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Review Article

# Modeling Weight Growth in Farm Animals

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## Abstract

Statistical modeling offers a sure way and improves the accuracy of mathematical description for quantitative trait of farm animals. It simplifies making breeding decisions regarding provided summary information's. Different empirical mathematical functions have been proposed to describe weight growth.

By describing the growth by simple functions whose parameters have most often biological significance, growth curves allow comparison of the rate of development of animals, or to assess the effects on growth of selection, gender or different ecological factors. Nevertheless, it is hard to believe that these functions with three or four parameters could explain in a precise way a phenomenon as complicated as growth from birth to death. It is important to choose the right model because an inappropriate model can lead to errors in the conclusions and less precise estimates.

**Keywords:** Weight Growth; Modeling; Far Animals

## Introduction

Meat production is all about harnessing the growth potential of animals. This growth has a great economic importance and has two aspects

- A quantitative aspect: The growth
- A qualitative aspect: Development

In fact, the commercial value of an animal is linked to the amount of muscle in the carcass, but also to the quantity and quality of adipose tissue [1].

Modeling of biological phenomena in the field of agriculture and livestock for example, has grown considerably in recent decades, along with the advent and advances in computer tools.

According to Pavé (1994), the mathematical modeling consists in proposing a representation in the formal system of mathematics of an object or a phenomenon (in this case biological) in the real world.

### Growth physiology

Growth is a purely quantitative phenomenon, therefore accessible to a study simple mathematics that can give rise to a graphic representation (height, weight in time function). It is the result of two combined actions, multiplication and cell growth. Although defined as a purely quantitative phenomenon, it is however the essential engine of development because it is the differential growth of regions of the body which gradually shape the morphology and anatomy of the animal.

A Growth is a process characterized by morphological changes, physiological and chemical properties of the individual, leading to quantitative growth and complex qualitative development which confers new properties on the individual while preserving the unity and functional balance of the body.

Dudouet (2003) [1], defined it as the increase in body mass (live weight) by unit of time from conception to post-natal life, and that it represents the difference between what is built (anabolism) and what is destroyed (catabolism) in the animal body.

### Growth in utero or prenatal

It is mainly due to intense hyperplasia (cell multiplication). She may be subdivided into three periods:

### The zymotic period

This is the period of zygote growth that is to say free egg, which goes from fertilization to implantation; it is characterized by intense cell multiplication. Number of double cells at each division: 2, 4, 8, 16 cells. During this period of duration variable depending on the species, the relative increase is maximum and the weight gain per unit of time is regularly growing.

### The embryonic period

It starts from implantation and ends around 4 to 6 weeks gestation in cattle see even on the $34^{th}$ post-fertilization day [1]. It is characterized by the differentiation and placement of the main organs of the systems vital, in the following chronological order: nervous tissue, bone tissue, muscle tissue and finally adipose tissue.

### The fetal period

It extends from the end of the embryonic period until birth. It corresponds to the development of the fetus to its birth form [1].

### Post-natal growth

Post-natal growth is mainly due to cell hypertrophy (growth in length and diameter) especially for muscle fibers. She is essentially influenced by feed.

In the same framework, Prud'hon (1976) [2] adds that; this type of animal growth is largely dependent on environmental conditions (feed, farming method, climate ...), physiological adaptation mechanisms as well as neurohormonal regulation which is under genetic control.

### Description of the shape of the growth curve

The theoretical growth curve (CTC) is subdivided into two phases: prenatal and postnatal. CTC is performed on animals in perfect health and receiving a balanced diet and as desired. The environmental conditions are optimum.

The sigmoid curve(S-shaped) is characterized by two phases

- A phase of accelerated growth (1): it spreads from birth until the moment of the puberty During this phase, there is an increase in the size of the organs.
- A slowed growth phase (2): it lengthens during puberty until adulthood.

The inflection point (A): it most often corresponds to puberty. In general, the weight of the animal has reached 1/3 of the adult weight.

### Genetic parameters

Depending on Ducrocq (1992) [3], the genetic study of a quantitative nature and the evaluation of breeders require knowledge of genetic parameters: heritability, repeatability and genetic correlations, which are all functions of components of the total variance of the character. They are in fact essential ingredients in establishing methods of genetic evaluation of domestic animals. Plus, to that, the estimates of these parameters are precise the more reliable the animal evaluation method and therefore genetic progress will be greater [4].

### Heritability

Heritability is defined as the ratio of the variance due to the additive effects of genes and phenotypic variance. It is one of the most important properties of a measurable character [5]. It expresses according to Gaddoud and Surdeau (1975) [6] the accuracy of the most elementary concerning the additive genetic value of a candidate animal for selection. This is why this parameter is involved in many biometric relationships relating to livestock improvement and in the choice of breeding methods.

According to the definition proposed by Lush (1937) [7], we call heritability in the broad sense between genetic variance and phenotypic variance

$H^2 = s^2_A/s^2_P$

The higher the value of h2, the more the studied character is dependent on the genetic.

Heritability is therefore of particular importance in applied animal genetics [8] and his knowledge allows in particular to

- Predict whether genetic improvement by selection will be effective. In fact, the more heritability is strong the more the selection is effective
- Decide which improvement strategy to adopt.
- Estimate the additive value of an animal from production measurements of this individual or related animal.
- Predict the expected genetic progress.

## Repeatability

It is the correlation between the performances of the same animal. It is defined as the share of the total variance which is due to the genotypic variance and to the variance of the environment permanent. The repeatability value gives us the upper limit of heritability. It is also used in estimating the actual productive ability of an animal. On the other hand, high repeatability indicates that an animal's performance is almost identical and knowledge of a performance is sufficient. In contrast, repeatability low underlines the value of introducing several performances before making a final judgment on an animal [9].The repeatability of a character is further defined by

$r = (s^2_G + s^2_{EP})/s^2_P$

With

- **r:** repetability
- **$s^2_G$:** Genetic variance
- **$s^2_{EP}$:** Variance of the environment common to all performances
- **$s^2_P$:** phenotypic variance

## Genetic correlations

Quantitative traits are often genetically associated. Their additive values are not statistically independent. It is said that there is a genetic correlation between them. Knowledge of the value of genetic correlation is essential for genetic improvement due to the fact that selection on a trait necessarily leads to modification of the frequency of the other which may have favorable effects or unfavorable the development of improvement strategies for several characters simultaneously and finally the evolution of the effects that selection will have for a character over another genetically related (Minvielle, 1990).

## Mathematical modeling of weight growth

Growth curve modeling is a broad term that has been used in various contexts over the past century to denote a wide range of statistical models for repeated measurements [10,11].

Contemporary use of the long-term growth curve model refers generally using statistical methods that allow the estimation of inter-individual and intra-individual variability over time [11-13].

According to Hoch., *et al.* (2004), these models can be used to produce knowledge, even identify gaps in the consideration and formalization of the process. They can also constitute tools for synthesizing or predicting biological phenomena Generally, the possibilities of studying growth curves are reduced due to that the data is limited to weighing as is most often the case when setting on the basis of certain experimental protocols or genetic improvement schemes [14].

Several mathematical functions are then used to describe the growth curve living organisms, in particular farm animals. These mathematical models are a regular function (y = f (t)), which define the values of weight or height (y) according to of age (t), used as a management tool in livestock farming [15,16]. These models aim to explain the main characteristics of the growth phenomenon at different times [17].

According to Fitzugh (1976) [18], the analysis of the growth performance of animals according to the time is an interesting topic for researchers and breeders. It allows predicting the feed needs of the herds, identify the best slaughter age and establish the breeding programs based on inherent growth traits.

The curves of growth have several applications in animal production; it makes it possible to assess the animal response to different diets over time and animal identification heavier at a young age in a population [19,20].

The basis for choosing the growth curve according to Khon., *et al.* (2007) [15] are the interpretation biological parameters, its quality of fit to real data and its difficulty incalculation. Many linear and nonlinear mathematical functions are used to describe the growth curve of ruminants. Because a function that describes the shape of the curve real growth cannot be applied in a systematic way, it differs from a race to another [21] and is dependent on the differences observed at the level of genetic potential of individuals, the environment and especially driving.

All of these factors affect the shape and parameters of growth curves, the applicability of each model remains associated with an animal material and a defined environment, the equation suitable growth curve fit is the equation that correctly predicts the shape of the growth curve and which can be modified to give flexibility and maximum precision [22].

Moore (1985) [23] studied the growth curves of domestic mammals. He indicated that the linear and cubic models used for the adjustment of the growth curves of cattle, pigs, sheep, goats and rabbits provided growth charts standard.

Rekik., *et al*. (2008) [24] were found when adjusting the growth curves of lambs in the race D'Man that the nonlinear models are inefficient, so they proceeded to linear fits by random regression to characterize growth of lambs. Because the data collected concerned the first 4 months which correspond to the linear phase growth. But the most commonly used are Brody's nonlinear equations, Logistics, Von Bertalanffy, Gompertz et Richards [19]. All of these functions have a sigmoid shape with an inflection point, at which point the speed of maximum growth, followed by a phase during which the animal's weight approaches gradually from a maximum value called an asymptote [25,26].These mathematical functions seem to be very interesting as they allow the improvement of the accuracy of the genetic evaluation of the growth of animals using all available weighings without resorting to method of estimating weights at specific age intervals [27] Several authors have concluded during studies carried out for the adjustment of the growth of sheep at satisfactory coefficients of determination, Esenbuga., *et al.* (2000) [28] reported that the $R^2$ value of the Brody model for the curve fit of Growth of lambs of the Morkaraman, Awassi and Tushin breed was 99%. According to Lewis., *et al.* (2002) [16] the Gompertz function better describes the growth curve of lambs Suffok.

## Linear models

Linear regression is defined according to Searle (1971) [29] as a method of describing, a variable linked to one or more other measures having the same objective. In reality, this model has received, for a long time, the greatest attention in theory and even in practice because it can potentially be applied, according to Schaeffer (2004) to any situation that relates a measurable variable over time (age).

This is why the variations in the weight of the animals as a function of time have been conventionally described by a simple linear regression having the following form

$P_x = a + b_x$

- Represents a position parameter
- Represents a measure of the direction of the weight/age relationship

The validity of this model is based on the linearity of growth over the age period taken into account account. However, this assumption gradually becomes less and less reliable in as the interval considered lengthens. Faced with this eventuality, it is possible to refine the model by adding one or more terms to give it the shape of a polynomial. In this case the weight is written as follows

$P_x = b_0 + b_1 x_1 + b_2 x_2 + .... + b_n x_n$

Where $b_0 + b_1 x_1 + b_2,.. + b_n$ are unknown coefficients.

## Nonlinear models

Many authors have written the growth characteristics of lambs by nonlinear mathematical functions, such as Brody, Gompertz, Logistique, Richard's et Von Bertalanffy [30,31]. These functions are easy to interpret biologically and easily compared between different production systems [32].

## RICHARD's model

The Richards curve is the general form of a family of curves that describes the weight (Pt) at age t using four parameters [26]

$P(t) = A (1 - B e^{(-Ct)})^{D}$

With

- **A:** Asymptotic value (A = Pt when t tends to infinity). It therefore corresponds to the weight adult. This value corresponds according to Bilgin., *et al.* (2004) [25] to the average weight reached by the animal without taking into account the temporary influences of the environment and the conduct such as food availability.
- **B:** Integration constant which adjusts to the situation in which the initial weight (P0) which corresponds to (t = 0) is different from 0. Biologically, this parameter represents the difference between the adult weight and the initial weight. It therefore corresponds to the potential gain that is still achievable by the developing animal.

- **C:** Parameter of growth rate in which the weight approaches the asymptote. It is frequently referred to as the ripening factor or growth rate.
- **D:** Shape parameters determining the position of the inflection point with respect to A. In particular, it determines the ratio of weight at inflection (Pt) to asymptotic weight A.

The RICHARDS curve translates into many other growth curves for different values of D. This is the equation of BRODY (D = 1), Logistics (D = -1), VON BERTALANFFY (D = 3) and GOMPERTZ (D = + ∞).

The inflection point of the RICHARDS curve, which depends on D, is not fixed and proportional to its asymptote. The time at the inflection point is [25]

$t_i = \ln(-BD)/C$

## BRODY's model

Many authors have cited that among the deterministic models, the growth curves of lambs modeled by the function of Brody (1945) have been widely used [22,24,30]. Indeed, according to Bathaei and Leroy (1998) [19] the Brody model was chosen because of the simplicity of interpretation and the ease estimation of these parameters. Bathaei and Leory (1998) [19] have cited that the growth performance, modeled according to Brody's model, P (t) of day t is described as

$P(t) = A(1 - B e^{-Ct})$

Where P (t) is the daily weight (kg/day) observed on day t. parameters A, B and C define the scale and shape of the growth curve Thus A represents the asymptotic value towards which the weight tends when t tends towards infinity, Biologically, it is the weight maximum mean around which successive weight measurements oscillate with age. The parameter B corresponds to the potential gain still achievable by the growing animal. So that the parameter C expresses the speed in which the weight approaches towards the asymptote, it is, in fact, a parameter indicative of the rate of growth frequently referred to as the maturation or growth rate. The success of this nonlinear model, cited by [33,34] is explained by its quality of fit and its capacity adaptation to the data. on the other side, Ben Hamouda (2012) [30] did not appreciate its quality adjustment to the weight growth of lambs of the Barbarine breed compared to others nonlinear functions.

## GOMPERTZ models

Winsor (1932) introduced the use of the Gompertz function as a curve of growth in 1932. The Gompertz function is a nonlinear sigmoid function with a inflection point at 36.8% of adult [30,35,36] cited that weight growth, modeled according to the Gompertz model, P (t) of day t is described in this form

$P(t) = A e^{(-Be^{(-Ct)})}$

Where the parameters A, B and C have the same mathematical and biological meanings as in the case of the Brody model.

Keskin., *et al*. (2009) [37] mentioned that Gompertz's model showed the best fit to the weight growth of lambs of the Konya Merino breed and it allows to predict the live weight at older ages from partially anticipated body weight data. Several studies have been carried out by [22,30] on the estimation of the parameters of the growth curves of different breeds (the breed Barbarine, Mengali breed, Awassi breed and Morkaraman breed). All these authors have well assessed the goodness of fit of the nonlinear Gompertz function to growth weight of lambs of these different breeds by these coefficients of determination the most the highest and the lowest SCER. With regard to other animal species [35,38] have well approved in their research studies on the description of the growth curve of poultry species, the flexibility and flexibility of adjusting the Gompertz model to growth data.

## VON BERTALANFFY model

Von Bertalanffy (1957) deduced his model for fitting growth curves from of simple physiological argument, This is the most widely used growth chart, in particular in fishing studies. The growth adjustment equation of the Von model Bertalanffy, Cited by [19,36,39] is in the following form

$Pt = A(1 - Be^{(-Ct)})^3$

Where the parameters A, B and C have the same mathematical and biological meanings as in the case of the Brody model.

Subsequently, this model was widely used in the field of fishing to adjust the mollusc growth (Lévéque. 1971) as he has been favored in adjusting lambs. According to [22], Von Bertalanffy's model and the best estimator of the growth curve of lambs of the Awassi breed. Ben Hamouda (2012) [30] also appreciated the efficiency and flexibility of this model when adjusting data from growth performance of the Barbarine breed.

### The logistic model

The logistic growth curve (also called the Verhulst model as it has been proposed as a model of population growth (Pierre Verhulst, 1845) is one of the most simple S-shaped growth curves.

Ben Hamouda (2012) [30], Keskin., *et al*. (2009) [37] et Malhado., *et al*. (2009) [39] cited that the weight growth, modeled according to the Logistics model, P (t) of day (t) is described in this form

$P(t)=A\ (1+B\ e^{(-ct)})^{-1}$

Where the parameters A, B and C have the same mathematical and biological meanings as in the case of the Brody model.

### The methods of estimating the parameters of the growth curve

### Estimation of the parameters of linear equations

To solve a simple linear equation, it suffices to minimize the sum of the squares of the residual differences weighted by headcount. However, solving the equations second degree polynomials is much more complicated. It is resolved the same way that what will be described for nonlinear models

### Estimation of the parameters of nonlinear equations

According to Mingnon-Grasteau et Beaumont (2000) [26] the most common estimation method is the nonlinear regression. This procedure minimizes the sum of the squares of the differences between the weight predicted by the mathematical function and the observed weight. To improve significantly the adequacy of the estimated curve to the measured curve, a weighting is applied to observations, to take into account the increase in the variance of the weights with age. However, the complexity of systems of nonlinear differential equations makes it difficult to obtain the desired solutions using the latter method. What seems necessary to use an iterative Marquardt optimization method. This method is a compromise between the Gauss-Newton method and a previous method described by Marquardt in 1963 [14]. This method aims to minimize the sum of the residual differences weighted by the numbers of the transformed variables. More recently, Bayesian techniques have been used. They make it possible to estimate simultaneously the parameters of the growth curve and their genetic parameters [26] In this way, we can take into account the parameters of the growth curve not only of the performance specific to the individual, but also of those related parties. For the same number of measurements, this technique therefore allows a more precise estimation of parameters. According to these same authors, it is preferable to estimate the individual components by individual to take into account the variations in the kinetics of growth between animals. In addition, a correct estimation of the parameters requires, for each individual, a sufficient number of repeated measurements throughout growth.

## Conclusion

By describing the growth by simple functions whose parameters have most often biological significance, growth curves allow comparison of the rate of development of animals, or to assess the effects on growth of selection, gender or different ecological factors. Nevertheless, it is hard to believe that these functions with three or four parameters could explain in a precise way a phenomenon as complicated as growth from birth to death.

It is important to choose the right model because an inappropriate model can

- Lead to errors in the conclusions.
- Lead to models comprising too many parameters and consequently to less precise estimates.

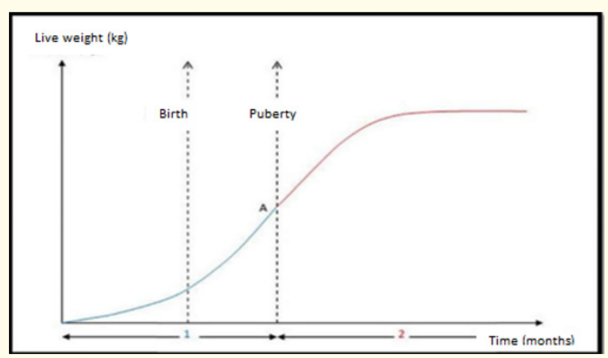


**Figure 1:** Theoretical growth curve.

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