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Nutrient requirements of heavy pig

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ASPA Commissions' activity

A methodological approach to assess nutrient requirements of heavy pigs in Italy

ASPA Commission "Nutrient requirements of heavy pig" [1]

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ABSTRACT

This paper reports the results of the work of the "Nutrient requirements of heavy pigs" ASPA Commission. The Commission work was mainly focused on the problem of identifying a good and flexible methodology for establishing nutrient requirements of heavy pigs in Italy, in a situation where the major part of the pigs are used for ham and other typical products. Nutrient allowance was considered to be a variable open to manipulation, since its optimal definition depends on the specific circumstances of each single production unit. It appeared that the most logical way to account for the many interactions involved was to integrate available information using computer simulation techniques. A methodology based on the following steps was proposed and analyzed: i) selection of a mathematical model to describe the chemical growth of pigs over time as result of the interactions of genotype, feed and climate; ii) developing suitable equations to predict the quality parameters of the carcass and, if possible, of the single cuts from the body's chemical status and implementation of these equations in the model; iii) identification of production targets and use of the model as a tool to simulate the effect of different genotypes, feed and climate on the productive and the economic results. A model strongly rooted in a theoretical framework, simple enough to be applied in practice and requiring a limited number inputs was selected from literature. From a preliminary evaluation, performed by using experimental calorimetric data, it was concluded that the model was potentially able to accurately predict the chemical growth of pigs under different conditions of feeding and climate. The major lack of knowledge regarded the values of genotypic descriptors of the national pig populations, the evaluation for which some simple experimental protocols are described in literature. Other lack of knowledge involved relationships to predict the anatomical growth and the evolution of quality parameters of carcass and cuts from the chemical composition of the body. If a correlation between the chemical composition of the pig's body and production targets is confirmed, then a link between the farmer and the industry can be established and the model could be used to identify more convenient feeding strategies. The conceptual basis and the way to assess nutrient requirements of heavy pigs have been clearly identified.

Key words: Heavy pig, Nutrient requirements, Growth model.

RIASSUNTO

UN APPROCCIO METODOLOGICO PER LA DEFINIZIONE DEI FABBISOGNI NUTRITIVI DEL SUINO PESANTE ITALIANO

Il lavoro riporta i risultati del lavoro della Commissione ASPA "Fabbisogni nutrizionali del suino pesante", focalizzato sul problema dell'identificazione di una metodologia sufficientemente flessibile per definire i fabbisogni nutrizionali dei suini allevati in Italia, in gran parte utilizzati dall'industria per la produzione di prosciutti e altri prodotti tipici. La Commissione ha ritenuto che i fabbisogni nutrizionali debbano considerarsi come variabili aperte, dal momento che i valori ottimali *dipendono dalle specifiche circostanze tecniche ed economiche delle singole unità di produzione. L'approccio considerato più conveniente, per tener conto delle numerose interazioni coinvolte in questa previsione, è quello di integrare le informazioni disponibili utilizzando tecniche di simulazione informatica. È stata quindi individuata e discussa una metodologia basata sulle seguenti tappe: 1) scelta e valutazione di un modello matematico in grado di descrivere nel tempo l'accrescimento chimico del suino come risultato dell'interazione del suo genotipo, delle disponibilità alimentari e dell'ambiente di allevamento; 2) implementazione del modello con equazioni in grado di prevedere la composizione anatomica e le caratteristiche qualitative dei tagli sulla base della composizione chimica corporea; 3) identificazione degli obiettivi di produzione e impiego del modello per simulare gli effetti di differenti genotipi, piani alimentari e ambienti di allevamento sui risultati tecnico-economici di allevamento. L'analisi della letteratura ha consentito di identificare e di discutere un modello di crescita, profondamente radicato in struttura teorico-concettuale, semplice da utilizzare nella pratica dal momento che richiede un limitato numero di* inputs*. Da una sua valutazione preliminare, effettuata confrontando le risposte di simulazione con dati di calorimetria, si è concluso che il modello è potenzialmente in grado di prevedere l'accrescimento chimico del suino in differenti condizioni di alimentazione e di temperatura ambientale. Diverse sezioni del modello possono essere migliorate con il contributo di vari centri di ricerca. Il vincolo maggiore è rappresentato dalla mancanza di informazioni inerenti i valori dei parametri genotipici necessari per descrivere le potenzialità di crescita delle popolazioni suine nazionali. Per la definizione di questi valori si sono individuati in letteratura alcuni semplici protocolli sperimentali. Vi è poi la necessità di espandere il modello con equazioni di previsione in grado di prevedere l'evoluzione quanti-qualitativa della carcassa e dei singoli tagli sulla base della composizione chimica corporea del suino. Se queste relazioni verranno definite si potrà stabilire un collegamento tra fase di allevamento e quella di trasformazione. Una volta definiti gli obiettivi quanti-qualitativi di produzione il modello potrà essere utilizzato per ottimizzare le strategie alimentari e di allevamento. La metodologia e le basi concettuali per la previsione dei fabbisogni nutrizionali dei suini pesanti sono state così chiaramente identificate.*

Parole chiave: *Suino pesante, Fabbisogni nutrizionali, Modelli di crescita.*

Introduction

The Scientific Association of Animal Production (ASPA) has appointed a working commission to study the nutrient requirements of heavy pigs. In Italy, the pig sector is traditionally devoted to the production of heavy pigs suitable for industrial transformation in cured ham and other typical products. The ham industry requires pigs of at least 9 months of age with a live weight around 160 kg in order to assure an adequate degree of meat maturity and equilibrate proportions of lean and fat in the processing cuts. This demand has profound consequences on the feeding practices adopted by pig farmers since they have to maintain a low the rate of growth and, at the same time, to modulate the carcass composition in order to obtain pigs with a optimal degree of fatness (Mordenti *et al.*, 1992).

Feed characteristics and feeding plans are often derived from tabulated values suggested by foreign research centers with some adjustments based on empirical results of sporadic trials as well as from practical experiences. However, empirical determination may lead to the erroneous conclusion that any animal at a given time needs only the amount and the quality of food found to be satisfactory in one or two experimental trials. Feeding plans formulated in this way, and applied irrespective of the genotype used and of environmental conditions within the shed, can result in an inefficient use of feed resources and can lead to a marked variability in the chemical and anatomical characteristics of the slaughtered pigs, as well as in the final quality and the price of products. Since the ultimate drive is to increase the profitability of the whole production system, recommended nutrient allowances must be considered as a flexible variable open to manipulation and their optimal definition becomes dependent on the specific circumstances of the production unit. A logical way to account for so many interactions is to integrate available information using computer simulation techniques. On this basis the Commission decided to deal with the problem of evaluating a possible methodology based on the following steps:

1) selection of a mathematical model to describe the chemical growth of pigs over time as result of the interactions of genotype, nutrient allowances and climate;
2) anatomical description of the pig by developing

suitable equations to predict the quality parameters of the carcass and, if possible, of single cuts from the body chemical status. Implementation of these equations in the model.

3) identification of possible targets of production and use of the model as a tool to simulate the effect of different genotypes and feeding strategies on the productive and the economic results.

The selection of a model

Several models have been proposed to predict pig performance in non-limiting and limiting conditions and several reviews are available in the literature (Black, 1995, Schinckel, 1999). Models differ from each other in the key issues they identify and the way they address such issues. A set of inter-related problems needs to be solved to select a model to predict growth, body composition and feed intake as responses to feed composition, environment and genotype over time. The first aspect regards the acceptability of theory on which the model is based. The theory describes how the biological system under investigation works, providing that the components of the system and their interrelationships are adequately identified and described. The second concern the characteristics that are helpful for using the model. The model should be as simple as possible, as general as possible in order to be extended to different situations and its structure should be flexible and adaptable to the advances of scientific knowledge. Among the various models, that proposed by Ferguson *et al.*, 1994 (see also Emmans 1988, 1997) can most closely meet these needs.

The theory

The theory of growth behind this model is believed to be applicable to all kinds of domestic mammals and birds and has been described by Emmans (1988). The immature animal is seen as a mover that seeks resource, such as food and water, because it seeks to grow. The following key points have been remarked (Kyriazakis, 1994):

i) "Animals have an inherent growth plan with respect to the rate and composition of growth, which will take them towards a mature final size and composition. Animals are assumed to possess the desire to attain this growth plan, and achieve their mature size in the shortest possible time.

ii) There are definable conditions that will allow the growth plan to be attained; these conditions will be termed 'non-limiting'. The growth of the animal under non-limiting conditions is called normal growth or potential growth.

iii) The anatomical and chemical components of the body under normal growth are, in general, related each other by mathematical functions of simple form, i.e. allometry. For the chemical components of the body the term potential growth is reserved for the lipid-free empty body and the protein, water and ash of which it is comprises; the term desired is used for the lipid.

iv) Any abnormality in the body composition with respect to the inherent growth plan at the end of a period of limitation or abnormal growth will be corrected over time once the non-limiting conditions are restored."

The system components

The system derived from this theory is described by three inter-related components: the pig genotype and its initial state, the feed and the environment (Ferguson *et al.*, 1994).

Genotype. Instead of predicting growth from the empty body as a whole, body protein is predicted and used as base component to predict the remaining three components, namely lipid, water and ash. The *potential* protein growth curve is a Gompertz function of time which is defined by giving numeric values to Pm (kg), mature protein weight at maturity, and B (d^{-1}), rate of maturing or precocity. The equation has the form:

$$P = P_m * \mathrm{EXP}(-\mathrm{EXP}(-B*(t-tp°))) \qquad \text{(kg)}$$

where P is the protein mass at a given time (kg), EXP means 'e to the power of' and $t_p°$ is a time constant, in days, defined at the point of inflection, where $P = P_m/e$ (Emmans, 1988). From this equation it follows that the potential daily protein deposition (dP/dt) is estimable as:

$$dP/dt = B*P*ln(Pm/P) \quad \text{(kg/d)}$$

Similarly, the *desired* lipid growth curve can be expressed by the function:

$$L = L_m * EXP(-EXP(-B*(t-t_l°))) \quad \text{(kg)}$$

where L is the lipid mass at a given time, Lm is the mature lipid mass (kg) and $t_l°$ is a time constant, in days, defined at the point of inflection, where $L = L_m/e$. Since the values of *B* is the same for the two equations (Emmans, 1988) it is possible to describe the weight of lipid a simple power function of the weight of protein as follows:

$$L = (Lm/Pm)*Pm^{1-b}*P^b \quad \text{(kg/d)}$$

The coefficient b depend only by the values of B and the two time constants only, since by a mathematical demonstration (Emmans and Kyriazakis, 1999) follows that:

$$b = EXP(B*(t_l° - t_P))$$

Thus, once defined Pm and B, the only one parameter needed to describe the desired lipid growth is *Lm/Pm,* the lipid to protein ratio at maturity.

A similar approach is used to describe the evolution over the time of water *(Wa)* and ash *(Ash)* but in these latter cases the coefficients of the corresponding equations can be considered almost constant, not only between individuals but also across species (Whittemore 1994; Emmans and Kyriazakis, 1995). Thus:

$$Wa = 3.04*(Pm)^{0.145}*P^{0.855} \quad \text{(kg)}$$

$$Ash = 0.21*P \quad \text{(kg)}$$

In conclusion, a small set of only 3 variables is used to describe pig genotype: *Pm, B* and *(Lm/Pm)*. Each pig is seen as having its value for each of these variables, and their values are expected to be different by sex and to change under selection (Ferguson *et al.*, 1997, Emmans and Kyriazakis, 1999).

The three variables make it possible to predict the rates at which the pig is seeking to gain protein and lipid and to calculate the corresponding energy and protein requirements and the desired feed intake. Effective energy requirement (EERQ) is quantified by the equation (Emmans, 1999):

$$EERQ = MH + 50*dP/dt + 56*dL/dt \quad \text{(MJ/d)}$$

where the maintenance heat, MH, is scaled and quantified as:

$$MH = M_E*Pm^{0.73}*(P/Pm) \quad \text{(MJ/d)}$$

and where the almost-constant maintenance value (M_E) is 1.63 MJ/unit day.

Similarly, ideal protein requirement (IPRQ) is predicted (Emmans and Oldham, 1988) as:

$$IPRQ = M_p*Pm^{0.73}*(P/Pm) + (1/e_p)*dP/dt \quad \text{(g/d)}$$

In which: the value of the maintenance constant M_p is around 10 g/unit day and e_p is the marginal efficiency of use ideal protein for growth predicted as described later.

Feed. Feed is described in terms of concentration of effective energy and ideal protein. The effective energy system described by Emmans, (1994) was preferred to those based on the expression of net energy because it allows a description of the feed independent from the animal metabolism and because it takes into account different energetic efficiencies of maintenance, protein retention and lipid retentions. Effective energy content of a feed (EEC) is the metabolizable energy measured at maintenance (zero nitrogen retention) less the amount of work associated with eating, the amount of work associated with urea synthesis, the amount of energy lost because of fermentation and corrected for the differences in the efficiency of use metabolizable energy to forming body lipid from feed lipid and non-lipid. The proposed equation is:

$$EEC = MECn - w_d*FOM - w_u*DCP + 12*z*DCL \quad (MJ/kg)$$

where MECn = metabolizable energy content at maintenance (MJ/kg); w_d = 3.8 MJ/kg, a constant measuring the heat increment due to the work of eating per kg of indigestible organic matter (FOM, kg/kg); w_u = 4.672 MJ/kg, is a constant measuring the heat associated to the work of excretion of the digestible crude protein (DCP, kg/kg), 12 MJ/kg is the difference in heat production of forming 1 kg of lipid from feed lipid and non-lipid constituents (16.4 - 4.4 MJ/kg); z is the proportion of lipid retained which apparently comes from the feed lipid (in some circumstances z = 0.9-1.0) and DCL is the feed digestible crude lipid (kg/kg).

If the energy loss due to fermentation is considered negligible, the effective energy content of the diet can be directly calculated from the digestible energy content (DEC) as follows:

$$EEC = DEC - a*(DCP) - W_d*FOM - W_u*DCP + 12*z*DCL \quad (MJ/kg)$$

Where a = 0.90 MJ/kg, is a constant measuring the amount of energy lost through the urine per kg of digestible crude protein (DCP, kg/kg).

Using this energy system the amounts of EE needed to replace 1 MJ of lipid loss (1 MJ) and to sustain positive retentions of 1 kg of protein (50 MJ) and of 1 kg of lipid (56 MJ) are then constant across diets and the energy description of the diet becomes independent from the animal energy partition. The EE values for ingredients can be easily calculated from data already in feed tables (Emmans, 1994) and the metabolizable energy content of the diet can be calculated later when the amounts of nitrogen retained and excreted are known.

Ideal protein is computed by multiplying the ileal digested protein content by its biological value (Whittemore, 1993). Biological value (V) is assessed with reference to a given protein, presumed to be ideal, with proportions r1, r2, …rn of amino acids 1, 2, …n.. Where in the dietary protein the proportion of these ileal digested amino acids are a1, a2, … an, the amino acid with the lowest ratio (a/r) is the first limiting one and the corresponding ratio is used as a measurement of the biological value of protein. Examples of ideal patterns of essential amino acids in the reference protein are given in the reviews of Batterham (1994) and Whittemore *et al.*, (2001). The marginal efficiency of use of ideal protein supply above maintenance for growth (e_p) is assumed to be directly proportional to the ratio of metabolizable energy on digestible protein contents of the food up to a maximum value of 0.81 (Emmans and Kyriazakis, 1997).

An important aspect is the choice of using static or dynamic values to describe feed digestible content of energy and nutrients. Static values can be obtained by using some of the various equations available in literature (Wiseman and Cole, 1983; Morgan *et al.* 1987; Batterham, 1990; Whittemore, 1993) which are mainly based on chemical composition of feeds. These equations do not account for differences between feedstuffs due to their physical properties, for the presence of some non-nutrient compounds that may have direct anti-nutritional effects, for differences due to the age or weight of the pig and the level of feed intake. Simulations can be sensitive to variation in nutrient availability in particularly when that nutrient is limiting. From the theoretical and practical point of view, the quantification of the ideal protein raises some problems:

1. there is a considerable potential for errors in amino acid analysis of feeds. Despite considerable effort on improving analytical methods, amino acid analysis remains a difficult procedure. Modern protocols provide data with a within laboratory repeatability of about 5% and a reproducibility between laboratory around 10% (Moughan *et al.*, 1999);
2. there is a considerable source of error also in giving a set of values to the proportions of "chemically available" amino acids which are absorbed from the gut and other non negligible questions inherent to the use of apparent or true digestibility coefficients (Moughan 1995);
3. the ideal profile of the reference protein should be assigned in a dynamic way taking into account the usage of amino acids for maintenance (turn over of body protein, integumental amino acid loss, gut endogenous amino acid loss, synthesis of other compounds, urinary amino acid losses) and growth (protein accretion, support costs and preferential amino acid catabolism) (Moughan *et al.*, 1999; Whittemore *et al.*, 2001).

It can be noted that the accuracy of the prediction will depend by the theoretical and functional scheme proposed, which can be modified and expanded according to the advance in the scientific knowledge, and by the choice of a coherent set of values. The problem of making a description of food consistent to what is present in the digestive tract of a pig remains an important task of research.

Climatic environment. There are some physiological relationships between genotype, feed intake, growth performance and climatic environment. In hot environments, intrinsically 'lean' growing pigs are forced to reduce their metabolism (and the associated heat production) to a larger extent than fatter pigs, while in cold conditions, lean growing pigs profit from their larger heat increment of protein synthesis even though fatter animals have a better thermal insulations (Knap, 1999). Many models have been proposed in the literature to describe the effects of the environment on feed intake and growth of pigs (Knap, 1999) but they often require a very large number of inputs which reduce their possibility of application. A simplified scheme, proposed by Schiavon and Emmans (2000), describes the climatic conditions

Table 1. Possible values for the growth parameters for different kinds of pigs (Emmans and Kyriazakis 1999, modified). The parameters are: Pm, the mature protein weight; Lm/Pm, the ratio of lipid to protein at maturity; and B, the Gompertz rate of maturing parameter[a].

Kind of pig	Sex	Pm (kg)	B (day^{-1})	Lm/Pm
Best of 1998	Boar	50.0	0.0140	2.0
	Castrate	45.0	0.0112	3.6
	Gilt	38.0	0.0140	3.0
Moderate 1998	Boar	45.0	0.0125	2.8
	Castrate	40.0	0.0100	4.6
	Gilt	34.0	0.0125	4.2
Poor of 1998	Boar	40.0	0.0100	3.6
	Castrate	36.0	0.0088	5.5
	Gilt	30.0	0.0100	4.5

[a] *As consequence of genetic improving Pm and B are likely to increase while those of Lm/Pm are likely to fall.*

only in terms of environmental temperature. In order to grow, a pig needs an environment in which it can lose the heat produced. The comfort temperature of a pig receiving a given diet is that at which the environmental demand for heat is exactly met by the amount of heat the pig will dissipate, without the need of increasing evaporation. Below the comfort temperature the environmental demand of heat increases, to some quantifiable extent, so that the pig must increase heat production by eating more food, if possible, or by modifying the partition of the available energy. Above the comfort temperature a thermo neutral range is defined according to the ability of pig of increase up to a maximum, the amount of heat lost by evaporation. Above this limit the pig must reduce feed intake because it must to maintain heat production equal to the environmental heat demand.

Feed intake and chemical growth prediction. The three above-described components are bringing together in a framework that allows the computation, day by day, of intake and growth performance in non-limiting and limiting conditions. First, the desired feed intake (DFI), which is the rate at which the pig tries to eat its feed to just meet its requirements for the first limiting resource, is computed as described by Kyriazakis and Emmans (1999). If feed and the environment are such that the desired feed intake can be achieved, then the model assumes that the pig will achieve its potential rate of gain of protein. If energy is the first limiting resource it will also achieve its desired fatness. But, if energy is not the first limiting resource, and DFI is attained, then an excess of energy is eaten which is converted to excess lipid.

In addition to the already mentioned hotness of the environment, some other constraints may operate to limit intake over the time: i) the restricted feeding; ii) gut capacity. The first, being a choice of the farmer, is input data, the second sets the upper limit of feed intake in function of body weight and dry matter digestibility of diet (Whittemore 1993). Where conditions are such that some constraints affect intake, their consequence will be deficits for the first limiting nutrient (i.e. some amino acid) or energy. In these cases a simple set of rules is used to predict protein and energy partition: ii) body protein gain is set by the rate of intake of ideal protein available for growth, subject to not exceeding the potential growth rate and ii) use the effective energy supply firstly for maintenance and protein growth (and for cold thermogenesis if any) and the remainder for lipid retention.

Once the daily retention of protein (d*P*/dt), water (d*Wa*/dt), lipid (d*L*/dt) and ash (d*Ash*/dt) have been quantified, the partition of the absorbed nutrients can also be predicted by making the following assumptions (Schiavon and Emmans, 2000): i) the digested protein that is not retained is completely oxidized; ii) digested lipid is retained with an efficiency (z) of 0.9-1.0, so that its contribution to lipid retention can be evaluated as dL_{DL} (kg/d) = 0.9*DCL. Then, the lipid retention from carbohydrates is calculated as LR_{DCHO} (kg/d)= $dL/dt - dL_{DL}/dt$. It could be desirable to improve this scheme by subdividing the term DCL in two components, one referring to the polyunsaturated dietary lipid (or linoleic acid) and the other one to the remaining lipid. This should lead to a prediction of the unsaturated and saturated lipid masses which are accumulated in the pig's body over time.

Providing that initial body status (weight and body composition), genotype, feed allowances and composition, and climatic environment are adequately described over time, from the functions and the values of the parameters assumed the entire growth of body protein, water, ash and lipid can be predicted.

Setting the model

The model is deterministic in the sense that it refers to an individual pig and that the many parameters in the model take a single value for the one pig at a single time. The problem to move from the subject to a population concerns the distinction between those variables which are the same for all individuals and those which are different (Ferguson *et al.* 1997). For the latter, the means, variances and covariances need to be quantified. Where more than a few variables are considered as being distributed, the model becomes rapidly more complex than can probably be justified. It has been proposed that the three genetic growth parameters can be considered as key variables to describe a population and some indicative values have been suggested by Emmans and Kyriazakis (1999) (Table 1) and the relationship between body protein mass and potential protein growth are given in Figure 1.

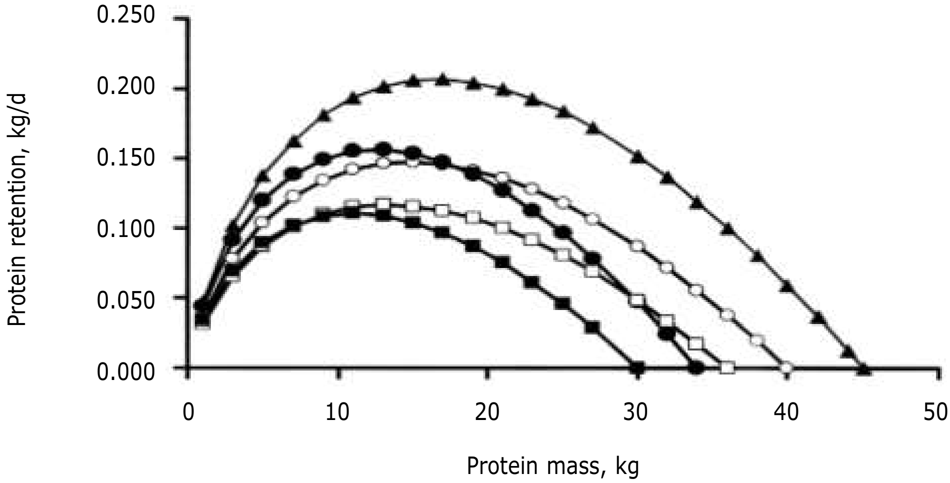
Since the selection programs in Italy have put less emphasis on the genetic improvement of growing rate, with respect to other countries, the values describing Italian pig populations are probably close to the middle-bottom values given in Table 1. However, the only way to be certain of the values of a given population is to measure them in a sample of the population using one of the three kinds of simple protocols described by Ferguson and Gous (1993a,b). The approach requires a small number of pigs which are slaughtered and chemically analyzed in at least two periods of age, in order to have two points to fit the Gompertz curve. It is not necessary to slaughter pigs at maturity but great care must be taken to assure non limiting conditions of feeding and of climate. Investigations are clearly needed in this area. For initial screening it may be sufficient to typify a population by approximate average values and by basing the simulations on these.

Testing and evaluation

The major problems in the evaluation of a model have been described by Black (1995b). The term “testing” refers to the evaluation of the model in terms of logical, mathematical and numerical correctness while the term “evaluation” refers to establishing the appropriateness and the accuracy of predictions over a range of simulated conditions. The described model is strongly rooted in a theoretical framework which is derived from translating concepts in functional forms and giving values to the constants and parameters involved throughout an ongoing process of summarizing the advance in the scientific knowledge.

It has been demonstrated that a validation of a model is not possible (Black, 1995b). In fact a model like the one proposed uses successive days to represent time in a dynamic way. Thus, simulation depends on properly defining the initial state of the pig, the change that occurs each day and combining these to determine the final state after n days. In animal experiments, time cannot

Figure 1. The relationship between the protein mass and potential protein growth rate in 5 different genotypes: Boar moderate 1998 ▲, Castrate moderate 1998 ○, Gilt moderate 1998 ●, Castrate poor 1998 □; Gilt poor 1998 ■. The genotypic values are given in Table 1.



be dealt with on a day-by-day basis, so that results are averaged over several days or weeks or over weight interval. In the published papers as well, the inputs required for the model are frequently missing or given in inappropriate or unusable forms (i.e. age, feed intake and composition, environmental temperature over long period of time). This leads to the need to introduce some assumptions to run the model. In addition, the model assumes that the feed is exactly as specified, and it does not consider the effects of sub-clinical disease, social competition and so on. Thus, it is to be expected that the model could predict higher levels of performance than those observed in the field. However, some form of comparison of the model outputs with experimental data is needed, in particular if the responses of the model are intended to be used for economical analysis. The model should be evaluated for its usefulness, the pattern, the magnitude and the realisticity of response.

Material and methods

A preliminary evaluation of the model was completed using data coming from two independent experiments of Close (1978) (see also Close and Mount, 1978; Close *et al.*, 1978) and Verstegen *et al.* (1973). The experiments were chosen because they provide calorimetric data of energy partition obtained on piglets under variable conditions of feed intake and of environmental temperature over short periods of time. In the first experiment 19 pairs of castrated LW piglets of 20 to 40 kg of live weight were housed in calorimeters for 14 days. Piglets received variable amounts (from 0.5 to 2.5 kg/d) of a feed of known composition and were kept under environmental temperatures ranging from 10 to 30°C. Feed contained 18% of crude protein, 4% of crude lipid, and 13.4 MJ/kg of dry matter of ME. In the experiment of Verstegen *et al.* (1973), 8 groups of 4 piglets, with an initial live weight of about 25 kg, were housed, for three weeks, in a calorimeter under environmental temperature ranging from 8 to 20°C. Piglets were fed a compound feed (from 0.99 to 1.30 kg/d) containing 20% of crude protein, 3% of crude lipid and 14.1 MJ/kg of dry matter of metabolizable energy. The two experiments provided data about ME intake, heat production and net energy retention as lipid and protein as average of group. To run the model it was necessary to assume the following values to describe the genotype, the initial state and the feed:

a) genotype: Pm= 41 kg; B = 0.010 d^{-1} and Lm/Pm = 5. These values were fixed by considering the maximum rate of protein retention observed among the various group of piglets in the two experiments in order not to introduce factors limiting the prediction of potential protein growth. The initial body protein mass was assumed to be 15% of live weight.
b) feed: apparent digestibility of organic matter 82%
   apparent digestibility of crude protein 80%
   apparent digestibility of crude lipid 75%
   ileal apparent digestibility of Lysine 80%
   ileal apparent digestibility of methionine plus cystein 78%

The biologic value of the protein was set at 80% and the rate of sensible heat loss was assumed to be 0.27 MJ/C°/m^2

The model was run 23 times in order to simulate the ME partition of each group of piglets over periods of time corresponding to the experimental ones. The simulated ME intake, heat production, net energy retention as lipid and protein within each group of pig over the time were averaged by day and compared to the measured ones by analyzing the parameters of linear regressions.

Results and discussion

Simulated versus measured values of ME intakes are given in figure 2. The values of the intercept, close to 0, of the slope, close to 1, and the low residual variability were expected since the experimental values of feed intake were used as inputs in the model. Possible sources of variation are due to the assumed digestibility coefficients and by the urinary losses of nitrogen, which have probably been influenced by the individual variability.

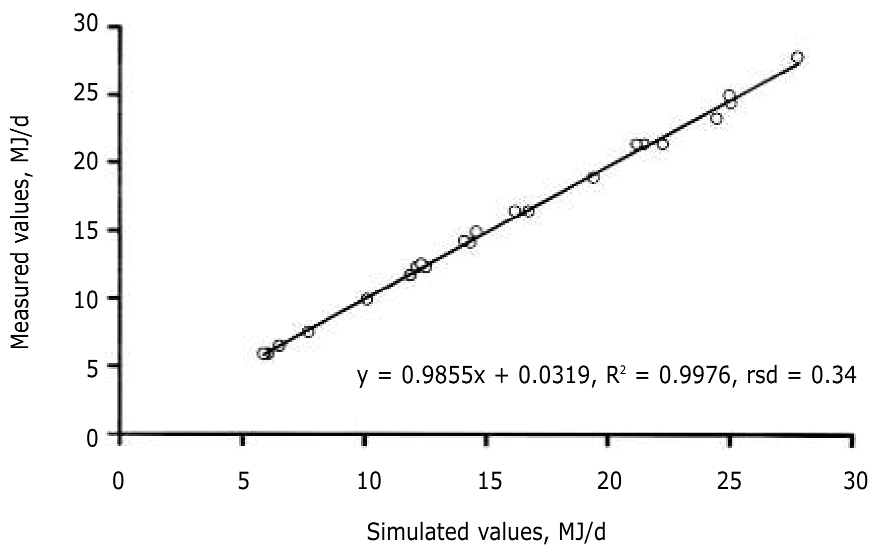
In Figure 3 the simulated and the measured values of heat production are compared. The slope of the regression had a value of 0.87 and that of the intercept was close to 0.9 MJ/d. The model explained about 93% of the total variability and the residual standard deviation was 0.66 MJ/d, corresponding to a casual error of about 7% on the mean value. These values are mainly due to a single record corresponding to a pair of piglets receiving very small amount of feed (0.49 kg/d) at high temperatures (30° C). If this observation is excluded from the data set, the intercept becomes 0.2 MJ/d, very close to zero, and the slope becomes 0.97, not significantly different from 1. The simulated and measured values were considered to be comparable. Some of the variability can be due to the choice of using a fixed value to the coefficient representing the rate of sensible heat loss per unit of body surface and per °C. This is surely an approximation, since the pigs have the possibility to change the rate of sensible heat loss according to the climatic environment by activating some physiological mechanism and by modifying their behavior (Knap, 1999).

Figure 4 describes the relationship between the simulated and the measured values of net energy retained as protein. The intercept of the regression was not different from zero and the value of the slope was 1.11. If the intercept was set to zero, the value of the slope becomes 0.95. The residual standard deviation of the regression, 0.24 MJ/d, was low in absolute terms, but it represents about the 13% as respect to the average value. This dispersion is partially due to the use of fixed values to represent the genotypic parameters of the various groups of pig used in the trial. Other sources of variation are probably due to the assumption made about the dietary amino acid content, the ileal amino acids digestibility and the biologic value of protein. On average, however, the model was considered to give sufficient precision and accuracy of the estimates.

Figure 5 represents the relationship between the simulated and the measured values of net energy retention as lipid. Both the intercept and the slope values were very close to the expectation. According to the experimental data, the model correctly predicted negative lipid growth in the presence of positive protein retention. Negative lipid growth was observed for the groups of piglets receiving the lowest amount of feed at the lowest temperatures.

From this preliminary evaluation it was concluded that the model provides outputs comparable to experimental data. The pattern, the magnitude and the realisticity of response were consistent with the expectation, even under extreme

Figure 2. Simulated *versus* measured values of ME intake



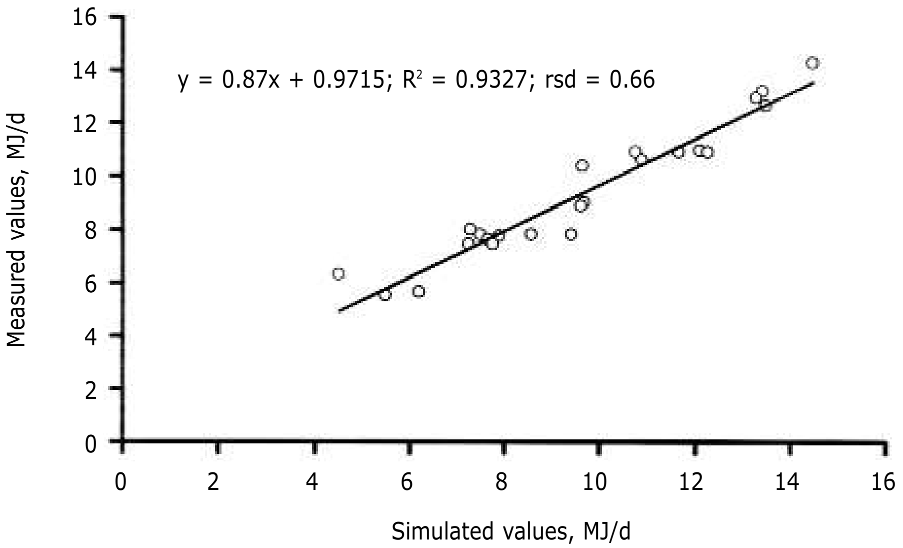
conditions. It was concluded that the model can be considered a useful tool to predict the chemical growth of pigs under different conditions of feeding and climate.

However, further evaluations are needed before the model can be applied in the field. Studies providing data over a larger range of live weight are desirable but care should be taken in using these data as inputs in the model and in comparing the results. Testing trials should be projected in order to provide an accurate description of the production conditions such as the environmental temperature, the age, the initial and final body weight with some measurements of fatness, feed intake, available nutrients levels in the diets (including amino acids), number of diets fed. All the data should be provided over periods of time that are as short as possible. The development of some relationships to estimate changes of body composition from empty body weight and backfat thickness over time are desirable. Information relating to the description of the pig production potential is also highly desirable, but this remains a difficult task. For practical purposes and by approximation, it could be sufficient to estimate the maximum protein retention on a group of pigs kept under non limiting conditions of feeding and climate between approximately 50 to 80 kg of live weight (Moughan and Verstegen, 1988). This value can be compared to that obtained by deriving a family of potential protein Gompertz curves to estimate some indicative values for the parameters P*m* and B.

Prediction of carcass and anatomical parameters

Actual knowledge of body development is insufficient to predict the evolution over time of carcass and anatomical parameters. Due to the lack of fundamental knowledge concerning body development, physical conversion of chemical body composition is usually performed in a rather empirical way (De Greef, 1995). In the majority of cases, these relationships relate to the prediction of dressing percentage, carcass weight, lean content and different measurements of backfat thickness in light animals, since they have an economic value within the commercial schemes of payment in use. Some examples of relationships between chemical and physical parameters have been proposed by Moughan *et al.* (1987), Rook *et al.* (1987) and Whittemore (1993). These equations may not provide accurate predictions when applied to heavy pigs produced in Italy, not only because of different range of slaughtering weight, but also due to the different definition of fatty and lean tissues, as well as to

Figure 3. Simulated *versus* measured values of heat production.



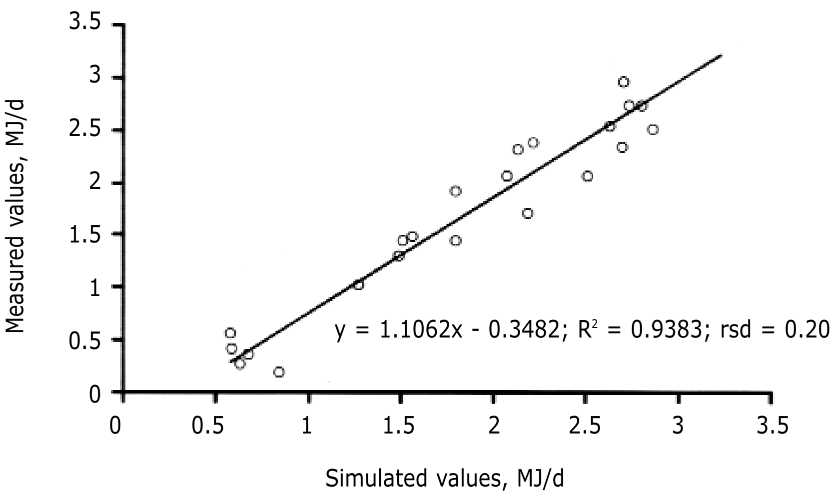
different dissection techniques applied in the various countries (De Greef 1995).

Even if carcass weight and lean content are considered poor predictors of the technological properties of cuts, they are still used as the main parameters of carcass evaluation in Italy (Russo, 1990; Rossi *et al.* 2001). Equations to evaluate the partition of body chemical compounds between carcass and non carcass fractions, among lean, fat, skin and bone and among the various cuts are then desirable. It is interesting to note that analysis of literature data (Susenbeth and Keitel, 1988) found a rather constant pattern of partition of the whole-body protein to different fractions at a given body weight. Small effects due to genotype, sex and the dietary regimen were observed. Thus, estimation of physical body composition from chemical composition appears to be possible (De Greef 1995) with a useful data set and by using allometric relationships to describe the partition of each single body chemical compound in different body portions as suggested by Rook *et al.* (1987).

A potential future step in the development of the model is to study the correlation between the chemical composition of each single cut and its quality parameters. Quality of fresh ham is an aggregate of properties which define the aptitude of fresh ham to be cured and that largely affects the economic value of the final product (Russo and Nanni Costa, 1995). The aptitude of fresh ham to be cured mainly depends on: i) dimensional parameters such as ham weight and globosity; ii) anatomical parameters such as the proportion and the physical distribution within the joint of bone, lean and fat. The fat component, in particular, is mainly evaluated in terms of depth of subcutaneous fat, firmness and degree of unsaturation (number of iodine; and content of linoleic acid). Many of these parameters are reasonably thought to depend (at least partially) on the chemical status of the pig as result of its genotype and its nutritional history and differences among populations cannot be ignored (Franci *et al.*, 1996; Della Casa *et al.*, 1999; Pantaleo *et al.*, 2000, Bosi *et al.*, 2000). Thus, some further potential relationships to be studied and applied in the model are:

- Prediction of fat free mass depot in different joints from fat free empty body mass;
- Prediction of lipid mass depot in different joints from empty body lipid mass;
- Prediction of depths of subcutaneous fat in different points of the carcass and of the ham from empty body lipid mass and from some size measurements (i.e. protein or fat free mass);
- Relationships between *in vivo* and *post mortem* measurements of subcutaneous fat depth;
- Prediction of dimensional measurements of

Figure 4. Simulated *versus* measured values of net energy retained as protein.

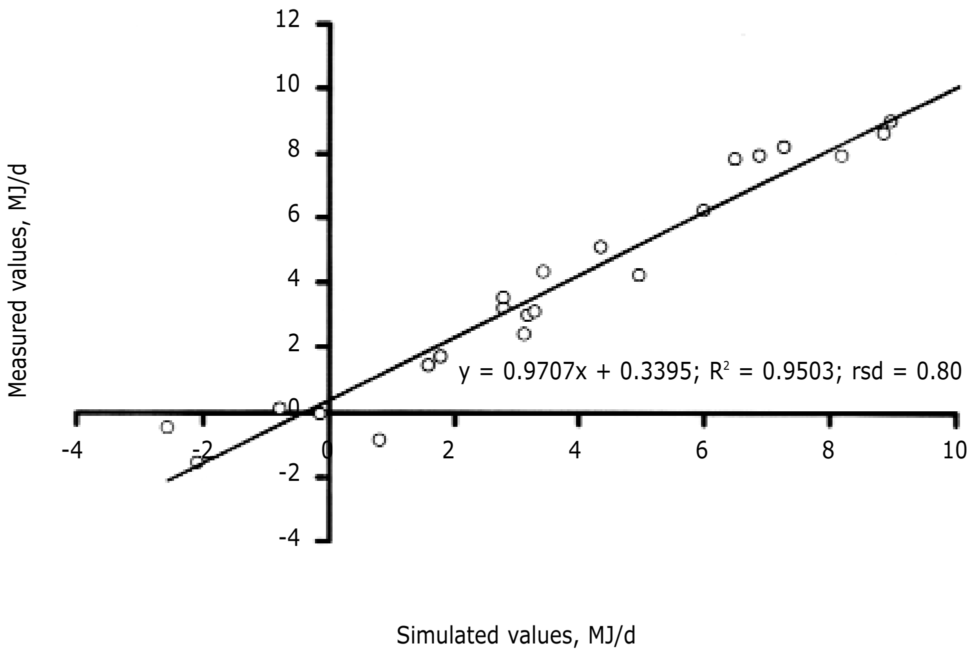


ham from fat free and fat empty body mass;
- Prediction of polyunsaturated lipid mass in the ham from empty body polyunsaturated lipid mass.

Conclusions

The Commission has identified and analyzed a methodology to evaluate nutrient requirements of heavy pigs. The farmer can manipulate, to some extent, the feed, environment and genotype in order to control the growth and the chemical composition of pigs. A promising mathematical model was identified and analyzed in order to get a tool to predict the result of different production strategies. This model is strongly rooted in a theoretical framework, it appears simple enough to be used in practice, it requires a limited number of easily recordable inputs, it can be extended to analyze different situations and its structure is flexible and adaptable to the advances of scientific knowledge. From a preliminary evaluation, it was concluded that the model is able to predict the chemical growth of pigs under different conditions of feeding and climate. Useful field data are required to test the model under practical conditions. The major constraint, however, is the lack of some description of the genotypic parameters of the Italian pig populations for the evaluation of which some simple experimental protocols have been found in the literature. Many steps of the model can be improved by the contribution and the cooperation of different research centers. Since the main objective of the domestic commercial production is to efficiently produce pigs with good aptitude to be transformed by the industry in ham or in other traditional products, further research is needed to evaluate the relationships between the chemical, the physical, the anatomical composition and the quality parameters of carcass and cuts used by the industry. Much work should be done in this area and it is hoped that the various Italian research centers may collaborate together to this end. Communication between researchers and producers are also necessary to establish the criteria of evaluation of final products and production targets. If the correlation between chemical composition of the pig and target of production is confirmed, then a link

Figure 5. Simulated *versus* measured values of net energy retained as lipid.



between the farmer and the industry can be established and the final model could be use as a tool to identify the more convenient feeding and rearing strategies to maximize the profit of the whole production system. It is clear that the problem cannot be resolved in a short time but the conceptual basis and the way to reach this objective are clearly identified.

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