Life cycle assessment to predict individual environmental impacts: towards selection for sustainable pig production

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Abstract

A life cycle assessment approach is proposed to quantify four environmental impacts at the individual pig level. The approach was applied to two lines divergently selected for feed efficiency, including simulations of performances with two diets. Significant line differences were obtained with least-cost diets for environmental impacts and profit ($P < 0.001$), with a general advantage of the more efficient line. The optimised diets reduced the disadvantages of the less efficient line. Correlations between profit and environmental impact were high for feed efficiency (> 0.85), and moderate (< 0.45) for growth rate and body composition. Applied to pedigreed populations, this framework will provide genetic parameters of environmental impacts to improve the sustainability of livestock production.

Introduction

The Western pig production systems affect global warming potential (GWP), terrestrial acidification potential (AP), freshwater eutrophication potential (EP), and land occupation (LO) (McAuliffe *et al*., 2016). However, early attempts to quantify environmental impacts (EI) in pigs essentially focused on nitrogen (N) and phosphorus excretion estimated at the animal level (Shirali *et al*., 2012; Saintilan *et al*., 2013). We propose a broader approach to predict the four EI at the individual level via a life cycle assessment model (LCA). It was applied to two pig lines with simulations of two nutritional strategies. Finally, a bio-economic model was used to evaluate the correlations between environmental impacts and profit.

Materials & Methods

LCA model. A LCA model of typical pig farms in France was developed with a cradle-to-farm-gate system boundary (Soleimani and Gilbert, 2020) to evaluate GWP (kg CO_2 eq), AP (kg SO_2 eq), EP (kg P eq), and LO (m^2 a crop eq) from individual performance traits (Soleimani and Gilbert, 2021). The functional unit was 1 kg body weight of a pig at the gate. The ReCiPe Midpoint 2016 (H) V1.02 was used, together with the Ecoalim dataset of the AGRIBALYSE® database and the Ecoinvent inventory databases in SimaPro V8.5.4.0 on the MEANS platform, to obtain the impacts of diets and individual pig performance profiles.

Bio-economic model. The bio-economic model was developed from a linear profit model. The model mimicked the LCA model modules and ran from the same individual performances. It included the main costs of feed and water, labour, building and capital, energy, manure disposal, health, maintenance and repair (Soleimani *et al*., 2021). Prices of diet ingredients (May 2020), energy consumption per kg pig and water to feed ratios were based on French averages. Revenue was from sales of live pigs, computed according to the French price grid from the baseline of a 100 kg carcass with lean meet percentage (LMP) of 56%, corrected for actual carcass weight and composition (July 2020).

Data. Experimental data were collected from the fifth generation of Large White pig lines divergently selected for residual feed intake (RFI, Gilbert *et al*., 2017)). Fifty seven male pigs from each line (LRFI, more efficient pigs; HRFI, less efficient pigs) had *ad libitum* access to a one phase conventional diet during growth-finishing. Records for daily feed intake, average daily gain (ADG), feed conversion ratio (FCR) and back fat thickness (BFT) were available.

Diet formulations and performance simulations. Diet formulation was based on wheat, barley, corn, oats, peas, triticale, rapeseed meal, sunflower meal, soybean meal, sunflower oil, and synthetic L_lysine, L_threonine, L_tryptophan and DL_methionine. Compositions were obtained from the INRA-AFZ feed ingredients database (Sauvant *et al*., 2004).

Individual nutritional requirements profiles were computed from individual performance imported to InraPorc® (Brossard *et al*., 2014), using a Gamma function. Two diets were formulated within line, covering the average nutritional requirements of the line, to either minimize cost (least-cost diet) or minimize a combination of cost and environmental impacts (optimised diet). This cost and environment multi-objective was a linear function of the sum of the four environmental impacts of the ingredients, considering equal weights for the four EI (EI score), and the sum of the ingredients costs. The relative weights of the environmental and economic objectives was optimized for each line (Soleimani and Gilbert, 2021), using a Pareto-optimal front curve. Next, the individual performances of pigs offered one or the other diet formulated for their line were simulated until slaughter weight (120 kg live weight) with InraPorc®. The resulting fattening traits for each individual were used as input parameters to the LCA and bio-economic models, to compute individual environmental impacts and profit.

Statistical analyses. Analyses were computed in R (R Core Team, 2019). The line differences for performances, environmental impacts and profit were tested with linear models including the fixed effect of the line (lm procedure). To illustrate correlations between variables, principal component analyses (PCA, PCA procedure) were applied to performances, environmental impacts and profit for the full dataset before and after adjusting for line effects.

Results

Table 1. Environmental impacts, environmental score (EI score) and price per unit of net energy of the least-cost (LC) and optimised diets for the low (LRFI) and high residual feed intake (HRFI) lines.

Diet		GWP, kg CO_2 eq	AP, g SO_2 eq	EP, g P eq	LO, m^2 a crop eq	EI score	Price, 0.01€
LRFI	Least-cost	0.541	0.613	0.0526	0.181	0.430	2.01
	Optimised	0.486	0.663	0.0505	0.152	0.394	2.10
HRFI	Least-cost	0.483	0.683	0.0599	0.141	0.399	2.03
	Optimized	0.490	0.643	0.0496	0.163	0.395	2.06

[1] GWP=global warming potential; AP=acidification potential; EP=eutrophication potential; LO=land occupation

Diets. Pigs from the LRFI line had higher average requirements than HRFI pigs ($P < 0.05$). For instance, digestible lysine was 0.91±0.20 g/MJ net energy in LRFI and 0.86±0.18 in HRFI. As a result, diet compositions differed between lines and formulation objectives: the LRFI least-cost diet contained essentially triticale (55%) and barley (26%), the HRFI least-cost diet contained corn (50%), triticale (17%) and barley (15%), whereas the optimised diets were more diverse (LRFI: corn (38%), triticale (22%), barley (12%); HRFI: barley (36%), corn (17%), triticale (16%), wheat (11%)). Then, as compared to the least-cost diet, the optimized diets had lower EI scores (Table 1), but not all the environmental impacts were reduced. Their prices per MJ of net energy were 1.5 (HRFI) to 4.5% (LRFI) higher.

Table 2. Mean (standard deviation) and P-values of line differences (*P*) for simulated production traits, environmental impacts for 1 kg live weight at the gate, and profit for low and high residual feed intake lines (LRFI, HRFI) fed least-cost or optimised diets.

	Least-cost diets			Optimised diets		
Trait[1]	LRFI	HRFI	*P*[2]	LRFI	HRFI	*P*[2]
Production						
ADG (kg/d)	0.77 (0.09)	0.80 (0.07)	*	0.78 (0.09)	0.82 (0.07)	*
FCR (kg /kg)	2.68 (0.17)	2.58 (0.17)	**	2.53 (0.18)	2.64 (0.19)	**
BFT (mm)	16.4 (1.1)	17.6 (1.0)	***	16.3 (1.1)	17.4 (1.0)	***
Environment						
GWP, kg CO_2 eq	2.02 (0.10)	2.09 (0.10)	***	1.96 (0.10)	2.02 (0.10)	***
AP, g SO_2 eq	33.1 (1.99)	37.1 (2.22)	***	34.6 (2.26)	35.3 (2.23)	***
EP, g P eq	1.39 (0.08)	1.56 (0.09)	***	1.36 (0.08)	1.40 (0.09)	*
LO, m^2 a crop eq	4.35 (0.25)	3.97 (0.22)	***	3.89 (0.23)	4.22 (0.25)	***
Profit, €	17.75 (5.56)	14.47 (7.01)	**	16.86 (5.68)	15.58 (5.64)	ns

[1] ADG = average daily gain; FCR = feed conversion ratio; BFT = back fat thickness; GWP = global warming potential; AP = acidification potential; EP = eutrophication potential; LO = land occupation

[2] *** P < 0.001; ** P < 0.01; * P < 0.05; ns = non-significant

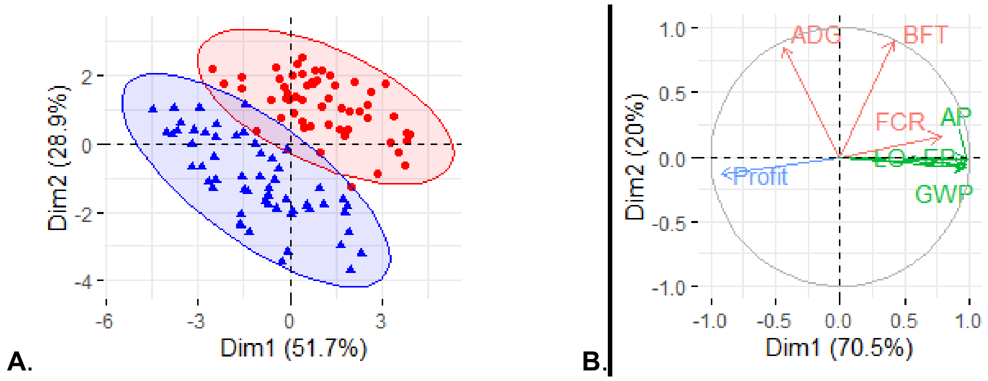

Figure 1. Principal components analyses of the least-cost diets dataset non-adjusted (A, red circles = HRFI pigs, blue triangles = LRFI pigs) and adjusted (B) for line effect.

Environmental impacts and profit. As expected, the simulated performances with the two diets were very similar within line (Table 2), and corresponded to known differences between the lines (Gilbert *et al*., 2017). The environmental impacts of producing 1 kg of body weight with the least-cost diets were lower in the LRFI line than in the HRFI line, by 3.5% for GWP to 12.2% for EP ($P < 0.001$), except for LO (-8.7%), as expected from other studies (Monteiro *et al*., 2021). With optimised diets, these impacts decreased for both lines by 2.2 to 10.6% compared to the least-cost diets, except for AP for LRFI and LO for HRFI. Line differences reduced in simulations with optimised diets, from 2.0% for AP ($P < 0.05$) to 8.5% for LO ($P < 0.001$)), but LRFI pigs still had reduced impacts compared to HRFI pigs.

With the least-cost diet, the LRFI pigs provided on average 3.28€ additional profit per pig, compared to the HRFI pigs ($P < 0.01$). With performances and costs simulated with the optimized diets, the profit slightly decreased for the LRFI line (-0.89€/pig), whereas it was increased by 1.11 €/pig in the HRFI line, leading to a reduced and non-significant profit difference between lines with the optimised diets.

The correlations between variables did not differ between diets and Figure 1 only shows results for the least-cost diets. The PCA applied to non-adjusted variables mainly separated lines (Figure 1.A.). After adjusting for line effects (Figure 1.B.), environmental impacts had strong positive correlations with each other, and high negative correlations with profit (-0.84 to -0.86). FCR had a correlation of -0.76 with profit and ~0.65 with environmental impacts, whereas ADG and BFT had correlations < 0.46 in absolute value with these variables.

Discussion

The LCA framework developed considers individual performances. This enables quantifying the main environmental impacts of individual pigs. In divergent lines, we showed how selection and diet formulation strategies result in different environmental impacts, but also that including environmental objectives in diet formulations could reduce the disadvantages of the less efficient line by using different feed ingredients. The proposed LCA framework, applied to large populations, will provide genetic parameters of environmental impacts to be used in breeding objectives, to contribute to the sustainability of livestock production.

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