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AIC-Based Selection of Growth Models: The Case of Piglets from Organic Farming

Katharina Renner-Martin[1], Manfred Kühleitner[1], Norbert Brunner[1], Werner Hagmüller[2]

[1]Institute of Mathematics, University of Natural Resources and Life Sciences, Vienna, Austria
[2]Institute of Organic Farming and Farm Animal Biodiversity, Agricultural Research and Education Centre (AREC), Thalheim/Wels, Austria
Email: kathi.renner-martin@gmx.de, manfred.kuehleitner@boku.ac.at, norbert.brunner@boku.ac.at, werner.hagmueller@raumberg-gumpenstein.at

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Abstract

The selection and comparison of different growth models for describing weight gain of piglets raised in organic farming is investigated by using the Akaike's Information Criterion (AIC). In total, 49,699 data points of 5188 piglets recorded between 2007 and 2013 were considered. From the day of birth, up to 40 days (*i.e.* until weaning) the *model of von Bertalanffy* was favored by the AIC. This model is with 60.32% more likely to truly reflect reality than any other of the analyzed models. Up to 105 days, the *two-linear model* was favored by the AIC (probability 99.75%). The intersection point of the two-linear model was calculated by 53.8 days, which fitted well to the actual change in the food situations.

Keywords

AIC, Growth Curve, Growth Model, Weight Gain, Piglet, Organic Farming

1. Introduction

Modeling weight gain or growth of livestock is an important tool for optimizing management decisions and production systems [1]. Amongst considered livestock were cattle [2]-[6], sheep [7]-[9], chicken [10] [11], ducks [12] [13] or turkeys [14]. Several hundred papers deal with growth curves for fisheries.

There exist also studies dealing with the growth patterns of intensive piglet production [15] [16] or a pig breed used as laboratory animal [17]. But organic livestock farming differs from intensive livestock farming in many respects. Animal husbandry, feeding, weaning age and drug administration are the main aspects of that difference. Thus piglets from organic farming are kept under different rearing conditions than piglets in intensive production systems. It is of interest if this difference finds expression in a different growth pattern. There-

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fore, the aim of this study is the analysis of weight gain of piglets from organic farming.

There are two types of growth models: models with a rather mathematical motivation, such as data fitting (linear or polynomial regression, splines), and models with a biological motivation [18]-[20]. The latter models explain growth e.g. from balancing anabolism and catabolism (von Bertalanffy model). Intermediates between these types are unified approaches, which in essence describe the biologically motivated models by differential equations that generalize the logistic growth model [21]-[23]. As the models differ by the number of parameters, with more parameters enabling a better fit, the model selection is based on the Akaike Information Criterion AIC [24], which combines the good fit with a penalty for the number of parameters.

Amongst the considered models, only two fitted the piglet data properly: the initial growth phase with only minimal human influence could best be described by the biologically motivated Bertalanffy model, while the long term growth with different phases of human interaction was best described by the two-linear model.

2. Material Studied, Area Descriptions, Methods, Techniques

2.1. Animals and Farm Characteristics

The applied data were recorded in one research center in Upper Austria. In that facility piglets are bred and raised under organic conditions until they reach an age of about 100 days. On that farm there are about 30 breeding sows kept for piglet production. The sows are enabled to litter in farrowing pens. Thus, group suckling is implemented. All piglets were born and raised on that farm.

2.2. Data

A total of 49,699 live weight data were recorded between January 2007 and December 2013 from 5188 piglets aged between 0 and 105 days. The piglets usually were weighed at the day of their birth, at the latest on the first or second days of live, and then once a week. The body weight of each piglet was recorded with a weighing scale with smallest range of 20 g pre-weaning and with an accuracy of 500 g post-weaning and entered in an Excel chart. A macro was programmed to convert the chart in an optimal pattern for editing and analyzing the data.

Some piglets are so-called runts, meaning that they are backward in development and die within the first days or weeks of live. In such a case just a few recordings per piglet exist. Since such animals usually increase less in weight and therefore have a lower body weight than their same-aged conspecifics, a dataset including just the piglets with 6 or more body weight recordings was generated. This dataset contains 48,284 data points of 4393 piglets.

In both datasets, the body weight mean values of each day of live were calculated. The mathematical modeling was performed using these body weight mean values. Data fitting was done in Excel using the Solver add-in and the least squares method.

2.3. Description of the Growth Models

Thirteen growth functions were fitted to the body weight data of the piglets. The equations of the considered growth models are shown in **Table 1**.

The choice of models was guided by the following aspects: First, in order to avoid numeric integration of differential equations, only models with explicit growth equations were considered. For the same reason, the number of parameters was limited to four. These models include polynomials of degree at most three and splines of two lines (two-linear model), the three biologically motivated models (mentioned in the introduction), and several variants of exponential and logistic growth curves.

2.4. Model Comparison

The models were compared by using Akaike's Information Criterion (AIC) [24], which is based on the following benchmark AIC (or more specifically $\mathrm{AIC_L}$):

$$\mathrm{AIC_L} = 2K - 2 \cdot \ln\left(\text{maximize dlikelihood}\right) \tag{14}$$

where K is the number of parameters in the growth model.

In case of a least squares estimation with normally distributed error term, the following formula can be used to compute the AIC (more precisely: $\mathrm{AIC_S}$)

Table 1. Functions applied in this study for modeling the growth curve of piglets from organic farming.

Growth models	Equation	Equation number
Proportional	$y = at$	(1)
Linear	$y = at + b$	(2)
Quadratic	$y = at^2 + bt + c$	(3)
Quadratic/zero	$y = at^2 + bt$	(4)
Parabola	$y = at^2 + c$	(5)
Cubic	$y = at^3 + bt^2 + ct + d$	(6)
Exponential	$y = ae^{bt}$	(7)
Restricted exponential	$y = a - be^{-ct}$	(8)
Logistic	$y = \frac{abe^{ct}}{ae^{ct} + b - a}$	(9)
Von Bertalanffy [18]	$y = \left(\frac{a}{b} - \frac{1}{b}e^{-\frac{bt}{3} - \frac{cb}{3}}\right)^3$	(10)
Parks [19]	$y = a - be^{-ct - dt^2}$	(11)
Richards [20]	$y = \frac{a}{\left(1 + be^{-cdt}\right)^{\frac{1}{d}}}$	(12)
Two-linear model	$y = \max\left(a + bt; c + dt\right)$	(13)

y = live weight (kg), t = age (days), a, b, c and d = specific parameters of the growth functions.

$$\mathrm{AIC_S} = N \ln\left(\frac{SS}{N}\right) + 2K \tag{15}$$

where SS is the sum of squares, N is the number of data points and K again is the number of parameters in the model. Due to the fact that both formulas do not show the same result, AIC = $\mathrm{AIC_S}$ in this study.

In general it has to be noted that a conclusion about the quality of the goodness of fit is not possible if the AIC of just one individual model is considered. Only the comparison of several AIC values is convincing. The model with the smallest AIC is said to be the one fitting the data best. The greater the AIC difference the more militates for the model with the smaller AIC value.

The following formula specifies the probability of the right model selection, where Δ is the difference between two AIC values [25].

$$\text{probability} = \frac{e^{-0.5\Delta}}{1 + e^{-0.5\Delta}} \tag{16}$$

The ratio of the relative probabilities of two models can also be calculated directly with

$$\text{relative probabilities ratio} = \frac{1}{e^{-0.5\Delta \mathrm{AIC}}} \tag{17}$$

3. Results

3.1. Pre-Weaning

Table 2 presents the results up to and including the age of 40 days. The von Bertalanffy model best describes the weight gains of the piglets, followed by the cubic and the quadratic model. The difference of the AIC values between the von Bertalanffy model and the cubic model is 0.837. Therefore the probability of the von Berta-

Table 2. Results pre-weaning.

Growth model	a	b	c	d	SS	AIC	
Proportional	0.276				13.773	−42.725	
Linear	0.235	1.105			0.789	−157.983	
Quadratic	4.85E−04	0.215	1.231		0.638	−164.683	#3
Quadratic/zero	−0.002	0.337			8.240	−61.786	
Parabola	0.006		2.821		18.031	−29.680	
Cubic	−2.40E−05	1.91E−03	0.193	1.296	0.605	−164.845	#2
Exponential	2.423	0.039			11.333	−48.721	
Restricted exponential	414.932	413.842	5.74E−04		0.834	−153.713	
Logistic	1.658	12.685	6.65E−03		1.351	−133.917	
Von Bertalanffy	0.217	7.82E−02	78.433		0.623	−165.683	#1
Parks	230.359	229.125	9.38E−04	2.69E−06	0.636	−162.792	
Richards	18.629	−0.374	−0.200	−0.167	0.672	−160.575	
Two-linear	1.150	0.231	0.397	0.256	0.697	−159.061	

lanffy model is 60.32%. (This model is with 60.32% more likely than the cubic or any other of the following models.) A graphic representation of the piglets' body weight mean values of each day of live and the von Bertalanffy model is given in **Figure 1**.

3.2. From Birth to 105 Days of Age

The results of all piglets from their birth to an age of 105 days are shown in **Table 3**. The two-linear model has the smallest AIC value and the best fit with a point of intersection at 53.8 days of age. The difference of the AIC values between the two-linear model and the quadratic model is 12.013. Therefore, the probability of the two-linear model is 99.75%. A graphic representation of the piglets' body weight mean values of each day of live and the two-linear model is given in **Figure 2**.

4. Discussion

The von Bertalanffy model describes weight gain of piglets in the first weeks of live until weaning best. Considering the whole piglet rearing the most natural nutrition is given during the suckling period. Provided that the piglets remain with the sow the ingested amounts of milk as well as the frequency of suckling are not influenced by the animal owner.

The biologist von Bertalanffy developed his model for all animal species under natural living and nutritional conditions. The model concept is based on physiological processes that are responsible for growth. Growth is defined as a consequence of anabolism and catabolism and will take place as long as building processes outweigh degradation processes. In young animals the primary function of the ingested food is rapid growth, thus it can be seen as a natural limitation of growing capabilities. In this sense the model concept is suited to describe growth development in this early period of live. This model is based on the idea of growth as a biological process until achieving a species-specific weight in adult age. By contrast, during the fattening period the hogs are supplied with much more energy than they would need for natural growth in order to reach as high weight gain as possible in a minimum of time. Thus, the results of the paper confirm that this model appears to be optimal for close to natural conditions.

Among the thirteen growth models the two-linear model describes the weight gain of piglets from organic farming best. This model aims at two different growth periods which actually are caused by the general conditions of the piglets' rearing. At the age of about 40 days the piglets are weaned. From this moment on the piglets have no longer the opportunity to suckle milk. This implies that solid feed is the only food source and likewise

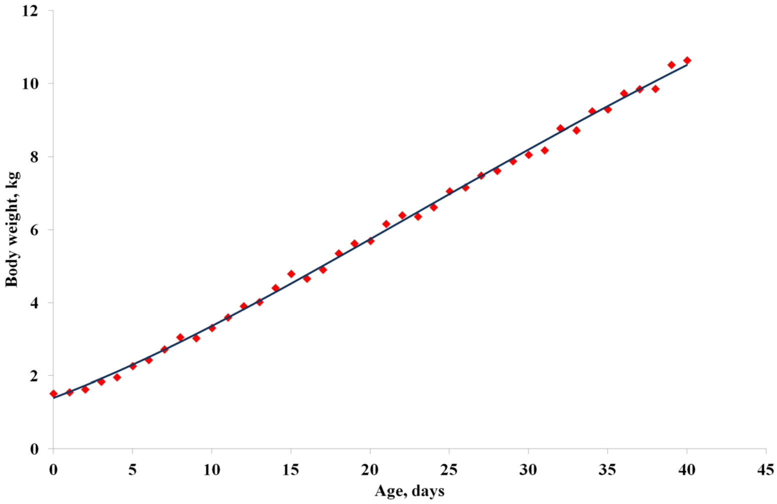

Figure 1. Body weight mean values of each day of live and the von Bertalanffy model.

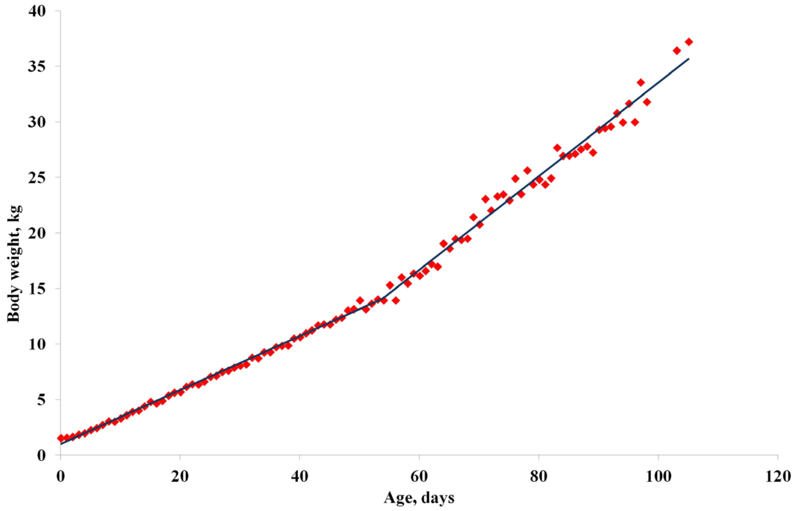

Figure 2. Body weight mean values of each day of live and the two-linear model.

Table 3. Results from birth to an age of 105 days.

Growth model	a	b	c	d	SS	AIC	
Proportional	0.307				241.618	90.096	
Linear	0.323	−1.086			211.234	78.522	
Quadratic	0.002	0.156	1.730		43.617	−78.808	#2
Quadratic/zero	0.001	0.224			76.994	−23.410	
Parabola	0.003		4.641		183.928	64.542	
Cubic	1.91E−06	0.001	0.164	1.710	43.404	−77.301	#3
Exponential	4.506	0.021			235.199	89.377	
Restricted exponential	413.777	415.031	0.001		238.837	92.927	
Logistic	2.907	48.317	0.001		65.796	−37.284	
Von Bertalanffy	0.073	0.007	1207.058		59.392	−47.628	
Parks	230.626	228.859	0.001	8.70E−06	44.643	−74.459	
Richards	90.476	−0.006	−7.466	−0.002	50.275	−62.460	
Two-linear	0.982	0.243	−8.643	0.422	37.966	−90.821	#1

water is the only source of liquid. Due to the loss of the familiar surroundings the piglets furthermore have to cope with new drinking and feeding troughs, new stable mates, new climate control and also a new germ flora. In addition to the stress attributable to weaning the immune protection of the maternal antibodies that were ingested with the colostrum directly after birth decrease and the piglets' own immune system is still under development. In this context sometimes antibiotics are administered prophylactically in intensive livestock farming. This is not standard in organic farming with the result that in the first days of post-weaning the weight gain declines or stagnates completely. Not until after coming through that period piglets show an increased weight gain, what corresponds with the point of intersection of the two straight lines of the model at an age of about 50 days. In contrast to De Behr [4], who described a step-wise linear growth model for Belgian Blue cattle less than 20 month of age, the point of intersection was not fixed in advance, but it was determined from the growth data only through the goodness of fit.

5. Conclusion

Akaike's Information Criterion points out that not necessarily the model with more parameters (resulting in a better fit) should be recognized as the optimal model, as more parameters may result in an over-fit. Furthermore, AIC allows comparing models that are not nested; also probabilities of models can be calculated. Therefore, Akaike's Information Criterion provides a comprehensive comparison of all kinds of models. On the basis of this criterion, the initial forty days of growth, where conditions are close to natural ones, can be described by a biologically motivated model. Overall, over 105 days, growth can be described by maximal utilization of food resulting in approximately linear growth, with different slopes depending on the change of the food-situation.

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