA seems an interesting strategy to reduce GWP impact, as shown by Kebreab et al. (2016) and Monteiro et al. (2016).

However, the Brazilian government and the industrial sector have made efforts to identify soybean produced in deforested areas from the Amazon Biome, using the Soy Moratorium (ABIOVE, 2016). Therefore, soybean production in these areas has reduced in recent years (Gibbs et al., 2015), which justifies the use of soybean from non-deforested areas, in current and future evaluations of Brazilian scenarios.

Manure management had the greatest contribution to GWP impact (Figure 2), due to the direct effect of room temperature on the amount of methane emitted during manure storage (Rigolot et al., 2010) and methane is a gas with GWP 25 times higher than that of CO_2 (IPCC, 2007).

Experimental feeds with high IAA addition showed higher CED, per kg of feed (Table 1). This was expected, because according to Mosnier et al. (2011) and Kebreab et al. (2016), the production of IAA and phytase demands high amounts of non-renewable energy. Despite this high contribution of feed production to CED impact (almost 54 %; Figure 2), the IAA addition did not significantly affect CED per kg BWG.

Garcia-Launay et al. (2014) observed a reduction of CED impact of fattening pig production in France when dietary CP content was reduced. However, the authors took into account that 100 % of soybean was obtained from Brazil (mainly from the Central West) with a high-energy demand at the transport step. In our study, when we hypothesized that most soybean (98 %) came from the Central West, we did not find the same trend (Table 4). This could be due to the worst feed conversion ratio for piglets fed with reduction in dietary CP (Table 3). As mentioned before, feed intake represents 54 % of CED impact, expressed per kg of BWG.

Considering 100 % of soybean production in southern Brazil, the same region of pig production, Monteiro et al. (2016) also observed an increase in CED impact per kg BWG when dietary CP was reduced. The difference in CED impact between high and low CP diets found by these authors was slightly lower than 9 %, a value close to the difference observed in our study for soybean from the south (9 %; Table 4). However, the difference was significant in their study probably because the authors used simulated data from 2,000 pigs and in our study the number of pigs per treatment was seven.

Our results are in agreement with Kebreab et al. (2016) and Monteiro et al. (2017b), who also did not observe differences of CED between diets with different CP and total phosphorus levels. Kebreab et al. (2016) concluded that the high non-renewable energy used during IAA production could be an area where the industrial sector could act to reduce impacts.

Potential of acidification and eutrophication

The reduction of dietary CP content led to a slight increase in AP and EP impacts per kg of feed (Table 1). This result was also observed in previous studies (Mosnier et al., 2011; Garcia-Launay et al., 2014; Mackenzie et al., 2016; Monteiro et al., 2016, 2017b).

Feed production showed the highest contribution for AP and EP impacts (Figure 2), which is consistent with the results reported by other authors (Basset-Mens and van der Werf, 2005; Garcia-Launay et al., 2014). Although low CP diets showed higher AP and EP impacts, per kg of feed, several authors reported that these diets could modify several steps of pig chain, reducing the amounts of nitrogen excreted, consequently, reducing nitrogen gas emissions during housing and manure management (Garcia-Launay et al., 2014; Monteiro et al., 2016), as well as nitrate losses during manure application.

Nitrogen and phosphorus contribute to the eutrophication process and nitrogen contributes to the acidification process by ammonia emissions (Guinée et al., 2002). For this reason, most research evaluating the effect on dietary CP reduction for pigs reported a reduction on AP and EP with low CP diets (Ogino et al., 2013; Garcia-Launay et al., 2014; Mackenzie et al., 2016; Kebreab et al., 2016). In the above-mentioned researches, data were not evaluated statistically and the effect of between-animal variability was also not taken into account. Similar trends were observed in our study with about 9 % reduction of AP and EP impacts per kg of BWG; however, the differences were not significant.

Terrestrial ecotoxicity and land occupation

The high TE per kg of feed (Table 1) in low CP diets was related to higher IAA addition. Copper and zinc are the elements that most contribute to the TE impact (Guinée et al., 2002) and are found in small amounts in fertilizer and herbicides used during grain production, compared to their amount during IAA manufacturing. Garcia-Launay et al. (2014) calculated that TE impact for L-lysine manufacturing was 82 % higher than for soybean meal production. For the other IAA (L-tryptophan, DL-methionine and L-valine), the authors estimated an impact 91 % higher than soybean meal. In this context, because feed production contributed to more than 90 % of total TE impact (Figure 2), the diet with LowCP with the highest IAA addition, presented a 9 % higher TE impact per kg BWG, compared to HighCP diet, although the differences between treatments were not significant. These results are in agreement with the results observed in previous studies by Garcia-Launay et al. (2014) and Monteiro et al. (2016) who observed a 4 - 11 % increase of TE impact of fattening pig production with low CP feeding strategies.

Regarding LO, the increase in IAA addition reduced the impact per kg of feed (Table 1), once low CP diets resulted in lower soybean inclusion and higher maize and IAA inclusion. Considering the grain production in Brazil, Silva et al. (2014) reported LO impact for soybean meal more than twice as high as for maize.

Due to the high contribution of feed production to LO impact (Figure 2), which is 100 %, reducing the impact per kg of feed, consequently reduced the LO impact of piglet production (Table 4). The reduction in LO through IAA addition in pig diets has already been demonstrated in fattening pigs or during the entire pig production system (Mosnier et al., 2011; Garcia-Launay et al., 2014; Monteiro et al., 2016).

Potential for reducing environmental impacts through crude protein reduction

As mentioned earlier, the huge challenge for livestock production is to meet the growing demand for food in the next decades, without compromising environmental integrity. The reduction of dietary CP through the IAA addition has been considered as an efficient strategy to reduce the environmental impact of pig production (Dourmad and Jondreville, 2007), because it reduces nitrogen excretion. Recently, with LCA application in livestock production, this strategy continued to be considered effective to reduce the impact under some categories, such as acidification and/or eutrophication (Eriksson et al., 2005; Ogino et al., 2013; Garcia-Launay et al., 2014; Kebreab et al., 2016; Mackenzie et al., 2016; Monteiro et al., 2016).

For GWP impact, reducing dietary CP has also been found to be efficient in many studies (Eriksson et al., 2005; Ogino et al., 2013; Garcia-Launay et al., 2014; Cherubini et al., 2015; Mackenzie et al., 2016). However, more recent studies have shown that this strategy is mainly effective when protein-rich ingredients with high impact are used, for instance soybean meal associated with deforestation or transported at long distances, regardless of the pig production context considered in the LCA (Kebreab et al., 2016; Monteiro et al., 2016).

Almost all these results were obtained on fattening pigs. The results in our study obtained on post-weaning piglets are overall in line with the results found for fattening pigs. The results of reducing dietary CP on GWP and CED are limited with even a tendency to have increased impact on low CP diets. Differences are more pronounced for EP, AP ad LO, with about 9 % reduction with low CP diets. However, due to the variability between animals, most of these differences are not statistically significant.

Another point observed in our study is the lack of national IAA production, which contributes to increasing the impact under CED of Brazilian pig production, once IAA must be imported, except for L-lysine. From the moment that IAA is produced nationally, low CP diets could present an environment benefit in pig production, given CED and TE reduction.

Conclusions

Our results indicated that the dietary CP reduction for piglets from 15 to 30 kg of BW, through the IAA supplementation, reduced the environmental impact under LO, considering soybean meal from southern Brazil.

The use of observed individual data of performance and excretion to perform the LCA did not provide differences statistically significant for most impact categories, due to the variability between animals.

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References

Alvarenga, R.A.F.; Silva, V.P.; Soares, S.R. 2012. Comparison of the ecological footprint and a life cycle impact assessment method for a case study on Brazilian broiler feed production. Journal of Cleaner Production 28: 25-32.

Andretta, I.; Pomar, C.; Rivest, J.; Pomar, J.; Lovatto, P.A.; Radünz Neto, J. 2014. The impact of feeding growing-finishing pigs with daily tailored diets using precision feeding techniques on animal performance, nutrient utilization, and body and carcass composition1. Journal of Animal Science 92: 3925-3936.

Associação Brasileira das Indústrias de Óleos Vegetais [ABIOVE]. 2016. Soy moratorium: mapping and monitoring of soybean production in Amazon biome and 9th year = Moratória da Soja: mapeamento e monitoramento do plantio de soja no bioma Amazônia e 9° ano. Available at: http://www.abiove.org.br/site/_FILES/Portugues/10012018-100904-relatorio_da_moratoria_da_soja_2016.pdf [Accessed Sept 19, 2016] (in Portuguese).

Association of Official Analytical Chemists – International [AOAC]. 2005. Official Methods of Analysis. 18ed. AOAC, Gaithesburg, MD, USA.

Basset-Mens, C.; van der Werf, H.M.G. 2005. Scenario-based environmental assessment of farming systems: the case of pig production in France. Agriculture, Ecosystems & Environment 105: 127-144.

Brossard, L.; Dourmad, J.Y.; Rivest, J.; van Milgen, J. 2009. Modelling the variation in performance of a population of growing pig as affected by lysine supply and feeding strategy. Animal 3: 1114-1123.

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. Animal Production Science 54: 1939-1945.

Cherubini, E.; Zanghelini, G.M.; Tavares, J.M.R.; Belletini, F.; Soares, S.R. 2015. The finishing stage in swine production: influences of feed composition on carbon footprint. Environment, Development and Sustainability 17: 1313-1328.

Companhia Nacional de Abastecimento [CONAB]. 2016. Monitoring of the Brazilian grain harvest: harvest 2016/2017 = Acompanhamento da safra brasileira de grãos: Safra 2016/17. Available at: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/16_06_09_09_00_00_boletim_graos_junho__2016_-_final.pdf [Accessed Mar 3, 2017] (in Portuguese).

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. Livestock Science 112: 192-198.

Eriksson, I.S.; Elmquist, H.; Stern, S.; Nybrant, T. 2005. Environmental systems analysis of pig production: the impact of feed choice. International Journal of Life Cycle Assessment 10: 143-154.

Federação das Indústrias do Estado de Santa Catarina [FIESC]. 2014. Santa Catarina data = Santa Catarina em dados. Available at: http://fiesc.com.br/sites/default/files/medias/25_set_sc_dados_2014_em_baixa_para_site.pdf [Accessed Mar 1, 2017] (in Portuguese).

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. Livestock Science 161: 158-175.

Gibbs, H.K.; Rausch, L.; Munger, J.; Schelly, I.; Morton, D.C.; Noojipady, P.; Soares-Filho, B.; Barreto, P.; Micol, L.; Walker, N.F. 2015. Brazil's soy moratorium: supply-chain governance is needed to avoid deforestation. Science 347: 377-378.

Gloaguen, M.; Le Floc'h, N.; Corrent, E.; Primot, Y.; van Milgen, J. 2014. The use of free amino acids allows formulating very low crude protein diets for piglets. Journal of Animal Science 92: 637-644.

Guinée, J.; de Bruijn, H.; van Duin, R.; Huijbregts, M.A.J. 2002. Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Springer, Leiden, Netherlands.

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007: the physical science basis. Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-frontmatter.pdf [Accessed Mar 10, 2015]

Kebreab, E.; Liedke, A.; Caro, D.; Deimling, S.; Binder, M.; Finkbeiner, M. 2016. Environmental impact of using specialty feed ingredients in swine and poultry production: a life cycle assessment. Journal of Animal Science 94: 2664-2681.

Kleiber, M. 1932. Body size and metabolism. Hilgardia 6: 315-353.

Mackenzie, S.G.; Leinonen, I.; Ferguson, N.; Kyriazakis, I. 2016. Can the environmental impact of pig systems be reduced by utilising co-products as feed? Journal of Cleaner Production 115: 172-181.

McAuliffe, G.A.; Chapman, D.V.; Sage, C.L. 2016. A thematic review of Life Cycle Assessment (LCA) applied to pig production. Environmental Impact Assessment Review 56: 12-22.

Monteiro, A.N.T.R.; Dourmad, J.-Y.; Pozza, P.C. 2017a. Life cycle assessment as a tool to evaluate the impact of reducing crude protein in pig diets. Ciência Rural 47: e20161029.

Monteiro, A.N.T.R.; Bertol, T.M.; Oliveira, P.A.V.; Dourmad, J.-Y.; Coldebella, A.; Kessler, A.M. 2017b. The impact of feeding growing-finishing pigs with reduced dietary protein levels on performance, carcass traits, meat quality and environmental impacts. Livestock Science 198: 162-169.

Monteiro, A.N.T.R.; Garcia-Launay, F.; Brossard, L.; Wilfart, A.; Dourmad, J.-Y. 2016. Effect of feeding strategy on environmental impacts of pig fattening in different contexts of production: evaluation through life cycle assessment. Journal of Animal Science 94: 4832-4847.

Mosnier, E.; van der Werf, H.M.G.; Boissy, J.; Dourmad, J.-Y. 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: 1972-1983.

National Research Council [NRC]. 2012. Nutrient Requirements of Swine. 11ed. NRC, Washington, DC, USA.

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.

Noblet, J.; Bellego, L.L.; van Milgen, J.; Dubois, S. 2001. Effects of reduced dietary protein level and fat addition on heat production and nitrogen and energy balance in growing pigs. Animal Research 50: 227-238.

Ogino, A.; Osada, T.; Takada, R.; Takagi, T.; Tsujimoto, S.; Tonoue, T.; Matsui, D.; Katsumata, M.; Yamashita, T.; Tanaka, Y. 2013. Life Cycle Assessment of Japanese pig farming using low-protein diet supplemented with amino acids. Soil Science and Plant Nutrition 59: 107-118.

Park, B.C. 2006. Amino acid imbalance-biochemical mechanism and nutritional aspects. Asian Australasian Journal of Animal Sciences 19: 1361-1368.

Rigolot, C.; Espagnol, S.; Robin, P.; Hassouna, M.; Béline, 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.

Rostagno, H.S.; Albino, L.F.T.; Donzele, J.L.; Gomes, P.C.; Oliveira, R.F.; Lopes, D.C.; Ferreira, A.S.; Barreto, S.L.T. 2011. Brazilian Tables for Poultry and Pigs: Feedstuffs Composition and Nutritional Requirements = Tabelas Brasileiras para Aves e Suínos: Composição de Alimentos e Exigências Nutricionais. Editora UFV, Viçosa, MG, Brazil (in Portuguese).

Silva, V.P.; van der Werf, H.M.G.; Soares, S.R.; Corson, M.S. 2014. Environmental impacts of French and Brazilian broiler chicken production scenarios: an LCA approach. Journal of Environmental Management 133: 222-231.

Silva, V.P.; van der Werf, H.M.G.; Spies, A.; Soares, S.R. 2010. Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios. Journal of Environmental Management 91: 1831-1839.

Sommer, S.G.; Maahn, M.; Poulsen, H.D.; Hjorth, M.; Sehested, J. 2008. Interactions between phosphorus feeding strategies for pigs and dairy cows and separation efficiency of slurry. Environmental Technology 29: 75-80.

Toledo, J.B.; Furlan, A.C.; Pozza, P.C.; Piano, L.M.; Carvalho, P.L.O.; Peñuela-Sierra, L.M.; Huepa, L.M.D. 2014. Effect of the reduction of the crude protein content of diets supplemented with essential amino acids on the performance of piglets weighing 6 to 15 kg. Livestock Science 168: 94-101.

van Milgen, J.; Valancogne, A.; Dubois, S.; Dourmad, J.-Y.; Sève, B.; Noblet, J. 2008. Inra porc: a model and decision support tool for the nutrition of growing pigs. Animal Feed Science and Technology 143: 387-405.

Vítek, M.; Pulkrábek, J.; Vališ, L.; David, L.; Wolf, J. 2008. Improvement of accuracy in the estimation of lean meat content in pig carcasses. Czech Journal of Animal Science 53: 204-211.

Wilfart, A.; Espagnol, S.; Dauguet, S.; Tailleur, A.; Gac, A.; Garcia-Launay, F. 2016. ECOALIM: A dataset of environmental impacts of feed ingredients used in french animal production. PLoS ONE 11: e0167343.