Comparison of growth models between artificial neural networks and nonlinear regression analysis in Cherry Valley ducks

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Primary Audience: Duck Producers, Researchers, Geneticists, Nutritionists, Computer Scientists

SUMMARY

The objective of this research was to compare growth models of Cherry Valley ducks. The multilayer perceptron (MLP) method and the radial basis function (RBF) method are both artificial neural networks that offer an alternative to nonlinear regression analyses (asymptotic exponential, logistic, cubic curvilinear, and Gompertz). To describe the growth curve, average BW was used. Training data consisted of alternate-day BW beginning with the first day, and validation data consisted of BW on other days. The R² and root mean square error of each model were determined for the training data. Mean absolute deviation and mean absolute percentage of error were used as the error measurements for the validation data. The RBF improved R² and root mean square error more than did the cubic curvilinear, Gompertz, logistic, asymptotic exponential, and MLP models. The error measurements of the Gompertz, RBF, and cubic curvilinear models were significantly lower than that of MLP. However, the mean absolute percentages of error of the asymptotic exponential, logistic, and MLP models were not significantly different from each other. It could be concluded that RBF produced more accurate predictions than MLP, but it did not produce more accurate predictions than the Gompertz and cubic curvilinear functions for estimating the BW of Cherry Valley ducks.

Key words: artificial neural network, Cherry Valley duck, growth curve, nonlinear regression analysis, radial basis function

doi:10.3382/japr.2010-00223

DESCRIPTION OF PROBLEM

Currently, artificial neural networks (ANN) are being applied to livestock production as alternatives to regression analysis for forecasting egg prices [1, 2], selecting the feed mix in the feed industry [3], and predicting the amino acid composition of feed ingredients [4, 5]. The advantages of ANN have been reported. Unlike regression analyses, ANN do not require that a mathematical model be specified before prediction. To describe the growth curve in poultry, a sigmoid or S-shaped curve is normally used. This curve is divided into 3 phases, namely, self-accelerating, linear, and self-decelerating [6], and so responds to nonlinear models [7], such

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as the exponential function, logistic function, cubic curvilinear function, and Gompertz non-linear regression model [7–10]. However, ANN could also adequately predict bird growth [11–13]. Moreover, the growth curve model using ANN and nonlinear regression analysis has not been reported in ducks, although these could be very important for estimating nutrient requirements and production management on commercial duck farms. Therefore, the objective of this study was to find successful models for estimating the BW of Cherry Valley ducks.

MATERIALS AND METHODS

Bird Data

Thirty male and 30 female ducks [14] were reared in individual metabolic cages (0.6 × 0.5 m; 0.3 m² of floor space per duck) that included an evaporative cooling system. The ducks were maintained and treated in accordance with Kasetsart University standards for bird welfare. The lighting period was 23 h/d for the first 3 d and was reduced by 1.0 h every day until it reached 18 h/d. The temperature was set at 35°C during the first 3 d and was then reduced by 1.0°C every day until it reached 27°C. The ducks were fed a starter 1 diet (22.0% CP and 2,850 kcal of ME/kg) from 0 to 9 d, a starter 2 diet (20.0% CP and 2,900 kcal of ME/kg) from 10 to 16 d, a grower diet (18.5% CP and 2,900 kcal of ME/kg) from 17 to 42 d, and a finisher diet (17.0% CP and 2,950 kcal of ME/kg) from 43 to 52 d. Water and feed were offered ad libitum throughout the experimental period. Individual duck BW were recorded at 1700 h on each day for 52 d.

Model Development

ANN Models. An ANN is a processing system that executes activities similar to those of the human brain by replicating the operations and connectivities of biological neurons [15]. Multilayer perceptrons (MLP), the most popular neural network architecture, typically consists of 3 connected feed-forward layers of neurons [16] (Figure 1). The hyperbolic tangent function and the linear activation function are used in the hidden and output layers, respectively, and are represented by these functions:

Hyperbolic tangent:

\[ f(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}, \]

and

Linear:

\[ f(x) = x, \]

where \( x \) represents the weighted sum of inputs to the neuron and \( f(x) \) indicates the outputs from the neuron.
In this research, the MLP for the input, hidden, and output layers were designed according to Kolmogorov’s theorem (with each layer connected to the previous layer) [17]. A back-propagation algorithm was used for training by iteratively changing the interconnecting BW until an error minimum was found [18–20].

The radial basis function (RBF) is also a feed-forward network and consists of 3 layers [21]. It represents an alternative to ANN and provides several advantages over the MLP [22, 23]. The RBF simulates a function by using a network of Gaussian functions in the hidden layer and linear activation functions in the output layer. The Gaussian function is shown below:

Gaussian function:

\[ f(x) = e^{-\frac{x^2}{2\sigma^2}} , \]

where \( x \) represents the weighted sum of inputs, \( \sigma \) is the sphere of influence or width of the basis function, and \( f(x) \) is the corresponding output from neurons.

The RBF involves the basis functions, which use an algorithm to cluster data in the training set. It is a local-processing network in which the effect of a hidden unit is usually concentrated in a local area centered at the weight vector. It is different from the MLP, which are distributed-processing networks, in that the effect of a hidden unit can be distributed over the entire input space (as illustrated in Figure 1). Moreover, the RBF can be trained more rapidly than an equivalent MLP [24, 25].

**Regression Analysis Model.** Four nonlinear regression models were determined following those of Koenen and Groen [7], Rogers et al. [8], and Joneset et al. [26]. The models are shown below:

Cubic curvilinear:

\[ y = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 , \]

Logistic:

\[ y = \frac{\alpha}{1 + (\beta \times e^{-\gamma t})} , \]

Asymptotic exponential:

\[ y = \alpha[1 - (\beta \times e^{-\gamma t})] , \]

Gompertz:

\[ y = \alpha \times e \left[ -\log \left( \frac{\alpha}{\gamma} \right) \times e \left( -\beta t \right) \right] , \]

where \( y \) is the BW to age (t), \( \alpha \) is the asymptotic mature BW, \( \gamma \) is the rate of mature BW, and \( \beta \) is a rate constant. The cubic curvilinear, logistic, asymptotic exponential, and Gompertz nonlinear models were calculated using the NLIN procedure of the SAS statistical program [27].

The accuracy of each predictive model was determined [28] as follows: 1) by the regression coefficient squared (R\(^2\)), computed as

\[ R^2 = 1 - \frac{\text{SSE}}{\text{SST}} , \]

where SSE is the sum of squared errors, and SST is the sum of squares for treatments; 2) by the root mean square error (RMSE), computed as

\[ \text{RMSE} = \sqrt{\frac{\sum_{t=1}^{n} (y_t - \hat{y}_t)^2}{n}} , \]

where \( y_t \) is the observed value at time \( t \), \( \hat{y}_t \) is the estimated value, and \( n \) is the number of observations; 3) by the mean absolute deviation (MAD), computed as

\[ \text{MAD} = \frac{\sum_{t=1}^{n} |y_t - \hat{y}_t|}{n} , \]

where \( y_t \) is the observed value at time \( t \), \( \hat{y}_t \) is the estimated value, and \( n \) is the number of observations; and 4) by the mean absolute percentage error (MAPE), computed as

\[ \text{MAPE} = \frac{\sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right|}{n} \times 100 \quad (y_t \neq 0) , \]

where \( y_t \) is the observed value at time \( t \), \( \hat{y}_t \) is the estimated value, and \( n \) is the number of observations.

The growth curve obtained in this experiment is presented in Figure 2. A total of 1,590
individual BW observations, representing 30 ducks for each day from d 1 to 53 were used for training and validation. BackPropagation-3 of the ANN program, developed using C programming, was used in this research. The training was conducted with a 0.001 learning rate and 1,000 iterations. The data were randomized for validation during the training process to prevent overfitting. The predicted values were tested by using the actual average daily BW.

The training data statistics for the nonlinear regression analysis and ANN were determined by using $R^2$ and RMSE. The error measurements of the validation data, MAD, and MAPE were analyzed by ANOVA of SAS [27]. The differences between means of each error measurement were compared by Tukey’s studentized range test (honestly significant difference). A probability of $<0.05$ was taken to indicate significant differences. All statistical analyses were computed in accordance with the method of Steel and Torrie [29].

## RESULTS AND DISCUSSION

The statistical potential for the models is presented in Table 1. The RBF improved the $R^2$ and RMSE more than the cubic curvilinear, Gompertz, logistic, asymptotic exponential, and MLP models, respectively. The following equations were generated for each model:

- **Cubic curvilinear:**
  \[ y = 42.9680 + 0.5589t + 3.6070t^2 - 0.0454t^3, \]

- **Logistic:**
  \[ y = \frac{3.538}{1 + 26.4947 \exp^{-0.1205t}}. \]

- **Asymptotic exponential:**
  \[ y = 48038.4 \left( 1 - 1.0069 \exp^{-0.00164t} \right), \]  and

- **Gompertz:**
  \[ y = 4033.6 \exp \left( -\log \left( \frac{4033.6}{33.7250} \right) \exp (-0.0657t) \right). \]

Table 2 presents estimated duck BW using nonlinear regression analyses and ANN. The growth curve is shown in Figure 3. The Gompertz, RBF, and cubic curvilinear models were better fitted with the actual BW validation data.
However, the logistic, asymptotic exponential, and MLP models were significant different from the actual BW validation.

Error measurements were used to select the best fitting model. These were calculated from the absolute difference between actual and estimated values. The differences between means of each error measurement are illustrated in Figure 4. The MAD of the Gompertz, RBF, cubic curvilinear, and logistic models were not significantly different from each other ($P > 0.05$). Moreover, the MAD of the Gompertz, RBF, cubic curvilinear, and logistic models were significantly lower than those of the asymptotic exponential and MLP models, respectively ($P < 0.05$). The MAPE of the Gompertz, RBF, and cubic curvilinear models were significantly lower than that of the MLP model ($P < 0.05$) but were not significantly different from those of the logistic and asymptotic exponential models ($P > 0.05$).

### Table 1. Statistics from nonlinear regression analyses and artificial neural networks (ANN)$^1$

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Cubic curvilinear</th>
<th>Logistic</th>
<th>Asymptotic exponential</th>
<th>Gompertz</th>
<th>MLP</th>
<th>RBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.9786</td>
<td>0.9767</td>
<td>0.9669</td>
<td>0.9781</td>
<td>0.9750</td>
<td>0.9801</td>
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<tr>
<td>RMSE</td>
<td>172.825</td>
<td>180.0542</td>
<td>214.8425</td>
<td>174.4703</td>
<td>192.1120</td>
<td>171.4869</td>
</tr>
</tbody>
</table>

$^1$MLP = multilayer perceptrons; RBF = radial basis function; RMSE = root mean square error.

### Table 2. Estimated BW (g) and error measurements using nonlinear regression analyses and an artificial neural networks (ANN)$^1$

<table>
<thead>
<tr>
<th>Day</th>
<th>Actual BW</th>
<th>Logit</th>
<th>Cubic curvilinear</th>
<th>Asymptotic exponential</th>
<th>Gompertz</th>
<th>MLP</th>
<th>RBF</th>
</tr>
</thead>
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<tr>
<td>2</td>
<td>63.33</td>
<td>162.14</td>
<td>55.92</td>
<td>-173.07</td>
<td>60.78</td>
<td>147.44</td>
<td>55.48</td>
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<tr>
<td>4</td>
<td>99.87</td>
<td>203.78</td>
<td>95.54</td>
<td>-15.20</td>
<td>101.89</td>
<td>309.12</td>
<td>99.04</td>
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<tr>
<td>6</td>
<td>163.32</td>
<td>255.31</td>
<td>159.66</td>
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<td>457.31</td>
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<td>8</td>
<td>238.02</td>
<td>318.62</td>
<td>246.10</td>
<td>299.00</td>
<td>238.41</td>
<td>610.75</td>
<td>253.82</td>
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<td>310.62</td>
<td>395.74</td>
<td>352.68</td>
<td>455.33</td>
<td>337.74</td>
<td>762.96</td>
<td>358.33</td>
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<tr>
<td>12</td>
<td>467.52</td>
<td>488.69</td>
<td>477.22</td>
<td>611.15</td>
<td>458.36</td>
<td>913.79</td>
<td>478.38</td>
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<td>14</td>
<td>592.28</td>
<td>599.31</td>
<td>617.54</td>
<td>766.45</td>
<td>599.11</td>
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<td>728.98</td>
<td>771.46</td>
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</table>

$^1$MLP = multilayer perceptrons; RBF = radial basis function.
In addition, the MAPE of MLP was not significantly different from those of the logistic and asymptotic exponential models ($P > 0.05$).

Artificial neural networks are the appropriate function used to solve the complicated challenge of estimating growth. They can simulate the model by learning the data, and have the advantage that there is no requirement that the function be selected before calculating the equation [30], which is preferable to nonlinear regression analyses. There are several types of ANN that rely on the topology structure and a learning
process [25]. We suggest that the RBF was the best fit to estimate the growth curve because its error measurements were not different from those of the Gompertz and cubic curvilinear models. Although the MAPE of the logistic and asymptotic exponential models were not significantly different from that of the RBF, these models did not fit the actual BW data well and the asymptotic exponential was obviously the negative BW at hatching (see Figure 3). Moreover, the error measurements of the MLP were higher than those of the RBF because local processing of RBF gave a better fit with the actual BW than did the distributed processing of the MLP [24, 25].

Nevertheless, the MLP with the back-propagation algorithm could accurately predict BW better than nonlinear regression analyses [12, 13]. Yee et al. [11] reported that back-propagation and nonlinear regression analysis could produce adequate models to predict the BW of Sprague-Dawley rats. Additionally, Cravener and Roush [5] stated that back-propagation did not increase the statistical potential when compared with linear regression.

CONCLUSIONS AND APPLICATIONS

1. The RBF could be used for estimating the BW of Cherry Valley ducks. It also produced more accurate predictions than the MLP, but not compared with the Gompertz and cubic curvilinear functions.

2. The RBF is an alternative to MLP and nonlinear regression analyses for application in livestock.

REFERENCES AND NOTES


14. Cherry Valley, Rothwell, Lincolnshire, UK.


Acknowledgments

The authors express their sincere thanks to Sumitomo Chemical Co. Ltd. (Chuo-ku, Japan) for providing funding. We also appreciate the assistance of the staff of the Animal Research Farm, Department of Animal Science, Kasetsart University (Bangkok, Thailand).