Description of a growth model: The linear-plateau model

Susanne Hermesch*, Egbert Kanis[1]; Jaco Eissen[1]

Wageningen Agricultural University, Animal Breeding and Genetics Group, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

Introduction

Feed costs are a major cost component of pig production and the optimal use of feed for production is therefore of high importance in an economic and sustainable pig industry. The amount of food eaten by the growing pig is used for maintenance and growth which includes lean meat as well as fat growth. The aim in pig production is to produce lean meat most efficiently which is achieved by optimising fat and lean deposition together with feed intake. In breeding programs selection for efficient lean meat growth has focussed on selection for growth rate, lean meat percentage and feed conversion ratio mostly recorded under ad libitum feeding. However, this selection emphasis has led to a decrease in feed intake which ultimately is limiting growth rate. Examples of proposals to counterbalance reduction in food intake are the proposals by Krieter (1986) to put more emphasis on growth rate, and the suggestion by Brandt (1987) to define an index which does not lead to a change in feed intake. An alternative to these suggestions might be to incorporate knowledge from growth models in breeding decisions. One growth model which is used extensively world wide is the linear-plateau model. This concept is also used in the "Technisch Model Varkensvoeding" (TMV, 1994) (TMV model) developed in The Netherlands. Based on this model the effect of differences in parameters of the linear-plateau model on protein and lipid deposition as well as the traditional performance traits growth rate, lean meat percentage and feed efficiency are illustrated.

Concept of linear-plateau model

The concept of the linear-plateau model was proposed by Whittemore and Fawcett (1976) and was experimentally demonstrated in Australia by Campbell et al. (1983), Campbell et al. (1985) and Campbell and Taverner (1988). Since then this concept has been incorporated into a number of growth models (Moughan et al., 1987; Watt et al., 1987; Pomar et al., 1991 and TMV, 1994). The concept of the linear-plateau model is graphically shown in Figure 1. The model assumes that for an animal in a specific weight range an increase in energy intake, together with a sufficient supply of amino acids, results in a linear increase in protein deposition until a plateau in protein deposition is reached. This plateau, also called the **maximum protein deposition** (Pd_{max}) is 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. This **ratio between protein and lipid deposition** is a further characteristic of the linear-plateau model. Within the model the optimum feed intake (FI_0) is defined as the minimum

* *Collaborator via a fellowship under the OECD Co-operative Research Programme: Biological Resource Management for Sustainable Agricultural Systems.*

amount of food (energy) required to meet the intrinsic maximum protein deposition. An energy intake below this optimal feed intake is partitioned in protein and lipid deposition according to the ratio between protein and lipid deposition (linear part of model). Any extra energy intake above the minimum amount of energy required to meet maximum protein deposition is then deposited as extra lipid which results in a steeper slope of lipid deposition (plateau part of model).

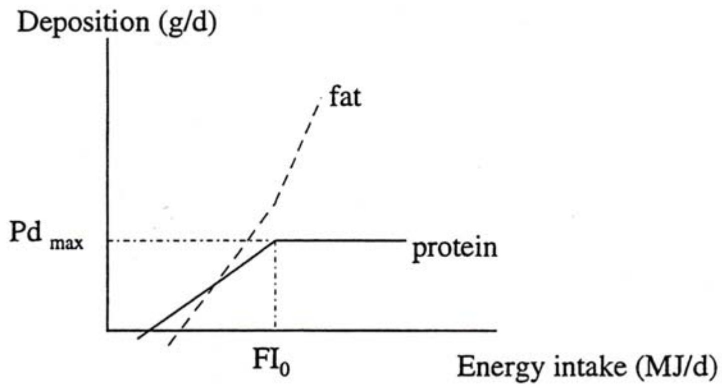

Figure 1: Conceptual relationship between daily energy intake and protein and lipid deposition

Basic principles of “Technical Model for Pig Feeding” (TMV) model

The starting point of the TMV model is daily feed intake (in kg feed) specified for a defined weight range. Given that the energy density of feed used is known, daily feed intake multiplied by the energy density of the food gives the amount of energy available for maintenance and growth. The requirements for maintenance then depend on the weight of the animal, with heavier animals requiring more energy for maintenance. As mentioned above the characteristics of the linear-plateau model are maximum protein deposition and the ratio between lipid and protein deposition. De Greef (1992) showed that the ratio between lipid and protein deposition increases with heavier weights. This ratio becomes larger with heavier weights meaning that heavier pigs put on relatively more fat than lean in comparison to lighter pigs. These results are incorporated in the TMV model and therefore we talk about the **marginal ratio** between lipid and protein deposition. The marginal ratio is obtained by multiplying the weight of the animal with a constant which typically ranges from 0.02 for very lean pigs to 0.09 for fatter pigs. This constant is referred to as the **b-value of marginal ratio**.

The intrinsic factors maximum protein deposition and marginal ratio are specific for each pig and are influenced by genotype and sex of the animal. These factors together with feed intake determine the potential of a pig for protein and lipid deposition. Knowing the partitioning of nutrients into lipid and protein allows us to determine growth rate, lean meat percentage and feed conversion ratio. It is therefore possible to demonstrate relationships between parameters of the linear-plateau model and these performance traits.

Protein deposition and lipid deposition

Protein deposition depends on whether feed intake is sufficient to meet requirements for maximum protein deposition. When feed intake is sufficient to meet requirements for maximum protein deposition actual protein deposition is equivalent to the maximum protein deposition and does not increase with any further increase in feed intake (plateau part of model). However, once feed intake is not sufficient to meet the requirements for maximum protein deposition, protein deposition is determined by the marginal ratio which defines the increase in protein deposition with any increase in feed intake (linear part of model). The energy available for protein deposition is derived from the amount of food eaten minus the requirements for maintenance.

In a similar way the amount of energy available for lipid deposition is derived from the amount of energy available minus requirements for maintenance and protein deposition.

1. Effect of different levels in feed intake and marginal ratio on protein deposition

The relationship between average feed intake and average marginal ratio over a weight range from 25 to 115 kg live weight with protein deposition is shown in Figure 2 for a range of feed intake and b-values of the marginal ratio which can be found in different pigs. Feed First, protein deposition is increasing with larger feed intake (linear part of model). This increase is of course higher with a lower marginal ratio since marginal ratio is the ratio between protein and lipid deposition and a low marginal ratio implies that relatively less lipid but more protein is deposited with each extra kg of feed. Within this graph and all following graphs a maximum protein deposition of 150 g was assumed. The minimum amount of feed intake to reach this maximum protein deposition depends on the marginal ratio. When the marginal ratio is low less feed is required to meet the maximum protein deposition. On the other hand a higher marginal ratio implies that a higher feed intake is required in order to reach the maximum protein deposition.

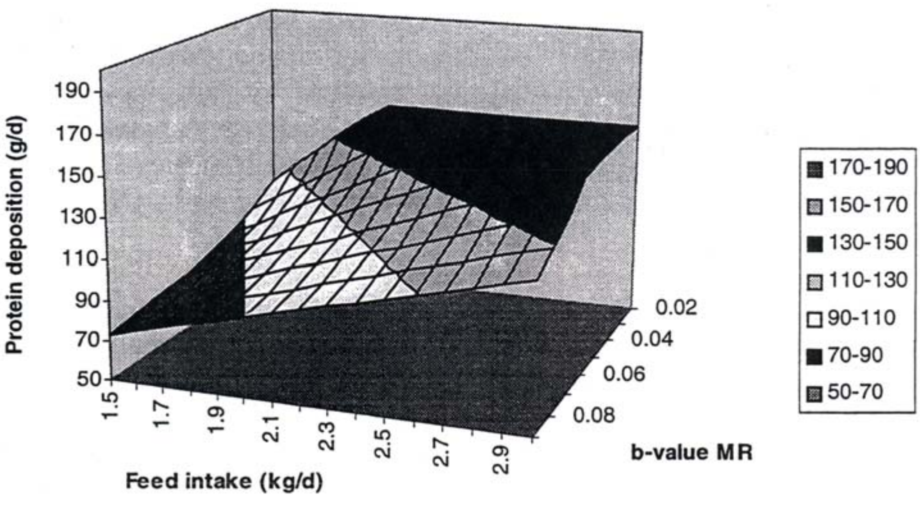

Figure 2: Relationship between feed intake and marginal ratio (MR) with protein deposition (assuming a maximum protein deposition of 150 g).

2. Effect of different levels in feed intake and marginal ratio on lipid deposition

The effects of differences in average feed intake and average marginal ratio on lipid deposition are shown in Figure 3. Lipid deposition increases with higher feed intake and higher marginal ratio. However, comparing the effect of higher feed intake and marginal ratio on protein deposition and lipid deposition shows that lipid deposition is more strongly influenced by level of feed intake while protein deposition is relatively more dependent on marginal ratio. Although it can not be seen that well in Figure 3, lipid deposition increases more strongly with each extra kg of food eaten once feed intake is sufficient to meet the maximum protein deposition. Extra energy is not used for deposition of extra protein but only used for additional lipid deposition. In practice this would be a pig with a high feed intake which becomes fatter but does not put on much additional lean with more feed eaten as is seen in higher weight classes, for example. This is also more the case in gilts than in boars since gilts are characterised by a higher marginal ratio and a lower maximum protein deposition than boars (Campbell et al., 1985).

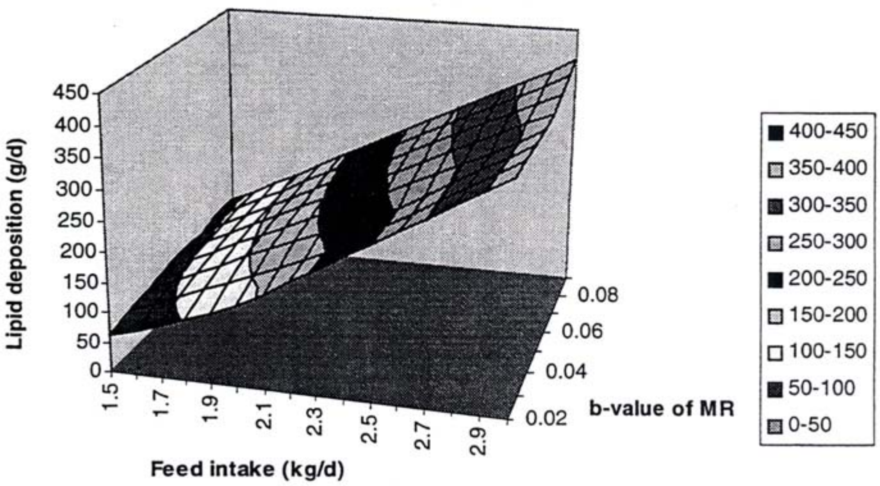

Figure 3: Relationship between feed intake and marginal ratio (MR) with lipid deposition (assuming a maximum protein deposition of 150 g).

Growth rate

Growth is the sum of protein, lipid, ash and water deposition. The two remaining effects not described yet, ash and water deposition, depend solely on protein deposition. For each one g of protein deposited 0.19 g of ash and approximately 4.5 g of water are deposited, meaning that meat mainly consists of water. Furthermore, De Greef (1992) showed that more water is deposited with each unit of protein in modem lean genotypes.

1. Effect of different levels in feed intake and marginal ratio on growth rate

Growth rate depends on protein and lipid deposition. It is therefore not surprising that the increase in growth rate with higher levels of feed intake follows the pattern of protein and lipid deposition (Figure 4). Protein deposition has a higher effect on growth rate since protein deposition determines ash and, more importantly, water deposition which form a large part of growth. As a consequence, growth rate increases more per unit change of feed intake and marginal ratio for low levels of feed intake capacity in combination with a low marginal ratio. However, once the maximum protein deposition is reached growth rate does not increase to the same extent as during the linear part of the model with any increase in feed intake and decrease in the marginal ratio. This increase in growth rate is only due to a further increase in lipid deposition (plateau part of model).

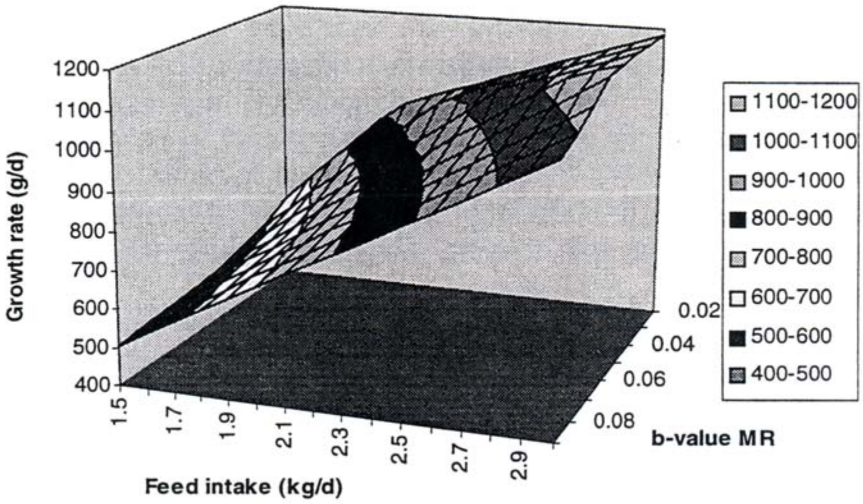

Figure 4: Relationship between feed intake and marginal ratio (MR) with growth rate (assuming a maximum protein deposition of 150 g).

Lean meat percentage and feed conversion ratio

1. Effect of different levels in feed intake and marginal ratio on lean meat percentage

Once protein and lipid deposition are known lean meat percentage of the carcase is easily derived. Lean meat percentage is highest when feed intake is low and the marginal ratio is low (Figure 5). Lean meat percentage decreases with higher levels of feed intake. This decrease in lean meat percentage with increase in feed intake is stronger once the maximum protein deposition of 150 g is reached. In this case marginal ratio does not influence lean meat percentage since the plateau part of the model has been reached and the marginal ratio only determines the slope of protein and lipid deposition with increasing feed intake (linear part). Within the linear part lean meat percentage is decreasing with higher levels of the marginal ratio.

2. Effect of different levels in feed intake and marginal ratio on feed conversion ratio

The relationship between feed intake and marginal ratio with feed conversion ratio is shown in Figure 6. Within the linear part of the model where feed intake is not sufficient to meet maximum protein deposition feed conversion ratio decreases with higher levels of feed intake. Any extra feed intake leads to an increase in protein deposition which mainly determines growth rate. 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. On the other hand, feed conversion ratio increases with increasing feed intake when feed intake is higher than required in order to meet maximum protein deposition. This is because any further increase in feed intake only results in an increase in lipid deposition and growth rate does not increase to the same extent any more.

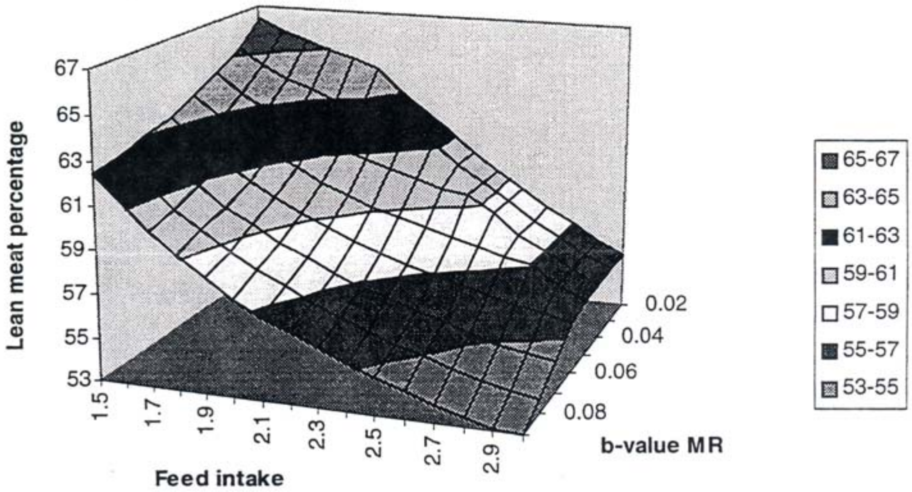

Figure 5: Relationship between feed intake and marginal ratio (MR) with lean meat percentage (assuming a maximum protein deposition of 150 g).

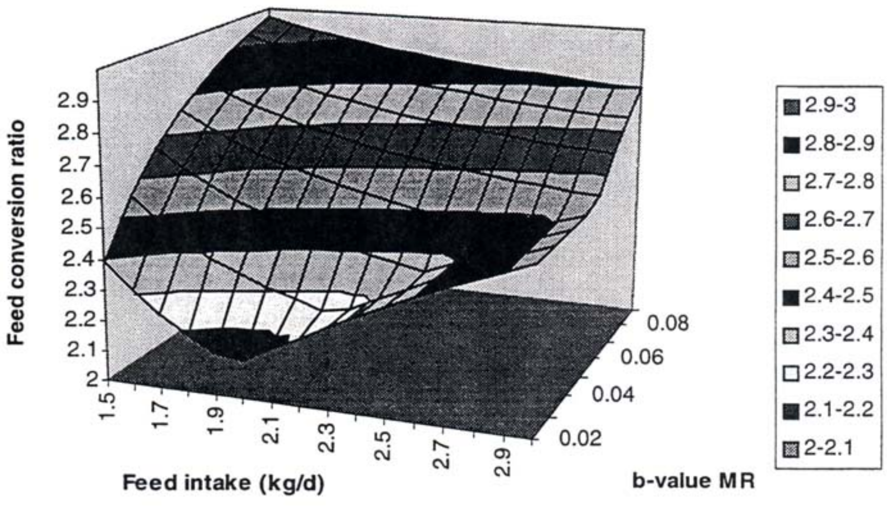

Figure 6: Relationship between feed intake and marginal ratio (MR) with feed conversion ratio (assuming a maximum protein deposition of 150 g).

Similar to lean meat percentage, feed conversion ratio is not influenced by the level of marginal ratio once feed intake is sufficient to meet the requirements for maximum protein deposition. However, in the linear part of the model where feed intake is not sufficient to meet these requirements, feed conversion ratio is lower for lower values of the marginal ratio. Pigs with low levels of the marginal ratio are the leanest pigs and deposition of lean not only increases growth rate more strongly (through deposition of water) but also requires less energy than deposition of lipid.

How can this knowledge be used in animal breeding?

A main focus in animal breeding has been to improve efficient lean meat growth. There are a number of different strategies to improve feed conversion ratio and an overview has been given recently by Cameron (Cameron, 1998). A first step to understanding differences between different selection strategies is to understand the biological background of growth and the partitioning of nutrients into lipid and protein. Knowing biological background of performance traits helps to avoid making wrong selection decisions. For example, it helps to understand why selection for higher lean meat content leads to a reduction in feed intake as has been observed in the past. In addition, differences in genetic parameters between restricted and ad libitum feeding can be explained by this growth model. However, this will be the topic of a further talk within this workshop. In conclusion, in order to find the best selection procedures for efficient lean meat growth and to understand implications of these selection decisions it is essential to understand the biological background of growth.

A next step might then be to incorporate knowledge about this growth model into breeding decisions. One alternative which I investigated while staying in Wageningen was to include marginal ratio, maximum protein deposition and feed intake in the breeding objective as opposed to growth rate, lean meat percentage and feed intake. Obviously, a good understanding of the growth model is essential for this approach. Within the Wageningen project genetic parameters between characteristics of the growth model and performance traits were assumed since they are not known yet. However this will be the task of a new PRDC funded project and knowing the principles of the linear-plateau model is essential for estimating these genetic parameters. Feed costs are a major part of pig production and any possibility to enhance the transformation of nutrients into saleable lean meat has to be investigated. This requires that researchers cooperate across disciplines in order to make use of all available information.

Summary

The growth model used in this study is the “Technisch Model Varkensvoeding” (TMV) model which is based on the concept of the linear-plateau model. This model assumes that protein deposition increases linearly with increasing feed intake until the maximum protein deposition is reached (linear part of model). Any further increase in feed intake will not lead to an increase in protein deposition (protein deposition has reached the plateau). A further characteristic of the linear plateau model is the marginal ratio between protein and lipid deposition which describes the amount of lipid deposited with each unit of protein deposition. The effects of differences in feed intake, the marginal ratio between protein and lipid deposition and maximum protein deposition on performance traits are shown.

Within the linear part of the model, protein deposition increases with larger feed intake. This increase is larger per unit increase in feed intake when the marginal ratio is low (less lipid is deposited per unit protein). Protein deposition is independent of feed intake once the maximum protein deposition has been reached.

Lipid deposition also increases with higher levels of feed intake. However, unlike protein deposition, lipid deposition is more strongly influenced by feed intake than by the marginal ratio when feed intake is insufficient to meet maximum protein deposition. When protein deposition is at its maximum (plateau part of model), lipid deposition increases more strongly with higher levels of feed intake. Extra energy is not used for extra protein but is used for more lipid deposition.

Growth is determined by protein deposition and lipid deposition. Increase in growth rate with higher levels of feed intake follows the pattern of protein and lipid deposition. However, growth rate is mainly determined by protein deposition which implies that the increase in growth rate with higher levels of feed intake is lower in the plateau part of the model.

Within the linear part of the model lean meat percentage increases most strongly per unit change in feed intake and in the marginal ratio when both factors are low. However, once feed intake is sufficient to meet the potential for maximum protein deposition (plateau part of model), lean meat percentage does not depend on the marginal ratio and decreases with increasing feed intake.

Feed conversion ratio decreases with higher levels of feed intake when protein deposition is below the maximum (linear part of model). This decrease is larger for animals with low marginal ratio in combination with low feed intake capacity. Feed conversion ratio is lowest when feed intake capacity equals the minimum feed intake required to meet requirements for maximum protein deposition. Once feed intake is higher feed conversion ratio is not influenced by marginal ratio any more but increases with higher levels of feed intake.

The growth model described helps to understand the biological background of growth. This knowledge provides a valuable tool to enhance the success of breeding programmes to improve efficient lean meat growth.

Acknowledgments

This work was carried out at the Wageningen Agricultural University while on leave from AGBU. The project was funded by the Pig Research and Development cooperation under the training and development award STU 122/1279 and project UNE20P.

References

Agricultural Research Council, 1981, The nutrient requirements of pigs. *Technical review* by an ARC Working Party. Farnham Royal, Slough, Commonwealth Agricultural Bureaux.

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 and Information*, 8: 29-33

Cameron, N.D. (1998). Across species comparison in selection for efficiency. *6th World Congress Applied to Livestock Production Science*, 25:73-80

Campbell, R.G. and M.R. Taverner (1988). Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. *Journal of Animal Science*, 66:676-686

Campbell, R.G., M.R. Taverner and D.M. Curie (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. *Animal Production*, 36:193-199

Campbell, R.G., M.R. Tavemer and D.M. Curie (1985). Effects of sex and energy intake between 48 and 90 kg live weight on protein deposition in growing pigs. *Animal Production*, 40:497-503

De Greef, K.H. (1992). Prediction of production. Nutrition induce tissue partitioning in growing pigs. PhD thesis Wageningen University

Krieter, J. (1986). [Development of selection methods for live weight and food intake capacity in pigs.] Dissertation, Christian Albrecht University, Kiel, Germany

Moughan, P.J., W.C. Smith and G. Person (1987). Description and validation of a model simulating growth in the pig (20-90 kg liveweight). *New Zealand Journal of Agricultural Research*, 30:481-489

Pomar, C., D.L. Harris and F. Minvielle (1991). Computer simulation model of swine production systems: I. Modelling the growth of young pigs. *Journal of Animal Science*, 69:1468-1488

TMV, 1994, Informatiemodel Technische Model Varkensvoeding. *Werkgroep TMV. Publicatie* 1.117, PV, Rosmalen

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. *Applied Agricultural Research*, 2:218-223

Whittemore, C.T. and R.H. Fawcett (1976). Theoretical aspects of a flexible model to simulate protein and lipid growth in pigs. *Animal Production*, 22:87-96