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Research Article

Modeling sow precision feeding based on farm-specific body composition reduces feed costs and environmental load

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ABSTRACT

Modern sows are heavier than those used 30 years ago to establish the equations linking body energy, protein and fat to body weight (BW) and backfat thickness (BT). These equations are among others used in nutritional models to assess individual daily requirements to implement a precision feeding strategy (PF). Using calibrations of equations and a simulation approach, the objective of the current study was to evaluate the impact of four feeding strategies over six successive gestations on sows' long-term performances. A database of 3098 gestations from 1121 sows containing sows' parity, BW, BT, feed intake, and litter performances was used to calibrate predictive equations of sows' body chemical composition in a nutritional model. During gestation, a conventional feeding strategy (CF, same amount for all sows) was compared to a standard feeding strategy (SF) adjusted on individual energy requirements (variable amount per sow), and to two PF strategies adjusted on sow energy and amino acids (AA) requirements (PF_{AA}, variable amount of feed per sow and variable amount of lysine content over days and sows) and with additional phosphorus (P) requirements ($PF_{AA\text{-}P}$, variable amount of feed per sow and variable amounts of lysine and P contents over days and sows). The database was split into a training set (to fit body chemical composition equations from literature) and a testing set (to evaluate the differences between observed and predicted BW and BT at farrowing with calibrated equations). For the calibrated equations, the root mean squared error (RMSE) of sows' BW and BT at farrowing were 10 kg and 1.7 mm, respectively. Compared to the parameters before calibration, RMSE of sows' BW increased by 3 kg and RMSE of sows' BT decreased by −5.2 mm. At the sixth farrowing, BT was 2 mm lower for CF compared to BT target and BT of other feeding strategies ($P < 0.001$). The BT variability in the herd was also 19% greater for CF than SF, $PF_{AA,}$ and $PF_{AA\text{-}P}$ ($P < 0.001$). Over six successive gestations, feed costs were reduced by 17 € and 26 €, while nitrogen efficiency and P efficiency increased by 30 and 5% and by 15 and 30%, respectively for PF_{AA} and $PF_{AA\text{-}P}$ strategies compared to CF ($P < 0.001$). In conclusion, based on *in silico* results, feeding the gestating sows individually according to their energy requirements enabled to better

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Abbreviations: AA, amino acids; ATTD-P, apparent total tract digestible phosphorus; BT, backfat thickness; BW, body weight; EBW, empty body weight; CF, conventional feeding; H_{Lys}-H_P, high SID-Lys and high ATTD-P content; H_{Lys}-S_P, high SID-Lys and standard ATTD-P content; L_{Lys}-L_P, low SID-Lys and low ATTD-P content; L_{Lys}-S_P, low SID-Lys and standard ATTD-P content; MAE, mean absolute error; N, nitrogen; P, phosphorus; PF, precision feeding; PF_{AA}, precision feeding adjusted on energy and amino acids; $PF_{AA\text{-}P}$, precision feeding adjusted on energy, amino acids and phosphorus; RMSE, root mean squared error; RSD, residual standard deviation; S, standard gestation diet; SF, standard feeding adjusted on energy; SID-Lys, standardised ileal digestible lysine

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reach the target BT at farrowing with the succession of cycles. Adjusting the nutrient is to individual sow requirements, AA considered alone or in combination with P, reduces feed costs and enhances nutrient efficiencies in the long-term.

1. Introduction

The aim of precision feeding strategies for gestating sows is to provide the nutritional quantity and quality required to meet the individual and daily nutritional requirements of each animal (Brossard et al., 2023) and so achieve objective target body condition at farrowing. An optimal range of body weight (BW) per parity and fat reserves should be considered (Muro et al., 2023) to minimise the risk of peripartum issues inherent in sows, that are too fat (prolonged farrowing, more stillbirths; Oliviero et al., 2010) or too thin (lighter piglets at birth, lower milk production; Langendijk et al., 2023).

Previous researchers (Stewart et al., 2021; Gaillard and Dourmad, 2022; Cloutier et al., 2024) have reported the benefits of precision feeding (PF) adjusted for energy and amino acids (PF_{AA}) to reduce nitrogen (N) intake (from −12% to −25% per gestation), total N excretion (from −6% to −19% per gestation), and feed costs (−3 € per gestation) compared with a conventional feeding strategy (CF) performed with a single diet during the whole gestation. Over three consecutive cycles, this strategy made it possible to achieve the target backfat thickness (BT) at three consecutive farrowings, unlike the CF strategy with 4.4 mm less than the objective at the last farrowing, without any significant impact on sow productive performances (Ribas et al., 2024).

Nutritional requirements can be estimated using a nutritional model developed for gestating sows, that takes into account the parity or age, the individual BW and BT at insemination (Gaillard et al., 2019). Using available equations, energy (Whittemore and Yang, 1989; Everts and Dekker, 1995; Dourmad et al., 1997), protein (Miller et al., 2018) and lipid reserves can be predicted from BW and BT measured on empty sows. These body reserves evolve during gestation, depending on nutrients supplied to achieve the BW and BT targets set at farrowing. Existing equations (Quiniou, 2019) can be used to set BW target according to sow age at farrowing. A common BT target is usually used for all sows. However, with genetic selection for growth and leanness in fattening pigs, sows have become increasingly heavier and leaner than sows from 30 years ago (Bergsma et al., 2009, 2024). By simulating gestations with the nutritional model and the use of real farm data, it is possible to calibrate the parameters of existing equations.

Thus, the objective of this study was, firstly, to calibrate an equation for linking chemical composition with BW and BT and another equation linking BW to sow age, both calibrations based on data from a farm collected over the last decade. Secondly, the purpose was to evaluate the impact of PF strategies, using a simulation approach based on farm data, on the body characteristics throughout the productive career, feed costs and nutrient balances. We made the assumption that updating the parameters of the equations allows for a better adjustment of the model to the current body composition of sows. We also hypothesised that PF strategy using the calibrated equations reduces feed costs and N and phosphorus (P) excretions while maintaining optimal body condition through successive farrowing compared to CF.

2. Material and methods

This study was conducted in two parts. The first part involved calibrating the parameters of two equations using a database from a farm. The second part simulated four feeding strategies over six successive cycles using a nutritional model incorporating the calibrated equations and by using the same database.

2.1. Animals, feeding, housing and measurements used as database

Sows' performances were collected under commercial conditions at the experimental facility of Schothorst Feed Research B.V. (Lelystad, The Netherlands) from May 2012 to March 2023. It included 3098 gestations from 1121 crossbred Landrace × Large White (TN20 or TN70 from Topigs Norsvin genetic) sows. Data of sows followed for at least five gestations were grouped together in a restricted database (databased "**5 +**") representing 991 gestations from 178 sows.

Gestating sows were housed in dynamic groups of 150 individuals, with pens equipped with four automatic feeders each, and multiple hoppers making it possible to allocate different feeding plans between gilts and multiparous sows. Quantities of feed and the type of feed supplied, either a conventional diet (97% of the data) or an experimental diet, depending on whether the sows were followed during a feeding trial, were collected. Only conventional diet were subsequently retained. Under CF plan, sows were supplied with a single diet, that varied in quantity according to three gestation phases (insemination to day 42 of gestation, day 42–84, and day 85 until farrowing). Primiparous sows received 2.40, 2.75, and 2.90 kg/d of feed, regarding the respective phases, whereas multiparous sows received 2.90, 2.75, and 3.20 kg/d. The objective of BT at farrowing regardless of parity was set at 18 mm (current practice of the farm). After the transfer to the farrowing room (*ca.* 1 week before expected farrowing date), sows were housed in farrowing crates (0.60 × 2.50 m) in individual pens (2.25 × 2.50 m), equipped with a feeding trough and a feeder. The feed was available on request through pushing a metal bar in the feeder up to the daily maximum amount allowed by the feeding plan.

Within the first 24 h of life, piglets' sex, BW and status (alive, stillbirth or mummified) were recorded. If required, cross fostering was done within 48 h after birth and per parity to balance the litter size to 12–14 piglets. For genetic purpose, sows without health issues were kept until parity 5 and the greater parities culled out according to thresholds based on sow performances at farrowing. For the first insemination of gilts, during the transfer from the gestation room to the farrowing room (*ca.* 1 week before expected farrowing date), and on piglets weaning day (*ca.* 4 weeks after farrowing), each sow was weighed (ZM201, Avery Weigh-Tronix, Fairmont, MN, USA) and its BT (Renco Lean-Meater, Minneapolis, MN, USA) was measured at position P2, *i.e.* 6.5 cm on either side of the midline at the level of the last rib. Sow performances were summarised per parity in Table 1.

2.2. Model description

The sow nutritional model used in the current study was previously described by Gaillard et al. (2019). It corresponds to an upgraded version of the InraPorc mechanistic model (Dourmad et al., 2008), implemented under Python programming language, version 3.6 and still available for version 3.9 (Python Software, 2020). The model is used to estimate individual nutritional requirements for each day of gestation. The sow is considered as the sum of chemical compartments, *i.e.* body protein, body lipid and full uterus. In practice, body lipid, body protein and body energy (23.8 kJ/g protein, 39.5 kJ/g lipid) are predicted from empty body weight (EBW) and BT (Eq. 1; Dourmad et al., 2008). Using the current data for sows, BW and BT measured at weaning were used as initial BW and BT for the subsequent gestation, which started mainly five days after weaning. For gilts, BW and BT measured at insemination were used.

$$\textit{body content} = \mathrm{a} + \mathrm{b} \times \textit{EBW} + \mathrm{c} \times \textit{BT} \tag{1}$$

With:

$\textit{body content}$: *energy content in MJ or protein content in kg or fat content in kg*
$\textit{EBW}$: *empty body weight of the sow in kg calculated as* $0.96 * \textit{BW}$
$\textit{BT}$: *backfat thickness at P2 site in mm*
a, b, c : *parameters to fit*

During gestation, these body reserves change from an initial state to a final one, depending on the objectives set at farrowing, usually based on a common BT objective for all sows. The objective for individual sow BW depends on age and the historical litter performance within the farm. To set a BW target, a Weibull equation adjusted to the herd data is calibrated (Eq. 2; Quiniou, 2019). With the current database, sows were weighed when transferred to the farrowing room, not after farrowing. Therefore, final BW corresponds to this weighing minus the weight of the conceptus (Eq. 3; Dourmad et al., 1997).

$$\textit{Sow BW}(t) = \mathrm{a} \times \left(1 - \exp\left(-\left(\mathrm{b}/1000 \times t\right)^{c}\right)\right) \tag{2}$$

With:

$\textit{Sow BW}$: *maternal BW in kg*
t : *sow age in days*
a, b, c : *parameters to fit*

$$\textit{Conceptus weight} = 0.3 + 1.329 \times \textit{litter weight} \tag{3}$$

With:

$\textit{Conceptus weight}$: *weight of conceptus in kg*
$\textit{litter weight}$: *weight of the litter at birth in kg*

Table 1
Description of the database collected at an experimental farm averaged by parity.

						Initial[1]		Final[2]		Loss during lactation	
	Parity	Number of gestations	Litter size	Piglet birth weight (kg)	Litter weaning weight (kg)	BW (kg)	BT (mm)	BW (kg)	BT (mm)	BW (kg)	BT (mm)
	1	629	14.8	1.22	80.6	162	16.3	193	19.8	−20	−4.6
	2	512	14.5	1.42	98.8	175	15.2	214	19.4	−20	−4.7
	3	550	15.9	1.41	102.6	193	14.7	228	19.1	−17	−4.5
	4	494	16.8	1.34	102.0	210	15.2	240	19.6	−16	−4.3
	5	378	17.0	1.34	103.8	221	14.9	247	19.5	−14	−4.2
	6	264	17.2	1.31	103.9	231	15.9	256	20.3	−16	−4.0
	7	180	16.2	1.34	109.0	240	16.3	262	20.8	−13	−4.4
	8	91	16.3	1.32	104.9	249	17.0	268	21.4	/	/
Average	5	-	15.8	1.34	98.1	198	15.5	228	19.7	−17	−4.4
Sum	-	3098	-	-	-	-	-	-	-	-	-

BW, body weight; BT, backfat thickness.
[1] BW and BT measured at insemination and at weaning of the previous cycle for gilt and sows, respectively.
[2] BW and BT measured during the transfer from the gestation room to the farrowing room (*ca.* 1 week before expected farrowing date).

Changes in body composition during lactation were averaged according to litter weight gain per parity (Table 1) and were implemented in the new lactation function of the nutritional model. The known effects of lactating sow intake (Gauthier et al., 2021) and individual litter performances (Gauthier et al., 2022) on changes in body composition could not be taken into account in the simulation due to a lack of parameters. For this reason, the results will focus exclusively on the gestating sow. The percentage of each feed in the blend was calculated as such to achieve the nutritional quality required to meet individual daily requirements, either only in amino acids (AA) or both AA and minerals depending on the feeding strategy implemented. The optimal solution for each day and each sow was obtained using constrained linear optimisation with the pulp package (Mitchell et al., 2011).

2.3. Fitting data

A multivariate regression analysis with the curve_fit function from SciPy library (Virtanen et al., 2020) was used to calibrate the parameters of Eq. 1 and Eq. 2. It ran the Trust Region Reflective algorithm (Branch et al., 1999) and the Levenberg-Marquardt algorithm (Moré, 1978) for Eq.1 and Eq.2, respectively, towards the minimum sum of squares of the differences, *i.e.* residuals. Optimisation stopped when the change in cost function was below 10^{-4} to maintain optimisation that lasts for a maximum of one day. If this condition was never met, it stopped after 2,000,000 evaluations. Initial parameters for the optimisation were those described by Dourmad et al. (1997) and Gaillard et al. (2020) for Eq. 1 and Eq. 2, respectively. Parameters of each body chemical compartments, *i.e.* a total of nine parameters, were fitted to minimise the difference between final observed BW and BT with final predicted BW and BT. Final predicted BW and BT were obtained from the chemical composition of the sow after a simulation of a gestation with the nutritional model. The Weibull equation was fitted on observed sow BW at the arrival in the farrowing unit minus the weight of the conceptus to calibrate the parameters. To avoid overfitting, parameters of Eq. 2 were calibrated according a K-fold cross validation scheme from the Scikit-learn library (Pedregosa et al., 2011). Briefly, it consisted in dividing the dataset into K groups and fitting the parameters K times using K-1 groups of data to train and the remaining group of data was used to evaluate the prediction error. The performance of each validation was then evaluated by averaging the mean absolute error (MAE) and the root mean squared error (RMSE) for the K equations calibrated. The metrics MAE and RMSE were calculated as follows:

$$\mathrm{MAE} = 1/n \times \sum_{k=0}^{n-1} |y_k - \hat{y}_k|$$

$$\mathrm{RMSE} = \sqrt{1/n \times \sum_{k=0}^{n-1} (y_k - \hat{y}_k)^2}$$

With:

n : *number of samples*
y_k : *the k − th observed value*
$\hat{y}_k$: *the k − th predicted value*

The lower the value, the more accurately the model represented the data. Two-, five-, ten-, twenty-, and leave-one-out (number of samples) folds were evaluated (Table 2).

Table 2

Root mean squared error (RMSE) and mean absolute error (MAE) used as metrics to quantify and compare the quality of predictions of the BW according to the sow age with different K-folds cross-validation on two datasets: all the gestations available *i.e.* 3098 gestations or gestations from sows followed at least over 5 cycles (5 +) *i.e.* 991 gestations[a].

Item	All				5 +			
	N_{train}	N_{test}	RMSE	MAE	N_{train}	N_{test}	RMSE	MAE
Control[b]	-	3098	23.0	17.7	-	991	22.6	18.5
K-folds cross validations								
2	1549	1549	21.7	17.7	495	496	17.3	13.9
3	2065	1033	19.7	15.7	660	331	17.7	14.4
4	2323	775	19.3	15.4	743	248	16.7	13.4
5	2478	620	18.9	15.0	792	199	16.7	13.4
10	2788	310	18.4	14.5	891	100	16.3	13.0
20	2943	155	18.1	14.3	941	50	16.1	12.9
Leave-one-out	3097	1	17.7	14.0	990	1	15.9	12.7

BW, body weight; $N_{train,}$ number of samples used at each validation to train the model; $N_{test,}$ number of samples used at each validation to test the model.

[a] Prediction of BW according to age with a Weibull function (Sow BW(kg) = a × (1 – exp (- (b / 1000 × age, day)^{c}))) with a, b, and c parameters to fit; Quiniou (2019)).

[b] Prediction of BW according to Weibull function of Gaillard et al. (2020).

2.4. *Simulated feeding strategies*

Five simulated gestation diets (Table 3) were formulated to contain 9.0 MJ/kg of net energy and different contents of standardised ileal digestible lysine (SID-Lys; standard: 4.7 g/kg, low: 3.3 g/kg or high: 8.5 g/kg) and apparent total tract digestible phosphorus (ATTD-P; standard: 2.6 g/kg, low: 1.8 g/kg or high: 4.0 g/kg). Their chemical and nutritional characteristics were calculated with Evapig software (Dourmad et al., 2011) from a list of French raw materials. Simulations were performed with a 3-phase feeding plan, similar to the one used on the farm where the data comes from. Four feeding strategies were simulated. A CF strategy with a single standard diet (S), similar to the one used on the farm, and the feeding levels used on the farm; a standard feeding (SF) strategy using the S diet but with feeding levels modulated with regard to individual estimated energy requirements; a strategy adjusted on energy (like SF) but also on individual and daily AA requirements (based on SID-Lys), called PF_{AA} strategy, implemented through a customised mixture of low SID-Lys (L_{Lys}-S_P) and high (H_{Lys}-S_P) SID-Lys content diets; a strategy based on energy and AA (like PF_{AA}**)** but also on phosphorus requirement, called $PF_{AA\text{-}P}$, implemented through a blend with diets already used in the PF_{AA} strategy, and a low (L_{Lys}-L_P) or high (H_{Lys}-H_P) SID-Lys and ATTD-P diets.

Daily individual requirements of SID-Lys and ATTD-P were based on equations from Gaillard et al. (2019) and Quiniou et al. (2021), respectively, implemented in the nutritional model.

Gestation length was set at 115 days for all the sows. Sow's body loss during 28 days of lactation depends on the average daily gain of the litter per parity. Simulations were run over six successive cycles of gestation-lactation from first insemination as gilt to weaning after the 6th lactation to compare the four feeding strategies applied during gestation on body condition of the sow, nutrient intake, feed cost, and nutrient excretion. Each sow with data in the first gestation was used, making a total of 629 sows for simulation. As requirements were estimated in hindsight, final observed BW, BT, and litter weight at farrowing for each parity of each sow were used

Table 3

Ingredient, chemical composition, and price of simulated gestation diets with Evapig software (on as-fed basis).

Diet	S	L_{Lys}-S_P	H_{Lys}-S_P	L_{Lys}-L_P	H_{Lys}-H_P
Ingredient composition, g/kg					
Barley	301	288	180	327	171
Wheat	222	180	180	304	184
Maize	80	180	180	30	216
Wheat bran	100	110	114	110	40
Soybean meal, 48% crude protein	50	10	145	-	145
Rapeseed meal	37	39	50	-	50
Sunflower seed meal with hulls	50	37	21	60	62
Soya bean hulls	-	-	10	-	-
Soya bean oil	8	5	5	5	5
Sugar beet pulp, dehydrated	100	100	61	120	55
Sugar beet molasses	20	20	20	20	20
Limestone	12.6	13.7	14.1	10.5	24.2
Monocalcium phosphate	4.0	3.7	2.8	0	10.4
Salt	4	4	4	4	4
Sodium bicarbonate	6.4	5.1	2.0	5.0	2.6
Premix[a]	4	4	4	4	4
L-Lysine 50	-	-	4.2	-	4.2
Methionine hydroxy analog	-	-	0.9	-	0.7
L-Threonine	0.5	-	1.5	-	1.4
Phytase[b]	0.5	0.5	0.5	0.5	0.5
Chemical Composition, g/kg					
Dry matter	879	875	875	877	877
Crude protein	147	112	166	128	166
Ash	60	60	61	52	77
Crude fat	27	27	27	24	26
Crude fibre	65	68	64	66	64
Lysine	6.0	4.5	9.9	4.5	9.8
SID-Lys	4.7	3.3	8.5	3.3	8.5
Total calcium	8.0	9.6	9.6	6.5	14.8
Total phosphorus	5.1	4.9	5.2	3.9	6.7
ATTD-P	2.6	2.6	2.6	1.8	4.0
Electrolyte balance, mEq/kg	246	220	242	209	239
Metabolisable energy, MJ/kg	12.25	12.01	12.34	12.16	12.32
Net energy, MJ/kg	9.00	9.00	9.00	9.01	9.00
Price, €/ton	243	231	260	226	267

ATTD-P, apparent total tract digestible phosphorus; SID-Lys, standardised ileal digestible lysine; S, standard gestation diet; L_{Lys}-S_P, low SID-Lys and standard ATTD-P content; H_{Lys}-S_P, high SID-Lys and standard ATTD-P content; L_{Lys}-L_P, low SID-Lys and ATTD-P content; H_{Lys}-H_P, high SID-Lys and ATTD-P content.

[a] The same premix of vitamins and trace minerals was incorporated in all diets. It supplies at least the amounts of vitamins and trace minerals recommended for sow diets in France (Gaudré and Quiniou, 2009).

[b] Phytase (500 UI/kg of diet) which makes available 0.75 g of ATTD-P per kg of diet.

as the objective for the simulation. If data from the sow at the insemination was available, it was used as the starting point for the gestation. Otherwise, the body condition from the simulation of the previous gestation - lactation cycle and the average production performance for that parity from the database were used. Calibrated parameters obtained from the database in the first part of this study were used as parameters of Eq. 1 and Eq. 2 in the model.

2.5. Calculations of nutrient intake, feed costs, and nutrient balance

Nutrient intake per sow was calculated for each feeding strategy as the sum of each diet consumed during the six gestations simulated.

The prices of the S, L_{Lys}-S_P, H_{Lys}-S_P, L_{Lys}-L_P, and H_{Lys}-H_P were 243, 231, 260, 226, and 267 €/ton (Table 3), respectively according to diet content and price of each raw material used for each diet in March 2025 for France (IFIP, 2025).

For the six simulated gestations, total feed intake from all diets of each sow was used to calculate N intake as a function of CP ingested (total N × 6.25) and P intake as a function of total P content ingested (Table 3). Maternal retention of N and P over the six gestations equaled the sum of maternal retention for each gestation simulated using sow BW and BT and equations of Dourmad et al. (2008), (2021). Urinary N and P outputs equaled N or P absorptions (total intake minus faecal output) minus retentions. Based on the ATTD of N or P obtained from the diets, faecal N and P outputs were calculated. The efficiencies of N and P used equaled N and P retentions divided by N and P intakes, respectively.

2.6. Statistical analyses

Statistical analyses were performed using R software (v. 4.4.1; R Core Team, 2024). The influence of the feeding strategy (CF, SF, PF_{AA}, and $PF_{AA\text{-}P}$) on cumulative nutrient intake (feed, N, SID-Lys, and ATTD-P), feed costs, and N and P balances (retentions, fecal and urinary outputs) over the six gestations was analysed using a linear mixed effects model (lmer function of the *lme4* package; Bates et al., 2015). The feeding strategy was set as fixed effect; and the sow, which is the experimental unit with 629 replicates per strategy, as the random effect. Tukey's test for multiple comparisons of means was used to perform pairwise comparisons.

To evaluate the effect of the feeding strategy on count data (percentage of diet consumed), these data were analysed with a generalised linear mixed model (glmer function and family binomial of the *lme4* package; Bates et al., 2015). The same fixed and random effects were used as those for the linear mixed model.

To assess the effect of the feeding strategy on body composition of the sow at farrowing throughout the cycles of gestation, the gestation cycle and its interaction with the feeding strategy were added to the linear mixed model as fixed effects.

Assumptions of regression models (*i.e.*, linearity, normal distribution of errors, homoscedasticity of errors and independence of errors) were assessed for each model.

The residual standard deviation (RSD) of results was calculated as follows:

$$RSD = \sqrt{\sum_{k=0}^{n-1} (y_k - \hat{y}_k)^2 \Big/ (n-p)}$$

With:

n : *number of samples*
p : *number of parameters to estimate*
y_k : *the* $k - th$ *observed value*
$\hat{y}_k$: *the* $k - th$ *predicted value*

Significant differences were considered if $P \leq 0.05$ and trends with P from 0.05 to < 0.10.

3. Results

3.1. Parameters calibration of sow BW (Eq. 2) and body chemical compartments (Eq. 1)

For sow BW, the leave-one out cross validation on 5 + data resulted in the best metrics with a RMSE of 15.9 and a MAE of 12.7 kg (Table 2). Except for the 3-fold cross-validation for the 5 + database, increasing the number of K groups reduced the MAE and RMSE values. By using the Weibull equation without calibration as control on 5 + data, the RMSE of predicted BW of our current data was increased by 6.7 and MAE by 5.8 kg. Every cross validation ran in this study resulted in more accurate equation than the control. For the Eq. 2, calibrated a, b and c parameters on 5 + data with lowest RMSE and MAE were 347, 1.638, and 0.459, respectively (Table 4). This equation fitted our database better than other equations previously adjusted in other farms (Fig. 1).

For body chemical compartments, parameters were adjusted on data of 5 + parity sows (991 gestations) and evaluated with all other gestations not used to fit the equations (*i.e.*, 2107 gestations). The calibrated equations resulted for evaluated data for final BW and BT after simulating the gestation in a RMSE and MAE of 9.9 and 7.8 kg for BW, and 1.7 and 1.3 mm for BT, respectively. Compared to Eq. 1 without parameter calibration on the same evaluated data, RMSE and MAE of BW were increased by 2.9 and 2.2 kg whereas RMSE and MAE of BT were decreased by −5.2 and −4.6 mm, respectively. For the Eq. 1, calibrated a, b and c were −810 MJ,

Table 4
Adjusted prediction of sow net BW according to the age of sows and prediction of energy, protein, or fat content of sows as function of EBW and BT (adapted from Dourmad et al., 1998).

	Calibrated parameters[a]				
Item	a	b	c	RMSE	Authors
Maternal BW, kg	275	3.824	0.980	Not specified	Gaillard et al., (2020)
	340	2.506	0.815	16.2	Quiniou, (2019)
	347 ± 1	1.638 ± 0.001	0.459 ± 0.001	15.9	Current study
Energy, MJ	−870	12.6	54.2	186	Whittemore and Yang, (1989)
	−408	8.9	68.1	126	Everts and Dekker, (1995)
	−1074	13.7	45.9	198	Dourmad et al.,(1997)
	−810 ± 1	8.0 ± 51935	70.0 ± 0.2	Not calculable[b]	Current study
Protein, kg	−2.3	0.186	−0.22	1.8	Whittemore and Yang, (1989)
	1.7	0.175	−0.38	1.4	Everts and Dekker, (1995)
	2.3	0.178	−0.33	1.9	Dourmad et al.,(1997)
	4.1	0.17	−0.23	Not specified	Miller et al., (2018)
	−4.95 ± 2.13	0.211 ± 229223	−0.10 ± 0.01	Not calculable[b]	Current study
Fat, kg	−20.4	0.205	1.48	5.2	Whittemore and Yang, (1989)
	−10.4	0.110	2.00	3.1	Everts and Dekker, (1995)
	−26.4	0.221	1.33	6.1	Dourmad et al.,(1997)
	−8.7	0.187	0.850	3.3	Gill, (2006)
	−20.7	0.27	0.77	Not specified	Miller et al., (2018)
	−49.7 ± 0.1	0.329 ± 0.001	5.05 ± 0.50	Not calculable[b]	Current study

BT, backfat thickness; BW, body weight; EBW, empty body weight; RMSE, root mean squared error.

[a] Model as maternal BW (kg) = a × (1 − exp (- (b / 1000 × age, day)^{c}))) and as Y = a + b × EBW + c × BT for body content with EBW = 0.96 × BW, respectively). For the current study, values are presented as the mean ± the standard error.

[b] Without data of body chemical compartments, it is not possible to calculate the RMSE.

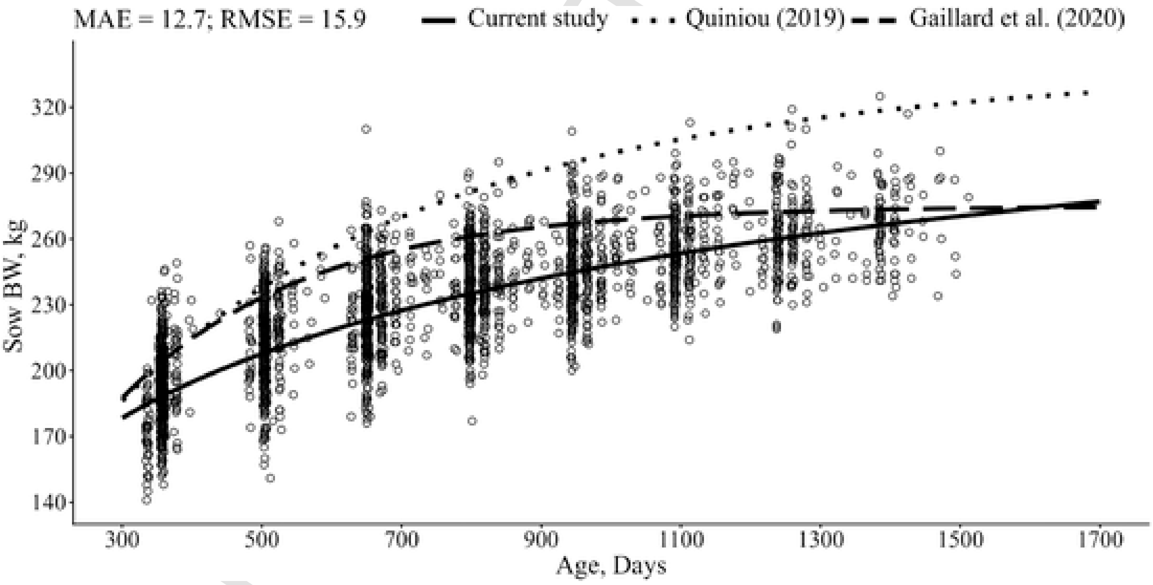

Fig. 1. Sow body weight (BW) according to age. Solid line is the Weibull equation calibrated on the data of the current study. Dashed line corresponds to adjusted equation from Gaillard et al. (2020) and dotted line from those of Quiniou (2019). MAE, mean absolute error; RMSE, root mean squared error.

8.0 MJ/kg and 70.0 MJ/mm, respectively, for energy content, −4.95 kg, 0.211 kg/kg and −0.10 kg/mm, respectively, for body protein, and −49.7 kg, 0.329 kg/kg, and 5.05 kg/mm, respectively, for body fat (Table 4). Parameters for BW and energy content and body protein (*i.e.*, 8.0 MJ/kg and 0.211 kg/kg, respectively) were calibrated with a standard error more than a thousand times greater than the mean value.

3.2. Nutrient intake, feed costs and body characteristics change throughout six successive cycles

Cumulative feed intake throughout six successive simulated gestations was influenced by the feeding strategy ($P < 0.001$; Table 5). Over six gestations, adjusting intake on energy requirements in SF, PF_{AA}, and $PF_{AA\text{-}P}$ strategies increased the amount of feed supplied by 15 kg compared to the CF strategy. Nutrient intake was dependent on the feeding strategy applied ($P < 0.001$). Compared to the CF strategy, N intake was 0.6% greater for SF, 21 and 11% lower for PF_{AA} and $PF_{AA\text{-}P}$ strategies, respectively. Over the six gestations, a sow with a CF strategy consumed 0.6% less than one with a SF strategy but consumed 31% more SID-Lys than sows with a PF_{AA} or a $PF_{AA\text{-}P}$ strategy did. Intake of ATTD-P was lower for the CF strategy compared with SF and PF_{AA} but only represented a small difference of 0.8% ($P < 0.001$). Adjusting ATTD-P supplies to the requirements reduced the intake by 40% for the $PF_{AA\text{-}P}$ strategy compared with the other feeding strategies ($P < 0.001$). Through six gestations, sows with a PF_{AA} strategy consumed mainly the L_{Lys}-S_P diet (94.9% of total intake) whereas those with the $PF_{AA\text{-}P}$ strategy mainly consumed the L_{Lys}-L_P diet (94.6% of total intake). The H_{Lys}-S_P diet was the second most consumed diet, *i.e.* 5.1% and 4.8% for PF_{AA} and $PF_{AA\text{-}P}$ strategies, respectively. For the $PF_{AA\text{-}P}$ strategy, L_{Lys}-S_P and H_{Lys}-H_P represented only 0.3% of total intake each.

Feed costs over a gestation differed among feeding strategies ($P < 0.001$; Table 5). Compared to the CF strategy, PF_{AA} and $PF_{AA\text{-}P}$ strategies reduced feed costs by 2.8 and 4.4 € per gestation, respectively, whereas the SF strategy increased them by 0.6 € per gestation. Throughout six successive gestations, feed costs ranged between 400 € and 530 € per sow for the PF_{AA} and $PF_{AA\text{-}P}$ strategies. It represented an average saving of 17 € and 26 € with PF_{AA} and $PF_{AA\text{-}P}$ strategies, respectively, compared with a CF strategy which feed costs averaged 483 € ($P < 0.001$). Only adjusting nutritional supplies on energy with the S diet in the SF strategy resulted in a 4 € increase in feed costs over six gestations compared to the CF strategy.

At farrowing, sow BW differed among feeding strategies across cycles (strategy x cycle interaction, $P < 0.001$; Fig. 2). Sows fed with the CF strategy had greater BW at the end of gestation during the first and second cycles, but lower BW during the fifth and sixth cycles, compared with the other feeding strategies (Tukey's test, $P = 0.003$). During the second and the third gestations, sow BW at farrowing was greater for sows with SF or PF_{AA} than sows with the $PF_{AA\text{-}P}$ strategy ($P = 0.004$). In all cases, averages varied slightly between strategies (3 kg) regardless of the cycle. The feeding strategy applied during gestation had an impact on BT at farrowing throughout the cycle of gestation (strategy x cycle interaction, $P < 0.001$; Fig. 3). At farrowing, BT was greater for sows fed CF than those of sows fed with other strategies from the first to the third gestations (Tukey's test, $P = 0.004$). On the contrary, it was lower in the sixth cycle (Tukey's test, $P < 0.001$) and did not differ with the other strategies in the fourth (Tukey's test, $P = 0.23$) and fifth cycles (Tukey's test, $P = 0.11$). For all strategies, the standard deviation increased between the first and sixth gestation. However, it rose from 3.1 to 3.8 mm for the CF strategy, while for the other strategies the standard deviation stabilised at 3.2 mm from the fourth gestation onwards.

3.3. Nutrient balances

Feeding strategies had an influence on the N balance throughout six successive gestations ($P < 0.001$; Table 6). Maternal retention of 5.27 kg of N for PF_{AA} and $PF_{AA\text{-}P}$ strategies was greater compared to those of CF and SF with an average of 5.16 and 5.23 kg each ($P < 0.001$). Urinary and faecal N excretions were significantly different between feeding strategies ($P < 0.001$) and were the lowest for PF_{AA} strategy followed by $PF_{AA\text{-}P}$ strategy then CF and finally SF. The N efficiency was greater for PF_{AA} than $PF_{AA\text{-}P}$ strategy

Table 5
Effects of the feeding strategy on feed and nutrient intake and feed costs throughout six successive simulated gestations.

	Strategy				RSD	P
Item	CF	SF	PF_{AA}	$PF_{AA\text{-}P}$		Strategy
Feed intake, kg/sow	1989^a	2003^b	2005^b	2005^b	34	< 0.001
Feed intake, kg/gestation	331^a	334^b	334^b	334^b	6	< 0.001
N intake, kg/sow	46.8^c	47.1^d	36.8^a	41.7^b	0.7	< 0.001
SID-Lys intake, kg/sow	9.35^b	9.41^c	7.16^a	7.16^a	0.16	< 0.001
ATTD-P, kg/sow	5.17^b	5.21^c	5.21^c	3.71^a	0.08	< 0.001
Percentage of diet consumed in gestation, %						
S	100^b	100^b	0^a	0^a	0.1	< 0.001
L_{Lys}-S_P	0^a	0^a	94.9^b	0.3^a	0.9	< 0.001
H_{Lys}-S_P	0^a	0^a	5.1^b	4.8^b	1.3	< 0.001
L_{Lys}-L_P	0^a	0^a	0^a	94.6^b	0.9	< 0.001
H_{Lys}-H_P	0^a	0^a	0^a	0.3^b	0.2	< 0.001
Feed cost, €/sow	483^c	487^d	466^b	457^a	8	< 0.001
Feed cost, €/gestation	80.5^c	81.1^d	77.7^b	76.1^a	1.3	< 0.001

ATTD-P, apparent total tract digestible phosphorus; SID-Lys, standardised ileal digestible lysine; CF, conventional feeding strategy with a unique diet throughout gestation; H_{Lys}-H_P, high SID-Lys and high ATTD-P content; H_{Lys}-S_P, high SID-Lys and standard ATTD-P content; L_{Lys}-L_P, low SID-Lys and low ATTD-P content; L_{Lys}-S_P, low SID-Lys and standard ATTD-P content; N, nitrogen; SF, standard feeding strategy with supplied adjusted to individual energy requirements; PF_{AA}, precision feeding strategy with energy and SID-Lys supplied adjusted to individual requirements; $PF_{AA\text{-}P}$, precision feeding strategy with energy, SID-Lys and ATTD-P supplied adjusted to individual requirements; RSD, residual standard deviation; S, standard gestation diet.
[a,b,c,d] Means within a row without a common superscript differ at $P < 0.05$.

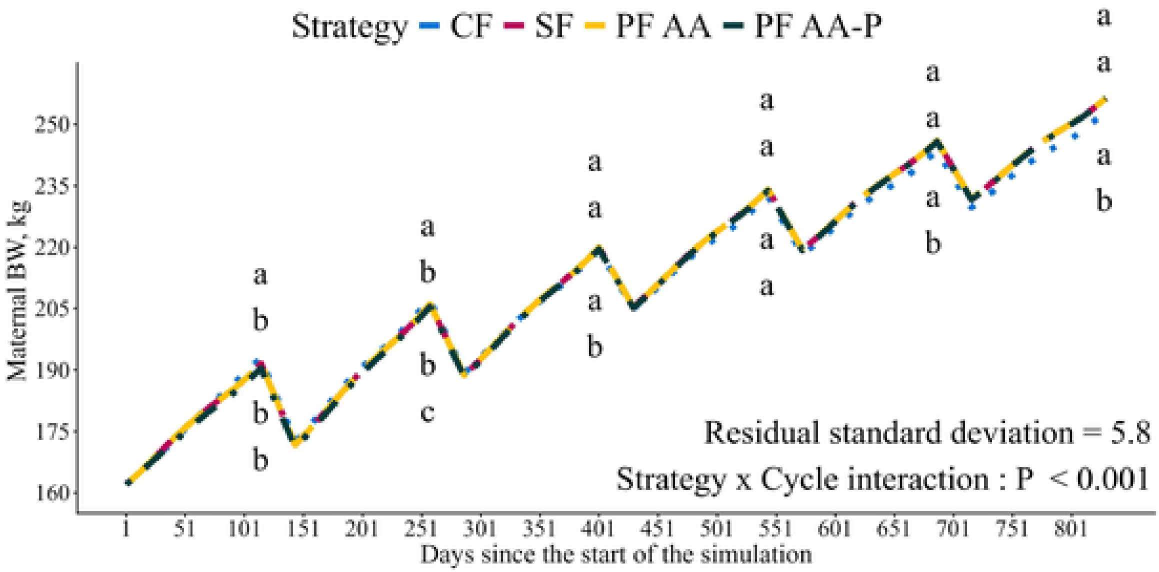

Fig. 2. Maternal sow body weight (BW) throughout six cycles in response to the feeding strategy applied (conventional feeding (CF) vs. standard feeding (SF) vs. precision feeding on amino acids (PF_{AA}) or amino acids and phosphorus ($PF_{AA\text{-}P}$)). a,b,c: means per feeding strategy for each cycle without a common superscript differ at $P < 0.05$.

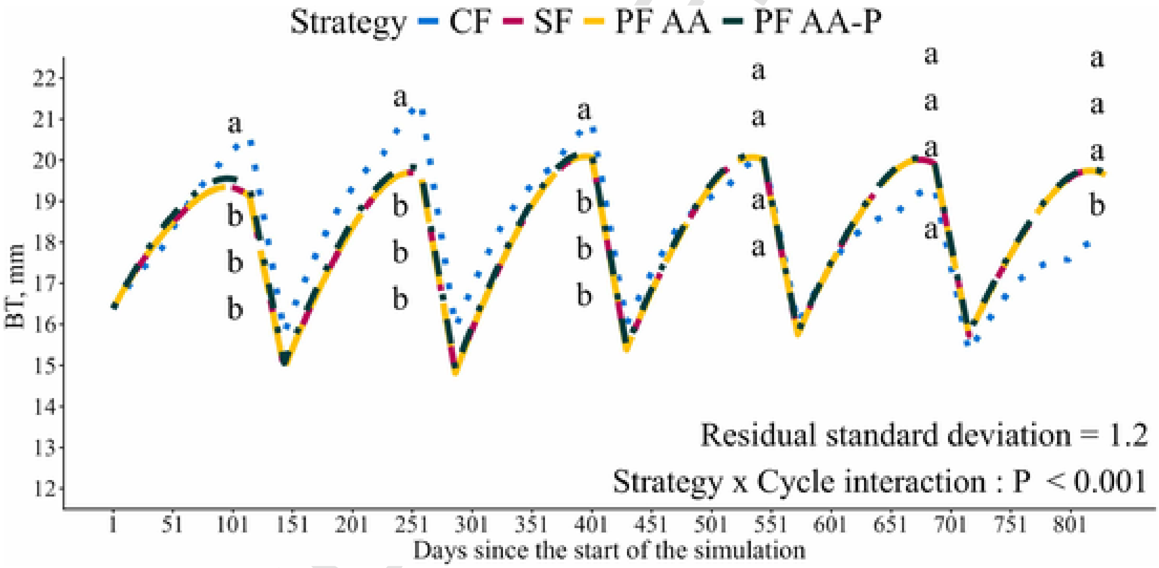

Fig. 3. Maternal sow backfat thickness (BT) throughout six cycles in response to the feeding strategy applied (conventional feeding (CF) vs. standard feeding (SF) vs. precision feeding on amino acids (PF_{AA}) or amino acids and phosphorus ($PF_{AA\text{-}P}$)). a,b,c: means per feeding strategy for each cycle without a common superscript differ at $P < 0.05$.

because of similar retention but greater intake for this latter ($P < 0.001$). The N efficiency was significantly different between CF and SF strategies but only represented a difference of 0.1 %age unit ($P < 0.001$). Their N efficiencies were 1.5 %age unit and 3.2 %age unit lower than those obtained with PF_{AA} and $PF_{AA\text{-}P}$ respectively ($P < 0.001$).

Total P intake was 21% lower for sows with $PF_{AA\text{-}P}$ strategy compared to other strategies ($P < 0.001$). It was 0.1 kg greater for SF than CF strategy which was itself 0.2 kg greater than for the PF_{AA} strategy ($P < 0.001$). Maternal P retention was different among CF, SF and PF strategies but with a difference lower than 1% ($P < 0.001$). Urinary and faecal P outputs were respectively 36% and 14% lower for $PF_{AA\text{-}P}$ strategy compared to CF and SF strategies ($P < 0.001$). Urinary output for the PF_{AA} strategy was similar to those of SF strategy but faecal output was 0.4 kg lower compared to this one ($P < 0.001$). The P efficiency was 10% and not significantly different between CF and SF. With a lower intake, PF_{AA} and $PF_{AA\text{-}P}$ strategies had greater P efficiency, *i.e.* 10.6 and 13.1% respectively ($P < 0.001$).

Table 6
Effects of the feeding strategy applied on nitrogen (N) and phosphorus (P) balance throughout six successive simulated gestations.

	Strategy				RSD	P
Item	CF	SF	PF_{AA}	$PF_{AA\text{-}P}$		Strategy
N balance						
Total intake, kg	46.8^{c}	47.1^{d}	36.8^{a}	41.7^{b}	0.7	< 0.001
Maternal retention[1], kg	5.16^{a}	5.23^{b}	5.27^{c}	5.27^{c}	0.07	< 0.001
Urinary output[2], kg	33.3^{c}	33.5^{d}	24.8^{a}	28.6^{b}	0.6	< 0.001
Faecal output[3], kg	8.3^{c}	8.4^{d}	6.8^{a}	7.9^{b}	0.1	< 0.001
Efficiency of use[4], % of intake	11.0^{a}	11.1^{b}	14.3^{d}	12.6^{c}	0.2	< 0.001
P balance						
Total intake, kg	10.1^{c}	10.2^{d}	9.9^{b}	8.0^{a}	0.2	< 0.001
Maternal retention[1], kg	1.03^{a}	1.04^{b}	1.05^{c}	1.05^{c}	0.01	< 0.001
Urinary output[2], kg	4.1^{b}	4.2^{c}	4.2^{c}	2.7^{a}	0.1	< 0.001
Faecal output[3], kg	5.0^{c}	5.0^{d}	4.6^{b}	4.3^{a}	0.1	< 0.001
Efficiency of use[4], % of intake	10.1^{a}	10.2^{a}	10.6^{b}	13.1^{c}	0.2	< 0.001

ATTD-P, apparent total tract digestible phosphorus; SID-Lys, standardised ileal digestible lysine; CF, conventional feeding strategy with a unique diet throughout gestation; SF, standard feeding strategy with supplied adjusted to individual energy requirements; PF_{AA}, precision feeding strategy with energy and SID-Lys supplied adjusted to individual requirements; $PF_{AA\text{-}P}$, precision feeding strategy with energy, SID-Lys and ATTD-P supplied adjusted to individual requirements; RSD, residual standard deviation.

[1] Retention calculated using equations of Dourmad et al. (2008), (2021) and BW and BT at insemination and farrowing.

[2] Urine output equals intake – (retention + faecal output).

[3] Faecal output calculated based on non-digestible N and P in feed intake.

[4] Efficiency of use equals retention/intake.

[a,b,c,d] Means within a row without a common superscript differ at $P < 0.05$.

4. Discussion

4.1. Prediction of body composition throughout simulation

The originality of our study is to use the simulation of the evolution of the chemical compartments during gestation through the nutritional model of Gaillard et al. (2019) and the equation of potential protein retention established by Dourmad et al. (1998) to fit estimated BW and BT with the model from the Eq. 1 with BW and BT observed at farrowing from the database.

The chemical equations available in the literature were mainly established on sows from 30 years ago (Whittemore and Yang, 1989; Everts and Dekker, 1995; Dourmad et al., 1997), whose productive performance no longer corresponds to the current one. Modern sows are leaner, weight more at the same age and produce more alive piglets per litter (+4 piglets; Muller, 2021; Bergsma et al., 2024). These equations use EBW and BT as predictors to estimate chemical composition because these data are easy to collect for each individual at the farm level compared to other methods such as the deuterium oxide dilution technique (Rozeboom et al., 1994) which requires infusing D_2O into the sow. However, these equations are dependent on the genotype used to establish them (Gill, 2006; Johannsen, 2025). If the sow line differs from the Large White x Landrace crossbreed used to establish these equations, the modeling results will have an increased margin of error. More recently, Miller et al. (2018) have established equations on non-gestating sows to link protein and lipid composition and body contents. They obtained more accurate results by adding sow parity as a predictor and obtained better predictions for protein composition ($R^2 = 0.93$) than lipid composition ($R^2 = 0.77$). Compared to the equation of Dourmad et al. (1997) used before calibration, calibrated equations in the current study degraded the final BW estimate by 2.9 kg of RMSE, while it improved the RMSE of the final BT by 5.2 mm. The adjusted parameters make it possible to better predict the BT observed at farrowing when estimating nutritional requirements. However, it should be noted that we have no data to validate the lipid content of individuals, given that the parameter linking BT to lipid content is multiplied by 3.8 compared with the initial situation. The lower precision of the BT measurement at P2 for assessing the total lipid content of the individual could explain this result (McEvoy et al., 2009). In addition, EBW is set at 0.96×BW as suggested by Dourmad et al. (2008) but lower than the range of 0.97–0.98 for a sow between 150 and 300 kg with the equation of Dourmad et al. (1997). The latter was developed with diets which energy content was greater, resulting in less digesta in the intestinal tract than current diets formulated with a greater fiber content (Serena et al., 2008). The setting of this coefficient has a unique value without considering BW. The use of sow BW at the transfer to the farrowing room minus conceptus weight instead of sow BW at farrowing may explain a fraction of the RMSE obtained for BW. Further research should investigate the protein deposition potential of sows to bring the available equations up to date with current sow performances.

A Weibull equation is usually used to evaluate sow BW according to its age and used to define the target BW at farrowing and associated requirements during gestation (Gaillard et al., 2020). The Weibull equation was adjusted on our farm data using a K-cross-validation procedure to avoid over-fitting the model to the training data and evaluate prediction performance with RMSE and MAE metrics. A RMSE of 15.9 kg for the fitted equation was obtained in the same range of values as the RMSE of 16.2 kg reported by Quiniou (2019) for a sow BW measured just after farrowing. In all cases, compared with an equation calibrated to data from another farm (Gaillard et al., 2020), the calibrated equation of the current study reduced by 4–6 kg the RMSE according to the number of K-splits between training and test datasets selected. Evaluating at the farm level allows to take into account the specific environmental conditions and management practices, which have a direct influence on sow BW. On a different note, Gauthier et al. (2022) were able to predict weaning litter weight better by adjusting parameters at farm level, which also reduced the time needed to estimate these parameters compared to fit on a multiple farm database. Taking into account data from sows that remained on the farm for a longer period, *i.e.* in our case at least five farrowing, reduced the RMSE by 2–3 kg compared with taking all the sows in the database.

4.2. Evaluation of feeding strategies regarding body characteristics, feed costs and nutrient excretion

By simulation, the evolution of BW and BT over six gestations was characterised with four different feeding strategies using the equations calibrated previously in this study. The BW varied slightly between strategies with values three times lower than the RMSE obtained, whereas BT showed greater variation between strategies over the cycles. The CF strategy resulted in sows with a greater BT at farrowing in the first three farrowing and a 2 mm lower BT than the other strategies in the sixth gestation, as well as a greater variability of BT at this time. In a previous *in vivo* study, Ribas et al. (2024) observed a lower BT for CF sows compared to PF sows at the third farrowing. However, the amount of feed delivered differed significantly between feeding strategies in their study, with a total difference of 111 kg over three cycles of gestation. In the current study, the difference was only 7.5 kg over three cycles between the CF strategy and the SF and PF strategies implemented, explaining a lower difference between feeding strategies on BT. A strategy that took into account the individual energy requirements of sows enabled to maintain the desired body characteristics. With the successive farrowings, this strategy reduces the variability of BT at farrowing, even with a similar average intake, and thus reduces peripartum risks (Muro et al., 2023).

In terms of feed costs, applying a feeding strategy adjusted to energy requirements alone required more feed than the CF strategy in our study, which automatically led to an increase in feed costs. However, taking into account the AA requirements of the animals resulted in the use of a less expensive diet because of its lower nutrient content on average during gestation. Hence, the PF_{AA} strategy resulted in savings 17 € on feed costs despite an extra supply of 15 kg over six gestations. Our results are in line with the literature (Gaillard and Dourmad, 2022; Cloutier et al., 2024) concerning a slight economic gain of 3 € per gestation with the application of a PF strategy adjusted on AA. Adding the ATTD-P requirements would improve these feed cost savings by 9 € over six gestations. These economic gains are relatively limited compared to the use of a single diet, but mineral precision feeding could bring benefits that indirectly impact costs, especially for the reduction of lameness and the lower risk of culling (Van Riet et al., 2013). Indeed, reducing the risk of lameness should improve the long-term performance of sows. Moreover, implementing such a strategy would also reduce P intake and excretion and, therefore, maximise P efficiency. Among the formulated diets, less than 1% of H_{Lys}-H_P was used by all the strategies, and less than 1% of L_{Lys}-S_P was used by the $PF_{AA\text{-}P}$ strategy, which may be difficult to use in commercial farms. Implementing a PF strategy in gestation requires major investments with the use of several silos for gestating sow diets and automatic feeders with multiple hoopers (Huber, 2025). To avoid multiple silos with a low-use diet, it might be possible, for example, to slightly increase the ATTD-P content of the S level to meet the needs of a larger number of sows and thus reduce the number of feeds and silos required while remaining below the total P limits set for gestating sow diets (Dourmad et al., 2016). As done in cattle (Uyeh et al., 2019), a multi-objective approach, that takes into account the needs of the sows in the herd when formulating feed (with the extremes of the needs for each nutrient), would reduce the number of feeds and favour minimum cost for the given production objective of the farm. In our specific case, we could reduce the SID-Lys content of the H_{Lys} diet.

The SID-Lys content of the standard diet is chosen to meet the requirements of the majority of sows in the herd at the end of gestation, when those are at their highest. Thus, during most of gestation, when requirements are lower, this single diet has a SID-Lys content too high in relation to requirements. Thus, as already demonstrated by Gaillard et al., (2020), Stewart et al., (2021) and Gaillard and Dourmad, (2022), the major benefit of PF_{AA} strategy lies in the savings in N excretion, ranging from −6% to −19%. These values are slightly lower than those simulated in our study (−26%), which could be explained by the low efficiency of use (% intake) obtained in our study. The method used to estimate the efficiency of use provides an overview of excretion based on weight gain, carcass leanness and chemical contents of the diets. Collecting excreta at the experimental level would yield more accurate numbers, which would certainly be greater than the current estimated efficiency. In our simulation, despite two distinct feeding strategies for ATTD-P supply, no difference in P retention was obtained. The equations used to estimate it are based on body proteins (Dourmad et al., 2021) while the major P stock is located in the bone (Crenshaw, 2001). Sows can mobilise their bone reserves to meet the needs of fetuses in the case of P or Ca deficiency during gestation. During lactation, their reserves are heavily mobilised for milk production (Van Riet et al., 2016). Criteria are seldomly available on farm to assess the evolution of sow bone mineral content through the reproductive cycle. The bone compartment should be added to better characterise P requirements through P flows and its interaction with Ca throughout gestation (Ribas et al., 2025). New equations linking feed intake to retention would make it possible to refine the effect of the feeding strategies for minerals.

4.3. Current challenges to simulate in the long-term

Our study focused on sow feeding strategies during gestation and its long-term effects on sow performance. We made the choice not to incorporate variability during lactation by averaging the body responses of individuals by parity and used a fertility of 100% during six gestations in order to obtain significant responses to the effects of sow feeding during gestation. There are two major points to consider with regard to our simulation results. The first point involves the individual nutrient requirements during lactation. Voluntary intake and feeding pattern during lactation depend on the sow (Van Gheluwe et al., 2025). Voluntary intake is negatively correlated with sow body reserves at the start of lactation (Zhou et al., 2018). A greater average daily gain of the litter associated with a greater milk production increases sow requirements (Gauthier et al., 2019). These factors influence the nutritional balance and consequently the mobilisation of reserves during lactation. The second point deals with sow fertility and longevity. In the long term, excessive variations in protein and fat reserves during the reproductive cycles encourage farmers to cull the sows early (Dourmad et al., 1994), *i.e.* before their fifth parity without reaching their full potential. This early culling can be explained by a drop in reproductive performances in sows with poor body conditions at farrowing and at weaning. In lactation, the disproportionate loss of muscle mass has a greater negative effect than weight loss on performance during subsequent gestation (Hoving et al., 2011b). Sows mobilising more than 12% of their body protein mass during lactation have a prolonged weaning to oestrus interval (Clowes et al., 2003), as sows with high productive performances and suboptimal nutrient intake (Bergsma et al., 2009). Excessive mobilisation leads to reproductive failure (Quesnel, 2005). It has a negative impact on ovulation rate (Hoving et al., 2011a; Rempel et al., 2015), and embryo quality for the next gestation (Strathe et al., 2017). It is therefore important to achieve optimal body condition at farrowing to stimulate sows to achieve optimal nutritional intake during lactation (Ren et al., 2017; Choi et al., 2019). In addition, the lactation nutritional strategy aims to minimise the mobilisation of maternal body reserves (Tokach et al., 2019) and thus maximise lifetime productivity. Strategies like PF could provide indirect gains through a reduced latency of heat return, and thus fewer unproductive days when the sow consumes feed. Also, PF strategies could result in fewer heterogeneous litters due to poor embryo quality at insemination.

Other factors such as health status, environmental conditions (Gaillard et al., 2021), social behaviours (Durand et al., 2023), productive performances and lactation length (Van Der Peet-Schwering and Bikker, 2019) should also be considered in the variation of response obtained between simulation and nutritional trials on farm. Simulation makes it possible to evaluate the effects of long-term strategies without the need for long and costly experiments. However, improvements to the model are needed, for example, better characterisation of specific periods, such as the end of gestation, with a different feeding program than used on other days of gestation.

5. Conclusion

Adjusting the weight and body composition equations at farm level enabled a more accurate assessment of the sow BW and BT through gestation and thus of their daily requirements. In the long term, compared with a CF diet, adjusting the sow diet according to their energy requirements, *i.e.* SF strategy, maintained the desired body condition at farrowing, and thus should reduce the potential risks peripartum and fertility issues for subsequent insemination. Applying a PF adjusted additionally for AA reduced feed costs by 17 € for six gestations and improved nitrogen use efficiency by 3 %age units. Making an additional adjustment to P increased feed cost saving by 9 € and improves P use efficiency by 3 %age units. Future studies could focus on sow individual responses (weaning to oestrus interval, litter size at birth) in consecutive lactations to fine-tune the evaluation of these strategies for sow longevity.

CRediT authorship contribution statement

Rob Bergsma: Supervision, Resources, Data curation. **Xandra Benthem de Grave:** Writing – review & editing, Resources, Investigation. **Charlotte Gaillard:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Nathalie Quiniou:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Lisanne M.G. Verschuren:** Writing – review & editing, Supervision, Resources. **RIBAS Clément:** Writing – original draft, Visualization, Software, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors did not use artificial-intelligence-assisted technologies in the writing process.

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Declaration of Competing Interest

The authors report no declarations of interest.

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