Modeling energy and amino-acid requirements of sows: a way towards the optimization of nutritional supplies

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ABSTRACT: In the recent years, the reproductive performance of sows has been drastically improved. Nowadays, in many farms, with the use of hyperprolific sows, the average litter size exceeds 14 piglets at farrowing and 12 at weaning. These changes in performance have been the major drivers for the evolution of sow's nutritional requirements during pregnancy and lactation. At the same time, a large amount of scientific knowledge has been produced over the last twenty years allowing, with the use of mathematical modelling, a holistic approach of energy, amino acids and minerals supplies to sows. The aim of the present presentation is to describe how the current state of knowledge on sow nutrition can be included in an integrated model, as well as in a software tool, designed for end-users, mainly nutritionists in the pig industry and students in animal nutrition. Different examples are also shown to illustrate how the use of such a model can help in optimizing the productivity of sows, whilst considering new priorities such as the reduction of the environmental impact of pig production which can be achieved through a more precise adjustment of nutrient supply to requirement, with the perspective of precision feeding.

Introduction

In mammals, the process of reproduction, from conception to weaning, can be considered as directed to buffer the progeny from nutritional distress (Oldham, 1991), involving both homeostatic and homeorhetic controls of nutrient partitioning. Reproductive problems, which may result in a reduction of the sow productivity and early culling, are often related to extreme variations in body reserves (Dourmad et al., 1994). During gestation, sufficient body reserves must be built to restore adequate body condition at farrowing and compensate for possible nutritional deficits that may occur in the following lactation. However, these reserves should not be excessive to avoid farrowing problems, which are typical for fat sows, or that may impair feed intake after farrowing (Dourmad, 1991). During lactation, it is recommended to adapt daily nutritional supplies to requirements to maximize milk production and growth of the piglets, and to minimize the risk of reproductive failure after weaning. In the past, most attention has been paid to the role of body fat reserves. However, recent results in high producing lean animals suggest that body protein mass also play an important role (Quesnel et al., 2005). Consequently, nutritional supplies to sows have to be modulated to maintain body reserves so that the sows will be in optimal condition throughout their productive life, thereby optimizing reproductive performance. On farm, this requires adjusting the feeding level and feed composition according to the performance of individual sows but also to housing conditions, which may affect nutrient utilization and voluntary feed intake.

Over the last 20 years reproductive performance of sows has been drastically improved. Maternal lines, most often Landrace and Large White breeds, have been intensively selected for prolificacy and, nowadays, hyperprolific sows are available in most countries. In some cases, the use of Chinese breeds in cross breeding or synthetic lines also contributed to that improvement of prolificacy. The selection for improved growth performance and carcass quality resulted in decreased sow body fatness and heavier mature body weight and size. The changes in sow performance have had major effects on their nutritional requirements. During pregnancy, the increase in prolificacy affects nutrients requirements for litter growth, especially during the last weeks of pregnancy. During lactation, the drastic increase, up to 100%, in milk production and litter growth rate results in an important increase of nutritional requirements, whereas sow's spontaneous feed intake remained quite constant and insufficient to meet energy requirements.

At the same time, from the results obtained in the last twenty years on energy, amino acid and minerals utilisation in sows, it has become possible to improve the determination of nutrients requirements through the development of models and decision support tools, such as InraPorc® (Dourmad et al., 2008), allowing a global approach to better understand nutrient use by sows.

The purpose of this paper is to illustrate how the use of such a model can help in optimizing the productivity of sows, whilst considering new priorities such as the reduction of the environmental impact of pig production which can be achieved through a more precise adjustment of nutrient supply to requirement. Because the reliability of the outcome of a simulation depends on the concepts used in the model, it is essential that model users have some knowledge about the model structure and the limitations of its use. For the purpose of this paper, we will focus only on the feed and sow modules of InraPorc (INRA, 2006). The tool can be downloaded from http://w3.rennes.inra.fr/inraporc/.

General description of the sow module of InraPorc

In InraPorc, the sow is represented as the sum of different compartments (i.e., body protein, body lipids, body energy, body minerals and uterus) which change during the reproductive cycle (Fig. 1). The main nutrient flows are energy, amino acids and minerals. In gestating sows, priority is given to maintenance requirements, physical activity and thermoregulation, requirements for the fetuses and the development of uterus and mammary gland. If the nutrient allowance exceeds these requirements, nutrients in excess contribute to the constitution of the sow body reserves. Conversely, body reserves can be mobilized when the nutrient demand is greater than the nutrient intake, especially in late gestation. In lactating sows, priority is given to maintenance and milk production, and body reserves often contribute to the supply for these priority functions. The different equations describing the utilization of nutrients and energy by gestating and lactating sows were derived from the literature and used to build a computerized simulator (Dourmad et al., 2008). This simulator determines on a daily basis the flow of nutrients and energy from the feed to storage in the body, excretion or dissipation.

Other functionalities were added to the simulator so that it can be used as a decision support tool (Fig. 2). An animal module ("*sow profile*") is used to describe the animal's characteristics. Three other modules are used to describe the types of feeds used ("*feed sequence plan*"), the quantity of feed consumed ("feed rationing plan") and the housing conditions ("*housing plan*"). The sow module is connected to the "*feed*" module that can be used to calculate dietary nutrients from feed ingredients using the INRA-AFZ (2004) database. When defining the sow profile, a calibration procedure is used to adjust some model parameters for each specific sow genotype/phenotype in relation to observed traits in a reference situation. This calibration is based on an automated optimization procedure that minimizes the difference between observed and predicted performances.

The model can then be used to determine the nutritional requirements according to a classical factorial approach, or to predict performance and analyze nutrient utilization, including nutrient excretion, through simulations. In the current version of the software, reproductive performance data (*ie* litter size, piglet weight, milk production) are considered as user inputs and are therefore not sensitive to nutrient supply.

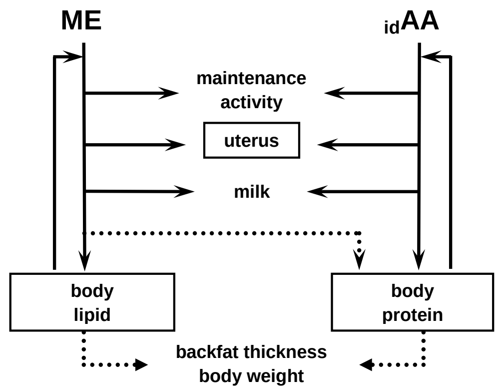

Figure 1. Description of nutrient utilization in InraPorc sow model (Dourmad et al., 2008).

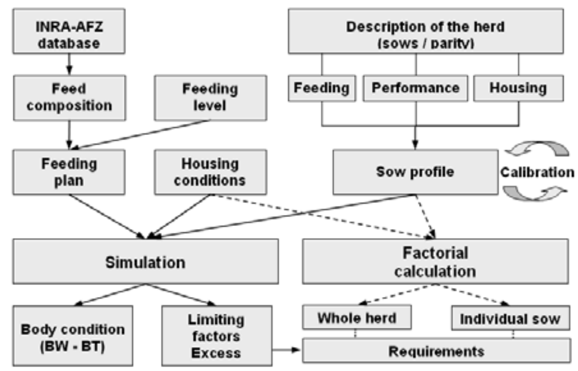

Figure 2. Description of InraPorc decision support tool for sow nutrition (Dourmad et al., 2008).

As an example of the use of InraPorc, the energy, amino acid and P requirements of sows from a herd weaning 30 piglets per sow per year, with respectively 13.8 and 12.1 piglets born alive and weaned per litter, have been calculated (Table 1). The daily energy requirement during gestation increases from parity 1 to parity 3 and remains constant thereafter. Conversely, the amino acid requirement (lysine), expressed per day or per kg feed, decreases with parity.

Table 1. Estimation of the average requirements for net energy, standardized ileal digestible lysine and apparent fecal digestible phosphorus (P) of sows according to parity[a]

Parity	1	2	3	4	5	6
Gestation *(at thermoneutrality)*						
Net energy, NE MJ /d	25.7	28.3	28.4	27.7	27.7	27.6
Digestible lysine[b]						
g/d	14.3	13.5	12.8	12.4	12.2	12.1
g/ kg feed	5.3	4.5	4.3	4.2	4.2	4.1
Digestible P[b]						
g/d	7.5	7.7	7.7	7.4	7.3	7.2
g/ kg feed	2.8	2.6	2.6	2.5	2.5	2.5
Lactation *(3.0 kg/d litter weight gain)*						
Net energy, ME MJ/d						
Requirement	73.9	77.5	81.7	82.5	82.0	81.2
Intake	51.2	59.2	64.7	64.7	64.7	64.7
Intake, % requirement	69%	76%	79%	78%	79%	80%
Digestible lysine[c]						
g/d	48.5	49.8	51.7	51.7	51.1	50.4
g/ kg feed	9.0	8.0	7.6	7.6	7.5	7.4
Digestible P[c]						
g/d	17.9	18.7	19.7	19.8	19.6	19.4
g/ kg feed	3.3	3.0	2.9	2.9	2.9	2.8

[a]calculated for a herd with an average productivity of 30 piglets weaned per sow per year, a mature body weight of sows of 270 kg, and an average herd lactation feed intake of 6.4 kg/d.
[b]SID lysine and digestible P requirement are calculated for the last month of gestation and for a diet containing 9.4 MJ NE/kg.
[c]for a diet containing 9.5 MJ NE/kg

The energy requirement for lactation also increases up to parity 4. On average, voluntary energy intake is sufficient to meet 77% of the energy requirement during lactation, with a lower coverage in primiparous sows (69%). During gestation, the amino acid requirement per kg feed is higher for first and second parity sows, mainly because of a lower feed intake and the further accretion of lean body mass.

Using the factorial calculation of requirements it also possible to evaluate the effect of stage of pregnancy or prolificacy, on SID amino-acid or digestible P requirements (Table 2), as well as the effect of litter growth rate and sow appetite on requirements during lactation (Table 3).

Table 2. Effect of litter size and stage of gestation on digestible phosphorus and SID lysine requirements of pregnant sows (parity 2)

Gestation stage		beginning (0-80d)	end (80-114d)		
Litter size			12	14	16
Digestible P	g/d	3.8	6.9	7.4	7.9
	g/kg diet	1.4	2.5	2.6	2.8
SID lysine	g/d	8.9	11.9	12.7	13.6
	g/kg diet	3.1	4.3	4.5	4.8

Table 3. Digestible phosphorus and SID lysine requirement of lactating sows according to litter growth rate and sow feed intake (parity 2)

Litter growth rate, g/d	2250	2500	2750	3000	3250
Digestible phosphorus					
g/d	14.7	16.0	17.3	18.5	19.8
g/kg (4 kg/d feed intake)	3.68	4.00	4.33	4.63	4.96
g/kg (5 kg/d feed intake)	2.94	3.20	3.46	3.70	3.96
g/kg (6 kg/d feed intake)	2.45	2.67	2.88	3.09	3.30
Digestible lysine					
g/d	40.3	43.3	46.4	49.4	52.5
g/kg (4 kg/d feed intake)	10.1	10.8	11.6	12.4	13.1
g/kg (5 kg/d feed intake)	8.1	8.7	9.3	9.9	10.5
g/kg (6 kg/d feed intake)	6.7	7.2	7.7	8.2	8.7

Short and long term simulation of performance

Models can also be used to simulate the short- and long-term effects of different housing or feeding strategies on nutrient utilization and body condition of the sows. The existence of nutrient deficiencies or excesses can be identified as illustrated in Fig. 3 which gives the example of simulation of energy and lysine utilization for a second parity sow over gestation and lactation.

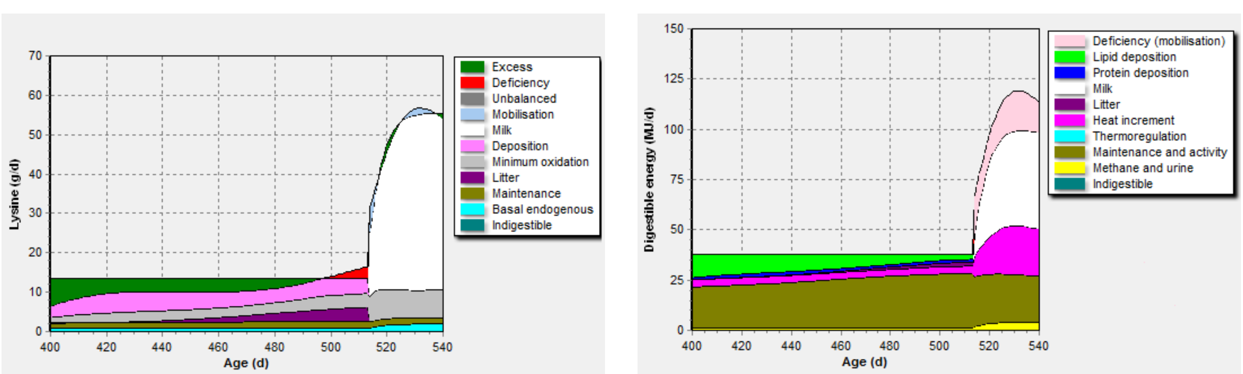

Figure 3. Example of a simulation with InraPorc of the dynamic partition of daily intakes of energy and digestible lysine over gestation and lactation, for a second parity sow.

Simulation approach can also be useful to predict the risk of an excessive mobilization or reconstitution of body reserves, which might impair long-term reproductive performance. As an example, the changes in body condition of sows for two phenotypes differing in average voluntary feed intake during lactation (L: 5.0 and H: 7.0 kg/d) were simulated over four successive parities. Feed supply during gestation was calculated so that sows attained mature body weight (BW) at parity 4, while maintaining a backfat thickness (BT) of at least 13 mm. The simulated evolution in BW and BT in these two situations is given in Fig. 4. The BW loss during lactation is much greater for L than for H sows, and this is compensated for by a higher weight gain during gestation. The same was observed for BT: L sows are leaner at weaning and fatter at farrowing. This results in an increased risk of reproductive problems in L sows, both at weaning because they are too lean, and at farrowing because they are too fat. Average daily feed intake over the complete reproductive cycle (3.5 kg/d) does not differ between L and H sows. However, amino acid and digestible P requirements during lactation are much higher, per kg feed, in L than in H sows, whereas no noticeable difference is found during gestation.

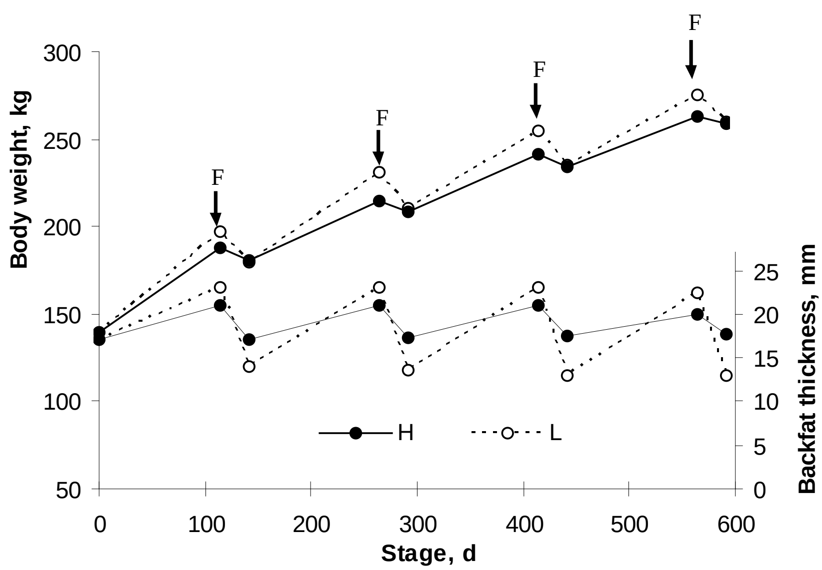

Figure 4. Simulated long-term effect of appetite during lactation (L: 5.0 kg/d, H: 7.0 kg/d) on the change in body weight and backfat thickness over the first 4 parities (F: farrowing) (Dourmad et al., 2008)

Dealing with the variability of requirements

An important question in the practical nutrition of sows is how to deal with variability in requirements among sows. This variability originates from variability in reproductive performance (*eg* litter size), in productive capacity (*eg* milk production), and appetite (*eg* during lactation). Moreover, the requirements also differ according to parity and physiological stage.

During gestation, the strategy to reach the target of body condition at farrowing is first to adapt the total energy or feed supply according to body condition at mating, parity, expected litter performance and housing conditions. In this context, measuring or estimating sow BW and BT is important to adapt the feeding allowance to the situation of each sow. This is illustrated in Fig. 5 with the data obtained from an experimental farm (Paboeuf et al., 2008) with a high productivity (30 piglets weaned per sow per year). Body weight of sows at weaning increases with parity (197 ± 18, 218 ± 19, 235 ± 21, 253 ± 21 kg for parity 1, 2, 3 and >3, respectively) whereas backfat thickness is more constant (13.2 ± 2.5, 12.7 ± 2.7, 12.4 ± 2.9, 12.5 ± 2.9 mm for parity 1, 2, 3 and >3, respectively). In all cases variability within parity is high resulting in a high variability in feed requirement (2.80 ± 0.26 kg feed per day).

When the total amount of feed or energy is defined, different strategies can be used to partition this amount over gestation. It is generally recognized that increasing feed allowance in late pregnancy, over the last three weeks, may improve piglet vitality and survival at birth, especially in hyperprolific sows. The optimal strategy during the first two-thirds of pregnancy is less clear and may depend on the type of housing and the available equipment for feed distribution. In Europe two strategies are mainly found in practice during that period: either a rather constant level of feeding, or a period of overfeeding of thin sows, over about 4 weeks, followed by a period of restriction. This second strategy, which allows a rapid reconstitution of sow body reserves in early gestation, is getting more common in the context of EU legislation on sow welfare, which requires group housing after 4 weeks of pregnancy. Defining a feeding strategy for gestating sows may also require adapting nutrient content (amino-acids, minerals, vitamins…) according to gestation stage and/or parity; although in practice the most common is still to use the same diet for all sows. Indeed, amino acid and mineral requirements decrease with parity and also vary according to gestation stage. Feeding the same diet for all pregnant sows results in an oversupply of nutrients in many situations and a risk of undersupply in late gestation, especially for primiparous sows. This could be improved by using two different gestation diets or multiphase feeding. The interest of such strategies will be described in the next section in the context of reduction of N and P excretion.

During lactation, nutrient requirements are mainly affected by milk production and appetite of sows. It is clear from the results presented in Table 1 that young sows have a lower appetite and should be fed a diet more concentrated in nutrients, especially amino acids and minerals. In practice, the appetite of lactating sows varies widely according to parity, ambient temperature, and body condition, etc. Moreover the potential for milk production varies among sows, increasing the variability of the requirement.

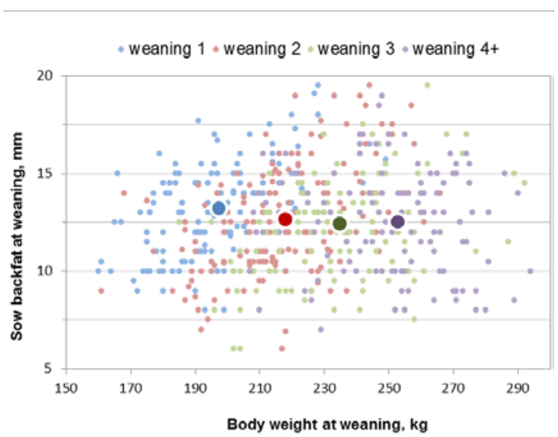

Figure 5. Variability in backfat thickness and body weight of sows at weaning (adap. from Paboeuf, 2008).

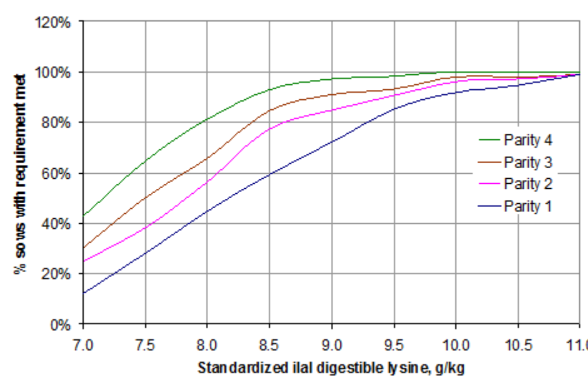

Figure 6. Effect of digestible lysine content on the % of lactating sows from different parities with their requirement met (adap. from Paboeuf, 2008).

Using individual data of litter growth rate (LGR) and feed intake from a farm with average LGR of 2970 g/d and feed intake of 6.5 kg/d, we calculated the digestible lysine requirement according to InraPorc. Average requirements for parity 1 to 4 amounted to 8.2 ± 2.7, 7.8 ± 2.5, 7.6 ± 2.4, 7.1 ± 2.2 g digestible lysine per kg feed, respectively. However, because of the variability, higher supplies are required to meet the requirements of all sows as illustrated in Fig. 4. For instance, to meet the requirement of 80% of all sows, a diet with 9.3 g/kg digestible lysine should be fed. From these results, the question could be raised of the opportunity of feeding a specific lactation diet for first parity sows or feeding a mixture of two diets differing in their nutrient content, according to the requirement of each sow.

Improving nutrient utilization and reducing excretion

As indicated in tables 1 and 2, nutrient requirements of pregnant sows, per kg diet, decrease with parity, and they are higher at the end than at the beginning of gestation. This means that the common feeding strategy in practice, with the same diet fed to all gestating sows, is not optimal in terms of nutrient efficiency or excretion, and can be improved by using two- or multi-phase feeding programs. Using InraPorc, we simulated three feeding strategies that differed in nutrient supplies during gestation. In the first feeding strategy all sows received the same gestation diet during the entire gestation period. In the second feeding strategy two gestation diets differing in their amino acid and mineral contents were formulated: a low-nutrient diet (3.8 g/kg SID lysine, 1.9 g/kg dig P) which was used during the first 80 days of gestation, except for first parity sows, and a high-nutrient diet (5.5 g/k SID lysine, 2.6 g/kg dig P) which was used in first parity sows throughout gestation, and in the other sows from d-80 of gestation. The third feeding strategy consisted in blend-feeding. Two diets differing in their amino acid and P contents (low: 3.0 g/kg SID lysine, 1.6 g/kg dig P; high: 5.5 g/kg SID lysine, 2.6 g/kg dig. P) were mixed in adequate proportions to meet, on a daily basis, the amino acid and phosphorus requirements, according to parity and stage of gestation. This can be realized in practice by using computerized automated feeding systems. The same lactation diet was used for all sows. All diets were formulated at least cost and other amino acid requirements were estimated from lysine according to the ideal protein for gestation.

The two-phase feeding strategy allowed for a much better adjustment of amino acids and P supplies to sow's requirements. With this strategy total consumption of crude protein, SID lysine and total P were reduced by 10%, 11% and 5%, respectively. This resulted in an average reduction of N and P excretion of 15% and 7%, respectively (Table 4). Further improvement was achieved by the use of blend feeding during gestation. Compared to the single-diet feeding strategy, blend strategy reduced intake of CP, SID Lys and total P by 14%, 17% and 9%, respectively, and N and P excretion by 20% and 13%, respectively (Table 5).

Table 4. Effect of different feeding strategies (One phase, Two-phase and blend feeding) of sows during gestation on N and P excretion, and cost of feed ingredients, over the whole gestation-lactation cycle.

	One-phase	Two-phase	Blend feeding
Cost of feed (€/sow)[1]			
Per cycle	80.7	76.0	74.4
% of strategy 1	100%	94%	92%
N excretion (g/sow)			
per cycle	8309	7071.5	6718
% of strategy 1	100%	85%	81%
P excretion (g/sow)			
per cycle	2150	1990	1875
% of strategy 1	100%	93%	87%

[1]with the prices of feed ingredients of 2010 in Western France.

The total cost of feed (gestation and lactation) was about 6% lower with the two-phase compared with the one-phase feeding strategy (Table 5), and 8% lower with blend feeding. This indicates that precision feeding of sows during gestation appears a promising approach to reduce N and P excretion whilst reducing feeding cost. It can be expected that similar benefits can also be expected from blend feeding of lactating sows.

Conclusion

Simulation models and decision support tools, such as InraPorc, can be used to evaluate feeding strategies for sows, from both a nutritional and environmental perspective. These tools address nutrient utilization in a dynamic way and allow identification of the limiting factors in the diets and/or excessive supplies. Knowledge on how N and P deposition evolve over time in relation to feed intake is essential if N and P excretion are to be reduced.

Adapting the feeding strategy during gestation to better account for the evolution of nutrient requirement appears a promising approach to reduce N and P excretion, without increasing feed cost. However, from a practical point of view, this may be difficult to achieve, especially in smaller herds. The two-phase feeding strategy during gestation requires differentiating the type of diets according to parity and stage of gestation. The multiphase or blend feeding strategy could be easier to adopt by using automated sow feeding stations. Moreover, this strategy allows to better account for the variability in nutrient requirements between sows, by considering individual body condition at mating.

For the future, different options can be identified for the evolution of sow nutrition models. The first approach would be to combine a sow nutrition model, such as InraPorc, and a sow farm model, such as the stochastic dynamic model developed by Martel *et al.* (2008). This would allow to better predict the individual variability of requirements. The second approach would be to use the set of equations from InraPorc model in order to develop algorithms for real-time calculation of nutrient requirements according to housing conditions and actual (and previous) performance of each individual sow, and implement these algorithms in automated sow feeders or feeding stations, as proposed by Pomar et al. (2010) for growing pigs.

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