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# MATHEMATICAL MODEL OF OPTIMIZATION ENERGY METABOLISM AND PROTEIN QUALITY TO SWINE

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***Abstract***

*The new systems which assess the nutritive value and determine the nutrient requirement triggered changes in the manner of formulation and development of optimized pig diets. The purpose of this paper is to present a viewpoint on a possible solution for diet optimization. We considered the determination of a possible „common denominator" between the nutritional requirements, mathematical algorithms that can be applied to the stated problem and the economic aspects assimilated as purpose functions in formulating the mathematical models that are used.*

***Key words**: mathematical modelling, energy metabolism, protein metabolism, pig nutrition.*

## INTRODUCTION

One of the characteristics by which we can estimate the stage of development of a certain discipline is its degree of mathematization. Thus, Galileo Galilei said that „The great book of nature can be read only by the one who knows language in which this book was written and this language is the mathematics".

Truly important is the effective contribution and not the sophistication or elegance of the used mathematical instrument.

A relatively simple mathematical idea ca have an unexpected effect if used with skill. On the other hand, very elegant mathematical considerations may be of no use for the actual problems of that particular discipline.

## MATERIALS AND METHODS

One can distinguish a number of 4 stages of the contribution of mathematics to the development of a scientific discipline:

**Stage 1**: Data collection, analysis and interpretation.

**Stage 2:** Quantitative formulation on scientifically principles and empirical laws.

**Stage 3:** Regarding the mathematical development of a model we can perceive two trends concerning the very operation of modelling. A first trend is the exaggerated simplification of the concrete situation, which has the advantage of increased possibilities for effective mathematical developments allowing the use of the model in a large range of different contexts.

A second trend, more and more present, due to the development of the computing capacity, is to include in the model as many as possible characteristics of the concrete situation and to use numeric methods to obtain the results.

**Stage 4:** Utilization of the mathematical models for the progress of the scientific knowledge

A mathematical model once developed and its predictions inferred by reasoning, we can ask ourselves can we use this material past its simple adequacy. In many cases the model and its predictions can lead us either to discovering and rendering evident unknown aspects or to clarifying others partially known.

## RESULTS AND DISCUSSIONS

### A mathematical model of the energy and proteic metabolism applied to pigs

NORMS FOR GROWING AND FATTENING PIGS

(1) Body weight and chemical composition assessment

The body weight (kg), function of age, is calculated with a Gompertz equation:

$$G = A \times e^{e^{B(t-t^x)}} \qquad [kg] \qquad (1)$$

where:

$A$ = body weight at maturity
$B$ = growth coefficient
$t$ = age in days
$t^x$ = inflexion point, the time in days when the gain peaks

The net weight *Gn* may be assessed with the formula:

$$Gn = G/1{,}05 \qquad [kg] \qquad (2)$$

and the net weight gain $\Delta Gn$ is the sum $Pr$ *(retained protein)*, $Lr$ *(retained lipids)*, $Cen_r$ *(retained ash)* and $Ar$ *(retained water)*.

The values $Pr$, were calculated with the formula

$$Pr = B \times Pt \times \ln\left(\frac{Pt}{P\hat{t}}\right) \qquad [kg] \qquad (3)$$

where $Pt$, kg is given by the relation:

$$Pt = P\hat{t} \times e^{e^{B(t-t^x)}} \qquad [kg] \qquad (4)$$

values $B$ and $P\hat{t}$ are given in the gable below, which also shows the maximal values of $Pr$ and of the minimal ratio $\frac{Lr}{Pr}$

The daily gain of lipids $Lr$ was calculated with the ratio $Lr/Pr$:

$$Lr = \propto \times Pr \qquad [kg] \qquad (5)$$

where $\propto$ was calculated differentiated by males, females and castrated pigs according to the age (Burlacu et al., 1996):

For young boars**:**

$$\propto = e^{-2{,}633+0{,}08t-0{,}0014t^2+0{,}0000154t^3-0{,}0000000793t^4+0{,}0000000001513t^5} \qquad [kg] \qquad (6)$$

For young sows**:**

$$\propto = e^{-2{,}633+0{,}08t-0{,}0014t^2+0{,}0000154t^3-0{,}0000000793t^4+0{,}0000000001513t^5} \qquad [kg] \qquad (7)$$

For castrated pigs**:**

$$\propto = e^{-2.074+0.6364t-0{,}001317t^2+0{,}0000168t^3-0{,}0000000977t^4+0{,}0000000000206t^5} \qquad [kg] \qquad (8)$$

The daily retained water and ash ($Ar + Cenr$) are calculated with the relation:

$$\mathrm{Ar} + \mathrm{Cenr} = \beta \times \mathrm{Pr} \qquad [kg] \qquad (9)$$

where β has the following values :

For young boars and castrated pigs**:**

$$\beta = e^{2.739-0.0434t+0{,}000421t^2-0{,}000001325t^3} \qquad [kg] \qquad (10)$$

For young sows**:**

$$\beta = 37.423 \times e^{-\frac{t}{10.703}} + 4.154 \times e^{-\frac{t}{744.84}}$$

The net weight $Gn$ ($[kg]$ $at\ age\ t + 1$) $= Gn + \Delta Gn$ ($at\ moment\ t$), where *t* initial = 35 days, and $Gn$ initial = 9.5 $kg$ for all sexes and categories

(2) Assessment of *EM* norms

$$\mathrm{EM} = \mathrm{EMm} + \mathrm{EPr} + \mathrm{ELr} \qquad [MJ/day] \qquad (12)$$

for the calculation of EM

$EMm$ = requirement of metabolisable energy for maintenance [MJ/day] $[kg]$ (11)
$EPr$ = requirement of metabolisable energy for body protein synthesis [MJ/day]
$ELr$ = requirement of metabolisable energy for body fat synthesis [MJ/day]
the following formulas are to be used:
$EMm = 1.75 \times Pt^{0.75}$ $[MJ/day]$(13)
$EPr = 54 \times Pr$ $[MJ/day]$(14)
$ELr = 53 \times Lr$ $[MJ/day]$(15)
where:
$Lr\ (lipid\ gain, in\ kg.) = 1{,}1 \times Pt^{0.07} \times Pr$

(3) Assessment of the norms of available protein and limiting amino acids

$PA = Pm + Pr : 0.813\ [kg] (16)$

where:

Pm (net protein for maintenance)

$$Pm = 0.04 \times Pt \quad [kg] \quad (17)$$

Pr = gain of body protein [kg] 0.813 is the output of $PA$ utilization for $Pr$

lysine requirement = $PA \times 70\ [g]$

met. + cys. requirement = $PA \times 40\ [g]$

tryptophan requirement = $PA \times 15\ [g]$

threonine requirement = $PA \times 45 [g]$

PARTICULAR CASES OF DIET CALCULATION (RESTRICTED FEEDING)

In the practice, we are often confronted with situations when feeding is restricted. In this situation (restricted feeding), the manner of calculating changes. Therefore, we are presenting subsequently the manner of calculation of the requirement of energy and amino acids:

Inputs: Body weight: $G$ [kg]

Average daily body weight: $\Delta G$ [kg]

Age: $t$ [days]

Parameters: $B, Pt, Pr, t^* -$ with the values and significance as shown above

**Stage I.** Calculation of the requirement of metabolisable energy and protein corresponding to the minimal $\frac{Lr}{Pr}$ ratio

The value of minimal $\frac{Lr}{Pr}$ ratio was calculated using the experimental data:

$$\left(\frac{Lr}{Pr}\right)_{min} = a + \frac{b}{1 + e^{-\frac{t-c}{d}}} \quad [kg] \quad (18)$$

where for the commercial castrated type we used the following values:

$a = 0.677$; $b = 1.95$;

$c = 148$; $d = 23.63$

The value of the retained protein is given in this case by:

$$Pr = \frac{\Delta G}{1.05\left(1 + \left(\frac{Lr}{Pr}\right)_{min} + \beta\right)} \quad [kg] \quad (19)$$

where: $\Delta G$ average daily gain [kg]

For $\beta, Pt, Pm, PA, EMm, EPr, Lr, ELr, EM, LizD, M + CD, TRID, TREONINAD$ the formulas from the above relations are to be used.

***OBSERVATION 1:*** The dimensions important in determining the requirement of energy and protein according to this system of calculation are the metabolisable energy $EM$ and the available protein $PA$.

The two calculation stages presented above show a striking fact, at first sight, but perfectly justified physiologically: for a restricted feeding and lower weight gains than the maximal values, there are variable values of the ratio $\frac{Lr}{Pr}$

$$\frac{Lr}{Pr} \in \left[\left(\frac{Lr}{Pr}\right)_{min}; \left(\frac{Lr}{Pr}\right)_{max}\right]$$

involves the existence of norms that belong to some intervals:

$$EM \in [EM_{min}; EM_{max}]$$
$$PA \in [PA_{min}; PA_{max}]$$

In other words, for a set daily gain, for each value $\frac{Lr}{Pr}$ there is a distinct norm of protein and energy.

Observation 1 is shown graphically in Figure 1.

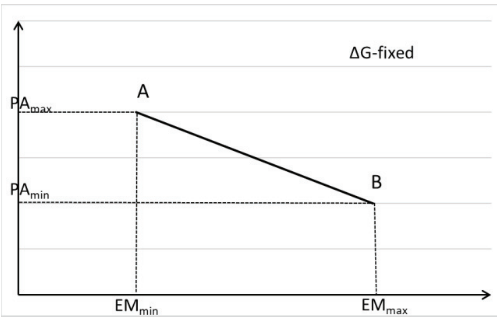


Figure 1. Observation 1

Any pair *EM, PA* of segment *AB* represents pertinent values to obtain the set weight gain. Obviously, each time there will be a different quality indicator as given by $\frac{Lr}{Pr}$ ratio.

***OBSERVATION 2****:* It can be immediately observed that the protein norms assessed with the system presented here eliminate the value of the digestible protein. Yet, diet optimisation also involves the essential use of an equation in *PBD.*

The connection between *PBD* and *PA* is given by the biological value of the diet:

$$VB = \frac{PA}{PBD} \Longrightarrow PBD = \frac{PA}{VB}; 0 < VB < 1$$

As *VB* cannot be known beforehand it results that the norm of *PBD* depends on the nature and structure of the dietary raw materials, since it is no longer unique the value of *PBD* can no longer be used traditionally in the “norm tables” even though diet optimisation is done using the digestible nutrients.

**Stage II.** The calculation of the requirement of metabolisabe energy and protein corresponding to the maximal ratio $\frac{Lr}{Pr}$.

We calculate the maximally ingested metabolisable energy:

$$EM_{max} = 44\left(1 - e^{-0.0204^{G}}\right), \qquad [MJ]$$

We calculate the maximal value of the retained protein with the formula:

$$PR_{max} = B \times Pt \times \ln \frac{P\hat{t}}{Pt}$$

With the formula

$$EPr = 54.6 \times Pr, \qquad [MJ/day]$$

we calculate the energy required to retain the protein corresponding to *Pr* max.

We calculate the energy required to retain lipids:

$$Elr = EM_{max} - EM_m - EPr - Q' \qquad [MJ]$$

Which gives the maximal value for the retained lipids:

$$Lr_{max} = \frac{ELr}{53.3} \qquad [kg]$$

Thus, we obtained the maximal ratio retained lipids / retained protein:

$$\left(\frac{Lr}{Pr}\right)_{max} = \frac{Lr_{max}}{Pr_{min}}$$

We then use the same procedure of calculation as in stage I, starting with the calculation of *Pr* inclusive.

The dependence of *PBD* requirement function of the biological value of the diet is shown in Figure 2.

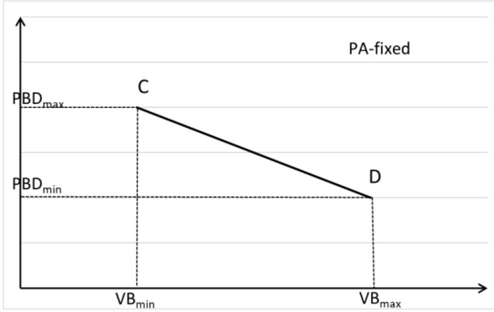


Figure 2. The dependence of *PBD* requirement function of the biological value of the diet

The dependence of *PBD* requirement function of the available protein is shown in Figure 3.

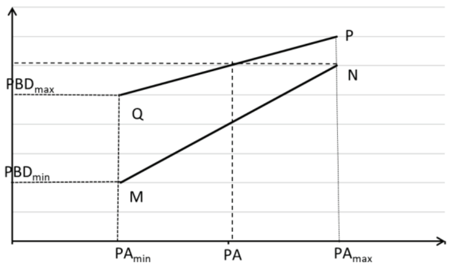


Figure 3. The dependence of *PBD* requirement function of the available protein

Figure 4 shows graphically the connection between *EM* and *PBD*.

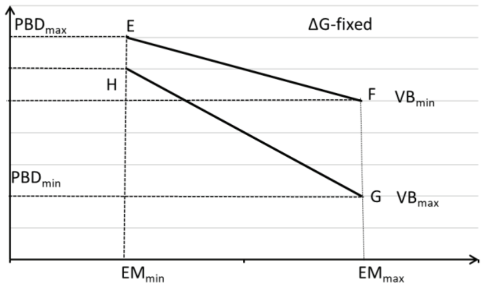


Figure 4. Connection between EM and *PBD*

Any point in the trapeze *EFGH* is a norm expressed in *EM, PBD* for a set $\Delta G$.

The existence of an area *EFGH* for the requirement of *EM* and *PBD* is due to the two parameters

$$\frac{Lr}{Pr} \in \left[\left(\frac{Lr}{Pr}\right)_{min}; \left(\frac{Lr}{Pr}\right)_{max}\right] \text{ and}$$

$$VB \in [VB_{min}; VB_{max}].$$

***OBSERVATION* 3**. For simplification, the tables may show the average values for *EM* and *PA* (and therefore for amino acids too).

$$EM_{tabel} = \frac{EM_{max} + EM_{min}}{2}$$
$$PA_{tabel} = \frac{PA_{max} + PA_{min}}{2}$$

## CONCLUSIONS

Mathematical modelling can contribute to the agricultural scientific knowledge in many ways, some of which are presented below:

(1) Biological hypothesis expressed in mathematical language can offer a description on quantitative understanding of the biologic problems.

(2) Stimulation of the mathematical modeling can prove a conceptual frame which can contribute to the discovery of unknown domains, and can stimulate the appearance of new ideas and of experimental approaches on more rigorous basis. The scientific researcher can waste the resources solving false problems, and the specialist in development can transmit these information to the producers, who might even use them.

(3) A mathematical model can provide a way through which the data accumulated by research can be put to use by the farmers in a readily accessible form.

(4) The practical advantages of the methods produced by search can be studied with a model, stimulating thus the use of improved methods.

(5) The mathematical modelling determines the appearance of experiments which are less ad-hoc, because with the help of is easier to design experiments which to answer certain research requirements, of to dissociate between alternative mechanisms.

(6) Within a system with more components, the model offers a manner of gathering the knowledge on the component parts in order to give them a correct image on the behavior of the whole system. Thus, the information regarding the energy content of a concentrate is useless in the absence of the data on prices of the end products.

(7) Modelling can contribute to securing a strategical and tactical backing for a research program, justifying the activity of the scientists and promoting collaboration.

(8) A model can be an efficient means to summarize data, and a prudent method of interpolating and extrapolating.

(9) The data becoming more and more precise, but more and more expensive, a model can use data more efficiently, sometimes using them better.

(10) The power of prediction of an efficient model can be used in many ways: research, development, managing, planning priorities. For example, a model can offer answers to questions such as: What if …?; Which would be the consequences of cutting the concentrate intake in cattle on the milk yield and forage requirement? Which would be the effect of increasing the weaning weight of calves on the subsequent meat production? etc.

In connection to the concrete activity in biomathematics we note there main directions: in genetics, physiology and biotechnology.

The differences existing between the three domains can also be found in the mathematical models mostly used. In genetics and breeding the population studies require probabilist methods while in the other two domains the determinist mathematical disciplines seem to be more adequated.

As concerns the problems connected to the interdisciplinary team we must say that any attempts of interdisciplinary study are useful. For the mathematicians the presence of another specialist for dialogue is essential. The quality of the model depends on the quality of the dialogue, and the quality of the dialogue depends on the quality of men and on the working atmosphere.

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