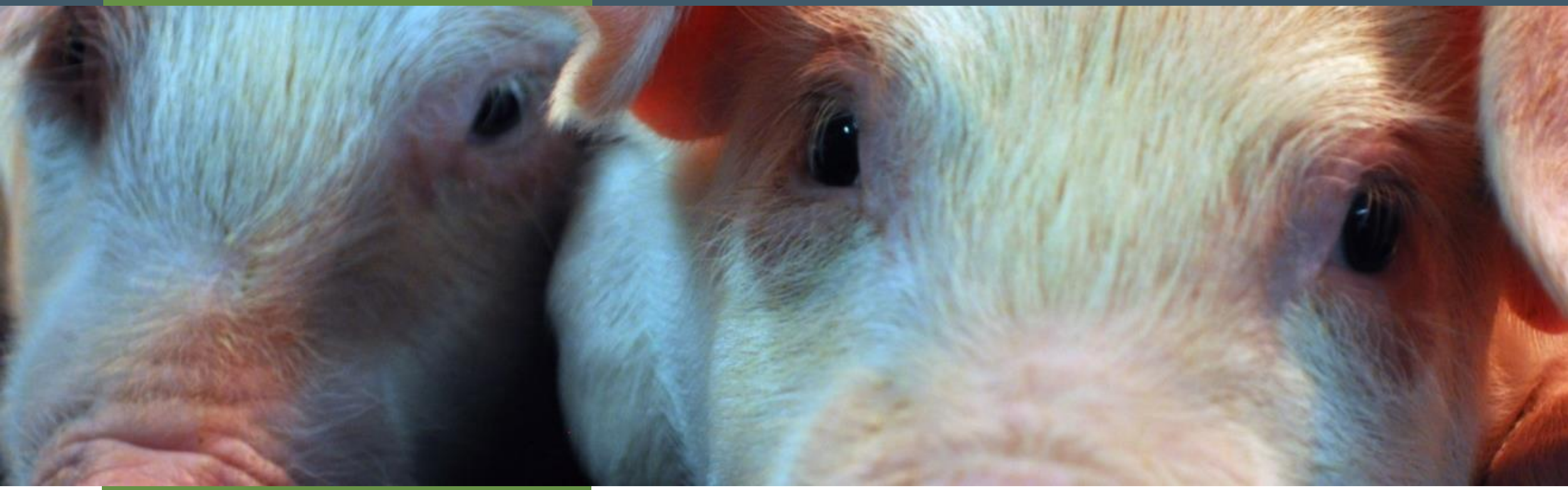
Evaluation using simulation of the nutritional and economic impact of a precision feeding strategy in gestating sows

October 2017 Report



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ISBN 978-2-924413-59-3

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Acknowlegements

This project has been made possible thanks to funding from the AgriInnovation Program, Industry-led Research and Development Stream in the Growing Forward2 (GF2) policy framework, a federal-provincial-territorial initiative and to the financial partnership with La Coop Seigneurie, JYGA Technologies, CDPQ, together with the Éleveurs de porcs du Québec.

Thanks also go to Dan Bussières from Groupe Cérès, Pierre Lessard from Olymel, Richard Bilodeau from F.Ménard, Marie Despars from Provimi, Emmanuelle Lewis from Agri-Marché and to Francis Simard from Shur-Gain, a Nutreco company for their time and advice in relation to this project.

Finally, thanks are due to La Coop fédérée and Shur-Gain, a Nutreco company, for the sow performance databases used for the simulations.

Summary

On today's farms, gestating sows are fed throughout the gestation (period) with a single feed of constant nutritional composition and this applies to all sows. Precision feeding in gestating sows involves the use of two feeds, one nutrient-poor and the other nutrient-rich. These are mixed in different proportions to more properly meet the sows' requirements.

This first part of the project aims to use simulation to assess the impact of precision feeding on the cost of feed for gestating group-housed sows, between Days 35 and 110 of gestation, i.e. between their time in the breeding area and the period in the farrowing unit.

The INRAporc ® estimation model was used for the analyses. A total of 2081 gestations from 1051 different sows were used for the simulations. Several scenarios were tested according to two feeding treatments (conventional feeding and precision feeding), different degrees of precision (individualized or parity values and according to average or targeted performances) and depending on the standardized ileal digestibility (SID) lysine (Lys) composition of conventional feed (0.50 and 0.55% Lys SID) and those used for precision feeding (0.65 and 0.70% for Feed A (rich) and 0.35, 0.40 and 0.45% for Feed B (poor)).

The results show that precision feeding makes it possible to better target end-of-gestation Lys (AA) requirements, and particularly for gilts where conventional feeding does not fully meet their Lys requirements. Concerning the degree of precision, specific feeding by litter order gave results comparable to individualized feeding. Given the amount of work involved in gathering individual data, feeding by litter order is a logical choice. Regarding the choice of Lys SID composition of the different feeds, this is very much influenced by the price context. For Feeds A and B, a change in the Lys composition of Feed A or B directly influences the use of the other feed and, depending on the price of the ingredients, it may sometimes be advantageous to vary the Lys compositions of these feeds. Finally, the results of the simulations show that precision feeding can substantially reduce the surplus of lysine and, consequently, the surplus of nitrogen. This would enable livestock farms to improve their environmental footprint.

To conclude, precision feeding has several advantages, the main ones being better feeding of sows at the end of gestation, better feeding of the gilts and a reduction in excess Lys. A commercial trial is currently underway to validate the actual impacts of precision feeding.

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1. Introduction and background

On today's farms, gestating sows are fed throughout gestation with a single feed of constant nutritional composition and this applies to the whole sow herd. Several studies have shown that the nutritional requirements of sows vary according to their stage of gestation (Levesque et al., 2011) and their individual characteristics such as weight, body condition, etc. (Pettigrew and Yang, 1997; Pomar, 2013). The lack of consistency between dietary intake and the needs of pregnant sows leads to wide fluctuations in sow body reserves, which affects the reproductive performance and sow longevity (Ball et al.,2008; Dourmad et al.,1994). For example, it is important to consider sow's age, since it has a significant effect on her nutritional needs. In fact, sows with litter order 1, 2 and even 3 continue to grow in addition to being pregnant, while sows with litter order 4 and above have reached their mature weight, meaning that their requirements are limited to their maintenance and gestation requirements. And so, this distinction between sows shows the relevance of developing feeding strategies that mean fed in a way that is tailored to their individual characteristics.

Precision feeding in gestating sows has been relatively little studied, but is now currently of interest due to, first, the change in management of sows, evolving from sow management in individualized crates to group-housing and, second, to the evolution of knowledge concerning precision feeding in pigs.

In particular, concerning changes in the management of gestating sows, the new Code of Practice for the Care and Handling of Pigs, released March 6, 2014, requires producers to group-house their gestating sows as of July 1, 2014 for all major renovation and new construction projects and starting July 1, 2024 for all producers (CSWSEP, 2014).This new sow management reality is raising a lot of interest now due, among other things, to the fact that the change in sow management to group-housing involves the purchase of new equipment, and leads producers to question whether it is worth their while to invest in precision feeding systems for blend feeding, i.e. a mix of two feeds which proportions change during the gestation.

Precision feeding has mainly been studied in finisher pigs (Pomar et al., 2015). Results of these studies indicate that this approach lowers feeding costs and improves nutrient utilization efficiency, especially of nitrogen (N) and phosphorus (P), thereby reducing emissions into the environment. The simulation work indicates that this approach would also be very promising for gestating sows (Bussières and Boyaud, 2013; Dourmad et al., 2013).

The aim of this project is therefore to evaluate the effect of precision feeding on the gestating sow on feeding costs, but also on zootechnical performances. Initially, simulations were done using sow performance databases to estimate the economic potential of this feeding strategy and to establish which model would be the most interesting to test in a commercial setting. This report focuses on this first phase of the project. In a second phase, the selected model will be applied in a commercial farm setting to validate the effects of precision feeding on the zootechnical performances of sows and their piglets. A second report will address the results of this second part of the project.

2. Objectives

The main objective of this work is to use simulation to evaluate the nutritional and economic impact of precision feeding of gestating sows.

More specifically:

- Using simulations, evaluate the nutritional and economic impact of the various models in the literature for estimating the nutritional requirements of gestating sows
- Given the large number of data records that some of these models require, simulate the nutritional and economic impact of simplified versions of these models
- Determine the model to be used for the experimental trial, according to which is the most interesting in terms of nutritional and economic impact and ease of implantation.

3. Material and methods

This section details the important milestones in meeting the projects objectives. First, to establish reference values, an estimation of individual lysine requirements (Section 3.3) was carried out. Subsequently, different feeding scenarios were developed (Section 3.4) and their lysine inputs were compared to baseline values (Section 3.5).The InraPorc® model (Section 3.1) and the observed data on thousands of gestations (Section 3.2) were utilized for all the stages of the project.

3.1 Estimation Models

The literature contains few models for estimating the nutritional requirements of gestating sows. The two main models are the National Institute for Agricultural Research InraPorc® model (Dourmad et al., 2008, 2013) and the NRC model (2012). The latter is also based mainly on the INRAporc® model.

The INRAporc ® model estimates sow maintenance requirements, fetal requirements (uterine content), requirements for uterine development, mammary gland development and sow growth requirements (Dourmad et al., 2013). These different types of requirements are determined according to several parameters: sow weight, back fat thickness, (P2), anticipated number of piglets, ambient temperature, physical activity, litter order and gestation stage. If the nutrients in the feed exceed sow requirements, the sow will use these nutrients for its body reserves in the case of energy or, in the case of protein and minerals, she will excrete them. The model makes it possible to determine the energy and protein requirements according to the desired weight and back fat gain during the gestation period, this in anticipation of the lactation period when mobilization of the reserves is important.
In summary, the procedure for determining the energy and nitrogen requirements of sows according to the INRAporc ® model is:

- Step 1: Establish the daily metabolizable energy for maintenance requirement (ME_m):
  $ME_m = f$ (Weight, additional activity, ambient temperature)

- Step 2: Establish the daily total nitrogen requirement (NR_{tot}) including nitrogen requirement for uterine (tissue) content (N_U):
  $N_{Rtot} = f$ (N_U, gestation day, litter order, available energy (ME_{Feed} – ME_{Ms}))
  or
  - N_U = f (litter size, average piglet weight, gestation day);
  - ME_{Feed} = metabolizable energy from feed;
  - ME_{Ms} = ME_M at breeding/mating;

- Step 3: Determine the daily metabolizable energy requirement for uterine content (ME_U), protein retention (ME_{PR}) and lipid retention in maternal tissues (ME_{LR}) :
  MEu = f (litter size average weight of piglets, gestation day, efficiency of the *ME* use for uterine deposits)
  ME_{PR} = f (maternal nitrogen retention (N_{Rtot} - N_U), protein retention efficiency, efficiency of the use of the ME for protein deposition)
  ME_{LR} = f (remaining energy, lipid retention efficiency, efficiency of ME for lipid deposition).

The lysine requirement is then determined simply by calculating 6.25 g of protein per g of nitrogen, 6.7% of lysine in the protein (Everts, 1994) and dividing by a lysine retention efficiency of 65% (Dourmad and Etienne, 2002). As example, Figure 1 shows the evolution of the lysine requirement per day of a litter order 3 sow. Readers interested in the details of these equations should consult Dourmad et al*.* (2008).

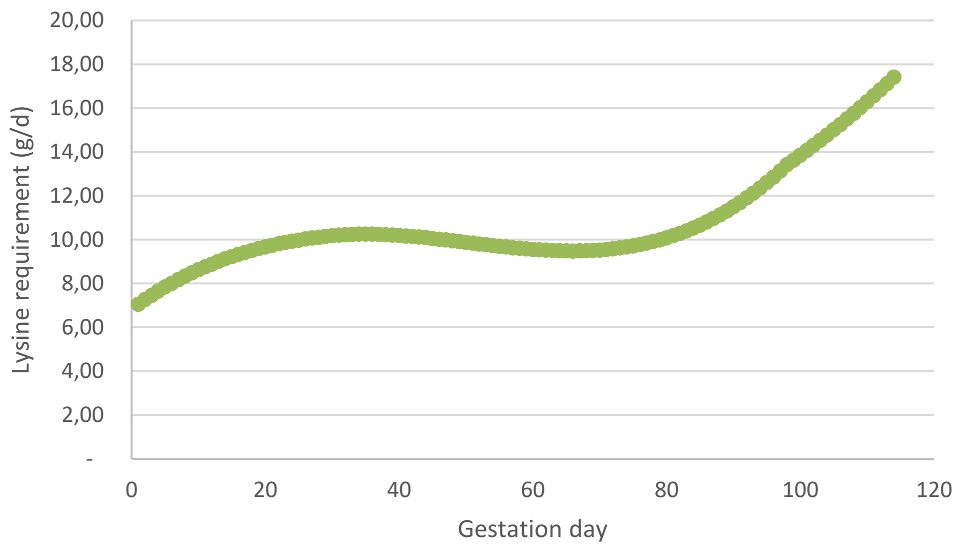

Figure 1. Lysine requirements of a litter order 3 sow according to gestation day; estimation made using InraPorc® software

Given that at present, the InraPorc® model is mainly used for herd feeding and, since performances vary from one herd to another, adjustment factors for the maintenance requirements and nitrogen retention were added to the model. These factors make it possible to adjust the requirements according to the actual zootechnical performances observed in each herd. Therefore, a producer can directly input the zootechnical performances of the previous batches into the INRAporc ® software and the model will adjust to his performances in order to better target the requirements of his herd. To estimate individual sow requirements using this model, these adjustment coefficients were used to adjust requirements to the individual performances actually observed (Section 3.3.1).

Regarding the NRC's nutritional needs assessment model, it is based largely on the INRAporc ® model although differences do exist (NRC, 2012). The main difference between the two models concerns the protein requirement, which is more fully decomposed. In fact, NRC's protein retention represents the sum of protein deposits associated with: protein deposition of the fetuses, breast tissue protein deposition, placental protein deposition, uterine protein deposition, and "energy intake-dependent and time-dependent maternal body protein deposition" (NRC, 2012).

The simulations in this project were done using only the InraPorc® model. Discussions with the researcher who developed the InraPorc® model led to the conclusion that both models would yield similar results (personal communication, Jean-Yves Dourmad, May 2016). In addition, thoroughly analyzing, understanding and then using a model to do simulations is quite complex besides which it was possible to collaborate throughout the project with the principal researcher who developed the INRAporc® model. For this reason, it was more logical to carry out the simulations using this model only. However, as mentioned earlier, the results observed in this project could very well be extrapolated to the NRC model.

3.2 Data Used

Researchers gathered the data on almost 8,000 gestations in commercial research farms for the project. Of these, 2511 gestations with a litter order less than, or equal to 8 had complete data for the input variables for the INRAporc ® model and could be used for the simulations. In the end, after the elimination of certain observations (see Section 3.3.1), 2081 gestations from 1051 different sows were retained. As well as the variables presented in Table 1, daily feed amounts for each sow were also used.

Table 2. Average characteristics by litter order for the gestations retained

Litter Order	Number of observations	Total number piglets	Weight piglets (g)	Weight at breeding (kg)	P2 at breeding (mm)	Weight after farrowing (kg)	P2 at farrowing (mm)
1	357	13.2	1406	163.0	17.7	205.4	19.2
2	329	13.3	1557	190.8	15.9	233.2	18.4
3	322	14	1523	209.5	15.0	246.8	17.9
4	314	14.8	1478	225.8	14.4	258.1	16.8
5	279	15	1469	233.8	14.2	265.2	16.4
6	211	14.8	1449	240.1	14.0	268.9	16.2
7	145	13.8	1440	244.6	14.4	272.5	16.3
8	124	13.8	1448	249.7	14.9	276.4	17.2
Total	**2081**	**14.1**	**1477**	**212.2**	**15.3**	**247.5**	**17.5**

3.3 Estimation of individual lysine requirements

The diagram in Figure 2 (left and centre sections) illustrates the approach used to estimate individual lysine requirements. Two sets of simulations were carried out using the INRAporc ® model.

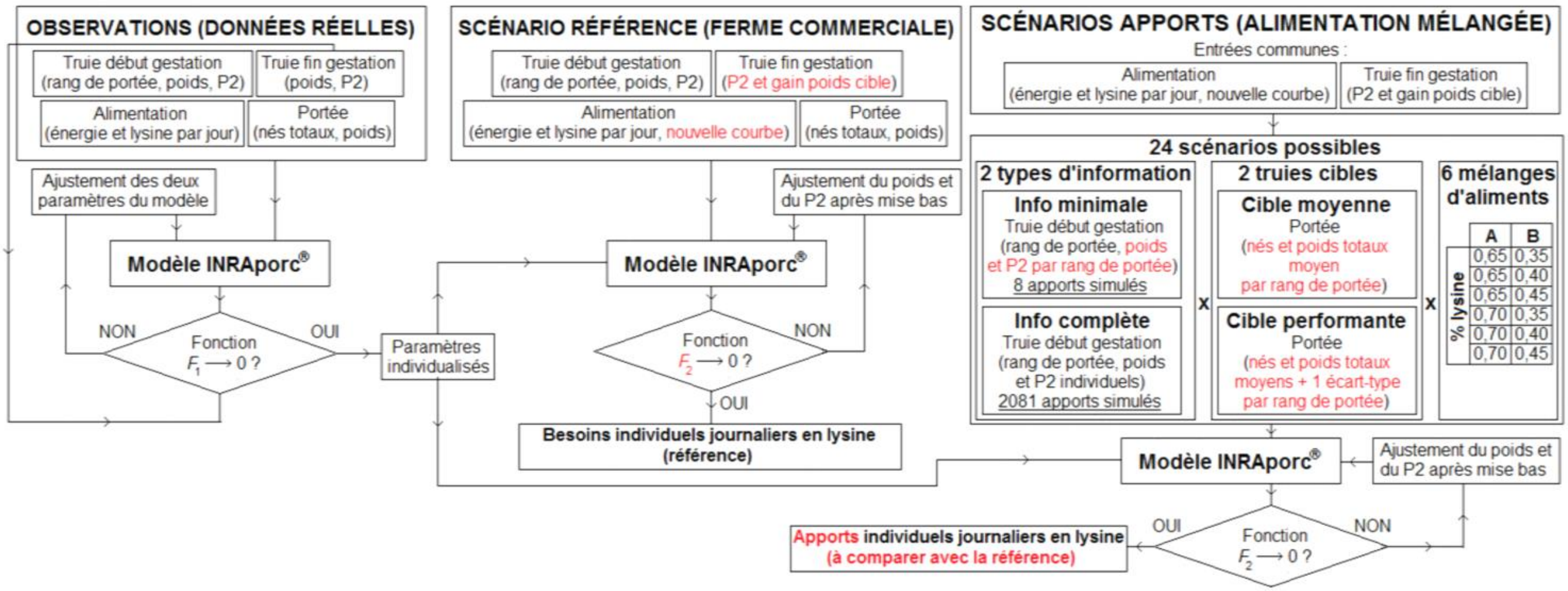

Figure 2. Diagram illustrating the estimation method for individual lysine requirements and intakes according to the different scenarios analysed

3.3.1 Calibration

The purpose of the first series of simulations (calibration simulations) was to obtain individualized parameters for each sow. The default values of the INRAporc ® parameters are considered correct to estimate the average requirements of a herd but they were not originally defined for the purpose of estimating individual needs. Therefore, two parameters, adjustment coefficients on maintenance requirement and nitrogen retention (Section 3.1) were adjusted for each sow. For this, the simulations were based on the data observed on-farm (Section 3.2). For each sow, litter order, weight at breeding, P2 at breeding, total number of births, litter weight and daily rations were entered into the model. The energy and lysine levels of the feed were not available but could be estimated in consultation with experts affiliated with these research farms. Observed weight and P2 data after farrowing were used when adjusting the parameters in this loss function:

$$F_1\left(c_1, c_2\right) = \left(X_{InraPorc}\left(c_1, c_2\right) - X_{obs}\right)^2 + \left(Y_{InraPorc}\left(c_1, c_2\right) - Y_{obs}\right)^2 \qquad (1)$$

where $X_{InraPorc}\left(c_1, c_2\right)$ and $Y_{InraPorc}\left(c_1, c_2\right)$ are the weight and P2 at-farrowing respectively simulated by the InraPorc® model with c_1 as the adjustment coefficient value in the nitrogen retention and c_2 as the adjustment coefficient value in the maintenance requirement; X_{obs} and Y_{obs} are the weight (kg) and the P2 (mm) observed at farrowing respectively. For each gestation, the selected parameter values minimized the function F_1. The GRG method (Generalized Reduced Gradient) ensured the convergence of the function F_1 to 0.

Two kinds of problem were encountered in the 2511 simulated gestations:

- For 25 gestations (1%), the function F_1 did not converge towards 0
- Even in cases where the F_1 function converged, the model sometimes arrived at lysine requirements considered improbable (e.g. feed lysine concentration > 1%).

To eliminate these two problems, only the 2081 gestations (83%) with nitrogen retention adjustment coefficient values ranging from 0.5 to 2 were retained.

3.3.2 Reference Values

A second series of simulations (reference simulations) was done with four modifications (shown in red on the centre section of Figure 2):

- This time the weight and P2 at farrowing are input into the model
- The weight and P2 values at farrowing used are not the observed values, but rather target values that could be applied on a commercial farm. The target weight at farrowing depends on the weight at breeding (Figure 3, on Left). The target P2 at farrowing was set according to the genetics of the sows used.
- The feeding regimen was modified to take into account what experts say are standard farm practices (Figure 3, on Right). For the first 35 days, different feed intakes were given for very fat sows (80% compared to an average weight sow), for fat (90%), lean (110%) and very thin (120%) sows. These classifications were given according to the P2. All sows followed the same feeding regimen from Day 36, with a 30% increase from Day 91.
- A new objective function F_2 targeting the sow's energy is used:

$$F_2 = \left(Z_{InraPorc} - Z_{target}\right)^2 \quad (2)$$

where Z_{target} and $Z_{InraPorc}$ are the energy of the target and simulated sow respectively. The energy equation is calculated as shown (slightly modified, compared to Dourmad et al., 2008):

$$Z_{target} = -1024.13 + 13.66\,X_{target} + 45.94\,Y_{target} \quad (3)$$

where X_{target} and Y_{target} are the targets for the weight (kg) and the P2 (mm) at farrowing, respectively. The variable $Z_{InraPorc}$ is calculated in the same way using the simulated weights and P2's.

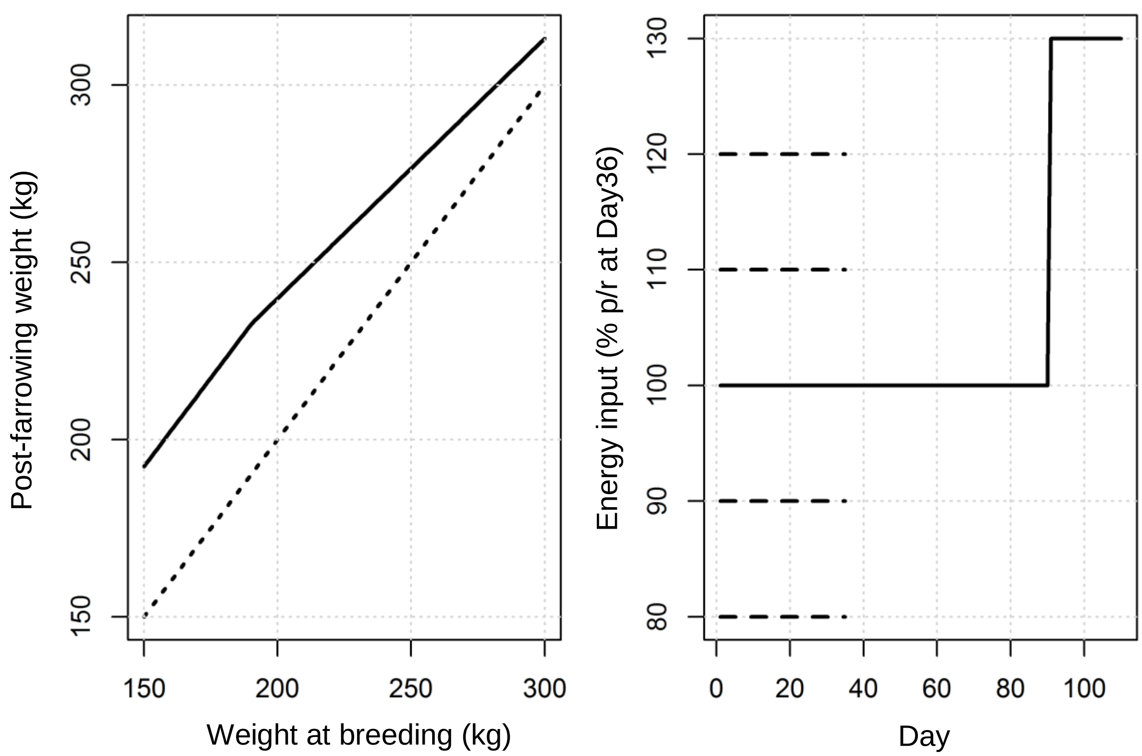

Figure 3. Left: Continuous line = Post-farrowing targeted weight according to weight at breeding. The difference between the continuous line and the dotted line is the target weight gain. Right: Energy feeding regimen for estimation of reference requirements.

The other variables remained unchanged from the calibration simulations and the individualized parameters were used. This is how 2081 daily series of lysine requirements representative of the actual requirements of gestating sows were estimated.

3.4 Feeding Scenarios Tested

The main goal of the project is to use simulation to evaluate the impact of precision feeding compared to conventional feeding. The impact of a feeding treatment also depends on factors such as the degree of precision (or simplification) taken into account and the choice of feed rations. The approach used to address these factors is detailed here:

3.4.1 Treatment

The two feeding treatments that were compared are:

- Conventional feeding: Sows are given only one feed *C*, throughout gestation;
- Precision feeding: Two feeds are mixed and given to the sow throughout gestation; *A* at a high concentration of lysine, and therefore of protein, and *B* at a low concentration. The proportion of each of the two feeds changes during gestation according to the targeted requirements (the proportion of the high-concentration feed increases during gestation).

The purpose of precision feeding is to better target lysine requirements compared to conventional feeding. Precision feeding can save costs by providing less lysine at the start of gestation and potentially improve performances by giving more at the end. In addition, it was assumed here that the conventional feeding is able to satisfy the energy requirements. Therefore, the feeds A, B and C considered in the simulations are isoenergetic (have the same energy). The feeding strategy (energy input per day) used for the reference simulations (Section 3.3.2, Figure 3, on right) was also applied to both treatments. However, instead of having one energy intake curve per individual, a total of two curves were kept: one for gilts and one for the other sows. The choice to keep two curves was made on the advice of experts, and according to the current on-farm practices. In both cases, the curve focuses on the average energy requirements arising from the reference simulations (Section 3.3.2).

The sole difference between the two treatments is the lysine intake. While it is constant (as a percentage of the feed) for conventional feeding, for precision feeding it increases with gestational day and varies from one sow to another. For this treatment, the choice of lysine intake curves per day is contingent upon the degree of precision targeted (shown here).

3.4.2. Degree of precision

Actual lysine requirements, estimated here by the reference simulations (Section 3.3.2), depend on variables that can be known at the start of gestation (weight, P2, litter order), but also on variables that are impossible to know precisely such as weight and P2 at farrowing, litter properties and sow potential, the individual differences of which are represented here by the two individuated parameters (Section 3.3.1). Thus, even if all the information that could be gathered in practice were considered in the development of a feeding scenario, it would be impossible to perfectly adjust inputs to actual requirements. In addition, information gathering may require substantial processing time and prove to be costly. From a practical and economic point of view, it may therefore be advantageous to collect a small amount of information, at the risk of possibly sacrificing the lysine intakes of certain sows.

Different scenarios were analyzed to identify a fair compromise between the lysine requirements to be filled and the amount of information to be gathered. Four combinations (two factors x two value levels per factor) were simulated using InraPorc® (Figure 2, on right). Intake values and sow targets at farrowing were the same as for baseline simulations, but data at breeding and about the litter were changed (shown in red in Figure 2 on right):

- Information gathered:
  - "Minimum": The weight and the P2 at breeding inputs are the averages by litter order (a daily lysine intake curve by litter order)

- "Complete": The litter order, weight and P2 at breeding of each sow are used as input (a daily lysine intake curve by gestating sow)

- Targeted sow (relative to neonates and total litter weights):
  - "Average": Average by litter order
  - "Productive": Average plus one standard deviation by litter order (corresponds roughly to the 84th percentile, as is the case for the normal distribution).

Means and standard deviations per litter order were determined from the 2081 gestations used (Section 3.2). The values "Minimum information" and "Average sow" have the benefit of their lower cost. The terms "Complete information" and "Productive sow" have the advantage of producing a better lysine intake.

3.4.3 Feed Choice

The impact of feed choice depends on the treatment. In conventional feeding, the challenge is to reach a reasonable compromise between costs and needs. Feed with a higher lysine concentration will cost more but will better meet end-of-gestation requirements. The best choice is not necessarily time-specific since it may depend on the price context. Based on current practice, two standardized ileal digestible lysine concentrations were retained for conventional feeding (Feed *C*): 0.50 and 0.55% (Figure 4).

For precision feeding, targeted lysine inputs (Section 3.4.2) can normally be achieved, except in some cases at the very end of gestation. Choosing a less high Feed *A* would increase the number of cases where the targeted intakes are not met. Conversely, the choice of a less high Feed *B* could lead to a lysine surplus for sows in early gestation. This being said, it remains that, in precision feeding, cost is the main influencing factor in the choice of feeds.

Evaluating the cost of precision feeding is more complicated than for conventional feeding. To compare two feeds in conventional feeding, it is enough to know the difference in price between the two feeds and multiply it by the quantity consumed. In the case of precision feeding, the choice of a Feed *B* that is higher in lysine (and therefore more expensive) could prove to be less costly, since it will lower the proportion of Feed *A* (the most expensive feed) to give to the animal. Based on expert opinion, 6 combinations of Feeds *A* and *B* were tested (Figure 2, on right); two of Feed *A* (0.65 and 0.70% lysine) were each tested with three of Feed *B* (0.35, 0.40 and 0.45%).

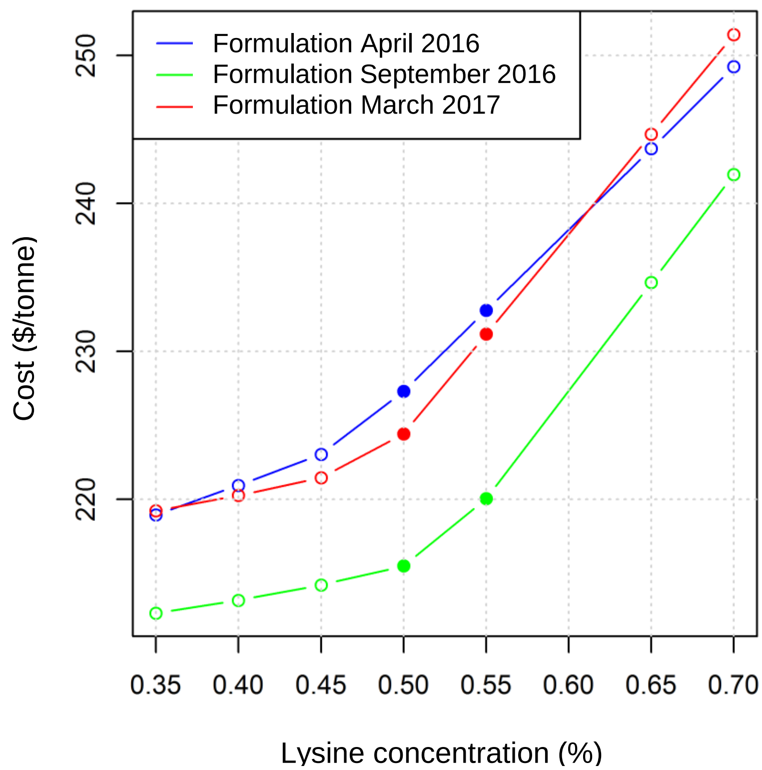

Figure 4. Cost of seven feeds formulated at three different times depending on the lysine level. Solid circles correspond to Feed *C* (conventional feeding). The empty circles on the right and left of the solid circles correspond to Feeds *A* and *B* respectively (precision feeding).

The impact of the price context was analyzed by integrating seven feeds (two *A*, three *B* and two *C*) formulated at three different times over a 13-month period (Figure 4). These feeds are isoenergetic and the ingredients may vary depending on availability and price. These feeds were used on three separate occasions to evaluate the different scenarios. This approach aims to represent the impact of precision feeding and feed selection in the context of real and practical application. It should be noted that a second approach to assessing the economic potential of longer-term precision feeding will be presented in a separate report.

3.5 Evaluation of the scenarios

In all, the 78 scenarios (Table 2), i.e. 26 feeding scenarios x 3 price context, were assessed according to three criteria: Economic, Nutritional and Environmental. In all cases, measurements were calculated on the 2081 gestations retained (Section 3.3.2). Average measurements by litter order were calculated and then a global average for a herd was calculated by weighing according to the proportions by litter order dataset in Table 3. In addition, the analyses specifically targeted gilts (Litter Order 1) that had higher lysine requirements (in%) compared to other gestating sows.

Table 3. Scenarios tested according to feeding treatment

Treatment	Factor Values Degree of precision x	Feed choice x	Price context =	Number of scenarios
Conventional feeding	-	2	3	6
Precision feeding	4	6 (3 *A* x 2 *B*)	3	72
			Total :	**78**

Table 4. Percentage of sows by litter order for the fictional herd used in evaluation of the scenarios.

Litter order	1	2	3	4	5	6	7	8	Total
Percentage of sows	20.0	17.7	15.7	13.3	11.3	8.7	6.3	7.0	100.0
Number of sows (fictional herd)	60	53	47	40	34	26	19	21	300

3.5.1 Economic

In this report, the economic feeding criterion is based only on the cost of food. Potential additional revenues related to precision will be estimated in Part Two of the project (commercial farm trial) and discussed in an upcoming report.

The cost is brought back to cost per year per sow assuming 2.5 gestations per sow per year on average. Two measurements were calculated: one takes the view that the treatments begin at the sow's exit from the breeding area (Day 36), and the other assumes that it is possible to start the treatment as soon as breeding starts (Day 1).

3.5.2 Nutritional

The nutritional criterion is defined according to the requirements that are met with lysine. Let $L_{d,k}$ be the lysine intake (in grams) with Scenario k (Section 3.4) on Day_d for a given sow, and R_d *the* reference lysine requirement (in g) on Day_d for the same sow (Section 3.3.2).The lysine deficit $D_{d,k}$, on Day_d with Scenario k for this sow is given by

$$D_{d,k} = \max\left(R_d - L_{d,k}, 0\right) . \quad (3)$$

This equation gives no advantage to a scenario that overfeeds lysine relative to a scenario that targets the lysine requirements. The relative cumulative deficit with Scenario k for a given sow was calculated over the entire period (Days 36 to 110):

$$D_{total,k} = \frac{\sum_{d=36}^{110} D_{d,k}}{\sum_{d=36}^{110} R_d} \quad (4)$$

and by targeting the end of gestation (as in Table 4) :

$$D_{end,k} = \frac{\sum_{d=91}^{110} D_{d,k}}{\sum_{d=91}^{110} R_d} \tag{5}$$

Table 4. Example of a relative cumulative deficit at the end of gestation (Equation (5)) calculated for a given sow and a given scenario.

Day	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**
Need (g)	13.6	13.8	14.0	14.2	14.4	14.6	14.8	15.0	15.2	15.4
Intake (g)	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Deficit (g)	0	0	0	0	0	0.1	0.3	0.5	0.7	0.9
Day	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**
Need (g)	15.5	15.7	15.9	16.1	16.3	16.5	16.7	16.9	17.0	17.3
Intake (g)	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Deficit (g)	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8
									Deficit Days 91-100 (g)	21.7
									Need Days 91-110 (g)	308.6
									Relative cumulative deficit (%)	**7.0**

The distribution of individual deficits at the end of gestation was also generated assuming a herd of 300 sows (Table 3). The j^e smallest relative deficit at gestation end for the Litter Order *i* ($i \in \{1,\ldots,8\}$) sows in the fictional herd for Scenario *k* denoted $D^*_{end,k}(i_d)$, is given by

$$D^*_{end,k}(i_d) = D_{end,k}\left(i_{\left(\frac{d}{n_{i+1}}\right)}\right) \tag{6}$$

where $D_{end,k}\left(i_{\left(\frac{d}{n_{i+1}}\right)}\right)$ is the order quantile $\frac{d}{n_i+1}$ of the relative deficit at gestation end for Scenario *k* calculated based on the reference requirements (Equation (5)) only on Litter Order *i sows* and where n_i is the number of Litter Order *I* gestations in the reference data (Table 1). Figure 5 illustrates the procedure.

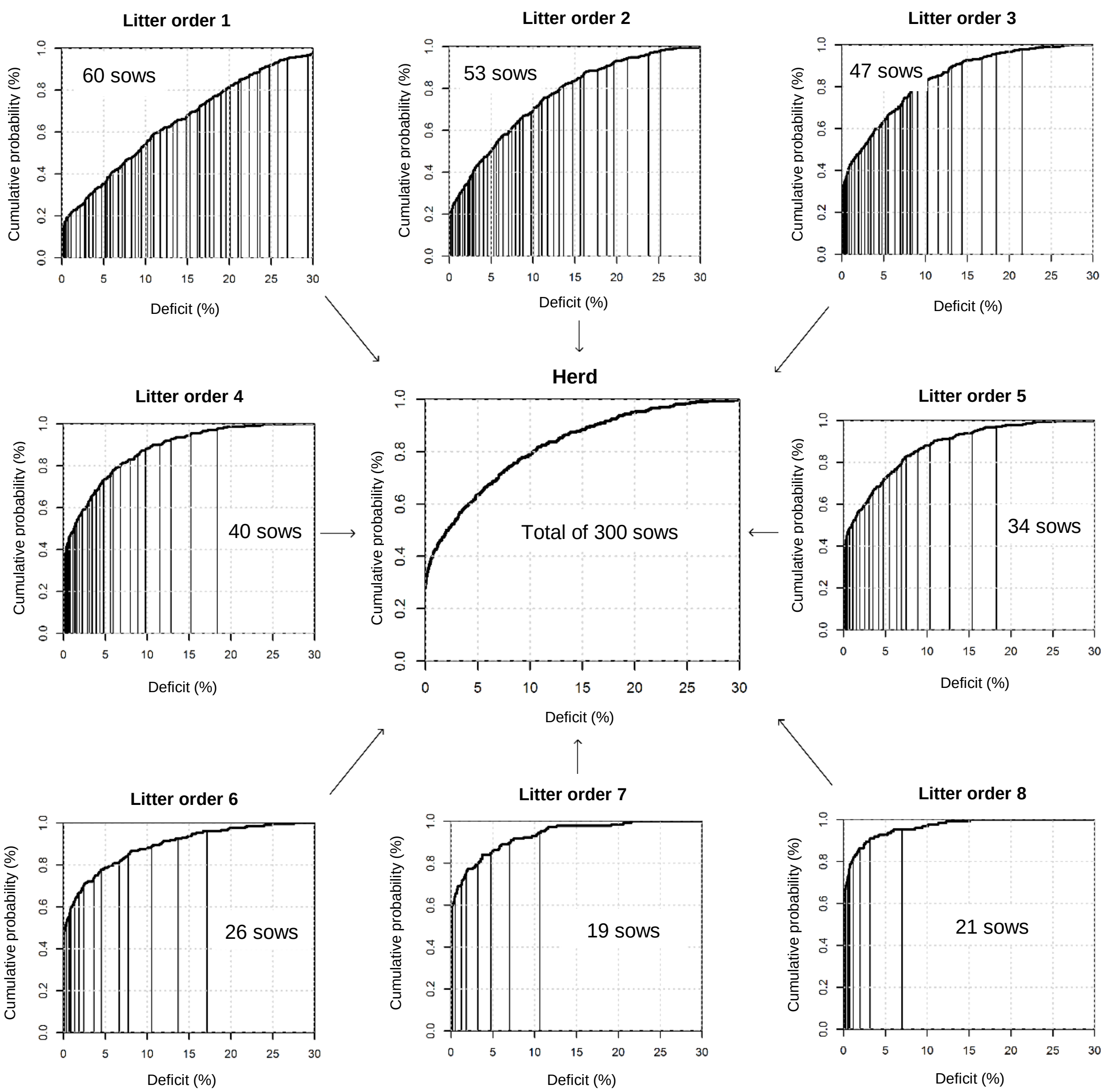

Figure 5. Example of individual deficits at gestation end for a fictitious herd (centre) calculated according to Equation (6). Vertical lines represent the sows in the reference dataset used for the fictitious herd.

3.5.3 Environmental

The same principle as for the nutritional criterion is applied for the surplus lysine (*S*), which is defined as follows for Day *d* and Scenario *k* for a given sow:

$$S_{d,k} = \max\left(L_d - R_{d,k}, 0\right) . \tag{7}$$

The relative cumulative surplus is calculated only over the total period (Days 36 to 110):

$$S_{total,k} = \frac{\sum_{d=36}^{110} S_{d,k}}{\sum_{d=36}^{110} R_d} . \tag{8}$$

As the environmental criterion was associated with the entire farm, the surpluses were not calculated specifically for gestation end, or for the sows individually.

4 Results

4.1 Herd – Days 36 to 110

Figure 6 shows the performance of the 78 scenarios for a herd from Day 36 to day 110 for each pair of criteria. Several conclusions can be drawn:

- Not only does the price context affect feed costs, it also affects cost differences between treatments; Prices vary slightly less with precision feeding.
- For conventional feeding, the average impact of switching from a feed with 0.50% lysine to a 0.55% feed is a 1.2% reduction of the lysine deficiency, an 11.8% increase in the lysine surplus and an increase in annual cost per sow of $2.21 to $3.27 depending on the price context.
- For precision feeding, there are several factors to analyze separately:
  - The impact of the information gathered (Minimal vs. Complete, Section 3.4.2) is practically zero on average for the three performance criteria.
  - Targeting the Productive instead of the Average sow (Section 3.4.2) leads to an average surplus increase of 2.2% to 4.7%, but reduces the average deficiency by about 1% to 2% with an increase in the annual cost per sow of only $0.63 to $1.16. Variations depend mainly on the Feed B selected and very little on the price context.
  - Selecting a Feed A at 0.65% instead of 0.70% makes it possible to slightly reduce the cost per sow (between $0.01 and $0.43 depending on the scenario) without impacting the lysine deficiency and the average lysine surplus.
  - The effect of selecting a Feed B at 0.45% instead of 0.35% varies depending on the targeted sows; When average sows are targeted, the deficit reduction is around 2% and the surplus increases by about 13%; When high performance/productive sows are targeted, the reduction of the deficiency is around 1% and the surplus increases by about 10%; The cost impact varies depending on the price context and may result in a reduction of $1.05 to an increase of $0.43 per sow per year.

These findings are valid only for the herd average calculated over the entire treatment period (Days 36 to 110). Before selecting the best scenario(s), further analysis was necessary.

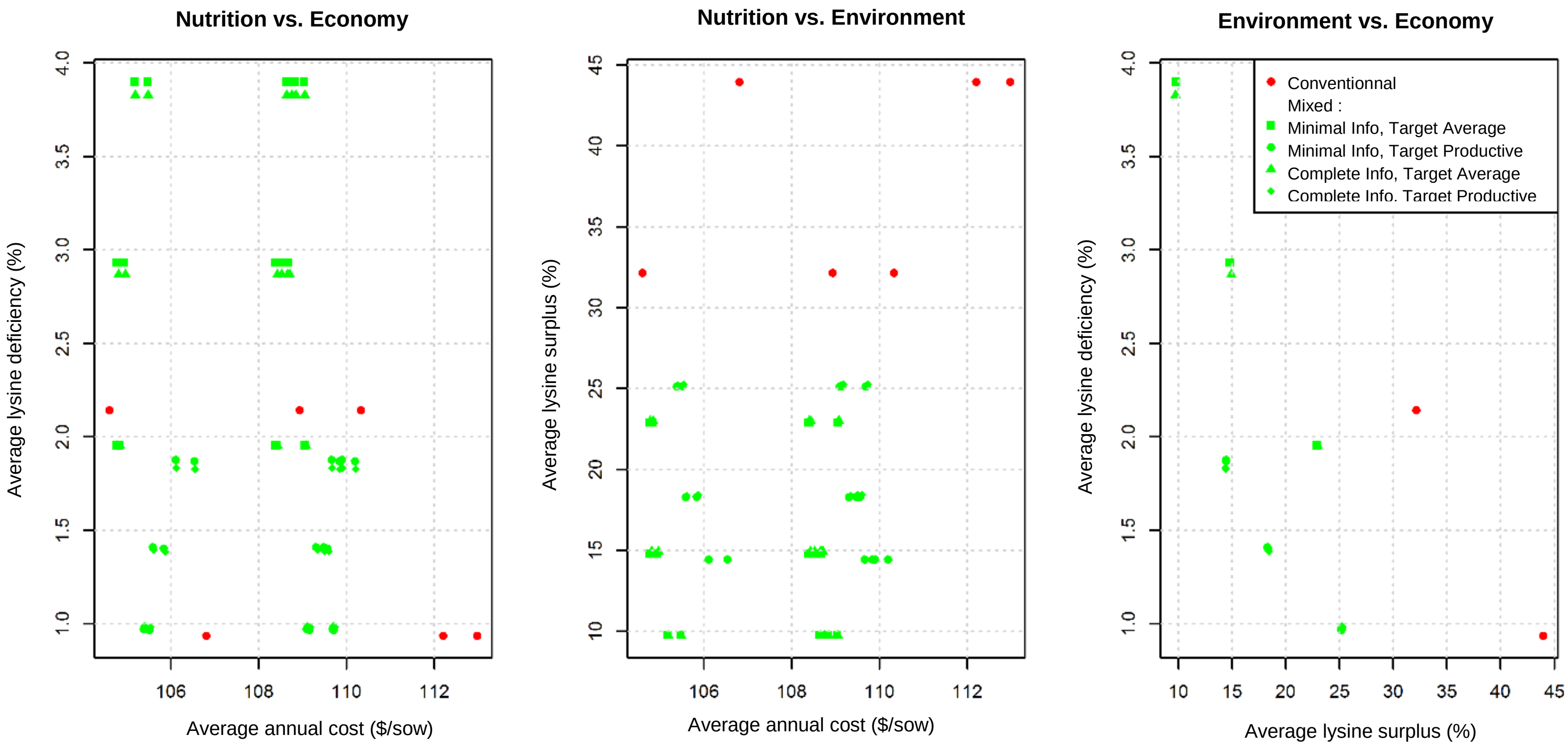

Figure 6. Performance of the tested scenarios against the three criteria evaluated on the herd average between Days 36 and 110. Symbols of the same color and shape share the same feeding treatment (Section 3.4.1) and the same degree of precision (Section 3.4.2), but the feeds and/or price contexts are different (Section 3.4.3)

4.2 Herd and Piglet – Day 91-110

Lysine requirements are higher at the end of gestation and it is not surprising that a lysine deficiency at the end may have a greater impact than in mid-gestation. In fact, fetal growth increases significantly during the last days of gestation (McPherson et al., 2004). However, the analysis of the average deficiency in the previous sub-section may confuse a feeding scenario that results in a low deficiency over the whole period with a strategy that produced no deficiency at first but led to a greater end-of-gestation deficiency (Figure 7). Despite the best adjustment of the precision feeding scenario, it actually shows an average deficiency of 3.9% from Day 36 to Day 110, compared to 2.1% for the conventional feeding scenario. It is important to analyze the end-of-gestation lysine deficiency separately (Figure 8), especially for the gilts who have greater requirements (in %).

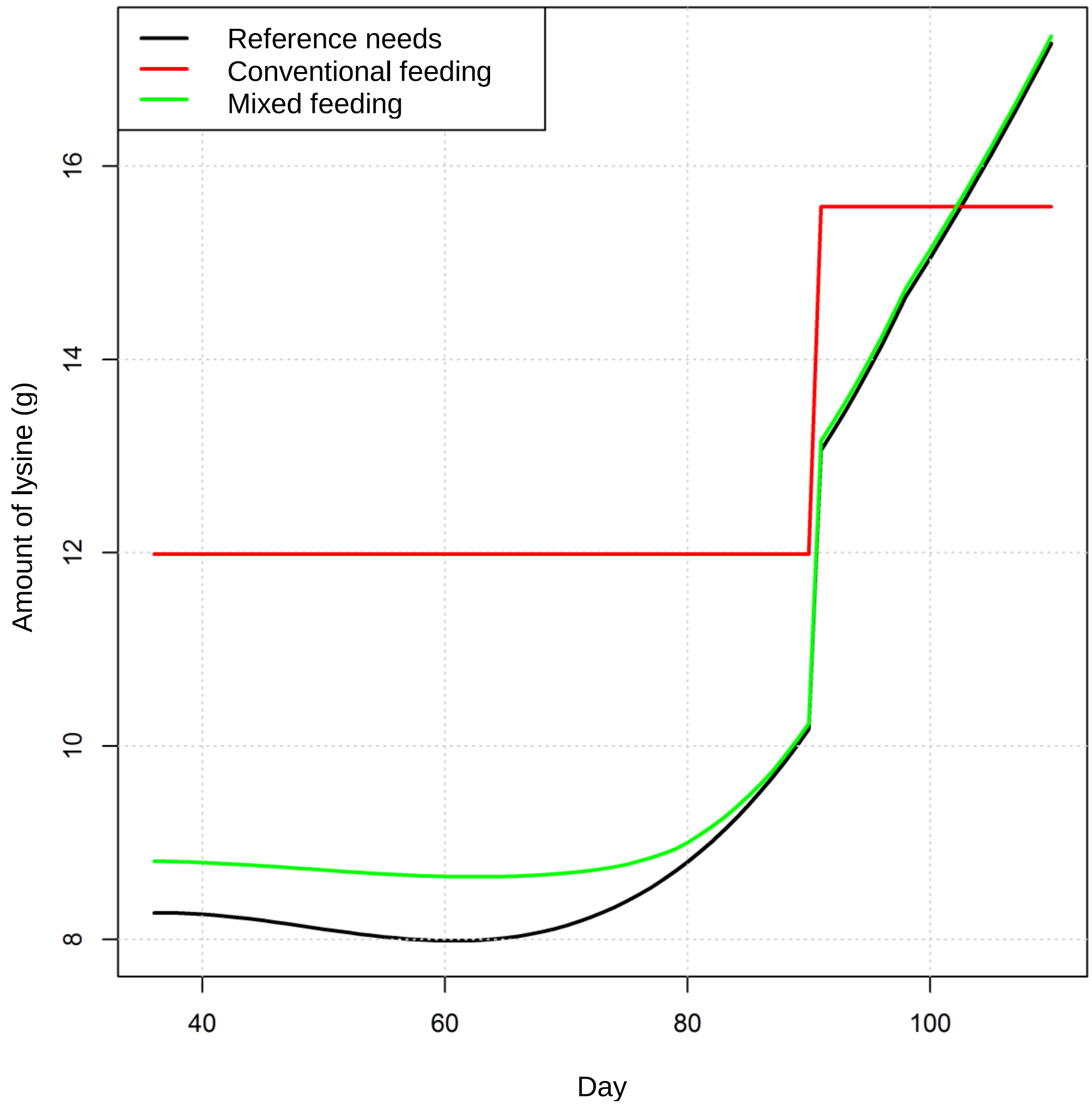

Figure 7. Average lysine requirement (black curve) and average intake for a conventional feeding scenario (Feed C at 0.50% lysine, red curve) and a precision feeding scenario (Minimum information, Target - average sow, Feed A at 0.65% lysine and Feed B at 0.35% lysine).

New conclusions can be drawn:

- For all scenarios, the average deficiency is greater at end of gestation than over the entire period (Days 36 to 110), but the increase is less for the precision feeding scenarios.
- When average sows are targeted (Section 3.4.2), selection of Feed B has little impact on end-of-gestation deficiencies. The impact is zero when productive sows are targeted;
- For gilts, all precision feeding scenarios produce lower average deficiencies in late gestation than the conventional feeding scenarios.

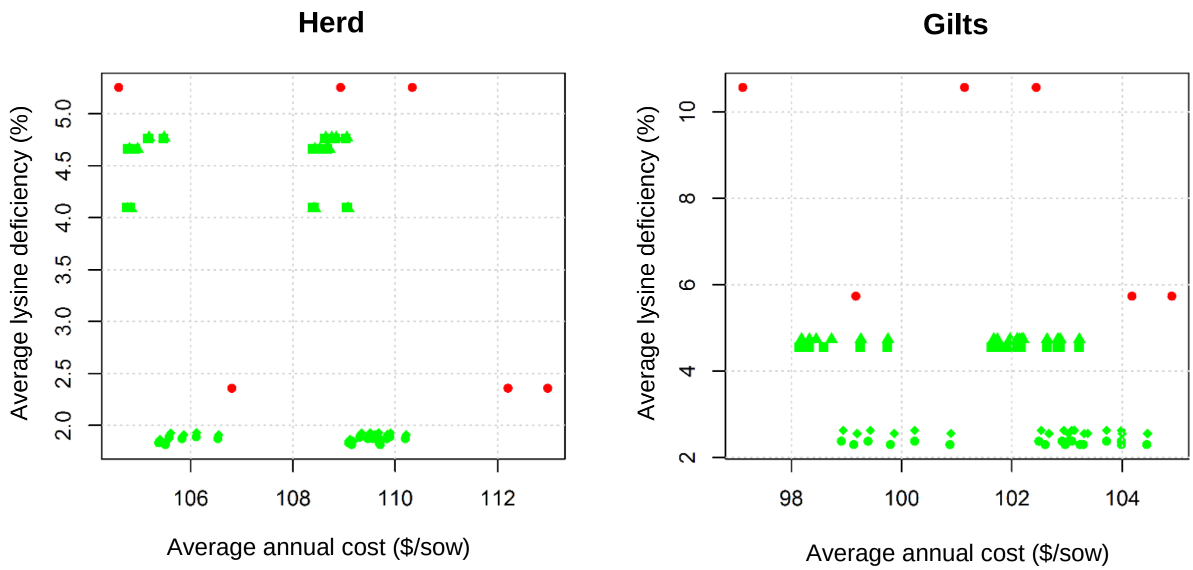

Figure 8. Performance of the tested scenarios against the economic and nutritional criteria at end of gestation (Days 91 to 110). Left: Performance assessed on the herd average. Right: Performance assessed on gilts only. For both graphs, symbols that are the same color and shape, share the same feeding treatment (Section 3.4.1) and the same degree of precision (Section 3.4.2), but the feeds and/or price contexts are different (Section 3.4.3).

Just as for the entire period, targeting productive sows gives even lower deficiencies in late gestation than targeting average sows. Similarly, the impact of the information gathered is practically nothing on the average deficiencies at end of gestation. However, there may be an impact at the individual level.

4.3 Individual Deficiencies

Precision feeding is intended not only to better feed the herd on average, but also to properly feed all individual animals according to their specific requirements. To compare the individual deficiencies of the feeding scenarios, a fictional herd of 300 sows was created based on the reference dataset with ratios according to litter order in Table 3 (Equation (6)).

The empirical cumulative distribution of the end-of-gestation lysine deficiency was calculated for this herd (Figure 9, Left) and for the 357 gilts in the reference dataset (Figure 9, Right) for each scenario. In fact, Figure 9 shows only four feeding scenarios, two in conventional feeding and only two in precision feeding. Indeed, only the target sow has an impact on the simulated individual end-of-gestation deficiency for precision feeding. The selection of Feeds A and B (Section 3.4.3) and the information collected (Section 3.4.2) have virtually no impact on the individual gestation deficiency (not shown).

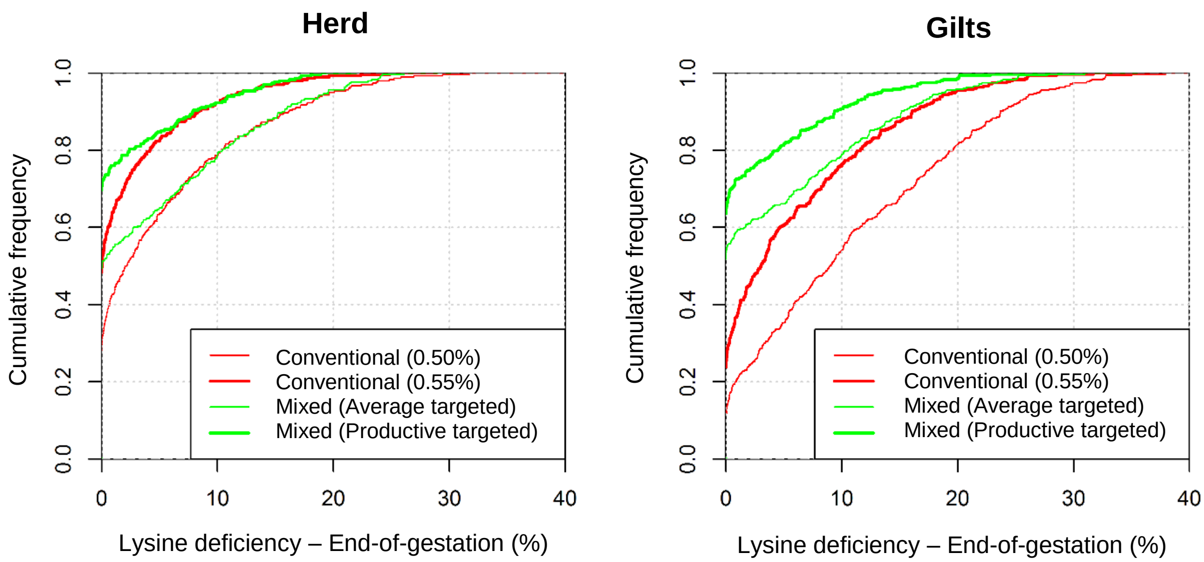

Figure 9. Cumulative empirical distribution of lysine deficiency at end of gestation (days 91-110) for four tested scenarios. Left: Deficiency calculated on a fictional herd of 300 sows. Right: Deficiency calculated on the 357 gilts in the reference dataset. For the precision feeding scenarios of the two graphs (green curves), the information collected is minimal (Section 3.4.2), and Feeds *A* and *B* are at 0.65% and 0.35% lysine, respectively.

These individual/uncorrelated results bring new information:

- For late gestation deficiencies greater than 5%, the empirical cumulative distribution calculated on the herd is similar for these two pairs of scenarios:
  - Conventional feeding with 0.50% lysine and precision feeding with Average targeted
  - Conventional feeding with 0.55% lysine and precision feeding with Productive targeted
- For precision feeding scenarios, distributions are substantially the same for the fictitious herd and the gilts.
- For gilts, the individual deficiencies for precision feeding scenarios are less than those for conventional feeding scenarios for all quantiles.

5 Discussion

5.1 The Feeding Scenarios Retained

Because of the results obtained, the number of potentially interesting feeding scenarios was reduced to four. The two conventional feeding scenarios were retained. The scenario with the 0.50% lysine feed is less expensive and leads to less of a lysine surplus whereas the 0.55% lysine feed lowers lysine deficiencies. For precision feeding, these aspects were studied :

- The information gathered (Section 3.4.2) has virtually no impact on the criteria being evaluated; and so it is not worthwhile to retain the scenarios with Complete information, only the scenarios with Minimum information, i.e. with a feeding curve by litter order.
- For targeted sows (Section 3.4.2), each of the two modalities has its strong points: targeting Average sows saves costs and produces less surplus whereas targeting Productive sows lessens lysine deficiency.
- The two Feed *A*s give roughly the same results, but the one at 0.65% lysine is always slightly less expensive when price context is considered. Only Feed *A* at 0.65% was retained.
- The three Feed *B*s give roughly the same costs. The main difference is during Days 36 to 90 when the feed at 0.45% lysine acts as a safety factor by slightly limiting lysine deficiencies (up to 2% reduction compared to the feed at 0.35%). However, at the same time, it gives an increase in the surplus (10% to 13% compared to the feed at 0.35%). Since mid-gestation deficiencies are low and have less importance on performances than end-of-gestation deficiencies, only the Feed *B* at 0.35% lysine was retained.

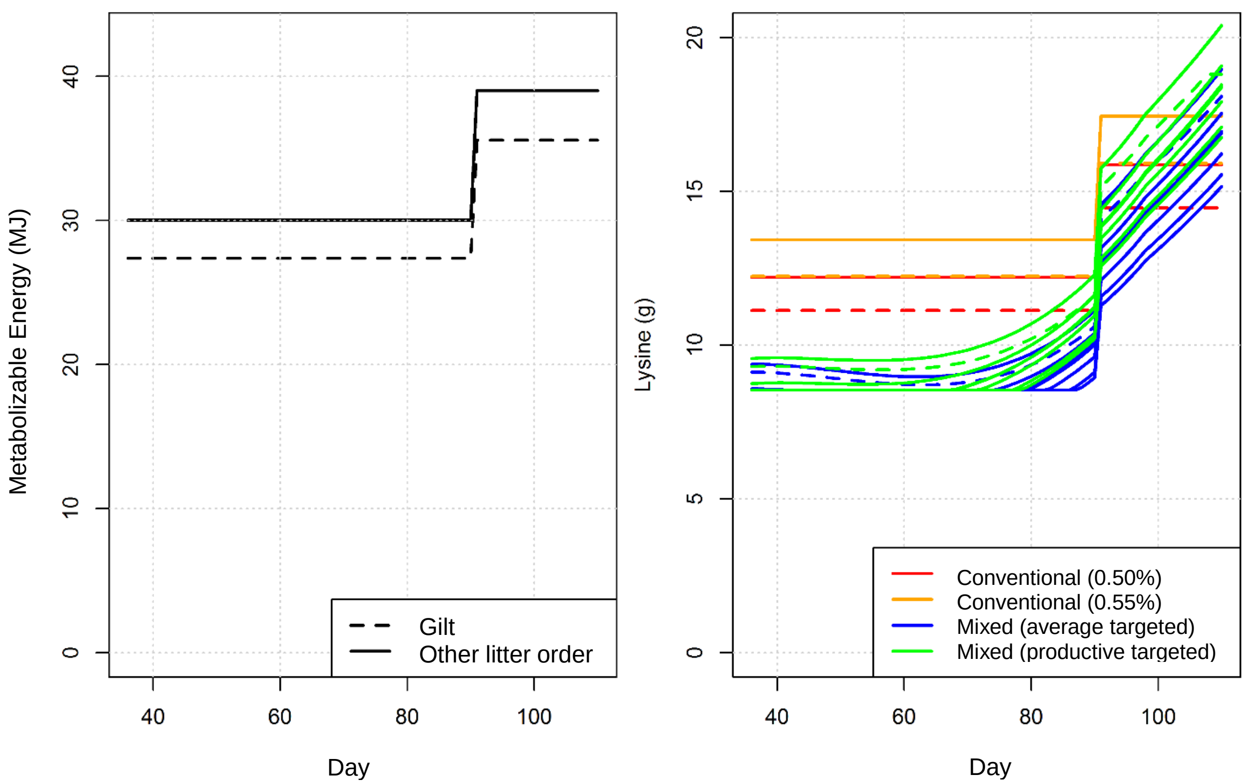

Figure 10. Left: Energy intake by litter order, identical for the four scenarios retained. Right: Lysine intake by litter order for the four scenarios retained. Dotted lines show the gilts.

Consequently, two precision feeding scenarios were considered, namely, with Average and Productive sows targeted, both with Minimum information (a feeding strategy curve according to litter order), Feed *A* at 0.65% lysine and Feed *B* at 0.35% lysine. Figure 10 shows the energy and lysine intakes in the four scenarios retained and Table 5 summarizes their performance according to the economic, nutritional and environmental criteria. A new economic variable appears in Table 5, namely the cost of feed, assuming that the feeding treatments are applied starting from breeding (Day1 to Day110). Applying precision feeding during the first 35 days would save from $0.50 to almost $3 per sow per year compared to conventional feeding.

Table 5. Summary of the performance of the four retained scenarios. For each performance variable, the best scenario is in bold.

Feeding Scenario	Cost ($/sow x year) April 2016 D36-110	April 2016 D1-110	September 2016 D36-110	September 2016 D1-110	March 2017 D36-110	March 2017 D1-110	Lysine Deficiency (%) D36-110	Lysine Deficiency (%) D91-110	Lysine Surplus (%) D36-D110
Conventional (0.50% lysine)	110.33	158.00	**104.60**	**149.79**	108.93	156.00	2.1	5.3	32.2
Conventional (0.55% lysine)	112.98	161.80	106.81	152.96	112.20	160.69	**0.9**	2.4	44.0
Mixed (Average targeted)	**108.62**	**154.67**	105.17	149.82	**108.83**	**154.94**	3.9	4.8	**9.8**
Mixed (Productive targeted)	109.66	155.73	106.11	150.78	109.90	156.03	1.9	**1.9**	14.4

At this stage, it is difficult to objectively conclude which of the four scenarios is the best. The three criteria do not all have the same units and do not all have the same impact for sows and producers. For the purposes of comparison, it would be appropriate to express lysine deficiencies and surpluses in dollars per sow per year as is done for the cost of feeding. For lysine deficiency, this involves assessing the impact of dietary scenarios on short-term performance (mean weight of piglets born and average weight gain of lactating piglets) and long-term performance (sow longevity) and calculating the economic impact of the variations for each of these variables. The next part of this project aims to evaluate the impact of precision feeding on the short-term performance of sows in a commercial farm trial. At the end of this investigation, it will be possible to more precisely estimate the potential gain for producers from precision feeding, either by summing the potential reduction in feeding costs (estimated in this report) and the potential additional revenues related to performance improvement, should it be the case.

For the environmental criterion, the conversion of the lysine surplus to dollars per sow per year is more complex. The potential economic gain to producers of a reduction in surplus is not direct. Potential benefits are mainly collective, whether through a reduction in greenhouse gas emissions or a reduction of odor problems.

5.2 Scope of the Results

Before extending the findings to other application contexts, it is necessary to be aware of the factors that make it possible, or that may limit the scope of the results.

First, the results obtained depend on the data used (Section 3.2). A large number of gestations were available, but they are not necessarily representative of all farrowing units. The gestations came from sows that all had the same genetic makeup. Results could vary for different genetics. Also, certain information, mainly related to feeding, was not available and had to be approximated. This lack of information and, to a lesser extent, possible measurement errors add uncertainty to the requirements to be assessed. In some cases, this uncertainty has led to unrealistic requirement values, which lead to values far from what is expected for the model's adjustment coefficients and consequently to the rejection of the gestation (Section 3.3.1). In other cases, uncertainty may have led to plausible requirement values, but still farther from the average requirement than the actual requirement. And so, in all likelihood, the distributions of simulated individual requirements and deficiencies are more extensive than the actual distributions. The result is a probable overestimation of deficiencies and simulated inputs for the productive sow. The impact of uncertainty on average requirements and deficiencies should be more limited. Note also that most of the information needed for the simulations was known and expert advice was used for missing information to limit the impact of uncertainty.

Second, the model itself is a source of uncertainty. Any model, however complex, is a simplified representation of real processes and InraPorc® is no exception. This simplification could lead to a systematic bias on the requirements. Although there is no indication that the InraPorc® model is biased, it is advisable the on-farm trial be based on observed data and practices already applied on-farm for anything not related to the relative lysine requirement, the estimate of which was the main reason for applying the InraPorc® model .The simplification processes of the model can also increase uncertainty and have the same impact as uncertainty on input data. Using the model that is the reference in the literature and having relied on the expertise of the principal investigator who developed the model certainly made it possible to limit the risks of misinterpretation of the results.

Third, the impact of precision feeding on feed costs is highly variable, depending on the price context and the company doing the formulation. In this report, the same company formulated the ingredients on three occasions at a 13-month interval. The economic results that we present are descriptions of actual and realistic cases, but the exact impact per sow per year will vary constantly over time and from one company to another. As mentioned earlier, a follow-up report will analyze the impact on feed costs in precision feeding over a longer period.

On the whole, the values obtained may vary according to context, but certain observations are robust, assuming correct employment of the precision feed:

- If the targeted sow in precision feeding is carefully selected, and if she finishes up with an end-of-gestation deficiency equal to that of conventional feeding, the cost of precision feeding should be substantially lower.
- Similarly, if conventional and precision feeding scenarios end up costing the same amount, the lysine deficiency should be substantially less for the precision feeding. The impact on performances remains to be determined.
- The impact of precision feeding should be greater for gilts.
- Nitrogen excretion, related to lysine surplus, should be less with precision feeding.

6 Conclusion

The main aim of this report was to use simulation to evaluate the impact of precision feeding on feed costs for gestating sows. The InraPorc® estimation model (Dourmad et al., 2008, 2013) was used for the analyses.

The results show that precision feeding allows better targeting of end-of-gestation lysine requirements. For a herd, if conventional feeding is adjusted to provide a late gestation lysine intake equivalent to that of precision feeding, conventional feeding usually costs more than precision feeding for the actual price contexts analyzed. For gilts, no conventional feeding scenarios were found to meet lysine requirements just as well as precision feeding scenarios.

Furthermore, by feeding at different levels of lysine according to litter order, it was possible to obtain equivalent intakes, regardless of whether weight and P2 at breeding was taken into account. These results suggest that it is not necessary to increase the number of measurements usually taken on-farm when targeting lysine requirements with precision feeding.

Besides, precision feeding can substantially reduce lysine surplus, which can potentially lead to reduced greenhouse gas emissions and odor problems. That being so, group-housing would be facilitated, which can represent an indirect economic advantage for precision feeding.

In the end, four scenarios, two for conventional and two for precision feeding strategies, were retained. Each one has strong points, either low feeding costs or a better end-of-gestation lysine intake. At this stage, selection of the best scenario cannot be made since it depends on the actual impact of the lysine deficiency on performances. An on-farm trial is currently underway in this project to assess this impact. It is expected that better lysine intake at end of gestation could be help improve the average weight of piglets born, in particular. If such an advantage were demonstrated in the on-farm trial, this would add to the benefits of precision feeding.

References

Ball, R.O., Samuel, R.S. et S. Moehn. 2008. Nutrient requirement of prolific sows. Advances in Pork Production, 19 : 223-236.

Bussière, D. et D. Boyaud. 2013. Les tendances actuelles et futures en nutrition des truies, Déjeuner AQAZ, 19 novembre.

Conseil national pour les soins aux animaux d'élevage (CNSAE). 2014. Code de pratiques pour le soin et la manipulation des porcs. [En ligne] https://www.nfacc.ca/pdfs/codes/porcs_code_de_pratiques.pdf (Consulté le 4 avril 2017).

Dourmad, J.Y., Van Milgen, J., Valancogne, A., Dubois, S., Brossard, L. et J. Noblet. 2013. Modeling nutrient utilization in sows, a way towards the optimization of nutritionnal supplies. International Symposium : Modelling in pig and poultry production, 18-20 June, Jaboticabal, Sao Paulo, Brésil.

Dourmad, J.Y., Étienne, M., Valancogne, A., Dubois, S., Van Milgen J. et J. Noblet. 2008. InraPorc : A model and decision support tool for the nutrition of sows. Animal Feed Science and Technology, 143(1-4) : 372-386.

Dourmad, J.Y. et M. Etienne. 2002. Dietary lysine and threonine requirements of the pregnant sow estimated by nitrogen balance. Journal of Animal Science, 80 : 2144–2150.

Dourmad, J.Y., Etienne, M., Prunier, A. et J. Noblet. 1994. The effect of energy and protein intake of sows on their longetivity: A review. Livestock Production Science, 40(2) : 87-97.

Everts, H., 1994. Nitrogen and energy metabolism of sows during several reproductive cycles in relation to nitrogen intake. Ph.D. thesis, Wageningen Agricultural University, The Netherlands

Levesque, C.L., Moehn, S., Pencharz, P.B. et R.O. Ball. 2011. The Threonine requirement of sows increases in late gestation. Journal of Animal Science, 89(1) : 93-102.

McPherson, R.L., Ji, F., Wu, G., Blanton, J.R. et S.W. Kim. 2004. Growth and compositional changes of fetal tissues in pigs. Journal of Animal Science, 82 : 2534-2540.

National Research Council (NRC). 2012. Models for estimating nutrient requirements of swine. Dans: Nutrient requirement of swine. 11th revised edition. Washington: National Academy Press, pp. 127-156.

Pettigrew, J.E. et H. Yang. 1997. Protein nutrition of gestating sows. Journal of Animal Science, 75(10) : 2723-2730.

Pomar, C., Pomar, J., Rivest, J., Cloutier, L., Letourneau-Montminy, M.P., Andretta, I. et L. Hauschild. 2015. Estimating real-time individual amino acid requirements in growing-finishing pigs : towards a new definition of nutrient requirements? In Nutritional modelling for pigs and poultry Eds. NK Sakomura, R Gous, I Kyriazakis and L Hauschild), pp. 157-174. CAB International, Wallingford, UK.

Pomar, C. 2013. Repenser l’alimentation des truies. Impact d’une alimentation multiphase, Déjeuner AQAZ, 19 novembre.

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