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Authors
Kuhi, H Darmani
Kebreab, E
France, J

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Application of the law of diminishing returns to partitioning metabolizable energy and crude protein intake between maintenance and growth in egg-type pullets

H. Darmani Kuhi,*[1] E. Kebreab,† and J. France‡

**Department of Animal Science, Faculty of Agricultural Science, University of Guilan, PO Box 41635-1314, Rasht, Iran; †Department of Animal Science, University of California, Davis 95616; and ‡Centre for Nutrition Modeling, Department of Animal & Poultry Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1*

Primary Audience: Nutritionists, Researchers, Broiler Breeder Producers

SUMMARY

Experiments designed to investigate the effect of dietary nutrient concentrations on the growth and development of pullets are relatively long term and expensive to conduct. As the cost of research increases, mathematical models become valuable tools to answer research and development questions. Modeling growth curves allows nutritionists and poultry researchers to predict dynamic or daily nutrient needs more adequately than using fixed requirements. The potential and validity of a specially reparameterized monomolecular model to partition nutrient intakes between requirements for maintenance and growth was previously demonstrated in relation to ruminants, pigs, chickens, turkeys, and broiler breeder pullets. In the current study, the model was evaluated for its ability to estimate ME and CP requirements for maintenance and growth in egg-type pullets. On the basis of the results of this study, along with those previously reported for chickens, turkeys, and broiler breeder pullets, this model is advantageous because it can predict the magnitude and direction of responses of growing poultry to dietary ME and CP intakes without requiring initial assumptions. The model also has the advantage of biological interpretability of the parameter estimates. One of the main consequences of this interpretability is that the results from several experiments can be pooled to obtain the best estimates of the response coefficients.

Key words: egg-type pullet, growth modeling, law of diminishing returns, metabolizable energy requirement, crude protein requirement

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DESCRIPTION OF PROBLEM

The growing period (0 to 17 wk) is the most critical time in a hen's life because inaccuracies in providing nutrients during this period are difficult to rectify later [1]. Many of the problems that occur during the early part of lay can be traced back to an insufficient or improper type

[1]Corresponding author: Darmani_22000@yahoo.com

of BW attained during the various stages of the growing period [2]. Although BW recommendations are readily available for the various commercial pullets on the market today, often little information is given on how to keep problem flocks close to these suggested BW. Experiments designed to investigate the effects of dietary nutrient concentrations on the growth and development of pullets are relatively long term and expensive to conduct. As the cost of research increases, mathematical models become valuable tools to answer research and development questions. Among the nutritional factors determining the rate of growth of an animal, dietary energy and CP content are the most important ones. A specially reparameterized monomolecular model [3] that partitions nutrient intakes into requirements for maintenance and growth was previously demonstrated to be useful in pigs, chickens, broiler breeders, and turkeys [3–12]. This model was considered advantageous because it could predict the dietary nutrient requirements for maintenance and growth on a daily basis for the entire growth period. In the current study, the model was applied to published data to evaluate its predictive ability for estimating ME and CP requirements for maintenance and growth in egg-type pullets.

MATERIALS AND METHODS

Data Source

A total of 3 time-course profiles with growing egg-type pullets, obtained from published results by the Hy-Line International Online Management Guide for different varieties of egg-type pullets [13], were used in this study in 2 separate analyses. A detailed summary of the data used in this study is given in Table 1.

The Model

A monomolecular function with diminishing returns behavior (equation 1) was used to investigate the relationship between scaled BW gain [g/g of live weight (**LW**) per day] and ME (kJ/kg of LW per day) and CP (g/kg of LW per day) intakes in egg-type pullets.

$$Y = a - (a + b)e^{-cx}. \quad [1]$$

The parameters a, b, and c are positive entities, with $y_{max} = a$ and $y_{min} = -b$. The equation was fitted separately to the data and the parameters were estimated. From these parameter estimates, ME and CP requirements for maintenance [ME_m (kJ/kg of LW per day) and CP_m (g/kg of LW per day), where LW gain = 0], and average efficiency of ME ($\bar{k}_{gME}$, g of BW gain/kJ of ME intake) and CP ($\bar{k}_{gCP}$, g of BW gain/g of CP intake) utilization for gain were calculated (equation 2):

$$ME_m \text{ or } CP_m = c^{-1} \ln[(a + b)/a]. \quad [2]$$

The instantaneous efficiency of ME and CP utilization for gain, k_{gME} (g of BW gain/kJ of ME intake) and k_{gCP} (g of BW gain/g of CP intake), is given by

$$k_{gME} \text{ (or } k_{gCP}) = \frac{dy(x)}{dx},\ y(x) > 0, \quad [3]$$

and the average efficiency between maintenance and Δ times maintenance (Δ > 1) is given by

$$\bar{k}_{gME} \text{ (or } \bar{k}_{gCP}) = \frac{y(\Delta ME_m)}{(\Delta - 1)ME_m},\ y(x) > 0 \quad [4]$$

(CP_m replacing ME_m for $\bar{k}_{gCP}$).

Body weight gain, ME intake, and CP intake were calculated for each data profile as follows:

$$\text{BW gain} = \frac{\text{difference of final and initial pullet BW each week}}{\overline{\text{LW}} \times 7},$$

$$\text{ME or CP intake} = \frac{\text{ME (or CP) intake for a specific week}}{\overline{\text{LW}} \times 7},$$

where $\overline{\text{LW}}$ is average LW. Average LW was calculated as the mean of BW at the beginning and end of each week.

Statistical Procedures

In the first analysis, statistical analyses were performed using the nonlinear regression pro-

Table 1. Data profiles of different varieties of egg-type pullets obtained from published results by the Hy-Line International Online Management Guide[1]

	Variety											
	Gray				W-98				Silver Brown			
Age, wk	LW, g	Dietary CP, g/kg	Dietary ME, MJ/kg	FI, g/d	LW, g	Dietary CP, g/kg	Dietary ME, MJ/kg	FI, g/d	LW, g	Dietary CP, g/kg	Dietary ME, MJ/kg	FI, g/d
1	70	200	12.05	13	65	200	12.46	14	70	200	12.07	13
2	115	200	12.05	20	110	200	12.46	17	115	200	12.07	20
3	190	200	12.05	25	180	200	12.46	21	190	200	12.07	25
4	280	190	12.05	29	260	190	12.68	29	290	183	11.98	29
5	380	190	12.05	33	350	190	12.68	39	380	183	11.98	33
6	490	190	12.05	37	450	190	12.68	43	480	183	11.98	37
7	590	175	12.00	41	550	180	12.46	46	590	175	11.77	41
8	710	175	12.00	46	650	180	12.46	49	690	175	11.77	46
9	810	175	12.00	51	750	180	12.46	52	790	175	11.77	51
10	920	175	12.00	56	850	180	12.46	54	890	175	11.77	56
11	1,020	175	12.00	61	930	180	12.46	55	990	175	11.77	61
12	1,120	175	12.00	66	1,000	180	12.46	57	1,080	175	11.77	66
13	1,190	155	12.00	70	1,070	160	12.35	59	1,160	155	11.40	70
14	1,260	155	12.00	73	1,130	160	12.35	60	1,250	155	11.40	73
15	1,330	155	12.00	75	1,180	160	12.35	62	1,340	155	11.40	75
16	1,400	155	12.00	77	1,230	155	12.35	64	1,410	155	11.40	77
17	1,460	160	12.00	78	—	—	—	—	1,480	165	11.40	80

[1]Hy-Line International Online Management Guide [13]. LW = live weight; FI = feed intake.

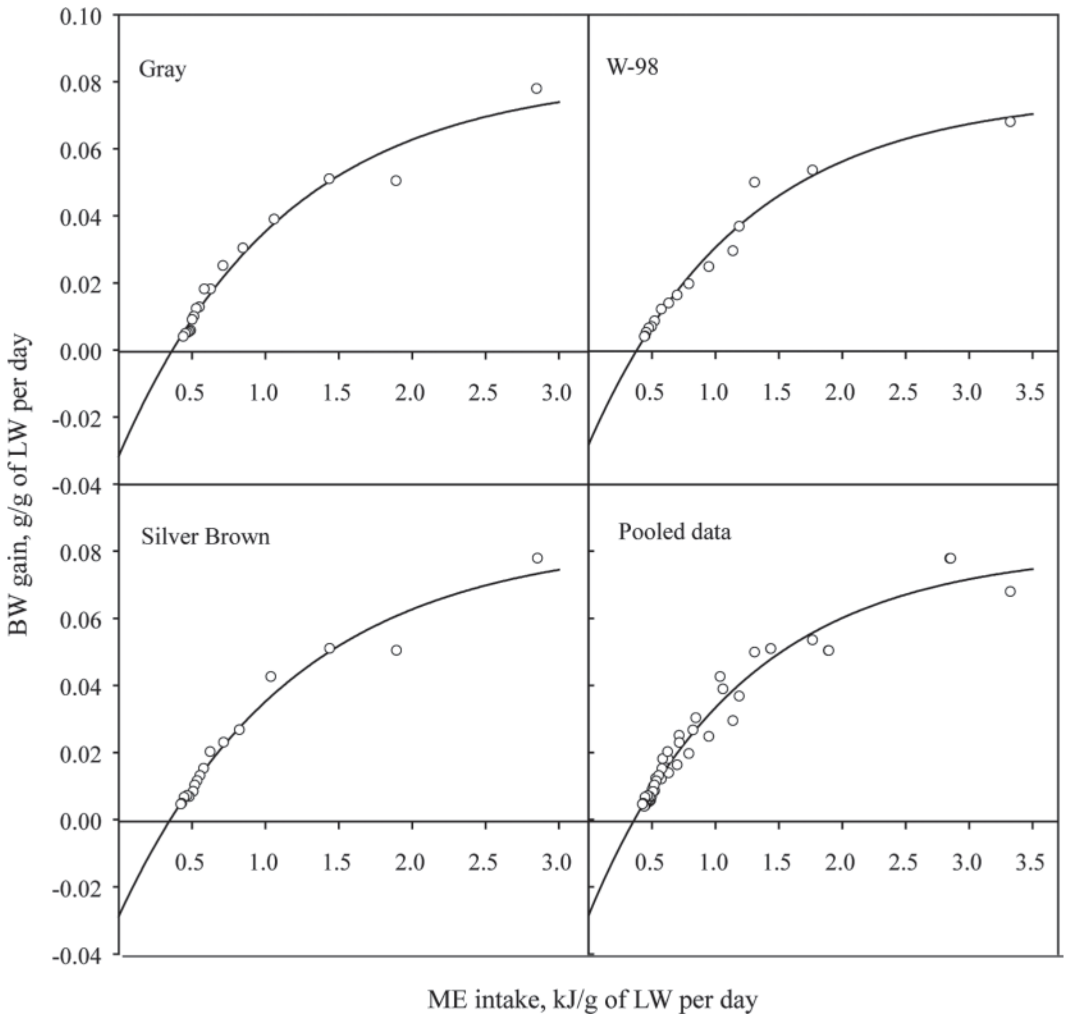

Figure 1. Plots of ME intake [kJ/g of live weight (LW) per day] against BW gain (g/g of LW per day), showing fits of the monomolecular model to data from different varieties of egg-type pullets.

cedure of SAS software [14]. For the second analysis, the data from the different varieties of pullets (Table 1) were pooled and the nonlinear mixed model procedure of SAS [14, 15] was used to estimate the parameters of the model. Mixed model analysis was chosen because the data were gathered from various bird varieties under different management conditions; therefore, it was necessary to include random effects of the studies. Varieties were considered as random samples from a larger set of the population. The distribution of random effects was assumed to be normal and the dual quasi-Newton technique was used for optimization with adaptive Gaussian quadrature as the integration method.

In both analyses, adequacy of the model was measured using model behavior when fitting the curves, statistical performance [using coefficients of determination (R^2), significance level of the parameters estimated, variance of error estimate, and its approximate SE], and comparison of biologically meaningful indicators obtained using the model.

RESULTS AND DISCUSSION

The results of fitting the monomolecular model to the data (Figures 1 and 2) show the model's capability in describing the relationship between ME (or CP) intake and BW gain in egg-type pullets. Performance of the model in describing the data based on statistical performance (SE, R^2, and σ^2_{error}) and the biological interpretability of the parameter estimates are shown in Tables 2 and 3. Based on the statistical criteria, the fit of the model to data is acceptable. With regard to the estimates of ME and CP requirements for maintenance (from 351 to 370 kJ/kg of LW per day for ME, and from 4.5 to 4.8 g/kg of LW per day for CP) and average ME and CP utilization for producing gain in BW calculated between 1 and 4 times maintenance (from 13.95 to 15.96 kJ/g of BW for ME, and from 0.50 to 0.56 for CP; Table 3), these estimates lie in the reported range [16–21]. The values of average net energy and protein utilization, defined as the increase in BW with each additional unit of ME (or CP) intake, are greatest at low intake levels and decrease as intake is increased. These results are supported by conventional wisdom, namely, that a gradual decrease in the efficiency of utilization of nutrients for producing BW gain occurs as intake increases [22–24]. This is partly due to a slight decline in digestive efficiency of the animal with increased feeding level and partly to the fact that anabolic processes are less efficient than catabolic ones. Protein turnover is higher as protein intake is increased because an excess in amino acid supply causes an increase in amino acid degradation rates [25–27]. There-

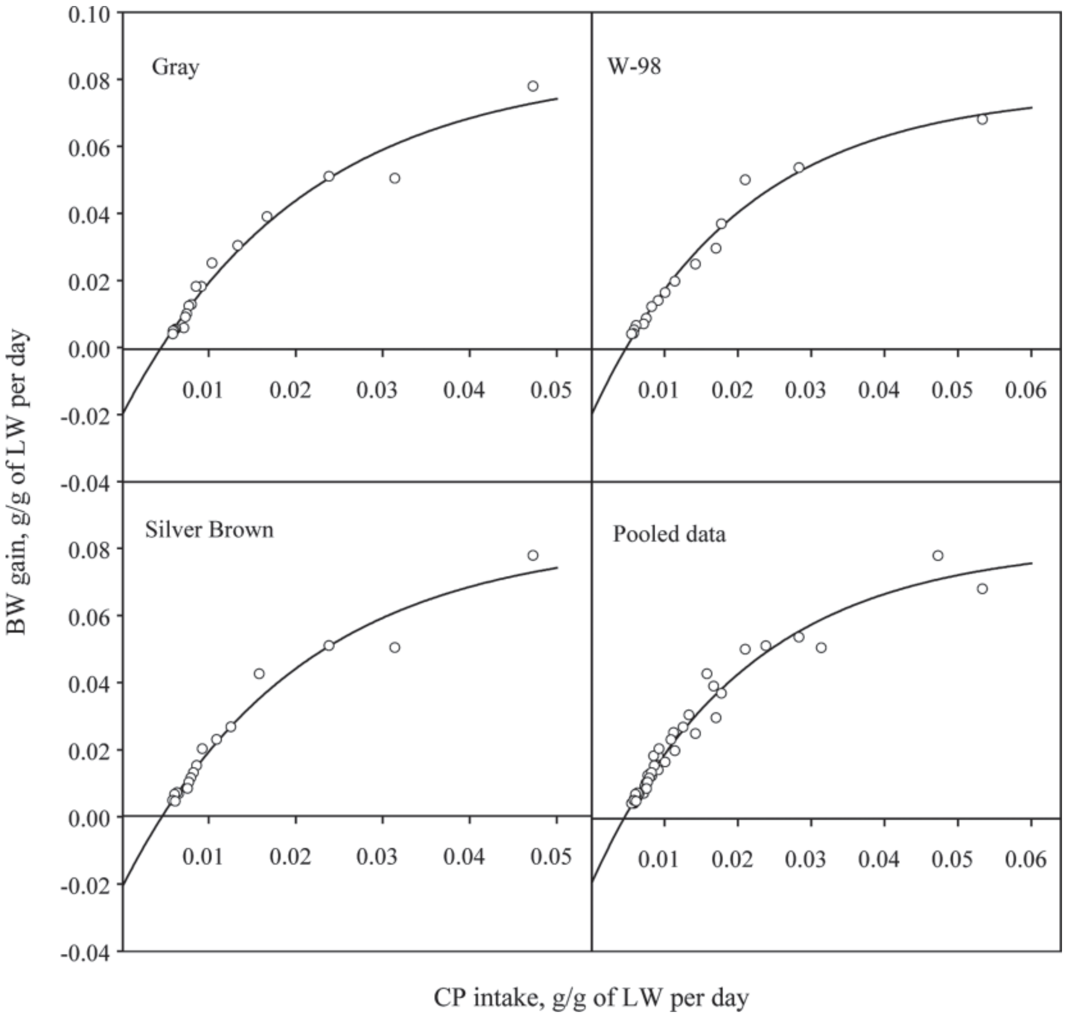

Figure 2. Plots of CP intake [g/g of live weight (LW) per day] against BW gain (g/g of LW per day), showing fits of the monomolecular model to data from different varieties of egg-type pullets.

Table 2. Parameter estimates obtained using the monomolecular model to regress BW gain [g/g of live weight (LW) per day] against ME intake (kJ of ME intake/g of LW per day) and CP intake (g of CP intake/g of LW per day)[1]

	Parameter estimate				
Variety	*a*	*b*	*c*	R^2 [2]	σ^2_{error} [3]
Hy-Line Gray					
ME	0.082 (0.007)	0.032 (0.007)	0.895 (0.178)	96.97	—
CP	0.085 (0.008)	0.019 (0.005)	46.37 (9.04)	97.40	—
Hy-Line W-98					
ME	0.076 (0.006)	0.028 (0.001)	0.830 (0.128)	97.16	—
CP	0.077 (0.005)	0.020 (0.003)	48.98 (6.88)	97.69	—
Hy-Line Silver Brown					
ME	0.083 (0.008)	0.029 (0.007)	0.846 (0.170)	97.01	—
CP	0.083 (0.009)	0.021 (0.006)	49.35 (10.83)	96.51	—
Pooled data set					
ME	0.081 (0.004)	0.029 (0003)	0.848 (0.088)	96.41	0.00001 (0.000003)
CP	0.081 (0.004)	0.020 (0.003)	48.28 (4.97)	96.97	0.00001 (0.000002)

[1]Standard errors are given in parentheses.

[2]Adjusted R^2.

[3]Variance of error estimate.

fore, successive increments of daily nutrient intake result in progressively smaller increments in daily BW gain [28]. The results of fitting the model to the pooled data (Figures 1 and 2) show its capability in summarizing the data despite differences that exist between the varieties (Table 1). Therefore, the relationship between scaled BW gain (g/g of LW per day) and ME (kJ/kg of LW per day) and CP (g/kg of LW per day) intake is independent of variety and can be described mostly by ME (or CP) intake.

For a successful application of models in practice, the required model input should be easily available to the user. Moreover, the underly-

Table 3. Growth traits calculated from parameter estimates obtained using the monomolecular model to regress BW gain [g/g of live weight (LW) per day] against ME intake (kJ of ME intake/g of LW per day) and CP intake (g of CP intake/g of LW per day)

Variety	ME_m, kJ/kg of LW per day	NE_g,[1] kJ/g of BW	CP_m, g/kg of LW per day	$18 \times \bar{k}_g(1\text{–}4)$,[2] %	$\bar{k}_g(1\text{–}4)$[3]	$\bar{k}_g(1\text{–}2)$[3]	$\bar{k}_g(2\text{–}3)$[3]	$\bar{k}_g(3\text{–}4)$[3]
Hy-Line, Gray								
ME	366	13.95	—	—	0.050	0.063	0.045	0.033
CP	—	—	4.5	55	3.08	3.65	2.94	2.38
Hy-Line, W 98								
ME	383	15.96	—	—	0.044	0.055	0.040	0.029
CP	—	—	4.8	50	2.80	3.36	2.65	2.09
Hy-Line, Silver Brown								
ME	351	14.09	—	—	0.050	0.061	0.046	0.034
CP	—	—	4.6	56	3.08	3.68	2.93	2.33
Pooled data set								
ME	370	14.75	—	—	0.048	0.059	0.043	0.031
CP	—	—	4.6	53	2.97	3.53	2.83	2.26

[1]NE_g = the average net energy requirement for growth between 1 and 4 times maintenance, calculated as $0.7 / \bar{k}_g(1\text{–}4)$ based on the assumption that the average efficiency of utilization of ME for growth is approximately 70% for balanced diets in poultry (McDonald et al. [31]).

[2]The average net protein utilization for growth between 1 and 4 times maintenance, calculated based on the assumption that the chicken carcass contains approximately 18% CP.

[3]The average efficiency of utilization of ME (or CP) for growth [g of BW gain/kJ of ME (or g of CP) intake] between 1 and 2, 2 and 3, 3 and 4, and 1 and 4 times maintenance.

ing theories should be as simple as possible and sufficiently evaluated to gain user confidence [29]. The potential and validity of a specially reparameterized monomolecular model [3] to partition nutrient intakes between requirements for maintenance and growth was previously demonstrated in relation to ruminants, pigs, chickens, turkeys, and broiler breeder pullets [3–12]. In this study, the scope of the model was extended to egg-type pullets to verify its predictive ability for estimating ME and CP requirements for maintenance and growth.

CONCLUSIONS AND APPLICATIONS

On the basis of the results of this study, along with those previously reported for chickens, turkeys, and broiler breeder pullets [3–8, 11], the model is advantageous because

1. It can predict the magnitude and direction of the responses of growing poultry to dietary ME and CP intake, without making initial assumptions, which can be used in choosing and developing special feeding programs to decrease production costs.
2. The model has the advantage of biological interpretability of the parameter estimates. According to Morris [30], one of the main consequences following from this interpretability is that given the results of several experiments, one can pool them to obtain the best estimates of the response coefficients.

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