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Use of the Mitscherlich equation for estimating maintenance requirement for amino acids and their efficiency of utilization for accretion in growing swine

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ABSTRACT

Darmani Kuhi et al. (2001) developed a Mitscherlich equation to estimate energy and amino acid (AA) requirements by growing broilers for maintenance, gain and protein (or AA) accretion. In the study presented herein, the scope of the model was extended to growing swine to provide an estimate of their AA requirements for maintenance and growth using the results of four studies taken from literature. The equation was fitted by non-linear regression procedures to estimate parameters, from which other biological indicators were calculated. A number of criteria were used to evaluate general goodness of fit of the model, including model behaviour, biologically meaningful parameter estimates and statistical performance. The model estimated the maintenance requirements for lysine, sulphur amino acids and threonine to be in the range 37-74, 11-40 and 17-63 mg kg^{-1} of LW d^{-1}, respectively, depending on the data source and the live-weights (LW) of pigs (age). The values determined for average lysine requirement for body protein accretion varied from 6.5-7.3 g $100g^{-1}$ of protein accretion. For sulphur amino acids and threonine, the determined values were 3.95 and 4.35 g $100g^{-1}$ of protein accretion, respectively. The estimated maintenance requirements and the determined values of AA requirements for protein accretion were in good agreement with values reported previously by other researchers. Average efficiency of recovering AA in body weight and body protein was greatest at low intakes of AA and decreased as intakes increased.

Key words: Amino acids, law of diminishing returns, Mitscherlich equation, swine, maintenance and growth requirements

INTRODUCTION

Hendricks et al. (1931) first applied the law of diminishing returns to describe the relationship between feed consumption and live-weight in growing animals. Parks (1982) showed that a diminishing returns equation such as the Mitscherlich equation or monomolecular growth function (Mitscherlich, 1909; Thornley and France, 2007; Darmani Kuhi et al., 2010) can be used to describe change in size with age. Blaxter and Boyne (1978) proposed the Mitscherlich equation for describing the relationship between energy retention and feed intake, based on a detailed analysis of over 80 calorimetric experiments with sheep and cattle.The response of energy retention rate to increments in rate of feed intake obeys the law of diminishing returns over all levels of intake. The Mitscherlich equation forms an integral part of the metabolizable energy (ME) system used in feeding dairy cows in the United Kingdom (Agnew et al., 2004). However, in swine nutrition studies, a limited effort has been made to use of the law of diminishing returns. There are numerous studies suggesting that a limiting amino acid is utilized with constant efficiency over the range of intakes from maintenance to that required for maximal protein accretion (Batterham et al., 1990; Chung and Baker, 1992; Adeola, 1995). In contrast, Heger and Frydrych (1985) and Gahl et al. (1994) demonstrated that the utilization of amino acids declined as their intake required for maximum protein retention. Similarly, Fuller and Garthwaite (1993), studying the response of body protein accretion to ideal protein intake in individual pigs, found that the response could be described better by a curvilinear rather than a rectilinear model. The potential and validity of a specially re-parameterized Mitscherlich equation (Darmani Kuhi et al., 2001) to partition AA intakes between requirements for maintenance and growth has been demonstrated recently in relation to broilers using results from two types of studies, namely bioassay and nitrogen balance experiments (Kebreab et al., 2008; Darmani Kuhi et al., 2009; 2011; 2012). The present study aims to apply this model in order to provide estimates for AA requirements for maintenance and growth in growing swine.

MATERIALS AND METHODS

The Model

The re-parameterized Mitscherlich or monomolecular equation (Darmani Kuhi et al., 2001) takes the form:

$$y = y_{\max}[1 - e^{-k(x-x_m)}],\ x \geq 0,$$

where y is live-weight (LW) or protein accretion [g of LW or protein/kg of LW/d], $y_{\max}$ is the maximum attainable value for y, k is a fractional rate parameter [mg of AA/kg of LW/d]$^{-1}$, x is AA intake [mg of AA/kg of LW/d] and x_m is AA intake at maintenance. The average efficiency of AA utilization, $\bar{k}_g$, between Δ_1 times maintenance and Δ_2 times maintenance ($\Delta_2 \geq \Delta_1 \geq 1$) is determined by:

$$\bar{k}_g(\Delta_1,\ \Delta_2) = \frac{y(\Delta_2 x_m) - y(\Delta_1 x_m)}{(\Delta_2 - \Delta_1)x_m}.$$

Experimental Data

Results of four studies taken from the literature were used in this study (Batterham et al., 1990; Yang et al., 1997 a,b,c). Details of experimental characteristics of the data including sources, types of treatment and growth phases are shown in Table 1.

Table 1. Data sources used in the study

Source[a]	Growth phase (kg)	Consideration
Batterham et al. (1990) (M and F)	20-45	Effect of dietary lysine concentration on efficiency of lysine retention
Yang et al. (1997a) (M) Exp.1 Exp.2	 11-15 39-46	Development of model equation to subdivide lysine requirements
Yang et al. (1997b) (M) Exp. 1 Exp. 2 Exp. 3	 10.5-15 39-46 67-76	Development of model equation to subdivide Met. + Cys. requirements
Yang et al. (1997c) (M) Exp. 1 Exp. 2 Exp. 3	 11-14 39-46 67-76	Development of model equation to subdivide Threonine requirements

[a]M=male, F=female.

Statistical Procedures

Due to absence of a single robust criterion for model evaluation, three criteria were used to evaluate model adequacy: 1) model behaviour when fitting the curves using non-linear regression, 2) statistical performance and 3) comparison of biologically meaningful indicators obtained using the monomolecular. All statistical analyses were performed using the non-linear procedure of the statistical package SAS (SAS Institute Inc., Cary, NC, USA). The proportion of variation accounted for ($\bar{r}^2$), the amount of total variation about the mean value of y explained by the fitted curves, was used as a measure of adequacy of the model.

RESULTS AND DISCUSSION

Fig. 1 shows the fit of the model to the data on LWG (or protein accretion) versus AA intake. The resultant curves (Fig. 1) and general goodness of fit, based on variation accounted for ($\bar{r}^2$) and standard error (SE) estimated for the growth parameters, indicated that fits of the model to the data sets were acceptable (Table 2). Extrapolation of the curves shown in Fig. 1 gives the point at which LWG and protein accretion becomes zero. Therefore, intersection of the curves with the x-axis representing the maintenance level of AA requirements (Table 2). The maintenance requirements estimated using the model were in the range 37-74, 11-40 and 17-63 mg kg^{-1} of LW/d for lysine, sulphur amino acids and threonine, respectively, depending on the data source and the weights of pigs (age).

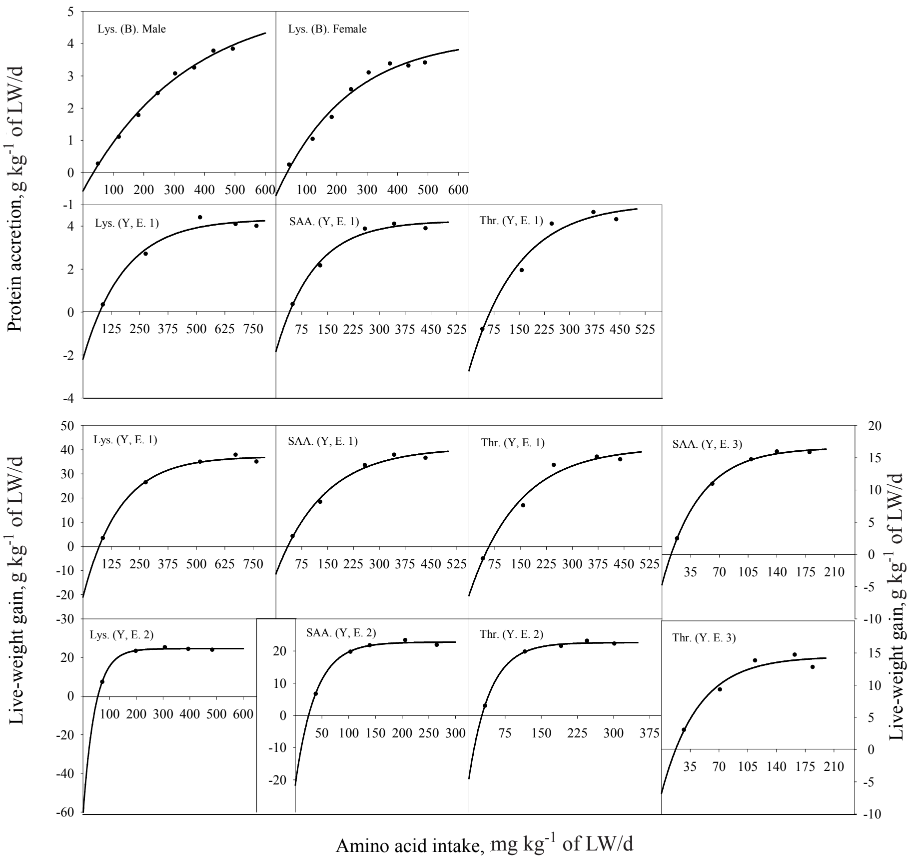

Fig. 1. Plots of live-weight gain (LWG) and protein accretion (g of LW (or protein) accretion/kg of LW/d) against AA intake (mg kg^{-1} of LW/d), showing fit of monomolecular equation to data. The AAs were: Lysine (Lys), Sulpher Amino Acids (SAA) and Threonine (Thr). The letters (B) and (Y) indicate fit of equation to data from Batterham et al. (1990) and Yang et al. (1997a,b,c). E1, E2 and E3 indicate Experiments 1, 2 and 3 in Yang et al. (1997a,b,c).

Indicators calculated from the Mitscherlich equation together with reported values of growth indicators are shown in Table 2. From Table 2 it is clear that the values determined for average lysine requirement for body protein accretion, with an average value of 6.9 g 100g^{-1} of protein accretion and those determined for sulphur amino acids (3.95 g 100g^{-1} of protein accretion) and threonine (4.53 g 100g^{-1} of protein accretion) are in good agreement with values reported by other researchers (*e.g.* ARC, 1981; Fuller et al., 1989; Heger et al., 2002). Average efficiency of recovering AA in body weight and body protein was greatest at low intakes of AA and decreased as intakes increased (Fig. 1).

Table 2. Growth indicators calculated from the Mitscherlich equation together with their reported values

Amino acid	Response variable	x_m mg kg^{-1} of LW/[d]	$\bar{r}^{2a}$	[0.1*(1/ kg)] [b] Model	(References)[c] values	
					Maintenance mg kg^{-1} of LW0.75/[d]	g 100g^{-1} protein
Lysine, Exp 1[d] Yang et al. (1997a)	Protein retention	73.8 (19.1)	94.63	6.5	36 (F), 39 (H)	7 (A), 6.8 (F), 7.8(H)
Lysine, Exp 1 Yang et al. (1997a)	Live-weight gain	71.8 (8.7)	98.67	-	-	-
Lysine, Exp 2 Yang et al. (1997a)	Live-weight gain	56 (5)	99.14	-	-	-
Lysine, Batterham et al. (1990)	Protein retention	34.6 (8.1)	99.17	7.3	-	-
Lysine, Batterham et al. (1990)	Protein retention	36.8 (13.2)	96.45	6.9	-	-
Met. + Cys., Exp 1 Yang et al. (1997b)	Protein retention	39.5 (8.6)	97.06	3.95	49 (F), 46 (H)	3.5 (A), 3.6 (F), 3.5 (H)
Met. + Cys., Exp 1 Yang et al. (1997b)	Live-weight gain	34.4 (9.6)	97.74	-	-	-
Met. + Cys., Exp 2 Yang et al. (1997b)	Live-weight gain	25 (3.3)	98.59	-	-	-
Met. + Cys., Exp 3 Yang et al. (1997b)	Live-weight gain	11.2 (1.4)	99.62	-	-	-
Threonine, Exp 1 Yang et al. (1997c)	Protein retention	63 (12.7)	93.99	4.53	53 (F), 49 (H)	4.2 (A), 4.7 (F), 4.5 (H)
Threonine, Exp 1 Yang et al. (1997c)	Live-weight gain	58.5 (11.2)	95.21	-	-	-
Threonine, Exp 2 Yang et al. (1997c)	Live-weight gain	26.9 (1.8)	99.38	-	-	-
Threonine, Exp 3 Yang et al. (1997c)	Live-weight gain	17.2 (7.7)	90.96	-	-	-

[a]Adjusted r^2.
[b]Average AA requirement for protein accretion between 1-4 times maintenance (g of AA/100 g of protein accretion).
[c]Reported values of amino acid requirements for maintenance and carcass amino acid composition of pigs. (A) ARC (1981); (F) Fuller et al. (1989) and (H) Heger et al. (2002).
[d]For details on different experiments (Exp 1, Exp 2 and Exp 3) see Table 1.

The response of nitrogen retention to nitrogen inputs is usually represented rectilinearly with an abrupt cut. The data, however, may support this or be more suggestive of a diminishing returns curve. Since, under controlled conditions, the slope of the curve describing the relationship between nitrogen retention and nitrogen input represents the quality of the protein fed (biological value, net protein utilization and nitrogen balance index), the assumption that the relationship is linear has tended to be adopted. Most data are linear to a good approximation, but a curvilinear response is probably a more precise interpretation (Boorman, 1980). Models based on the premise that growth rate determines requirements based on some fixed rate of nutrient utilization do not adequately represent the biological phenomena involved. Since responses of animals to dietary energy, protein and AAs are diminishing returns phenomena, they should be evaluated as such to estimate optimum economic levels, rather than as biological maxima (Pesti and Miller, 1997). Darmani Kuhi et al. (2001, 2009) developed a Mitscherlich equation to estimate energy and AA needed by growing broilers for maintenance, gain and protein accretion. In the study presented herein, the aim was to assess the applicability of this model in estimating AA requirements for maintenance, gain and protein accretion in growing swine. With regard to the estimates of AA requirements for maintenance and average AA requirement for protein accretion between 1 and 4 times maintenance (Table 2), the estimates lie in the range reported by other researchers (ARC, 1981; Fuller et al., 1989; Heger et al., 2002). Considering the values of average efficiency of recovering AA at different multiples of maintenance, the efficiency of utilization of AA is greatest at low intake levels and decreases as intakes increase.

CONCLUSION

Results presented here and those previously reported for poultry (Darmani Kuhi et al., 2001; 2009; 2011; 2012; Kebreab et al., 2008) can be considered as a basis for accepting the general validity of the Mitscherlich or monomolecular equation to predict the magnitude and direction of responses of growing animals to dietary energy and protein (or AA) intake without making any initial assumptions.

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