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Economic weights for feed intake in the growing pig derived from a growth model and an economic model

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ABSTRACT: Economic weights are obtained for feed intake using a growth model and an economic model. The underlying concept of the growth model is the linear plateau model. Parameters of this model are the marginal ratio (MR) of extra fat and extra protein deposition with increasing feed intake (FI) and the maximum protein deposition (Pd_{max}). The optimum feed intake (FI_0) is defined as the minimum feed intake that meets energy requirements for Pd_{max}. The effect of varying FI and MR on performance traits was determined. An increase in FI results in a larger increase in growth rate with lower MR. For a given MR, feed conversion ratio is lowest when FI equals FI_0. Lean meat percentage (LMP) is largest for a low MR in combination with a low FI. The decrease in LMP with higher FI is largest when FI exceeds FI_0. Economic weights for FI, MR and Pd_{max} depend on FI in relation to FI_0. Economic weights for FI are positive when FI is less than FI_0 and negative when FI is larger than FI_0. The MR has only then a negative economic weight, when FI is below FI_0. Economic weights of FI and MR have a larger magnitude with lower MR and lower FI. In contrast, economic weights for growth rate and FI derived from the economic model only change in magnitude and not in sign with different levels of these traits. The economic model always puts a negative economic weight on FI since it expresses profit due to a decrease in FI with constant growth rate and LMP. This holds the risk of continuous decrease in FI in pig breeding programs. In contrast, the use of growth models for genetic improvement allows direct selection for an optimum feed intake which maximizes feed efficiency in combination with maximum lean meat growth. It is concluded that recording procedures have to be adapted to collect the data necessary to implement growth models in practical pig breeding applications.

Key Words: Breeding, Economic Evaluation, Feed Intake, Growth Models, Pigs

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Introduction

Feed costs form a major part of the production costs of pork. Management practices and breeding strategies must therefore aim to optimize feed intake. Economic optimization of feed intake of the growing pig usually implies that feed intake is sufficient to maximize lean meat growth. However, maximum lean growth changes by genetic selection and to optimize feed intake genetically the proper economic weight should be assigned to it.

Growth models are used to parameterize biological characteristics of pigs and to evaluate their effect on performance traits and economic profit (e.g., De Lange et al., 2001). Parameters of growth models can also be used as breeding objectives, and their economic weights can then be derived from the change in profit as a result of changing each parameter. De Vries and Kanis (1992) used a growth model to derive economic weights for feed intake capacity in the growing pig. A similar model was used by Skorupski et al. (1995a,b) to derive economic weights based on simulation of life cycle pig production. The model described by De Vries and Kanis (1992) has been developed further (De Greef, 1992; Bikker, 1994) and implications of this change for deriving economic weights have been analyzed by von Rohr et al. (1999). However, the effect of different levels in parameters of the growth model in

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general and specifically the Technisen Model Varkersvoeding (**TMV**) model (TMV, 1994) on performance and economic weights has not been demonstrated. The aim of this paper is to derive economic weights for parameters of the TMV growth model, in particular for feed intake and to illustrate the effects of different levels in these parameters on performance traits and economic weights for parameters of the growth model. Changes in these economic weights are compared with the corresponding changes in economic weights for performance traits derived from an economic model as usually used in animal breeding.

Methods

Introduction of Growth Model

The growth model used to derive performances and economic weights is the TMV model (TMV, 1994). This growth model is based on the concept of a linear-plateau relationship between protein deposition and energy intake. The concept was proposed by Whittemore and Fawcett (1976) and was experimentally demonstrated by Campbell et al. (1983). The concept was then further adapted by De Greef (1992) and has been incorporated in the TMV model. The model assumes that for an animal in a specific weight range an increase in daily energy intake results in a linear increase in protein deposition until a plateau in protein deposition is reached. This plateau, also called maximum protein deposition (Pd_{max}), is considered an intrinsic factor for each pig. In addition, the model assumes that for each unit of protein deposited a minimum amount of fat is deposited. Each unit increase in energy intake results in extra fat and extra protein deposition, until maximum protein deposition is reached, in a ratio called the marginal ratio (**MR**) (De Greef, 1992). The marginal ratio increases with live weight of the animal. Within the model the optimum feed intake (FI_0) is defined as the minimum amount of feed (energy) required meeting the intrinsic maximum protein deposition (De Vries and Kanis, 1992).

The daily feed intake determines the metabolic energy, which is used for maintenance and protein and fat deposition. The main equations used in the TMV model used to derive the average growth performance over a given weight range are described below. Daily maintenance requirement (M) is assumed to be related to live weight of the animal in kilograms to the 0.63 power (ARC, 1981). Assuming a constant weight gain during the entire growing period the average daily maintenance requirement (M_a) for a specified weight range (wt_1 to wt_2) can be derived as (Foster et al., 1983):

$$M_a = \frac{1}{(wt_2 - wt_1)} \frac{0.719}{1.63}(wt_2^{1.63} - wt_1^{1.63}) \qquad [1]$$

The current calculations assume a live weight range of 25 to 115 kg. The average daily maintenance requirement for this weight range is 10.27 MJ ME. Energy not required for maintenance is used for protein and lipid deposition. It is assumed that the energy contents of 1 kg of deposited protein or fat are 23.8 MJ ME and 39.6 MJ ME, respectively. The efficiency of depositing protein and fat are assumed to be 0.45 (Metz et al., 1982) and 0.75 (ARC, 1981), respectively. Therefore, 53 MJ ME are required for deposition of 1 kg of fat or protein. The model described by De Vries and Kanis (1992) assumes that lipid as well as protein deposition are zero when pigs are fed at maintenance level. However, a number of studies (e.g., Black et al., 1986; De Greef, 1992) show that protein is still deposited, while fat is broken down when pigs are fed at maintenance level. Fat deposition is zero at an energy intake of 1.3 maintenance level (Bikker, 1994). Protein deposition at 1.3 maintenance level is derived as 0.3 maintenance requirements (M)/53. Equation 2 represents daily protein deposition (Pd) as a function of feed intake. This formula is only valid when feed intake is insufficient to meet the maximum protein deposition rate. Protein deposition is equal to the maximum protein deposition rate when feed intake is equal or greater than the optimum feed intake. Energy not required for maintenance or protein deposition is used for lipid deposition (Equation 3),

$$Pd = (0.3\ M)/53 + (FI - 1.3\ M)/53\ (1/(MR + 1)) \qquad [2]$$

$$Ld = (FI - M - 53\ Pd)/53 \qquad [3]$$

where FI is the energy intake in megajoules ME. The energy density was assumed to be 12.72 MJ ME/kg feed. The marginal ratio is defined as b × live weight in the TMV model (TMV, 1994). The default values for b are 0.04, 0.05, and 0.06 for barrows, gilts, and boars, respectively. De Greef (1992) summarized the range of marginal ratios for a given weight range from a number of studies. The corresponding b-values ranged from 0.02 to 0.09. Given the average live weight of 70 kg assumed in this study, values for average marginal ratio analyzed ranged from 1.40 to 6.30. Ash deposition is derived as 0.191 × protein deposition and daily water deposition (W_d) is derived from protein deposition and protein weight as

$$W_d = 1.05 \times 4.9\ ((P_m + P_d)^{(0.855)} - P_m^{0.855}) \qquad [4]$$

where P_m represents protein mass. Assuming a constant rate of protein deposition, the average daily water deposition (W_a) over a given weight range is derived as:

$$W_a = \frac{1}{P_{m2} - P_{m1}} \frac{1.05 \times 4.9}{1.855}((P_{m2} + P_d)^{1.855} - (P_{m1} + P_d)^{1.855} - ((P_{m2})^{1.855} - (P_{m1})^{1.855})) \qquad [5]$$

where P_{m1} and P_{m2} represent protein mass at the beginning and end of the empty body weight range, respectively. To derive average water deposition for a given weight range, the initial chemical body composition is required. The empty body weight is defined as 95% of the live weight. Based on results of De Greef (1992), the weights of protein, lipid, and ash at 23.75 kg empty body weight are derived as 0.512, 0.385, and 0.103 times the weight of dry matter in the empty body weight, respectively. The water content is derived as 1.05 times 4.9 (protein weight)$^{0.855}$ (De Greef, 1992). The protein and fat mass are derived iteratively. At 25 kg live weight protein and fat mass are 3.838 and 2.887 kg, respectively. The average daily water deposition and consequently the body composition at an empty body weight of 109.25 kg (115 kg live weight) are derived iteratively. The sum of average daily protein, lipid, ash, and water deposition represents 95% of the average daily gain during the considered body weight range.

In order to obtain lean meat percentage (**LMP**) of the carcass from input parameters of the linear plateau model a prediction equation is used in the TMV model (unpublished results, De Greef):

$$\text{LMP} = ((0.711 - 0.665\ (\text{carcass fat weight}/\text{empty body weight}))\ 100\% \qquad [6]$$

Profit

The profit is derived on a per slaughter pig basis. The payment system assumes that returns per slaughter pig depend on the carcass weight and the price per kilogram carcass weight. A base price of € 1.36 is assumed per kilogram carcass weight given a lean meat percentage of 55%. In addition, a bonus of € 0.0136 per kilogram carcasss weight is paid for each additional per cent increase in LMP from 55 to 65% with no additional bonus being paid if LMP percentage exceeds 65%. Similarly, a penalty of € 0.0136 is imposed per 1% lean meat lower than 55%. A carcass weight of 90 kg is assumed.

Costs per slaughter pig include feed costs, additional costs per day, and fixed costs per pig, which includes piglet price, veterinary costs, etc. The price per kilogram feed is assumed to be € 0.195. Fixed costs are assumed to be € 47.65 per pig and variable costs € 0.113 per day per pig. The number of days required to reach the carcass weight depends on ADG. The profit per pig is then derived from returns minus costs and is derived for a LMP below 65% as

$$\text{Profit}\ (€) = 90\ (1.36 + 0.0136\ (\text{LMP} - 55) - ((0.195 \times \text{FI} + 0.113)/\text{ADG})) - 47.65 \qquad [7]$$

Economic weights for feed intake are derived in two ways. Using the growth model, economic weights for feed intake and parameters of the growth model are derived by simulating changes in each parameter of the growth model and evaluating the corresponding economic changes in the profit function. Based on the economic model, economic weights for feed intake along with economic weights for further performance traits are directly derived from the first partial derivatives of this profit function with respect to the trait of interest (Eq. 8 to 10).

Breeding Objectives and Economic Weights

A common breeding goal for growing pigs contains the traits feed intake, average daily gain, and LMP, each weighted by its corresponding economic weight, which can be obtained by partially differentiating the profit equation with respect to the parameter

$$\text{dProfit/dADG}\ (€) = 90\ (0.195 \times \text{FI} + 0.113)/\text{ADG}^2 \qquad [8]$$

$$\text{dProfit/dFI}\ (€) = 90 \times -0.195/\text{ADG} \qquad [9]$$

$$\text{dProfit/dLMP}\ (€) = 90 \times 0.0136 \qquad [10]$$

Economic weights obtained in this (classic) way are called here economic weights derived from an economic model. Alternatively, the driving variables in the growth model, feed intake, MR, and maximum protein deposition determining the performance traits growth rate and LMP can also be considered as breeding objective traits. The respective economic weights can be obtained by changing each of these parameters in the growth model, while keeping the others constant and evaluating the corresponding economic changes in profit.

Results

Protein and Lipid Deposition

For the growth model, the effect of average daily feed intake and average b-value of the MR on protein deposition is shown in Figure 1. When feed intake is not sufficient to meet maximum protein deposition (Pd_{max} = 150 g/d), protein deposition increases linearly with rising feed intake (linear part of model). This increase is higher with a lower MR when relatively less lipid but more protein is deposited with each extra kilogram of feed intake. The minimum amount of feed intake to reach this maximum protein deposition, the optimum feed intake, depends on the MR. For a given maximum protein deposition, the optimum feed intake is low in conjunction with a low MR and increases with higher levels of the MR.

Lipid deposition increases with higher feed intake and higher MR for all levels of feed intake and b-values of MR. If feed intake is above the optimum feed intake,

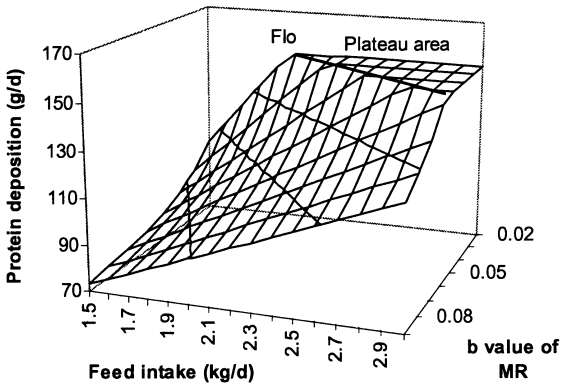

Figure 1. Protein deposition for different levels of feed intake and b value of marginal ratio (MR) (note: axis is reversed; FI_0: optimal feed intake).

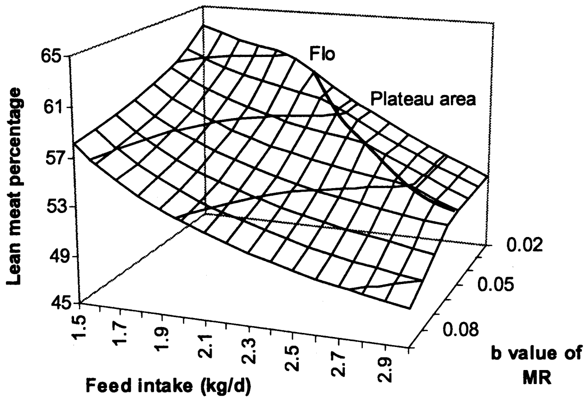

Figure 3. Lean meat percentage for different levels of feed intake and b value of marginal ratio (MR) (note: axis is reversed; FI_0: optimal feed intake).

the increase in lipid deposition is larger with each extra kilogram of feed eaten since extra energy is not used for deposition of extra protein but only for additional lipid deposition.

Growth Rate

The increase in growth rate with increasing feed intake follows the pattern of protein and lipid deposition (Figure 2) with protein deposition having a larger effect on growth rate since protein deposition determines ash and, more importantly, water deposition, which constitutes a large part of growth. As a consequence, growth rate increases more per unit increase in feed intake when feed intake is not sufficient to meet energy requirements for the maximum protein deposition in combination with a low MR. Within the plateau part of the model, growth rate is not influenced by the MR and increases with higher feed intake only slightly due to a further increase in lipid deposition.

Lean Meat Percentage

Lean meat percentage is highest when both feed intake and MR are low (Figure 3). A higher feed intake reduces LMP to a larger extent once feed intake exceeds the optimum feed intake. The MR does not influence LMP within the plateau part of the model.

Feed Conversion Ratio

For any given MR, feed conversion ratio is lowest when feed intake equals the optimum feed intake as defined by the linear-plateau model (Figure 4). Within the linear part of the model, feed conversion ratio decreases with higher levels of feed intake. In the plateau part, feed conversion ratio increases with higher levels of feed intake. During the linear part of the model, extra feed intake leads to an increase in protein deposition which mainly determines growth rate through water deposition. The extra gain in growth rate is proportionally higher than the increase in feed intake, resulting in a reduced and therefore improved feed conversion ratio. In contrast, during the plateau part of the model any further increase in feed intake only results in an increase in lipid deposition.

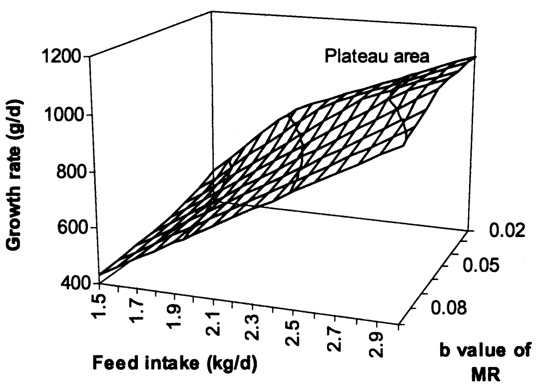

Figure 2. Growth rate for different levels of feed intake and b value of marginal ratio (MR) (note: axis is reversed).

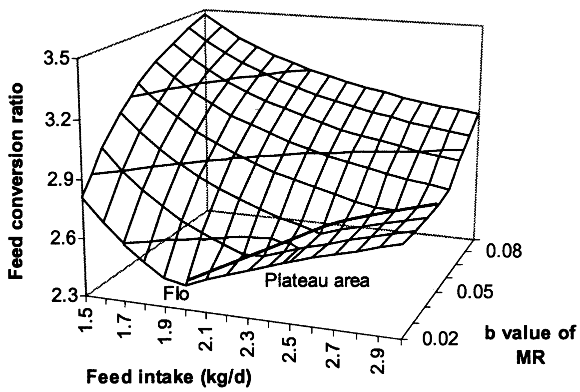

Figure 4. Feed conversion ratio for different levels of feed intake and b value of marginal ratio (MR) (FI_0: optimal feed intake).

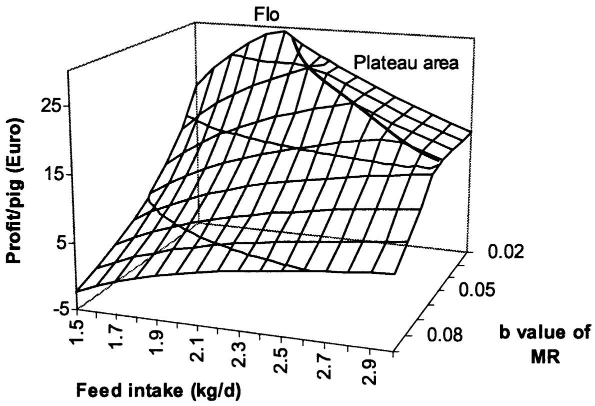

Figure 5. Profit per pig for different levels of feed intake and b value of marginal ratio (MR) (note: axis is reversed; FI_0: optimal feed intake).

Profit per Pig Derived Through the Growth Model

Different levels of feed intake and different b-values determining MR imply differences in feed conversion ratio, LMP, and growth rate which influence the profit per pig. The effect of feed intake and b-values of the MR on profit per pig is shown in Figure 5, again assuming a maximum protein deposition of 150 g/d. In the linear part of the model, profit per pig increases with lower levels of the MR. However, marginal ratio does not influence profit per pig within the plateau part of the model. In contrast, feed intake affects profit per pig during the plateau part as well as the linear part of the model. For a given MR and maximum protein deposition, profit per pig is maximized when feed intake equals the minimum feed intake required to meet maximum protein deposition. The optimum feed intake based on the growth model, therefore, equals the economic optimum. When feed intake is below this optimum feed intake, profit per pig increases with higher feed intake. Within the plateau part of the model, profit per pig decreases with higher levels of feed intake.

Economic Weights

Economic weights for parameters of the growth model are presented in Table 1 along with economic weights for performance traits derived from the economic model. The breeding goal based on the growth model includes MR, maximum protein deposition, and feed intake. Six different scenarios are presented consisting of two different b-values of the MR (0.03 and 0.05) each with three different levels of feed intake. The economic weight for feed intake based on the growth model is positive, when feed intake is below the optimum feed intake. The magnitude of this economic weight depends on the MR and is higher for a low MR. In contrast, feed intake has zero economic weight when it is optimum with respect to the growth model but has a negative economic weight when feed intake is above its optimum. The magnitude of the negative economic weight for feed intake (€ −13.89 and € −11.34 per pig) is not influenced by the MR but by differences in the absolute feed intake (2.5 vs 2.9 kg). The two remaining breeding objective traits using a growth model are the MR and the maximum protein deposition. Their economic weights also depend on the level of feed intake with respect to the optimum feed intake. The MR has a negative economic weight when feed intake is below or at the optimum level with its magnitude being larger for a smaller MR. In addition, the economic weight for the MR has a larger magnitude in combination with a higher feed intake. Performance traits and, therefore, profit per pig are only influenced by the maximum protein deposition when feed intake is equal to or above the optimum level. Differences in economic weights for maximum protein deposition are small between scenarios.

Economic weights derived from the economic model depend on the level of performance traits. These are derived from the input parameters of the growth model. Economic weights derived from the economic model do not change to the same extent for different scenarios. The economic weights for feed intake and growth rate are influenced by the level in growth rate. Economic weights for feed intake are always negative, while economic weights for growth rate decrease slightly with increasing growth rate. The economic weight for LMP does not depend on other performance traits and remains constant at € 1.23 per pig for these situations.

Discussion

Today, growth models are widely used to assist pig producers to evaluate alternative management systems and feeding strategies (Black et al., 1986; Pomar et al., 1991; TMV, 1994). The efficiency of pig production has improved using these models (e.g., Mullan et al., 1993). Pig breeders are looking at possible ways to incorporate this knowledge in animal breeding applications (Knap, 2000). The model used is based on a linear-plateau relationship between daily feed intake and daily protein deposition (Whittemore, 1983; De Greef, 1992) and assumes a constant daily weight gain and daily protein deposition over the considered growth period. These last assumptions were made to run the model on an average daily basis during the growth period. De Vries and Kanis (1992) use a similar approach and concluded that these simplifications do not hinder the use of this model for the estimation of economic weights for traits in the breeding objective.

De Lange et al. (2001) describe the MR and maximum protein deposition as two important aspects that characterize pig performance potential. Further, De Lange et al. (2001) summarize the difficulties in predicting feed intake for different groups of pigs managed under different conditions. Despite this, feed in-

Table 1. Performances and economic weights for growth model and economic model parameters at two b-values of the marginal ratio and three daily feed intakes

Item	Parameter	b-value = 0.03			b-value = 0.05		
		FI = 1.9	FI = 2.24[a]	FI = 2.5	FI = 2.5	FI = 2.775[a]	FI = 2.9
Performance	Daily gain, g/d	710	888	957	907	1,029	1,062
	Lean meat, %	59.2	58.0	55.4	53.8	53.1	52.1
Growth model	FI, €/(kg/d)	14.43	0	−13.89	5.58	0	−11.34
	b-value of MR, €	−634	−678	0	−426	−441	0
	Pdmax, €/(g/d)	0	0.33	0.32	0	0.31	0.30
Economic model	FI, €/(kg/d)	−24.73	−19.78	−18.33	−19.38	−17.06	−16.52
	Daily gain, €/(g/d)	0.086	0.064	0.059	0.064	0.054	0.054
	Lean meat, €/%	1.23	1.23	1.23	1.23	1.23	1.23

[a]Feed intake equals optimal feed intake.

take is often chosen to be a model input parameter. These traits, feed intake, MR, and maximum protein deposition, are included in the breeding objective based on the growth model. Maintenance requirements are assumed to depend on live weight of the animal and are not included in the breeding goal. A similar simplified growth model has been extended to take different maintenance requirements into account which arise from differences in protein turnover (Knap and Schrama, 1996) and thermoregulation (Knap, 1999). Knap (2000) discusses other factors influencing maintenance and concludes that only a limited proportion of the total variance in maintenance is related to body (growth) composition. It may be argued that selection for improved performance at a given feed intake results in an indirect selection response in lower maintenance requirements.

Parameters of the Growth Model Reflect Observed Performances

The level of maximum protein deposition is assumed to be 150 g in this study but differs between genotypes and is higher in entire males than in females (Campbell et al., 1985). The assumed level of 150 g is similar to the maximum protein deposition of 151 g and 156 g observed in Large White and Pietrain castrates by Quiniou et al. (1996). In contrast, Rao and McCracken (1992) and Quiniou et al. (1995) reported a maximum protein deposition of 194 g and 171 g for entire males.

The level of feed intake varies from 19 MJ ME to 38 MJ ME per day in this study and reflects mean voluntary feed intake levels observed in other studies. For example, the mean voluntary feed intake of pigs was 30.0 MJ DE (28.8 MJ ME) per day in a Pietrain population (Quiniou et al., 1995). Bikker (1994) found a voluntary feed intake of around 40 MJ DE (38.4 MJ ME) per day.

A reduction in feed intake causes the largest decrease in protein deposition in conjunction with a low MR. Protein deposition decreased by 6.1, 4.2, and 3.2 g per MJ ME decrease for b-values of the MR of 0.03, 0.05, and 0.07, respectively. Increase of protein deposition averaged 7.3 g/MJ DE in entire boars (Quiniou et al., 1995) in comparison to an increase in protein deposition of 3.8 g/MJ DE in hybrid gilts (Bikker, 1994). This sex effect was further confirmed by Quiniou et al. (1996) who found that each extra megajoule ME intake was associated with 6.1 g of extra protein deposition in entire crossbred Pietrain boars and 4.4 g and 4.7 g in crossbred Pietrain and Large White castrates. Corresponding increases in lipid deposition with higher levels of feed intake are similar in these studies between different types of pigs ranging from 13.2 to 13.9 g/MJ DE. In comparison, in the present study lipid deposition increased by 12.8, 14.8, and 15.7 g/MJ ME for b-values of the MR of 0.03, 0.05, and 0.07, respectively.

Profit Is Maximized for Optimum Feed Intake

The minimum level of feed intake to reach maximum protein deposition has been called optimum feed intake (De Vries and Kanis, 1992). Kanis (1995) showed in a simulation study that the highest returns per pig place per year were accomplished when feed intake was just sufficient to meet requirements for maximum protein deposition. Simulations in this study showed that profit was maximized for the optimum feed intake. The optimal feed intake minimizes feed conversion ratio and maximizes lean meat growth, two traits with a large influence on profit.

Economic Weights

Currently, breeding objectives are usually weighted by economic weights derived from an economic model. It was shown that economic weights for feed intake and growth rate depend on the level of performance in growth rate and feed intake. The use of economic models to derive economic weights for feed intake together with growth rate and LMP always leads to a negative economic weight for feed intake since a reduction in feed intake, assuming no changes in growth rate and LMP, reduces costs of production. Economic weights for LMP are constant as a result of a linear increase in price per kilogram carcass weight with higher LMP. Other payment systems are often nonlinear for lean meat also leading to changes in economic weights with different performance levels. Bioeconomic models as developed by Stewart et al. (1990) allow these nonlinear relationships to be taken into account in genetic improvement schemes.

Economic weights for parameters of the growth model depend, first, on the cost structure assumed, second, on the growth model used, and thirdly, on the level of performance in each parameter. For these reasons it is difficult to compare economic weights with other studies directly. The costs assumed in this study are lower than the costs presented in the studies of De Vries and Kanis (1992) and von Rohr et al. (1999). The influence of modifications in the growth model was analyzed by von Rohr et al. (1999) who showed that economic weights for feed intake are smaller under the modified linear-plateau model, also used in this study, in comparison to the conventional model used by De Vries and Kanis (1992). Changes in the level of parameters of the growth model analyzed in this study showed that economic weights for feed intake and MR (if feed intake is below the optimum feed intake) are of higher magnitude for low levels of each parameter. Other studies have not varied the parameters of the growth model and evaluated the effect of these variations on economic weights. Differences in economic weights for feed intake when feed intake exceeds the optimum feed intake are independent of the MR but depend on the level of feed intake and maximum protein deposition. In this study, the maximum protein deposition was kept constant and economic weights for feed intake (when feed intake exceeds the optimum feed intake) differed only slightly between the two scenarios shown.

Selection for Feed Intake

The use of an economic model to select for feed intake always places a negative economic weight on feed intake. Due to a strong emphasis on feed conversion ratio and leanness, selection has led to a reduction in feed intake (McPhee et al., 1981; Smith et al., 1991; Cameron and Curran, 1994) with the consequence that feed intake is below the optimum in some populations (Eissen, 2000). Different breeding objectives have been suggested to avoid a further reduction in feed intake selecting for lean tissue feed conversion (Fowler et al., 1976), implementing a restricted index on feed intake (e.g., Brandt, 1987) or placing a higher emphasis on growth rate (e.g., Krieter and Kalm, 1989). None of these approaches allows optimization of selection for feed intake directly. The use of a biological model in breeding programs provides an alternative breeding objective to directly select for the optimal feed intake with respect to the animal's potential for lean meat growth (Kanis and De Vries, 1992). This alternative breeding objective is of special interest in populations where feed intake capacity is below optimum feed intake. Although growth models and input parameters might differ between studies, von Rohr et al. (1999) showed that these differences in models lead to similar expected selection responses and that differences in models have limited implications for breeding objectives and selection strategies.

Implementing Growth Models in Breeding Programs

So far, genetic (co)variances are not available for parameters of growth models describing lipid and protein deposition with varying feed intake at a given live weight. First information on genetic variation is available from stochastic simulation studies as presented by Knap (1996). In addition, Knap and Jørgensen (2000) analyzed data from a serial slaughter trial and concluded that there is animal intrinsic variation in partitioning of body protein and lipid. Serial slaughter trial data, however, are rarely available and guidelines to estimate empirical relationships between "chemical" body composition defined in growth models by lipid and protein deposition and "physical" body composition like backfat and lean meat weight have been developed by De Greef (1995). Transforming current measurements into parameters of the growth model and therefore "inverting" growth models, however, does not provide additional information. Ultimately, recording procedures have to be extended to estimate parameters of the growth model. These recording procedures require performance testing of groups of pigs (i.e., full- or half-sib groups), where individual pigs are recorded on different feeding levels. Records of individual pigs, on different feeding levels, could then be treated as "repeated measurements" of a group of pigs. The level of protein deposition differs with varying feed intake which suggests the use of covariance functions (Meyer, 1998) to describe genetic and phenotypic variation of this longitudinal data. A further aspect is that model parameters depend on live weight and repeated measurements of live weight are necessary (Eissen, 2000). For practical breeding applications, however, live weight measurements have to be taken automatically. Such a technique is available with the development of electronic feeders that allow restriction of feed intake for individual pigs and are equipped with automatic scales (B. G. Luxford, personal communication). Further, video images of pigs obtained from electronic feeders while feeding (Schofield, 1993; Ramaekers et al., 1996) may be employed to obtain repeated measurements of (physical) body composition to obtain a measurement of lipid deposition. These recent developments in automated recording of weight, feed intake, and body composition allow the production of data sets necessary to use growth models for genetic improvement.

The first applications of such models in animal breeding may be to evaluate feed intake capacity of different genotypes with respect to the optimum feed intake. Eisen (2000) has performed such a study providing information about the desired direction of selection for feed intake capacity in each genotype analyzed. The next step may then be to base the breeding objective on parameters of the growth model since only this breeding objective allows emphasis to be placed directly on optimal feed intake.

Implications

Breeding objectives can be based on parameters of growth models, such as the linear-plateau model, which is based on three parameters: feed intake, marginal ratio, and maximum protein deposition. Economic weights for these parameters can be derived from their effects on profit. The minimum feed intake required for the maximum protein deposition maximizes profit and is called the optimum feed intake. Economic weights for parameters of the growth model depend on the level of feed intake in relation to the optimum feed intake, while conventional breeding objectives always put a negative economic weight on feed intake. Advances in performance recording procedures to obtain information necessary to implement growth models into breeding programs are required. Electronic feeders that are able to control the level of feed intake for individual pigs together with electronic scales and video images allow recording of the information necessary to implement growth models in genetic evaluation systems.

Literature Cited

ARC. 1981. The Nutrient Requirements of Pigs. Agricultural Research Council. Commonwealth Agricultural Bureaux, Farnam Royal, Slough, UK.

Bikker, P. 1994. Protein and lipid accretion in body components of growing pigs: Effects of body weight and nutrient intake. Ph.D. Thesis, Wageningen University, The Netherlands.

Black, J. L., R. G. Campbell, I. H. Williams, K. J. James, and G. T. Davies. 1986. Simulation of energy and amino acid utilization in the pig. Res. Dev. Agric. 3:121–145.

Brandt, H. 1987. Development and genetic aspects of feed intake in three breeds of pigs at German test stations and measures to prevent further deterioration. Pig News Infor. 8:29–33.

Cameron, N. D., and M. K. Curran. 1994. Selection for components of efficient lean growth rate in pigs. IV. Genetic and phenotypic parameter estimates and correlated responses in performance test traits with ad-libitum feeding. Anim. Prod. 59:281–291.

Campbell, R. G., M. R. Taverner, and D. M. Curic. 1983. The influence of feeding level from 20 to 45 kg live weight on the performance and body composition of female and entire male pigs. Anim. Prod. 36:193–199.

Campbell, R. G., M. R. Taverner, and D. M. Curic. 1985. Effects of sex and intake between 48 and 90 kg live weight on protein deposition in growing pigs. Anim. Prod. 40:497–503.

De Greef, K. H. 1992. Prediction of production; Nutrition induced tissue partitioning in growing pigs. Ph.D. Thesis, Wageningen University, The Netherlands.

De Greef, K. H. 1995. Prediction of growth and carcass parameters. In: P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld (ed.) Modelling Growth in the Pig. p 151. Wageningen Pers, Wageningen, The Netherlands.

De Lange, C. F. M., B. J. Maarty, S. Birkett, P. Morel, and B. Szkotnicki. 2001. Application of pig growth models in commercial pork production. Can. J. Anim. Sci. 81:1–8.

De Vries, A. G., and E. Kanis. 1992. A growth model to estimate economic values for food intake capacity in pigs. Anim. Prod. 55:241–246.

Eissen, J. J. 2000. Breeding for feed intake capacity in pigs. Ph.D. Thesis, Wageningen University, The Netherlands.

Foster, W. H., D. J. Kilpatrick, and I. H. Heaney. 1983. Genetic variation in the efficiency of energy utilization by the fattening pig. Anim. Prod. 37:387–393.

Fowler, V. R., M. Bichard, and A. Pease. 1976. Objectives in pig breeding. Anim. Prod. 23:365–387.

Kanis, E. 1995. Optimization of growth and body composition in pigs. In: Proc. 2nd Dummerstof Muscle Workshop, Rostock, Germany. p 191.

Kanis, E., and A. G. De Vries. 1992. Optimization of selection for food intake capacity in pigs. Anim. Prod. 55:247–255.

Knap, P. W. 1996. Protein turnover-dependent relations with body composition. Anim. Sci. 63:549–561.

Knap, P. W. 1999. Simulation of growth in pigs: evaluation of a model to relate thermoregulation to body protein and lipid content and deposition. Anim. Sci. 68:655–679.

Knap, P. W. 2000. Variation in maintenance requirements of growing pigs in relation to body composition. A simulation study. Ph.D. Thesis, Wageningen University, The Netherlands.

Knap, P. W., and H. Jørgensen. 2000. Variation in protein and lipid partitioning. Anim. Sci. 70:29–37.

Knap, P. W., and J. W. Schrama. 1996. Simulation of growth in pigs: approximation of protein turnover parameters. Anim. Sci. 63:533–547.

Krieter, J., and E. Kalm. 1989. Entwicklung von Selektionsmethoden für das Wachstum beim Schwein. Züchtungskunde 61:100–109.

McPhee, C. P., P. J. Brennan, and F. Duncalfe. 1981. Genetic and phenotypic parameters of Australian Large White and Landrace boars performance-tested when offered food ad libitum. Anim. Prod. 28:79–85.

Metz, S. H. M., N. P. Lenis, and A. W. Jongbloed. 1982. Voederbehoefte en voedernormen bij mestvarkens. Bedrijfsontwikkeling 13:821–825.

Meyer, K. 1998. Estimating covariance functions for longitudinal data using a random regression model. Gen. Sel. Evol. 30:221–240.

Mullan, B. P., G. T. Davies, and M. Charles. 1993. Formulating commercial grower diets using Auspig. In: E. S. Batterham (ed). Manipulating Pig Production IV. Proc. Australasian Pig Science Association, Canberra, ACT, Australia. p 220.

Pomar, C., D. L. Harris, and F. Minvielle. 1991. Computer simulation model of swine production systems: I. Modeling the growth of young pigs. J. Anim. Sci. 69:1468–1488.

Quiniou, N., J. Y. Dourmad, and J. Noblet. 1996. Effect of energy intake on the performance of different types of pig from 45 to 100 kg body weight. I. Protein and lipid deposition. Anim. Sci. 63:277–288.

Quiniou, N., J. Noblet, J. van Milgen, and J. Y. Dourmad. 1995. Effect of energy intake on performance, nutrient and tissue gain and protein and energy utilization in growing boars. Anim. Prod. 61:133–143.

Ramaekers, P. J. L., J. H. Huiskes, M. W. A. Verstegen, L. A. den Hartog, P. C. Vesseur, J. W. G. M. Swinkels, and C. M. C. van der Peet-Schwering. 1996. Modern techniques for automatic determination of individual body weight of group-housed growing finishing pigs. Übersichten zur Tierernährung 23:215–228.

Rao, D. S., and K. J. McCracken. 1992. Energy: protein interactions in growing boars of high genetic potential for lean growth. II. Effects on chemical composition of gain and whole-body protein turn-over. Anim. Prod. 54:83–93.

Schofield, C. P. 1993. Image analysis for non-intrusive weight and activity monitoring of live pigs. In: Proc. 4th Int. Symp. Livest. Environ., Univ. Warwick, Coventry, England. Am. Soc. Agric. Eng., St. Joseph, MI. p 503.

Skorupski, M. T., D. J. Garrick, H. T. Blair, and W. C. Smith. 1995a. Economic values of traits for pig improvement. I. A simulation model. Austr. J. Agric. Res. 46:285–303.

Skorupski, M. T., D. J. Garrick, H. T. Blair, and W. C. Smith. 1995b. Economic values of traits for pig improvement. II. Estimates for New Zealand Conditions. Austr. J. Agric. Res. 46:305–318.

Smith, W. C., M. Ellis, J. P. Chadwick, and R. Laird. 1991. The influence of index selection for improved growth and carcass characteristics on appetite in a population of Large White pigs. Anim. Prod. 52:193–199.

Stewart, T. S., D. H. Bache, D. L. Harris, M. E. E. Einstein, D. L. Lofgren, and A. P. Schinckel. 1990. A bioeconomic profit function for swine production: application to developing optimal multitrait selection indexes. J. Anim. Breed. Genet. 107:340–350.

TMV. 1994. Informatiemodel Technisch Model Varkensvoeding. Werkgroep TMV. Publicatie 1.117 PV. Research Institute for Pig Husbandry, Rosmalen, The Netherlands.

von Rohr, P., A. Hofer, and N. Kuenzi. 1999. Two growth models to estimate economic values for food intake capacity in pigs. Anim. Sci. 69:49–57.

Watt, D. L., J. A. De Shazer, R. C. Ewan, R. L. Harold, D. C. Mahan, and G. D. Schwab. 1987. NCCISwine: housing, nutrition, and growth simulation model. Appl. Agric. Res. 2:218–223.

Whittemore, C. T. 1983. Development of recommended energy and protein allowances for growing pigs. Agric. Systems 11:159–186.

Whittemore, C. T., and R. H. Fawcett. 1976. Theoretical aspects of a flexible model to simulate protein and lipid growth in pigs. Anim. Prod. 22:87–96.