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Contribution of modeling to the optimization of nutrient supplies to reproductive sows

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Introduction

In mammals, the process of reproduction, from conception to weaning, can be considered as directed to buffer the developing 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's productivity and early culling, are often related to extreme variations in body reserves (Dourmad et al., 1994). Nevertheless, body reserves should be considered more as an indicator of risk than as the cause of the problem. During gestation, sufficient body reserves must be built to restore adequate body condition 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. 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 problems of sows after weaning. 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.

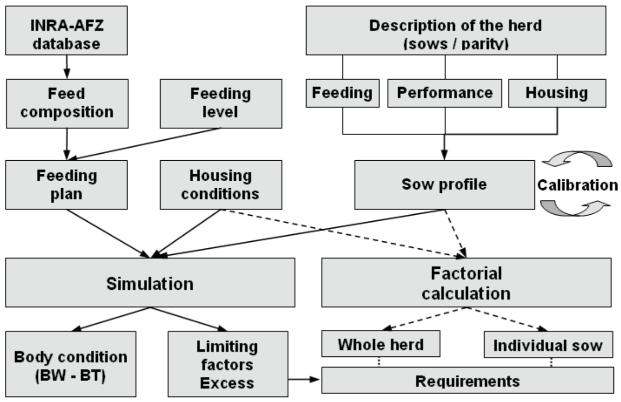
The experimental results obtained during the last 25 years on energy, amino acids and minerals utilization by the pregnant or lactating sow have been integrated in the InraPorc® model and decision support tool (Dourmad et al., 2008), allowing a global approach to better understand nutrient use by sows, including the resulting performance. This decision support tool includes a simulation model which represents on a daily basis (dynamic) the utilization of key nutrient pools (mechanistic) for a given sow (deterministic). The end-users of InraPorc® are mainly nutritionists and teachers and students in animal nutrition.

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 though 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. The tool can be downloaded from http://www.rennes.inra.fr/inraporc/. The growing pig module of InraPorc will not be addressed here, but a similar use of the model has been described by van Milgen et al. (2008).

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 and uterus) which change during the reproductive cycle. The main nutrient flows are energy, amino acids and minerals. In gestating sows, priority is given to maintenance requirements, 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's body reserves. Conversely, body reserves can be mobilized when the nutrient demand is greater than the nutrient intake. In lactating sows, priority is given to maintenance and milk production, and body reserves often contribute to the supply for these priority functions.

Figure 1. Description of the InraPorc® decision support tool for sow nutrition (Dourmad et al., 2008)



The different equations describing the utilization of nutrients by gestating and lactating sows were used to build a computerized simulator (Dourmad et al., 2008). This simulator determines 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. 1). An animal module ("sow profile") is used to describe the animal's characteristics and adjust some model parameters to account for variation in genotype and performance. 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" modules that can be used to calculate dietary nutrients from feed ingredients using the INRA-AFZ (2004) database. Amino acids supplies and requirements are expressed on a standardized ileal digestible (SID) amino acid basis (INRA-AFZ, 2004). The feed values and requirements for phosphorus (P) are expressed on an apparent fecal digestible basis. Energy is represented in the model as metabolizable energy (ME). However, a corrected ME value is calculated for the feed to account for the effects of diet composition on the utilization of ME according to the net energy (NE) system developed by Noblet et al. (1994). Energy requirements can be expressed as digestible energy (DE), ME or NE. 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.

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 the nutrient supply.

Factorial calculation of sow's requirements

As an example of the use of InraPorc, the energy, amino acid and P requirements of sows from a herd weaning 25 piglets per sow per year, with respectively 12.5 and 10.8 piglets born alive and weaned per litter are 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. The energy requirement for lactation also increases up to parity 5. On average, voluntary energy intake is sufficient to meet 83% of the energy requirement during lactation, with a lower coverage in primiparous sows (75%). 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.

The effect of different factors of variation (e.g. housing conditions or level of performance) on requirements can also be evaluated. In the previous example, when gestating sows are housed outdoors at 10°C ambient temperature, their energy requirement will be approximately 25% higher, while the lysine/energy requirement will be 20% lower (Table 1). Similarly, if the litter growth rate during lactation is higher (3.0 vs. 2.6 kg/d; +15%), energy and amino acid requirements increase by approximately 10%.

Table 1. Change in the requirements for 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 *(thermoneutrality)*						
Energy						
ME MJ /d	33.5	37.2	37.5	36.6	36.3	36.0
Dig. lysine						
g/d	13.5	12.9	12.2	11.8	11.6	11.4
g/ kg feed[b]	5.14	4.41	4.16	4.11	4.06	4.03
Dig. P						
g/d	7.1	7.4	7.4	7.1	6.9	6.8
g/ kg feed[b]	2.67	2.54	2.52	2.47	2.43	2.40
Lactation *(2.6 kg/d litter gain)*						
Energy, ME MJ/d						
Requirement	90.1	94.9	100.0	102.0	101.0	99.3
Intake	68.1	78.8	86.2	86.2	86.2	86.2
Intake, % req	75%	83%	86%	85%	85%	87%
Dig. lysine						
g/d	43.3	44.6	46.5	46.5	45.8	44.9
g/ kg feed[c]	8.3	7.4	7.0	7.0	6.9	6.8
Dig. P						
g/d	15.7	16.5	17.5	17.6	17.4	17.1
g/ kg feed[c]	3.22	2.93	2.84	2.86	2.83	2.77
Change in requirement (%)						
Gestation (*10°C)*						
ME supply	+24%	+25%	+27%	+29%	+30%	+31%
Lysine supply	-19%	-20%	-21%	-22%	-23%	-24%
Lactation *(3.0 kg/d litter weight gain)*						
ME supply	+11%	+10%	+10%	+10%	+10%	+10%
Lysine supply	+10%	+10%	+10%	+10%	+10%	+10%

[a]calculated for a herd with an average productivity of 25 piglets weaned per sow per year, with sows with a mature body weight of 270 kg and an average herd lactation feed intake of 6.2 kg/d.
[b]for a diet containing 12.7 MJ ME/kg,
[c]for a diet containing 13.0 MJ ME/kg

Short and long term simulation of performance

InraPorc can also be used to evaluate the short- and long-term effects of different housing or feeding strategies on nutrient utilization and body condition of the sows. The information required for running such a simulation and an example of the predicted responses are given in Table 2 for a first parity sow. In practice, these simulations can be useful to predict the risk of an excessive mobilization or reconstitution of body reserves, which might impair long-term reproductive performance.

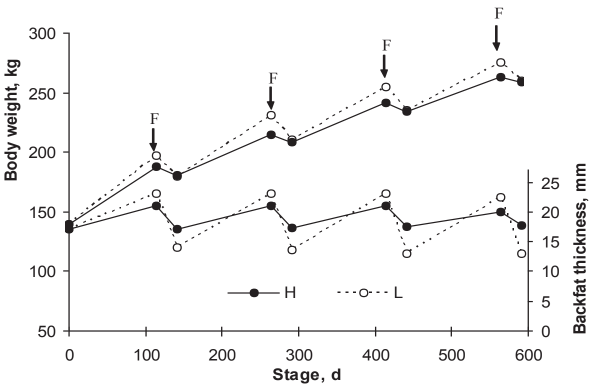
Table 2. Example of a simulation for a primiparous sow during pregnancy and lactation (Dourmad et al., 2008)

Sow and litter characteristics			
Animal profile	Large White x Landrace (270 kg body weight at maturity)		
Housing	Indoor on slatted floor		
Feeding	Standard gestation/lactation sequence		
	Born alive	**Weaned**	**Gain/d**
N° piglets	12.0	10.3	
Piglets, kg	1.40	8.00	0.244
Litter, kg	16.8	82.7	2.520

Simulated sow performance	Gest.	Lact.	Total[1]
Duration, d	114	27	149
Feed intake			
Total, kg	308	135	463
Total, kg/d	2.70	4.98	3.11
Body weight, kg			
Initial	140.0	198.0	140.0
Final	223.2	174.4	177.8
Total gain	83.2	-23.6	-
Net gain	58.0	-23.6	37.8
Backfat, mm			
Initial	14.0	19.0	14.0
Final	19.0	13.6	14.3
Gain	5.0	-5.4	0.3
Deposition, g/d			
Protein	73	-81	44
Lipid	171	-457	59
Milk, kg/d	-	8.85	-

[1]including period from weaning to mating

Figure 2. 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)



The existence of nutrient deficiencies or excesses can also be identified. For 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. 2. 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 is 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, SID Lys 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.

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 production capacity (*eg* milk production), and appetite (*eg* during lactation). Moreover, the requirements also differ according to parity and physiological stage.

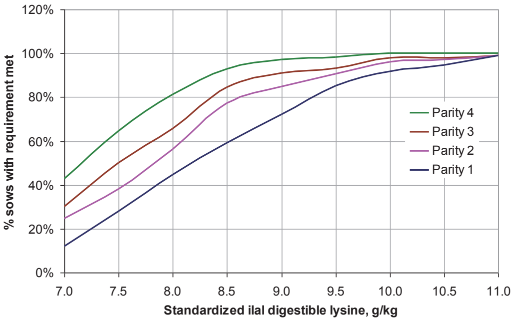
During gestation, the strategy to reach the target of body condition at farrowing is first to adapt the total energy or feed supply according to body condition at mating, parity, expected litter performance and housing conditions. In this context, measuring or estimating sow's BW and BT is important to adapt the feeding allowance to the situation of each sow. 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 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. 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's body reserves in early gestation, is getting more common in the context of the European regulation on sow welfare which requires group housing after 4 weeks of pregnancy. The other question about sow feeding during gestation is the interest of changing diet composition according to parity or gestation stage. Amino acid and mineral requirements decrease with parity and also vary according to gestation stage as illustrated in Fig. 4. 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.

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. Requirements for parity 1 to 4 amounted to 8.20±2.68, 7.81±2.53, 7.60±2.44, 7.10±2.15 g/kg digestible lysine, respectively.

However, because of the variability, higher supplies are required to meet the requirements of all sows as illustrated in Fig 3. 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 feeding a specific lactation diet for first parity sows.

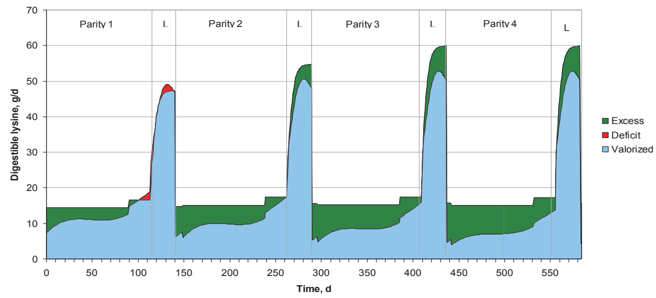
Figure 3. Effect of digestible lysine content on the % of lactating sows from different parities with their requirement met (unpublished data).



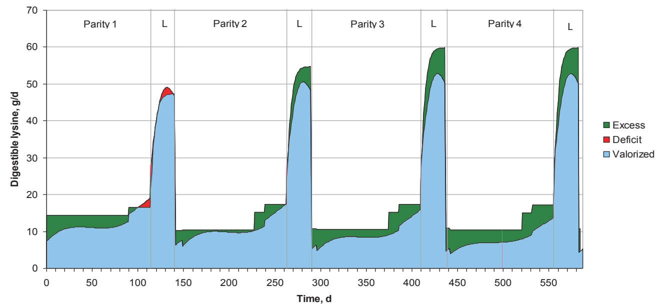
Improving nutrient utilization and reducing excretion
To improve the efficiency of nutrient utilization and consequently reduce excretion a first approach is to ensure an adequate protein and amino acid supply over time according to the production potential and physiological status of the animals (Rigolot et al., 2010). In sows, nitrogen (N) and P excretion can be reduced by 20 to 25% when specific diets are allocated for gestation and for lactation instead of providing a single diet for the whole period (Dourmad et al., 1999). In practice, this is already achieved in most farms. Nevertheless, excretion could be reduced even further by using two- or multi-phase feeding programs during gestation. However, this requires a precise evaluation of requirements, which can be achieved using modeling approaches.
Using InraPorc, we simulated over four parities the utilization of SID Lys by sows, with three different feeding strategies that differed in nutrient supplies during gestation. In the first feeding strategy (a) the sows received a single gestation diet during the entire gestation period and a lactation diet during lactation. The feeding level during gestation was adjusted according to body condition at mating and the objective at farrowing, and increased by 400 g/d during the last 3 weeks of gestation. During lactation, feed intake was assumed to be close to ad libitum. The composition of the diets is given in Table 3 and diets were formulated on a least–cost basis. From the results presented in Fig. 4a, it is clear that the digestible lysine requirement is much higher at the end than at the beginning of gestation. Moreover, the lysine requirement decreases with parity and this decrease is even more marked when the requirement is expressed per kg of feed rather than per day. This means that when the same diet is fed to all gestating sows, the amino acids and protein supplies exceed the requirement, especially during the beginning of gestation and in older sows. This can be improved by feeding two different diets for gestating sows, depending on parity and gestation stage. This strategy was evaluated (Fig. 4b) and two gestation diets were formulated differing in their amino acids and protein contents. The first diet contained 3.8 g digestible lysine and 102 g crude protein (CP) per kg of feed. It was used during the first 80 days of gestation, except for first parity sows. The second diet contained 5.5 g digestible lysine and 145 g CP per kg of feed and was used in first parity sows throughout gestation, and in other sows from d-80 of gestation. Other amino acids were supplied according to the ideal protein requirement. This two-phase feeding strategy allowed for a much better adjustment of amino acids supplies to sow's requirements

Figure 4. Simulated effect of different gestation feeding strategies on the utilization of ileal digestible lysine (a): one diet, (b): two diets in multiparous sows with a change at 80 d of gestation, (c): two diets mixed in adequate proportions to meet lysine and apparent digestible phosphorus requirements, and on the utilization of digestible phosphorus (d) with the same feeding strategy as (c)

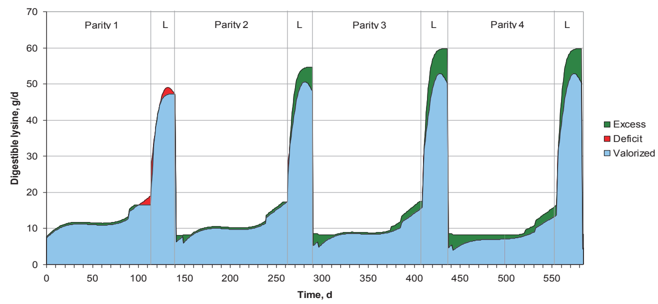
(a)



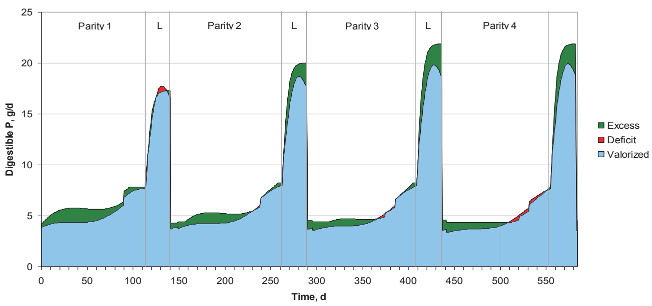
(b)



(c)



(d)



With this strategy total consumption of CP and SID Lys were reduced by 10 and 11%, respectively. This resulted in an average reduction of N excretion of 15% over the four parities (Table 3).

Further improvements can be achieved by the use of multiphase feeding during gestation. This can be realized in practice by using computerized automated feeding systems. Two gestation diets were formulated differing in amino acids and CP contents. The first and the second diets contained 3.0 g digestible lysine and 99.7 g CP, and 5.5 g digestible lysine and 145 g CP per kg of feed, respectively. The two diets were mixed in adequate proportions to meet, on a daily basis, the amino acid (and digestible P) requirement (Fig. 4c). Compared to the single diet feeding strategy, the multiphase strategy reduced intake of CP and SID Lys by 14 and 17% respectively, and N excretion by 20% (Table 3).

With this strategy, over the four parities, gestation diets 1 and 2 contributed to 35 and 65% of total gestation feed intake, respectively.

Compared to the one-phase feeding strategy, the two-phase and the multiphase feeding strategies reduced consumption and excretion of P by 5 and 9%, and by 7 and 12%, respectively. When the change of feeding strategy was combined with phytase supplementation, P excretion was reduced by 20% between the extreme strategies.

Table 3. Effect of different feeding strategies of sows on the N and P excretion and the cost of feed ingredients.

	One-Phase	Two-Phase	Multi-Phase
Diet composition (g/kg)			
Crude protein			
Gestation 1	-	102.1	99.7
Gestation 2	145.0	145.0	145.0
Lactation	160.0	160.0	160.0
Digestible lysine			
Gestation 1	-	3.80	3.00
Gestation 2	5.50	5.50	5.50
Lactation	8.75	8.75	8.75
Cost of feed (€/sow)[1]			
Per cycle	80.7	76.0	74.4
Per day	0.550	0.518	0.507
% of strategy 1	100%	94%	92%
N excretion (g/sow)			
Per cycle	8309	7071.5	6718
Per day	56.6	48.2	45.8
% of strategy 1	100%	85%	81%

[1]with the prices of feed ingredients of 2009 in Western France.

The effect of the feeding strategy on feed cost is not easy to assess because of its high sensitivity to the relative price of the different feed ingredients. Moreover changing the feeding strategy may induce extra costs for storage or distribution of feed when the number of feeds used on the same farm increases. The cost of feed is about 6% lower with the two-phase compared with the one-phase feeding strategy (Table 3), and 8% lower with multiphase feeding. This indicates that improving the feeding strategy of sows during gestation appears a promising approach to reduce N excretion whilst reducing feeding cost.

Conclusion

Models and decision support tools such as InraPorc® can be used to evaluate different feeding strategies for sows (or growing pigs), from both nutritional and environmental perspective. These tools address nutrient utilization in a dynamic way and allow identifying 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 attain, 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 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.

The equations used in the InraPorc model could be used to develop algorithms to calculate nutrient requirements (Dourmad et al., 2008), which can then be implemented in an automated sow feeding station, as proposed by Pomar et al. (2010) for growing pigs

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