Precision feeding can significantly reduce feeding cost and nutrient excretion in growing animals

C. Pomar\textsuperscript{1}, L. Hauschild\textsuperscript{1,2}, G.H. Zhang\textsuperscript{1,3}, J. Pomar\textsuperscript{4} and P.A. Lovatto\textsuperscript{2}
\textsuperscript{1}Agriculture et Agroalimentaire Canada, Sherbrooke, QC, J1M 1Z3, Canada; candido.pomar@agr.gc.ca
\textsuperscript{2}Universidade Federal de Santa Maria, Department of Animal Science, Campus Camobi, Santa Maria, RS 97105-900, Brazil
\textsuperscript{3}Northwest A&F University, Yangling, Shaanxi Province 712100, P. R. China
\textsuperscript{4}Universidat de Lleida, Department of Agricultural engineering, 25198 Lleida, Spain

Abstract

Precision feeding is an agricultural concept that relies on the existence of between-animal variation and involves the use of feeding techniques that allow the right amount of feed with the right composition to be provided at the right time to each pig of the herd. Precision feeding is proposed as an essential approach to improve nutrient utilization and thus reduce feeding cost and nutrient excretion. The potential impact of using precision feeding techniques on feeding cost and nitrogen (N) and phosphorus (P) excretion was evaluated in this study. The growing pig module of InraPorc\textsuperscript{®} was slightly modified and used to estimate lysine requirements and simulate growth of individual pigs and the overall population. Detailed information of body composition of individual pigs, feed intake and growth performance was used to calibrate the model. Simulated pigs were fed either according to a typical three-phase feeding program or individually with a daily tailored feed as could be provided using precision feeding techniques. Feeding cost was determined according to common commercial pig feeds sold in Quebec, Canada. As expected, simulated N and P retention was not affected ($P>$0.05) by the feeding method. However, feeding pigs with daily tailored diets reduced ($P<0.001$) N and P intake by 25\% and 29\%, respectively and nutrient excretions were reduced both by more than 38\%. Feed cost was 10.5\% lower for pigs fed daily tailored diets. In fact, population protein and P requirements were established to optimize average daily gain of the population. Estimated nutrient requirements did not include safety margins as normally used in commercial feeds and therefore, the simulated N and P reductions are probably underestimated. Phosphorus excretion should be interpreted with caution because actual models simulating P retention seldom take into account the effect of P intake in P retention and bone mineralisation. Precision feeding can be an efficient approach to significantly reduce feeding cost and the excretion of N and P in animal production systems.

Keywords: mathematical model, pigs, precision farming

Introduction

In industrial and semi-industrial swine production areas, feeding cost represents more than 60\% of the production cost. In growing-finishing pig production systems, feeding programs are proposed to maximize population responses at minimal feeding cost. However, nutrient requirements vary greatly between pigs of a given population (Brossard et al., 2009; Pomar, 2007) and for each pig over time following individual patterns. To maximize the desired population response, which is usually body weight gain, population requirements are associated with those of the most demanding pigs, with the result that most of the pigs receive more nutrients than they need and the efficiency of nutrient utilization is reduced (Hauschild et al., 2010; Jean dit Bailleul et al., 2000). This is because, for most nutrients, underfed pigs will exhibit reduced growth performance and overfed
Modelling nutrient digestion and utilisation in farm animals

Part 5

ones will exhibit near optimal performance. Given that unutilized nutrients (other than Carbone) are excreted via the urine or faeces, feeding pigs to maximize population responses is associated with high feeding costs and high levels of nutrient excretion.

Reducing feeding cost, the excretion of excess nutrients such as nitrogen (N) and phosphorus (P), and the use of non-renewable resources is essential to the development of sustainable pig production systems (Honeyman, 1996; Jondreville and Dourmad, 2005; Rotz, 2004). The excretion of N and P is affected mainly by the amount of N and P ingested, the metabolic availability of those nutrients, and the balance between dietary nutrient supply and the animals’ requirements (Jongbloed and Lenis, 1992). If feeding cost and nutrient excretion are to be minimized, it is essential that the composition of the available feed ingredients, their nutritional potential and the animals’ requirements be properly characterized and that the supply of dietary nutrients be accurately adjusted to match the requirements of the animals. For the feeding of a population, however, optimal feed composition is difficult to estimate, as the response of the population to rising concentrations of nutrients is affected by many factors, including genetics, gender and the environment as well as the variability between the individuals of the population to be fed. Optimal nutrient concentrations should be estimated, given that feeds are provided to heterogeneous populations over long periods (Leclercq and Beaumont, 2000; Pomar et al., 2003).

Precision feeding is an agricultural concept that relies on the existence of between-animal variation and involves the use of feeding techniques that allow the right amount of feed with the right composition to be provided at the right time to each pig in the herd. In commercial production systems, animals within a herd differ from each other in terms of age, weight and production potential and then each have different nutrient requirements. Therefore, precision feeding may be a powerful approach to reducing feeding cost and improving nutrient efficiency by reducing excesses of the most economically and environmentally detrimental nutrients without jeopardizing animal performance. The objective of this study was to evaluate the potential impact of using precision feeding techniques on feeding cost and N and P excretion in commercial production systems.

Material and methods

Animal data

Data from a population of growing-finishing female pigs from 25 to 105 kg of body weight were used in this study to characterize feed intake, body weight gain and nutrient requirement patterns of individual pigs of a population (Pomar, 2007). These pigs were used in a project comparing growth performance, body composition, and nitrogen and phosphorus excretion between a three-phase and a daily multiphase feeding program. Pigs were offered ad libitum complete diets obtained by combining two premixes for which composition was calculated to meet or exceed the animals’ requirements throughout the experiment (Letourneau Montminy et al., 2005). Feed consumption was measured throughout the experiment using an automated recording system (IVOG®-station, Insentec, Marknesse, Netherlands). The animals were weighed at least every two weeks. At the beginning and end of the experiment, total body fat and body fat-free lean tissues were estimated by dual-energy X-ray absorptiometry (DXA) using a densitometer (DPX-L, Lunar Corp., Madison, WI, USA). Total body protein and lipids were obtained by converting the muscle and fat values obtained with DXA into their chemical equivalents (Pomar and Rivest, 1996). Data from 68 animals with regular feed intake and growth patterns were used in the present study. The data set used includes measures of daily net energy intake, two-week interval body weight, and total body lipids and protein at the beginning and end of the experiment. The growth period lasted 83 days and was divided in three equivalent feeding periods.
Pig growth modeling

The growing pig module of InraPorc® (Van Milgen et al., 2008) was slightly modified and used in the present study to estimate the lysine requirements and simulate growth and of individual pigs and the overall population. A detailed description of model modifications has been given previously (Hauschild et al., 2010). Because this model estimate animal responses by simulating the utilization of nutrients based on concepts used in net energy and ideal protein systems, comparisons between simulation alternatives cannot be attributed to the model itself.

The model was slightly modified to optimize the utilization of the available animal data. Individual pigs were characterized by their voluntary feed intake and growth potential, which is defined respectively by the pig’s appetite expressed as net energy (NE) intake and its potential for protein deposition (PD). The model is based on the transformation of dietary nutrients into body protein (PT) and lipids (LT) (state variables), which are then used to estimate body weight (BW). Euler’s integration method is used to solve the differential equations with an integration step (dt) of 1 day. Rate variables are expressed on a daily basis, energy is in megajoules, mass in kilograms, and nutrient concentrations are expressed on a kilogram basis when not otherwise specified in the text. Because the animals’ appetite is expressed as net energy intake, standardised ileal lysine (Lys) requirements estimated by either method are expressed in relation to this element (Lys:NE).

As in a previous study (Hauschild et al., 2010), weight changes and daily net energy intake of each animal over time was simulated with a second-order polynomial function because individual growth does not always follow the typical Gompertz growth pattern observed in pig populations (Knap, 2000; Van Milgen et al., 2008). Although the parameters in this polynomial model have little biological meaning, they allow proper representation of the observed individual BW and feed intake data over the 83 days during which animals were fed in the original trial. All results presented in this paper were obtained with the modified InraPorc model. Thus, body weight is estimated in the model by a quadratic function of time (t) fitted to data from the four weightings of each pig. The first derivative of this function is used to estimate daily weight gain (\(\frac{\partial \text{BW}}{\partial t}\)), while PD is estimated as PD/\(\partial t\) = \(\frac{\partial \text{BW}}{\partial t}\) × (ADPG/ADG) (Schinckel et al., 2007), where PD/\(\partial t\) is the simulated daily protein deposition and ADPG and ADG are the average daily PD and weight gain calculated from initial and final BW and protein masses measured on individual pigs. PD/\(\partial t\) and \(\frac{\partial \text{BW}}{\partial t}\) are therefore always equidistant. Energy intake was estimated based on the daily measures of NE intake in relation to BW using a quadratic function. Body weight was chosen to drive NE intake to maintain the same driving forces as in the InraPorc model.

Initial LT and PT masses for each simulated pig were estimated from DXA measurements, from which simulated initial BW was estimated using the relationships proposed in InraPorc. However, initial BW was not normally distributed and showed low variability between animals (s.d. = 1.2 kg; CV <5%). Thus, a new population was generated randomly having normally distributed initial BW, the same average BW and an s.d. of 3.8 kg. The generated initial population variability was chosen to represent the observed variability of commercial conditions (Patience et al., 2004; N. Lafond, Aliments Breton Inc., Québec, personal communication). The body composition of the newly generated population was established by giving each new pig the identification and body protein and lipid proportions of the pig having the same weight rank in the original population (Hauschild et al., 2010).
Population and individual nutrient allowances

In this simulation study the generated population of pigs were fed ad libitum either according to a typical three-phase feeding program or a daily tailored feed to each pig as could be provided using precision feeding techniques (Pomar et al., 2009). In the three-phase feeding program all pigs of the population received a common feed which composition was previously estimated to maximise population growth. In the daily tailored feeding program, each pig received every day the feed that satisfied its nutrients requirements.

Lysine requirement for three-phase feeding program

The Lys:NE requirements were estimated by the modified growth model for each of the three 28-day feeding phases for which the initial BW averaged 24.5±4.1, 54.4±4.9 and 81.6±5.4 kg, respectively. The optimal population dietary Lys:NE concentration for each feeding period was estimated by simulating individual pig growth based on feeds containing 10 MJ NE/kg but graded levels of lysine. In this study, optimal population levels of lysine for each feeding phase were those maximising ADG. Maximal population ADG was reached at 1.09, 0.80 and 0.65 g/MJ of Lys:NE ratio in periods one to three, respectively (Hauschild et al., 2010).

Lysine requirement for daily tailored feeding program

The modified pig growth model was inverted to estimate the individual daily lysine requirement according to the animal’s current state and its potential for protein deposition (van Milgen et al., 2008). The optimum daily Lys:NE ratio was obtained by dividing the daily lysine requirement by the estimated NE appetite for this day.

Comparing feeding programs

The feeding programs were compared based on average animal performances, feeding cost and N and P balance in the overall growth period (83 days). Animal performance was assessed on the basis of simulated individual feed intake, ADG, feed conversion (FCR) and body PT and LT composition. Feed costs in the three-phase feeding program was estimated as Feed cost ($/kg) = 0.3272 + 0.0791 × Lys:NE, matching the cost of the most common commercial pig feeds sold in Québec from March to June 2008 to its Lys:NE content (N. Lafond, Aliments Breton Inc., Québec, personal communication). Feed cost in the individually tailored feeding program was estimated assuming that the reduction on crude protein and phosphorus was obtained by replacing the soybean meal by corn and by reducing the amount of phosphates in the original diets. The cost of soybean meal, corn and phosphates was 532, 201, and 748 $/t. The results from feeding programs were compared using GLM procedure of the SAS (SAS Institute Inc., 1999, NC, USA).

Results and discussion

Simulated and observed values were similar for both average daily feed intake (ADFI; 2.44 vs. 2.43 kg, $P=0.99$) and ADG (79.40 vs. 78.30 kg, $P=0.70$). Model accuracy as estimated by the mean square prediction error was 0.01 kg/d for ADFI and 3 kg for BW. Deviations between observed and simulated performance values were small, which is consistent with the fact that model parameters were estimated for each pig in the population. However, the slope between the predicted and observed ADFI was 1.15, which is higher than 1 ($P<0.001$), indicating that the model underestimated ADFI during the first feeding phase and overestimated this variable in older pigs. In fact, observed
feed intake seemed to approach a plateau at the end of the last feeding period, a trend that was probably not captured by the quadratic function used in this study (Hauschild et al., 2010).

The effect of feeding a population of pigs using a traditional three-phase (3P) or individually daily tailored diets (PF) as would be provided by precision feeding devices on growth performance, body composition, and N and P excretion was studied. Population protein and P requirements were established in this study to maximise population average daily gain and did not include any safety margins as normally used in commercial conditions. In today feeding systems all pigs of the population are fed with a unique feed during relatively long periods of time which are established in relation to the number of feeding phases. In the present study each feeding phases lasted 28 days. Because pigs were fed in the traditional 3P feeding program to maximise population growth, most pigs received more nutrients than required. Determining the optimal composition of this complete feed is complex, and when population responses are optimized, most of the pigs in the population will receive more nutrients than they need, and a small portion of the population will be fed above requirements (Figure 1). In the present study, maximal population ADG was 12% higher than the requirement of the average pig and corresponded to the requirement of pigs in the 82% percentile of the population (Hauschild et al., 2010). Feeding pigs under these requirements may contribute to reduce feeding cost but will also reduce population growth. In fact, the most performing pigs of the population are those that will be the most penalised with this strategy.

Most of the pigs fed in the 3P and all of the pigs in the PF program received every day the amount of nutrients or more required to satisfy their maintenance and growth needs. For most nutrients such as protein and P, overfed pigs will exhibit near optimal performance and therefore, average responses from populations fed according to both feeding programs obtained similar growth performances (Table 1). Furthermore, simulated protein and P retention was not affected by the feeding method (Table 2). However, feeding pigs with daily tailored diets reduced N and P intake respectively by 25% and 29%, and the corresponding excretions were reduced both by more than 38%. Feeding costs was estimated to be reduced by more than 8.7 $/pig which represents a feeding cost reduction of 10%. It should be noted, however, that the most performing pigs of the herd received more protein and P when fed the daily tailored diets than when fed in the three-phase feeding program. Protein and P requirements estimated in this study did not include any safety margin and therefore, the estimated N and P reductions are probably underestimated. Phosphorus estimations have however

![Figure 1. Estimated individual (——) and population (-----) optimal lysine concentration in diets fed to a heterogeneous population.](image-url)
be interpreted with caution because actual models simulating P retention seldom takes into account the effect of P intake in bone mineralisation.

Phase-feeding involves feeding a number of successive diets, each differing in its protein, energy or amino acid balance to match the evolving nutritional requirements of the growing pigs. It should be

Table 1. Initial and final animal body conditions and composition and overall growth performance of pigs fed according to a three-phase feeding program or individually daily tailored diets.

<table>
<thead>
<tr>
<th>Feeding method</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional three-phase feeding programme</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>27.2</td>
<td>0.47</td>
</tr>
<tr>
<td>Body protein (kg)</td>
<td>4.0</td>
<td>0.08</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>4.0</td>
<td>0.06</td>
</tr>
<tr>
<td>Final conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>107.9</td>
<td>0.83</td>
</tr>
<tr>
<td>Body protein (kg)</td>
<td>17.3</td>
<td>0.12</td>
</tr>
<tr>
<td>Body fat (kg)</td>
<td>22.2</td>
<td>0.50</td>
</tr>
<tr>
<td>Overall performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average daily feed intake (kg/d)</td>
<td>2.49</td>
<td>0.02</td>
</tr>
<tr>
<td>Average daily gain (g/d)</td>
<td>973</td>
<td>7.31</td>
</tr>
<tr>
<td>Feed conversion (kg/kg)</td>
<td>2.56</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Average values obtained from 68 pigs in an 83 days simulated experiment.

Table 2. Feeding costs and simulated nitrogen (N) and phosphorus (P) balance in pigs fed according to a commercial three-phase feeding programme or individually daily tailored diets.

<table>
<thead>
<tr>
<th>Feeding method</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional three-phase feeding programme</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed costs/ADG ($/kg)</td>
<td>1.022</td>
<td>0.01</td>
</tr>
<tr>
<td>N intake (kg)</td>
<td>5.69</td>
<td>0.05</td>
</tr>
<tr>
<td>N excretion (kg)</td>
<td>3.61</td>
<td>0.04</td>
</tr>
<tr>
<td>N retention (kg)</td>
<td>2.08</td>
<td>0.02</td>
</tr>
<tr>
<td>P intake (kg)</td>
<td>0.91</td>
<td>0.01</td>
</tr>
<tr>
<td>P excretion (kg)</td>
<td>0.49</td>
<td>0.01</td>
</tr>
<tr>
<td>P retention (kg)</td>
<td>0.35</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Average values obtained from 68 pigs in a 83 days simulated experiment.

Modelling nutrient digestion and utilisation in farm animals
expected that increasing the number of feeding phases in group-feeding facilities will reduce feeding costs, decrease nutrient excretion and improve feed efficiency. The economic and environmental benefits of this concomitant nutrient adjustment increase with the number of feeding phases (Bourdon et al., 1995; Van der Peet-Schwering et al., 1999). Thus, it has been demonstrated that daily multiphase feeding can reduce N excretion by 12% in comparison to a traditional 3P feeding program (Pomar et al., 2007). The application of daily multiphase feeding techniques in group-feeding facilities can hardly decrease further this 12% N excretion because the between-animal variation seems to be more important than the over-time variation of the population requirements. The utilisation of precision feeding techniques able to provide to each pig daily tailored diets is therefore a promising alternative to capture most of the observed between-animal variation on nutrient requirements and thus significantly improve nutrient efficiency.

The expected reduction in feeding costs and N and P excretion which can be obtained when feeding pigs with daily tailored diets will be affected by the cost of the available ingredients, the composition of the premixes and the animal variation. Feeds formulated with large safety margins and large amounts of excess nutrients for optimal response in heterogeneous populations (e.g. genetic potential, sex and weight) increase the excretion of nutrients. In these situations, it should be expected that the impact of feeding pigs individually with daily tailored diets will reduce feeding costs and improve dietary nutrient efficiency more than observed in the present study.

This study has demonstrated that in growing-finishing pig facilities precision feeding may be an effective approach for reducing feeding costs and improving nutrient efficiency by reducing excesses of the most economically and environmentally detrimental nutrients without jeopardizing animal performance. However, the proper implementation of precision feeding in livestock production systems ought to include (1) the proper evaluation of the nutritional potential of feed ingredients, (2) the precise determination of nutrient requirements, (3) the formulation of premixes that limit the amount of excess nutrients, and (4) the concomitant adjustment of the dietary supply and concentration of nutrients to match the evaluated requirements of each pig in the herd.

References


