InraPorc: A model and decision support tool for the nutrition of sows

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Abstract

From results obtained over the last 20 years on energy and amino acid utilisation in reproductive sows, it has become possible to improve the determination of nutrient requirements (factorial approach) and the prediction of an animal’s response to nutrient supplies (modelling). The objective of this project was to integrate the current state of knowledge in a nutritional model for growing pigs and for sows and make it available as a software tool to end-users, mainly nutritionists involved in the pig industry and students in animal nutrition. The aim of this paper is to describe the basis of the sow model. The sow is represented as different compartments that change over the reproductive cycle. Nutrient flows considered are those of energy and digestible amino acids. Nutrients are used with the highest priority for maintenance and uterine growth or milk production. Subsequently, deposition and/or mobilisation of body proteins and lipids are determined and used for estimating the changes in body weight and backfat thickness of the sow. A decision support tool was built from the set of equations given, with additional modules to describe animal’s characteristics and adjust some model parameters to account

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Abbreviations: ADGlitter, average daily weight gain of the litter during lactation; BT, backfat thickness; BW, body weight; EBW, empty body weight; dLact, duration of lactation; EMilk, energy in milk; ERc, energy retained in conceptus; ERmp and ERmf, energy retained as protein in maternal tissue as protein and fat, respectively; kc, efficiency of using ME for conceptus growth; kf, efficiency of using ME for lipid deposition; km, efficiency of using ME for milk production; kp, efficiency of using ME for protein deposition; kr, efficiency of using energy from body reserved for pregnancy; kmilk, efficiency of using energy from body reserves for milk production; LCT, lower critical temperature; LD, lipid deposition; LS, litter size; MEm, metabolisable energy for maintenance; ERm, energy from body reserves for milk production; NMilk, nitrogen in milk; NR, retained nitrogen; NRc, retained nitrogen in conceptus; PD, protein deposition; PDMax, maximum protein deposition

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1. Introduction

The process of reproduction, from conception to weaning, can be considered as directed to buffer the developing progeny from nutritional distress (Oldham, 1991) and involves both homeostatic and homeorhetic controls of nutrient partitioning (Bauman and Currie, 1980). Reproductive problems, which may result in the reduction of sows productivity or early culling, are often related to extreme variations in body reserves (Dourmad et al., 1994), although body reserves should be considered more as an indicator of the risk for rather than as the real cause of problems. During pregnancy, sufficient body reserves must be built to compensate for the eventual nutritional deficit that may occur in the following lactation. However, these reserves should not be excessive in order to avoid the occurrence of farrowing problems that are typical for fat sows, or to impair feed intake after farrowing. During lactation, it is recommended to adapt nutritional supplies to requirements in order to maximise milk production and piglet’s growth, and minimise reproductive problems of sows after weaning. Consequently, nutritional supplies to sows must be adapted to maintain body reserves in optimal condition all along their productive life and optimise their reproductive performance. On farm, this requires a precise adjustment of the feeding level and the feed composition according to the performance of sows but also to housing conditions, which may affect nutrient utilisation and voluntary feed intake.

Experimental results obtained during the last 20 years on energy and amino acid utilisation by the pregnant or lactating sow allow improvements in the determination of nutritional requirements according to a target performance (factorial approach), and to predict the response of the animal to nutrient supplies (modelling). Compared to growing pigs, only a few models have been published for sows (Williams et al., 1985; Dourmad, 1987; Pomar et al., 1991; Pettigrew et al., 1992; NRC, 1998), and most of these were research models. In this project, we have integrated the available information on nutrient utilisation by sows to build a decision support tool allowing a global approach to understanding sow nutrition and the associated performance. This decision support tool includes a simulation model that represents on a daily basis (dynamic) the utilisation of key nutrient pools (mechanistic) for a given sow (deterministic). The end-users of these decision support tools are mainly nutritionists involved in pig production and teachers and students in animal nutrition. The aim of the present paper is to describe the basis and the main principles of this tool, which is also available for download at http://www.rennes.inra.fr/inraporc/(INRA, 2006). The growing pig module of this tool is described in another paper of this special issue (van Milgen et al., 2008).
2. Nutrient utilisation by sows

2.1. General approach

A simplified description of nutrient utilisation by the sow is given in Fig. 1. 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 concern energy and amino acids. In pregnant sows, priority is given to maintenance requirements and requirements for foetuses, uterus and mammary gland development. If nutrient allowances exceed these requirements, nutrients in excess contribute to the constitution of sow’s body reserves. Conversely, body reserves will be mobilised in the case of a deficiency. In lactating sows, priority is given to maintenance and milk production. Body reserves often contribute to the supply for these priority functions.

The approach for representing energy supply in sows differs slightly from that chosen for growing pigs where energy originating from each different nutrient is considered separately in the model (van Milgen et al., 2008). It was preferred to maintain the concept of ME in the sow model because less information is available than in the growing pig and also, the efficiency of energy utilization varies according to the physiological status of the sow. However, a corrected ME value is calculated to take into account the effects of diet composition on the utilisation of ME according to the NE system proposed by Noblet et al. (1993a, 1994).

The supply of amino acids is considered as standardized ileal amino acid (INRA-AFZ, 2004), implying that the indigestible fraction and specific endogenous amino acid loss are combined together.
2.2. Nutrient utilisation during pregnancy (Table 1)

During pregnancy energy is partitioned between energy for maintenance, energy for growth of conceptus and energy for lipid and protein deposition in maternal body (Eq. (1)).

2.2.1. Maintenance

Under thermoneutral conditions and with moderate physical activity, ME for maintenance ($M_{Em}$) varies between 400 and 460 kJ/kg BW$^{0.75}$ (Beyer, 1986; Noblet and Etienne, 1987b; Noblet et al., 1989; Everts, 1994). When expressed per kg BW$^{0.75}$, $M_{Em}$ is very similar in primiparous and multiparous sows and can be considered as constant over pregnancy (Noblet and Etienne, 1987b; Everts, 1994). Thus, a constant $M_{Em}$ requirement of 440 kJ/kg BW$^{0.75}$ was assumed in the model (Eq. (2)).

From a literature survey, it was calculated that the energy cost of standing in sows ranged from 0.25 to 0.30 kJ kg BW$^{-0.75}$ min$^{-1}$, which is equivalent to doubling the instantaneous heat production during standing when compared to lying down. These values are 4–5 times higher than in ruminant species (Noblet et al., 1993b; Le Goff et al., 2002; Young et al., 2004). Under practical conditions, levels of physical activity can vary greatly between housing systems (e.g., indoor versus outside keeping) and between sows (stereotypic behaviour). In addition, some data indicate a higher level of activity in older or poor condition sows or under adverse climatic conditions (Cariolet and Dantzer, 1984). In all cases, physical activity can represent an important source of variability of energy requirements that has to be considered in the model (Eq. (3)).

Estimates for the lower critical temperature (LCT) of individually housed sow range from 20 to 23°C (Noblet et al., 1989). This relatively high value of LCT is mainly the consequence of the low energy levels fed during pregnancy. Furthermore, LCT becomes even higher in very thin sows (Hovell et al., 1977). On the other hand, straw bedding will decrease the LCT by about 4°C (Verstegen and Curtis, 1988). Because of behavioural adaptations, LCT is about 6°C lower in group than in individually housed sows (Geuysen et al., 1984). Literature data show that many factors affect the daily increment of heat production when temperature decreases, and values range from about 10 kJ°C$^{-1}$ kg BW$^{-0.75}$ in group-housed sows, to 15–18 kJ°C$^{-1}$ kg BW$^{-0.75}$ in individually-housed sows (Eq. (4) and (5)).

Obligatory losses of amino acids from the body need to be replaced in order to maintain body conditions. The metabolic weight (BW$^{0.75}$) of the sow was used to scale these losses (Table 1) (Eq. (12)).

2.2.2. Uterine and foetus development

Foetuses develop very slowly during the first third of pregnancy, and about 2/3 of foetal growth or energy deposition in the uterus occurs during the last 1/3 of pregnancy. A detailed description of the progressive increase in weight, energy and protein deposition in foetuses, foetal fluids, placenta and uterus was given by Noblet (1990) (Eq. (10) and (13)). Based on data of De Wilde (1980), Noblet et al. (1985) and Beyer (1986), total energy and protein deposited in the uterus over pregnancy (i.e., foetuses, placenta and fluids) averages 4.9 MJ and 150 g per kilogram of foetus at farrowing, respectively. From studies of Close et al. (1985) and Noblet and Etienne (1987b), the marginal efficiency of ME for uter-
### Table 1

Main equations describing nutrient utilization in gestating sows

**Energy utilisation**

\[
\text{ME} = \text{ME}_{m} + \text{ER}_{c}/k_{c} + \text{ER}_{mf}/k_{f} + \text{ER}_{mp}/k_{p} \tag{1}
\]

\(\text{ME}_{m}\): ME for maintenance; \(\text{ER}_{c}\): energy retention in conceptus; \(k_{c}\): efficiency of ME retention in conceptus; \(\text{ER}_{mf}\): energy retained as fat in maternal tissues; \(k_{f}\): efficiency of ME for body fat deposition; \(\text{ER}_{mp}\): energy retained as protein in maternal tissues; \(k_{p}\): efficiency of ME for body protein deposition

**ME for maintenance and effect of ambient temperature**

- **In thermoneutral conditions**
  \[\text{ME}_{m} = 440 \text{kJ BW}^{-0.75} \text{ d}^{-1} \text{ for 240 min d}^{-1} \text{ standing activity} \tag{2}\]

- **Physical activity**
  \[\text{Physical activity} = 0.30 \text{kJ kg BW}^{-0.75} \text{ d}^{-1} \text{ min}^{-1} \text{ standing} \tag{3}\]

- **Below lower critical temperature (LCT)**
  - **In individually housed sows**
    \[\text{LCT} = 20 - 22^\circ \text{C} \text{ and HP increases by } 18 \text{kJ kg BW}^{-0.75} \text{ d}^{-1} \text{ C}^{-1} \tag{4}\]
  - **In group-housed sows**
    \[\text{LCT} = 16^\circ \text{C} \text{ and HP increases by } 10 \text{kJ kg BW}^{-0.75} \text{ d}^{-1} \text{ C}^{-1} \tag{5}\]

**Efficiency of ME**

- \(k_{c} = 0.50\) (efficiency for conceptus growth) \(\tag{6}\)
- \(k_{p} = 0.60\) (efficiency for protein) \(\tag{7}\)
- \(k_{f} = 0.80\) (efficiency for lipids) \(\tag{8}\)
- \(k_{r} = 0.80\) (efficiency of energy mobilisation from body reserves) \(\tag{9}\)

**Nitrogen retention**

- \(\text{NR: total N retention (g d}^{-1}\), \(\text{NR}_{c}: \text{N in conceptus (g)}, \text{LS: litter size}
  \[\ln(6.25 \text{NR}_{c}) = 8.090 - 8.71 e^{-0.0149t} + 0.0872 \text{LS} \tag{10}\]

  When protein and AA are not limiting
  \[\text{NR} = 0.85(d(\text{NR}_{c})/dt - 0.4 + 45.9(t/100) - 105.3(t/100)^{2} + 64.4(t/100)^{3} + a(\text{ME} - \text{ME}_{m})) \tag{11}\]
  Where \(a = 0.571\) in the first pregnancy and is 0.366 later, \(\text{ME}_{m} = \text{ME}_{m} \text{ at mating}

  When amino acid supply is limiting (lysine)
  \[\text{NR} = (-0.036 \times \text{BW}^{-0.75} + 0.65 \text{ digestible lysine})/0.065 \tag{12}\]

**Energy retention**

- \(\text{ER}_{c}: \text{energy in conceptus (kJ)}
  \[\ln(\text{ER}_{c}) = 11.72 - 8.62 e^{-0.0138t} + 0.0932 \text{LS} \tag{13}\]

  in maternal tissues (LD = lipid deposition)
  \[\text{ER}_{mp}(\text{kJ/d}) = 23.8 \times 6.25(\text{NR} - \text{NR}_{c}) \tag{14}\]
  \[\text{ER}_{mf}(\text{kJ/d}) = 39.7 \text{LD} \tag{15}\]

\(^1\) In the factorial calculation of requirement, NE is calculated from ME using a NE/ME ratio of 0.74.

### 2.2.3. Maternal growth

In connection with frequent mobilisation of body reserves during lactation and the progressive attainment of mature live weight, maternal weight increases during pregnancy in addition to the weight gain of uterus and conceptus. The maternal weight gain to be achieved during pregnancy depends then on the composition and the amount of the weight loss during previous lactation, and the feeding strategy employed to attain targets for live weight and body fatness over successive parities.
Changes in maternal body weight and composition can be predicted according to nutrient partition as presented in Fig. 1. The nutrients available above maintenance and growth of the reproductive tissues and foetuses are utilised for maternal gain, and repartitioned between protein and lipid deposition. When protein and amino acid supplies are not limiting, protein deposition (PD) depends mainly on the energy supply and maximum potential protein deposition (PD\text{max}). In growing pigs, this is generally described by a linear-plateau relationship between protein deposition and ME intake (van Milgen et al., 2008). Williams et al. (1985) suggested a similar relationship for pregnant sows. However, the results of experiments in which energy intake increased up to 40 MJ ME/d failed to prove the existence of a plateau both in pregnant gilts (Kemm, 1974; Willis and Maxwell, 1984; Etienne, 1991; King and Brown, 1993) and multiparous sows close to mature body weight (parity 4 on average, Dourmad et al., 1996). This suggests that the energy level fed to pregnant sows in practical conditions is usually below the level required for maximum N retention. An empirical relationship (Eq. (11)) was calculated from literature data in order to predict potential N retention in pregnant sows (Dourmad et al., 1999). Two components are considered in that relationship: (i) the quantity of N retained in conceptus (NR\text{c}), calculated from the equation proposed by Noblet (1990) and (ii) N retention in maternal tissues which depends on parity, stage of pregnancy and the supply of ME above the maintenance requirement.

The amount of energy deposited as protein in maternal tissues (ER\text{mp}) is calculated from nitrogen retention (Eq. (14)). This value and the efficiency of ME for protein deposition (k\text{p}) are used to determine the corresponding amount of ME required (Eq. (7)). The calculation of the quantity of lipids deposited (LD) or mobilised is based on the amount of ME remaining (Eq. (15)) or missing and the efficiency of ME for fat deposition (k\text{f}) (Eq. (8)), or on the efficiency of energy mobilisation from body reserves to provide ME (k\text{r}) (Eq. (9)) in the case of energy deficit. Values for k\text{f}, k\text{p} and k\text{r} (Table 1) are derived from Noblet et al. (1990).

When dietary amino acid supply is below the requirement for maximal retention, NR increases linearly with amino acid intake until it reaches the maximum retention, which depends on gestation stage, energy supply, litter size and parity number (Eq. (11)). The response of lysine retention to digestible lysine intake during this limiting phase was measured by Dourmad and Étienne (2002) who found an efficiency of 65–67%, in agreement with the 65% value that can be derived from the study of King and Brown (1993) (Eq. (12)). The relationships for the other amino acids were derived from the ideal protein for gestation presented in Table 3 and obtained from a literature review. This was preferred to the use of specific profiles for maintenance and body gains, as used by NRC (1998), because the information about maintenance requirements in sows is very limited and the extrapolation, on the basis of metabolic BW, from data obtained on growing pigs to much heavier weights can lead to inadequate profiles as illustrated by Dourmad and Étienne (2002) in the case of threonine.

2.3. Nutrient utilisation during lactation (Table 2)

During lactation, energy is partitioned between energy for maintenance, energy for milk production and energy from lipid and protein mobilisation (or deposition) from maternal body (Eq. (16)).
Table 2
Main equations describing nutrient utilization in lactating sows

Energy utilization

\[
\text{ME} = \text{ME}_m + \frac{E_{\text{milk}}}{k_m} - \frac{\text{ER}_m}{(k_{\text{rm}} \times k_m)}
\] (16)

- \text{ME}_m: ME for maintenance;
- \text{E}_{\text{milk}}: energy in milk;
- \text{k}_m: efficiency of ME for milk production;
- \text{ER}_m: energy from body reserves;
- \text{k}_{\text{rm}}: efficiency of energy from body reserves for milk production.

ME for maintenance

\[
\text{ME}_m = 460 \text{kJ BW}^{-0.75} \text{d}^{-1}
\] (17)

Efficiency of ME

\[
\begin{align*}
\text{k}_m &= 0.72 \\
\text{k}_{\text{rm}} &= 0.87
\end{align*}
\] (18) (19)

ME and protein exported in milk

Mean production during lactation

\[
\begin{align*}
E_{\text{milk}}(\text{kJ/d}) &= (20.6 \times \text{ADG}_{\text{litter}} - 376 \times \text{LS}) \\
N_{\text{milk}}(\text{g/d}) &= (0.0257 \times \text{ADG}_{\text{litter}} + 0.42 \times \text{LS})
\end{align*}
\] (20) (21)

Per day of lactation

\[
\begin{align*}
E_{\text{milk}}(\text{kJ/d}) &= \text{average } E_{\text{milk}} \times (2.763 - 0.014 \times d_{\text{lact}}) e^{-0.025t} e^{-c(0.5-0.1t)} \\
N_{\text{milk}}(\text{g/d}) &= \text{average } N_{\text{milk}} \times (2.763 - 0.014 \times d_{\text{lact}}) e^{-0.025t} e^{-c(0.5-0.1t)}
\end{align*}
\] (22) (23)

N balance

\[
\text{NR}(\text{g/d}) = -14.2 + 1.335 \text{ digestible lysine } - 0.629 \text{N}_{\text{milk}}
\] (24)

2.3.1. Milk production

The average amount of nutrients exported in milk during lactation can be predicted from the litter growth rate and litter size using the relationships proposed by Noblet and Étienne (1989) (Eq. (20) and (21)). From the combination of these equations and with the milk production curve proposed by Whittemore and Morgan (1990), it is possible to estimate the daily nutrient output in milk according to mean litter growth and duration of lactation (Eq. (22) and (23)).

2.3.2. Nutrient utilisation for maintenance and milk production

During lactation, the energy requirement for maintenance was evaluated to 460 kJ ME/kg BW$^{0.75}$ (Noblet et al., 1990) (Eq. (17)). Because the LCT during lactation is much lower than during pregnancy (about 10–15°C), and ambient temperature in farrowing rooms is usually above that limit, it is generally assumed that lactating sows have no specific energy requirements for thermoregulation. Similarly, as lactating sows are only modestly active, the related energy expense is much lower and much less variable than in pregnant sows. For these reasons, we assumed that maintenance energy requirement of lactating sows was affected only by body weight.

Efficiency of ME for milk production ($k_m$) is about 72% (Eq. (18)) according to Noblet and Étienne (1987) and the values found in the literature vary between 68 and 79%. When energy from body reserves is used for milk production the efficiency ($k_{rm}$) is higher and close to 87% (Eq. (19)). In that situation, energy from mainly lipids is mobilised from body reserves and directly transferred to milk. This process occurs with a high metabolic efficiency.
<table>
<thead>
<tr>
<th>Table 3</th>
<th>Ideal amino acid profile for gestation and lactation (standardised ileal digestible amino acids)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gestation</td>
</tr>
<tr>
<td>Lysine</td>
<td>100</td>
</tr>
<tr>
<td>Methionine</td>
<td>28</td>
</tr>
<tr>
<td>Methionine + cystine</td>
<td>65</td>
</tr>
<tr>
<td>Threonine</td>
<td>72</td>
</tr>
<tr>
<td>Tryptophane</td>
<td>20</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>65</td>
</tr>
<tr>
<td>Leucine</td>
<td>100</td>
</tr>
<tr>
<td>Valine</td>
<td>75</td>
</tr>
<tr>
<td>Phenydalanine</td>
<td>60</td>
</tr>
<tr>
<td>Phenylalanine + tyrosine</td>
<td>100</td>
</tr>
<tr>
<td>Histidine</td>
<td>30</td>
</tr>
<tr>
<td>Arginine</td>
<td>–</td>
</tr>
<tr>
<td>Lactation</td>
<td>100</td>
</tr>
<tr>
<td>Methionine</td>
<td>30</td>
</tr>
<tr>
<td>Methionine + cystine</td>
<td>60</td>
</tr>
<tr>
<td>Threonine</td>
<td>66</td>
</tr>
<tr>
<td>Tryptophane</td>
<td>19</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>60</td>
</tr>
<tr>
<td>Leucine</td>
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</tr>
<tr>
<td>Valine</td>
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</tr>
<tr>
<td>Phenydalanine</td>
<td>60</td>
</tr>
<tr>
<td>Phenylalanine + tyrosine</td>
<td>115</td>
</tr>
<tr>
<td>Histidine</td>
<td>42</td>
</tr>
<tr>
<td>Arginine</td>
<td>67</td>
</tr>
</tbody>
</table>

It is more difficult to evaluate the efficiency of amino acid utilisation for milk production, because the contribution of body protein reserves is not precisely known. This is why the use of the empirical relationship proposed by Dourmad et al. (1998) between digestible lysine intake, N in milk and N balance of lactating sows was preferred (Eq. (24)). In the same approach as for gestation, the relationships for the other amino acids were derived from the ideal protein profile for lactation presented in Table 3.

2.3.3. Mobilisation of body reserves

The quantity and composition of body reserves mobilised during lactation depend on the nutritional deficit. Mobilisation of lipids from adipose tissue is predominant when energy supply is insufficient, whereas muscle protein is mainly mobilised in the situation of an amino acid deficiency. However, it is likely that the mobilisation of energy and protein are not completely independent. Pomar et al. (1991) suggested that body protein could also be mobilised for providing energy in the situation of an energy deficiency. Although this is not well documented in literature, it has a great impact on the prediction of body weight loss during lactation. The NRC (1998) model uses an empirical relationship, which does not depend on nutrient supply, for estimating chemical composition of body weight loss. Pomar et al. (1991) proposed a minimum value of 1:20 for the protein:lipid ratio on an energy basis, which will be used as the default value in the present model.

2.4. Relationship between the sow’s body condition and chemical composition

In practice, body condition of sows can be evaluated from their body weight and their backfat thickness (BT) measured using an ultrasonic device. Relationships where proposed by Dourmad et al. (1997) to predict body energy, protein and fat contents of sows according to empty body weight (EBW) and BT (Table 4, Eq. (25)–(27)) from a study conducted on about 190 sows from various parities and physiological stages. These relationships can be used to estimate energy, lipid and protein retention from changes in EBW and BT, or to predict EBW and BT from the amounts of body energy, lipids and energy. These equations give predictions in good concordance with the others published equations reviewed.
Table 4
Prediction of fat, energy and protein content of sows from empty body weight (EBW\(^1\), kg) and backfat thickness (BT at P2 site, mm)

<table>
<thead>
<tr>
<th>Component</th>
<th>Equation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (kg)</td>
<td>(= -26.4 + 0.221 \text{EBW} + 1.331 \text{BT}) (25)</td>
<td></td>
</tr>
<tr>
<td>Energy (MJ)</td>
<td>(= -1074 + 13.65 \text{EBW} + 45.94 \text{BT}) (26)</td>
<td></td>
</tr>
<tr>
<td>Protein (kg)</td>
<td>(= 2.28 + 0.178 \text{EBW} - 0.333 \text{BT}) (27)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) With EBW = 0.96 BW.

by Gill (2006). However, because such equations were generally obtained from genotypes selected for reduced fatness, they could be less adequate for genotypes with much greater depth of subcutaneous fat (Gill, 2006). In the future, these equations will need to be improved in order to better take into account the short term variations in BW related to the changes in weight of udder, uterus and intestinal contents, around farrowing and weaning.

3. Building a tool for decision making

The different equations describing utilisation of nutrients by pregnant and lactating sows were used to build a computerised simulator. This simulator determines, on a daily basis, the flow of nutrients and energy from the feed to storage in the body, excretion or dissem-ination (Fig. 1). Additional functionalities were added to the simulator so that it can be used as a decision support tool (Fig. 2). A first module (“sow profile”) was developed to describe animal’s characteristics and adjust some model parameters to account for variations in genotypes and performance, as observed under practical circumstances. Three other

Fig. 2. Configuration of the InraPorc decision making tool for sow nutrition.
modules are used to describe the feeds used ("feed sequence plan"), the quantity of feed consumed ("feed rationing plan") and the housing ("housing plan"). The information can then be used to determine the nutritional requirements according to the factorial approach, or to predict performance and analyse nutrient utilisation through a simulation.

3.1. Definition of a sow profile and calibration of the model

Most of the equations presented in Tables 1–4 were obtained from experiments conducted on Large White or Large White × Landrace crossbred sows. It can be assumed that most of the parameters describing nutrient efficiency can be used for other genotypes. However, this is not the case for all parameters and model inputs, and some of these require adaptation for each specific genotype. For instance, this includes the evolution (with parity) of reproductive performance, BW and BT, and voluntary feed intake of sows. This adaptation is obtained through a calibration procedure. The calibration is realised through the minimisation of the difference between simulated and measured values of BW and BT, the measured value being provided by the end-user of the model. For gestation, two model parameters are adjusted: (i) an adjustment factor for the maintenance energy requirement and (ii) the potential of protein deposition which is adapted to take into account its evolution with

Table 5
Evaluation of energy and lysine requirement of sows according to paritya

<table>
<thead>
<tr>
<th>Litter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestation (thermoneutrality)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy requirement (MJ ME/d)</td>
<td>33.5</td>
<td>37.2</td>
<td>37.5</td>
<td>36.6</td>
<td>36.3</td>
<td>36.0</td>
</tr>
<tr>
<td>Digestible lysine requirement</td>
<td>13.5</td>
<td>12.9</td>
<td>12.2</td>
<td>11.8</td>
<td>11.6</td>
<td>11.4</td>
</tr>
<tr>
<td>g/kg feedb</td>
<td>5.14</td>
<td>4.41</td>
<td>4.16</td>
<td>4.11</td>
<td>4.06</td>
<td>4.03</td>
</tr>
<tr>
<td>Lactation (2.6 kg/d litter weight gain)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (MJ/d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>90.1</td>
<td>94.9</td>
<td>100.5</td>
<td>101.6</td>
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<tr>
<td>Intake</td>
<td>68.1</td>
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<td>Intake (% requirement)</td>
<td>75.6</td>
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<tr>
<td>Digestible lysine requirement</td>
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<tr>
<td>g/d</td>
<td>43.3</td>
<td>44.6</td>
<td>46.5</td>
<td>46.5</td>
<td>45.8</td>
<td>44.9</td>
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<td>g/kg fedc</td>
<td>8.3</td>
<td>7.4</td>
<td>7.0</td>
<td>7.0</td>
<td>6.9</td>
<td>6.8</td>
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<tr>
<td>Change in requirement (%)</td>
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<td></td>
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<td></td>
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<tr>
<td>Gestation (outdoor, 10 °C)</td>
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<tr>
<td>Energy requirement (%)</td>
<td>+24</td>
<td>+25</td>
<td>+27</td>
<td>+29</td>
<td>+30</td>
<td>+31</td>
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<tr>
<td>Digestible lysine content (%)</td>
<td>−19</td>
<td>−20</td>
<td>−21</td>
<td>−22</td>
<td>−23</td>
<td>−24</td>
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<tr>
<td>Lactation (3.0 kg/d litter weight gain)</td>
<td></td>
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<tr>
<td>Energy requirement (%)</td>
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<td>+10</td>
<td>+10</td>
<td>+10</td>
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<tr>
<td>Digestible lysine content (%)</td>
<td>+10</td>
<td>+10</td>
<td>+10</td>
<td>+10</td>
<td>+10</td>
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</table>

a Calculated for a herd with an average productivity of 25 piglets weaned per sow per year, with sows with a mature BW of 270 kg and an average 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.
parity and the effect of mature body weight. The latter is calculated by parity as the ratio between the predicted and the measured protein retention in the reference situation. In the same way, two model parameters are also adjusted for lactation: (i) an adjustment factor for the maintenance energy requirement and (ii) the minimum contribution of body protein for energy mobilisation in case of energy deficiency.

3.2. Factorial calculation of requirements

As an example, the energy and amino acid requirements of sows from a herd weaning 25 piglets per sow per year, with an average 12.5 and 10.8 piglets born alive and weaned per litter, respectively, are calculated (Table 5). The daily energy requirement for gestation increases from parity 1 to parity 3 and remains constant thereafter. The same variation is observed for the daily amino acid requirement (lysine), whereas the requirement decreases

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Example of a simulation for a primiparous sow over pregnancy and lactation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sow and litter characteristics</td>
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<tr>
<td>Animal profile</td>
<td>Large White × Landrace (270 kg BW at maturity)</td>
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<tr>
<td>Housing</td>
<td>Indoor on slatted floor</td>
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<td>Feed sequence plan</td>
<td>Standard gestation/lactation sequence</td>
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<td>Feed rationing plan</td>
<td>Parity 1</td>
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<tr>
<td>Born</td>
<td>Born alive</td>
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<tr>
<td>Number of piglets</td>
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<tr>
<td>Piglets weight, kg</td>
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<td>Litter weight, kg</td>
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<td>Simulated sow performance</td>
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<td>Duration (d)</td>
<td>Gestation</td>
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<td>Feed intake (kg)</td>
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<td>Total</td>
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<td>per day</td>
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<td>Body weight (kg)</td>
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<td>Initial</td>
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<td>Final</td>
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<td>total gain</td>
<td>83.2</td>
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<tr>
<td>net gain</td>
<td>58.0</td>
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<tr>
<td>Backfat thickness (mm)</td>
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<tr>
<td>Initial</td>
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<tr>
<td>Final</td>
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<tr>
<td>Gain</td>
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<tr>
<td>Deposition (g/d)</td>
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<td>Protein</td>
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<tr>
<td>Lipid</td>
<td>171</td>
</tr>
<tr>
<td>Milk production (kg/d)</td>
<td>–</td>
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</tbody>
</table>
when expressed per kg feed. The energy requirement for lactation also increases with parity. On average, voluntary energy intake is sufficient to meet 83% of the energy requirement for lactation, this value being lower in primiparous sows (75%). As for pregnancy, the amino acid requirement per kg feed is higher for the first and second litter, mainly because of a lower feed intake of the sow.

The effect of different factors of variation (e.g., housing conditions or level of performance) on requirements can also be evaluated. For instance, in the previous example, in the case of pregnant sows housed outdoor at 10 °C ambient temperature, their energy requirement is increased by about 25%, and their lysine/energy requirement is decreased by 20% (Table 5). In the same way, if litter growth rate is higher (3.0 kg/d versus 2.6 kg/d; +15%) during lactation, energy and amino acid requirements increase by approximately 10%.

3.3. Short and long term simulation of performance

InraPorc can be used to evaluate the short- or long-term effects of different housing or feeding strategies on nutrient utilisation and body condition of the sows. The information required to run such a simulation and the predicted responses is given in Table 6 for a sow from parity 1. As an example, data from Everts and Dekker (1995) were used to test the model in terms of predicted BW and BT during three reproductive cycles. As illustrated in Fig. 3 predicted values were very close to measured value as well for BT and BW, although some deviations were observed in parity 1 for BT.

In practice, such simulations can be useful to predict the risk of an excessive mobilisation or constitution of body reserves, which might impair reproductive performance in the long-term. Also, the existence of nutrient deficiencies or excesses can be identified. For example, the changes in body condition of sows for two genotypes differing in voluntary feed intake during lactation (L: 5.0 and H: 7.0 kg/d on average) were simulated over four successive parities. Feed supply during pregnancy was fixed so that sows attained their mature body weight.

Fig. 3. Comparison of predicted (lines) and measured value of BW (circles) and BT (squares) over three reproductive cycles using data from Everts and Dekker (1995).
weight at parity 4, while maintaining a BT of at least 13 mm. The simulated evolution in BW and BT in these two situations is presented in Fig. 4. Body weight loss during lactation is much greater for L than for H sows, and this is compensated by a higher weight gain in pregnancy. The same is observed for BT, L sows are leaner at weaning and fatter at farrowing. This results in an increased risk of reproduction problems in L sows, both at weaning and farrowing. Average daily feed intake over the reproductive cycle (3.5 kg/d) does not differ between L and H sows. However, the type of diet to be fed differs between the two situations, lysine requirement during lactation being much higher in L than in H sows (0.95% versus 0.75% in first lactation), whereas no difference is found during gestation.

4. Conclusion

From the results obtained during recent years on energy and amino acid utilisation of sows, it is possible to improve feeding strategies. The factorial approach allows the user to precisely determine feeding requirements according to housing conditions, performance goals, and body condition of sows, for most usual pig production systems. With a prediction model, the medium- and long-term effects of a feeding strategy for a given type of sow in given housing conditions can be evaluated. This results in a dynamic approach towards nutrition and allows identifying the limiting factors in the diets and/or the excessive supplies. The development of specific computerised tools largely facilitates the use of these concepts by nutritionists or for teaching these concepts.

Acknowledgement

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References


