The development and evaluation of a mathematical nutrition model to predict digestible energy intake of broodmares based on body condition changes

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ABSTRACT: Mathematical nutrition models have been developed for beef and dairy cattle to estimate dietary energy intake needed to change BCS. Similar technology has not been used to improve nutrition and feeding strategies for horses. An accurate equine nutrition model may enhance feeding management and reduce the costs of unnecessary overfeeding and promote an optimal level of fatness to achieve reproductive efficiency. The objectives of this study were to develop and evaluate a mathematical nutrition model capable of accurately predicting dietary energy changes to alter BW, rump fat (RF) thickness, and overall body fat (BF), which is needed to maximize profitability and productivity of mares. Model structure was similar to a previously developed model for cattle, and literature data for Quarter Horse mares were used to parameterize the horse model in predicting DE requirement associated with BCS changes. Evaluation of the horse model was performed using an independent dataset comprising 20 nonlactating Quarter Horse mares. Pretrial BCS was used to assign mares to 1 of 4 treatment groups and fed to alter BCS by 1 unit as follows: from 4 to 5 (Group 1), 5 to 4 (Group 2), 6 to 7 (Group 3), and 7 to 6 (Group 4). The BCS, RF thickness, and BW were measured for each mare before the commencement of the feeding trial and once per week thereafter for the duration of a 30-d feeding trial. Initial and target BCS, percent BF, and BW data were collected from each mare and inputted into the model. Mares were individually fed according to the DE suggestions proposed by the model to achieve the targeted BCS change within 30 d. The coefficient of determination of observed and model-predicted values (model precision) was 0.907 (P < 0.001) for BCS, 0.607 (P < 0.001) for percent BF, and 0.94 (P < 0.001) for BW. The BCS was highly correlated to percent BF (r = 0.808; P = 0.01). We concluded the reparameterized model was reliable to predict changes in BW and BCS, but more work is needed to improve the predictions of initial and final body composition.

Key words: body condition, body weight, broodmares, digestible energy, nutrition

INTRODUCTION

Mares have long gestation periods, leaving a short amount of time for rebreeding to produce a foal each year. It is imperative to ensure the mare enters the breeding season as healthy as possible to maximize her ability to conceive and carry a foal to term. Previous studies have documented that inadequate nutrition can result in reproductive inefficiency and overfeeding does not benefit reproductive performance in mares (Henneke et al., 1981; Henneke, 1984). Tools that can aid equine breeders in maintaining their broodmares at an optimum level of nutrition will be beneficial.

Many factors play a role in the amount of dietary energy required by an animal. In the cattle industry, mathematical nutrition models have been developed to estimate energy requirements, which maintain cattle at a desired body composition. Nutrition models have spurred development of decision support systems designed to assist producers in maintaining an efficient herd at the least cost possible (Tedeschi et al., 2004, 2005). Previously, a program has been created to calculate least cost ration formulation (Strasser et al., 1990), but no models or computer programs have been
developed for use in horses that use changes in body composition and energy intake. Currently, the BCS of a horse is subjectively increased or decreased by simply altering dietary intake. A more accurate assessment of dietary adjustment is warranted to alter and maintain BCS at a desired level in the horse.

The main objective of the current study was to parameterize a previously developed nutrition model for cattle to predict DE intake (DEI) needed to change BCS and composition in mares to a desired level. A second objective was to evaluate this model for precision with an independent dataset. The foremost goal was to provide a method more reliable than visual appraisal alone; therefore, mare owners will be able to precisely change body condition of mares.

**MATERIALS AND METHODS**

Use of animals for this study were approved by the Texas A&M University Institutional Agricultural Animal Care and Use Committee using guidelines set forth by FASS (2007).

**Model Development**

The model developed for the current research project is based on that published by Tedeschi et al. (2006), which is based on the beef NRC (2000) equations, with parameterization based on horse data. Selected data from a previous project (Cavinder et al., 2009) with 24 Quarter Horse mares were used in the parameterization and modification of Tedeschi et al. (2006) published model to predict DE requirements needed to alter BCS in mares. Measurements included BCS, BW, and rump fat (RF) thickness of gestating mares and were collected once every 2 wk over a 9-mo period (October 2003 to June 2004). Information on the body composition of horses is scarce. The most variable component of the body is fat whereas the fat-free matter (FFM) body composition remains relatively constant over the lifetime of an animal. Therefore, the first step was to determine the body composition on a FFM basis.

**Determination of Body Water Content.** Several methods have been developed to estimate body water (BWa) content in horses. The most commonly used method is based on isotope-indicator dilution techniques (Julian et al., 1955; Elser et al., 1983; Lawrence et al., 1986; Andrews et al., 1997; Forro et al., 2000). Isotope-indicator dilution techniques involve the estimation of BWa based on the elimination of the isotope after administration via a jugular artery. Another method used in the estimation of BWa content in horses is bioelectrical impedance analysis (Forro et al., 2000; Fielding et al., 2004). Bioelectrical impedance analysis technique sends small electrical currents through the body via electrodes placed at various anatomic areas of the horse. A bioimpedance analyzer, then, records the resistance and reactance at varying frequencies. The resistance to electricity varies between different types of tissues and their water content. Because water is a good conductor of electrical current, the greater the amount of water, the lesser the resistance will be; therefore, standard equations can be developed and used to assess BWa based on resistance. Several studies reported water content in equines along with the methodology as summarized in Table 1. The weighted average of total BWa for horses is 64.24% (Table 1), which is within the range (62 to 68%) provided by NRC (2007) for adult horses. This value was used in the reparameterization of the nutrition model for horses.

**Determination of Body Protein and Ash Contents.** Two studies have provided information on equine body protein (BP) and body ash (BA) contents. Kane et al. (1987) provided body fat (BF; 13.03%), BP (18.5%), and BWa (61.05%) as percentages of empty BW (EBW) after cadaver dissection and carcass evaluation of horses weighing 281 to 474 kg. Because no values for ash were provided, the amount of BA (7.42%) was calculated by difference (BA = 100 – 13.03 – 18.5 – 61.05). Similarly, Elser et al. (1983) performed cadaver dissection and carcass evaluation in ponies and concluded that protein and ash as a percent of EBW were 19.5 and 5.37%, respectively. The weighted average of the results from both studies indicated 19.1% of total BW was protein and 6.14% of total BW was ash, as shown in Table 2. These values were used in the development of the horse model.

Therefore, the amount of FFM was 89.5% of EBW (64.2 + 19.1 + 6.14). When expressed as a percentage of FFM, BWa, BP, and BA values were 71.8, 21.4, and 6.86%, respectively. These values were used in computing total BF and total BP to calculate total body energy.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Method1</th>
<th>n</th>
<th>Animal type2</th>
<th>TBW2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrews et al. (1997)</td>
<td>D2O</td>
<td>6</td>
<td>Mixed breeds</td>
<td>62.3 ± 2.2</td>
</tr>
<tr>
<td>Forro et al. (2000)</td>
<td>BIA and D2O</td>
<td>8</td>
<td>Horses4 and ponies</td>
<td>67.7 ± 2.2</td>
</tr>
<tr>
<td>Julian et al. (1955)</td>
<td>T2O</td>
<td>6</td>
<td>Horses3</td>
<td>63.8</td>
</tr>
<tr>
<td>Elser et al. (1983)</td>
<td>Ethanol dilution</td>
<td>10</td>
<td>Ponies</td>
<td>65.9 ± 1.1</td>
</tr>
<tr>
<td>Lawrence et al. (1986)</td>
<td>Urea dilution</td>
<td>10</td>
<td>Horses and ponies</td>
<td>58.5 ± 2.8</td>
</tr>
<tr>
<td>Deavers et al. (1973)</td>
<td>T2O</td>
<td>8</td>
<td>Ponies</td>
<td>67.7 ± 5.9</td>
</tr>
<tr>
<td>Avg.</td>
<td>48</td>
<td></td>
<td></td>
<td>64.3</td>
</tr>
<tr>
<td>Weighted avg.</td>
<td>48</td>
<td></td>
<td></td>
<td>64.2</td>
</tr>
</tbody>
</table>

1D2O = D2O dilution and T2O = T2O dilution. D2O = deuterium oxide dilution, T2O = tritium oxide dilution, BIA = bioelectrical-impedance analysis.

2TBW = Total body water as a percent of BW.

3Equine breed used in study.

4Standardbred, Thoroughbred, and Percheron.

5Thoroughbred, Quarter Horse, Arabian, and American Saddlebred.
**Determination of Body Fat Content.** Among BWa, BF, BP, and BA, BF is the composition compartment that has received the most attention in horses. Ultrasonic RF thickness was found to be highly correlated \( r = 0.85 \) with actual RF thickness (Westervelt et al., 1976). The relationship between ultrasonic measurements and total BF as developed by Westervelt et al. (1976) is modeled by Eq. [1] (Table 3).

Westervelt et al. (1976) concluded that ultrasonography is a reliable tool in the estimation of fat cover in horses and ponies and ultrasonic RF measurement can aid in the prediction of total BF. Kane et al. (1987) confirmed that RF thickness is related to total BF using real-time ultrasonography. However, Kane et al. (1987) determined variations in RF thickness exist and are dependent on ultrasound probe placement on the hip of the horse. The greatest deposits of fat were located 6 cm anterior to the tailhead approximately 10 cm off the midline and the least amount of fat was located near the top of the croup. It was concluded that a standardized location for sampling RF thickness must be implemented for estimating body condition; therefore, a consistent placement of the probe during each RF measurement in the current study was made by measuring 5.08 cm from the midline and 10.16 cm from the point of the hip.

**Body Weight Measurements and Adjustments.**

Shrunk BW (SBW) is equivalent to the BW of an animal after an overnight fast without feed or water and is typically estimated as 96% of full BW (FBW) by the beef NRC (2000). Shrunk BW is used to compute NEm requirements, which are measured as fasting heat production and used to determine the amount of NE available for growth in the diet and target SBW gain. The EBW is the FBW minus the weight of the ingesta and is typically computed as 89.1% of SBW or 85.5% of FBW in cattle (NRC, 2000). Both SBW and EBW are used to determine changes in BW that are associated with mobilization and repletion of body mass of the animal in support of physiological needs and status (growing, lactating, gestating, or dry). In dairy cattle (NRC, 2001), EBW has been used to develop the equations to predict the energy required for target ADG because NE requirements are a function of the proportion of fat and protein in the empty body tissue gain (NRC, 2001). The prediction of body reserves in dairy is obtained using Eq. [2] and [3] (Table 3).

For mature lactating dairy cows, a change in BW does not always necessarily indicate changes in tissue reserves and vice versa (Tedeschi et al., 2006). As much as 40% variation in energy with no change in BW has been reported in dairy cows. Because of the inconsistency between actual changes in BW and energy reserves, the reparameterized nutrition model used actual FBW to compute EBW using Eq. [2] and [3] (Table 3).

**Predicting Changes in BW.** The information on FBW is not always available under practical conditions. Therefore, changes in BW associated with changes in BCS were used to assess changes in tissue reserves. The individual mare data collected by Cavinder et al. (2009) was used to describe the relationship between BCS and percentage of empty BF, EBW, and actual BW. Regression between BCS and EBW indicated that the mean EBW change associated with a BCS change was equivalent to 3.88% of the mean BW. This is approximately 56.6% of the value reported for dairy cattle (Tedeschi et al., 2006). Hence, a BW adjustment factor (WAF), similar to that developed by Tedeschi et al. (2006), was computed from the BCS to compute an adjusted EBW (aEBW) associated with changes in BCS (Eq. [4] and [5]; Table 3).

The initial EBW to estimate the initial WAF ratio (Eq. [5]; Table 3) computes the expected BW at BCS 5. The aEBW for each period assesses the variation in tissue energy from that, which would be provided by an animal at a BCS of 5.

**Table 3. Equations used in the formulation of the mathematical nutrition model to predict DE intake of broodmares based on body condition changes.**

<table>
<thead>
<tr>
<th>Equation number</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( Y = 8.64 + 4.70 \times X )</td>
</tr>
<tr>
<td>2</td>
<td>SBW = FBW \times 0.96</td>
</tr>
<tr>
<td>3</td>
<td>EBW = SBW \times 0.851</td>
</tr>
<tr>
<td>4</td>
<td>WAF = 1 - 0.0388 \times (5 - BCS [1-9])</td>
</tr>
<tr>
<td>5</td>
<td>aEBW = \text{initial EBW} \times \text{WAF/initial WAF}</td>
</tr>
<tr>
<td>6</td>
<td>TE = (9.367 \times TF) + (5.554 \times TP)</td>
</tr>
<tr>
<td>7</td>
<td>TF = aEBW \times BF</td>
</tr>
<tr>
<td>8</td>
<td>TP = aEBW \times BP</td>
</tr>
<tr>
<td>9</td>
<td>\Delta TEi = TEi - \text{TEi-1}; i \geq 2</td>
</tr>
<tr>
<td>10</td>
<td>\Delta TE &lt; 0, then \Delta ME = (\Delta TE \times 0.84)/0.644</td>
</tr>
<tr>
<td>11</td>
<td>\Delta TE &gt; 0, then \Delta ME = \Delta TE/0.726</td>
</tr>
<tr>
<td>12</td>
<td>\Delta DE = \Delta ME/0.85</td>
</tr>
<tr>
<td>13</td>
<td>\Delta DMI = \Delta DE/\Delta ME</td>
</tr>
</tbody>
</table>

1TBP = total body protein as a percent of BW, and TBA = total body ash as a percent of BW.
Total Energy Determination. Total body energy (TE; Mcal) is computed by multiplying the amount of BF and the amount of BP by their respective heat of combustion. Heat of combustion of fat in growing animals has been estimated at 9.367 Mcal/kg whereas the heat of combustion of protein has been found to vary from 5.554 to 5.686 Mcal/kg (Blaxter and Rook, 1953). The growing animal heat of combustion values of 9.376 Mcal/kg for fat and 5.554 Mcal/kg for protein have been adopted by the beef NRC (2000). These values were used in the development of the horse model as no values have been developed specifically for horses to date. The TE is computed as shown in Eq. [6] to [8] (Table 3).

Changes in TE (ATE) within a period are assessed by computing the TE of consecutive periods as shown in Eq. [9] (Table 3). Although the TE at the first time period remains constant, the TE of the subsequent period is computed by using Eq. [9] (Table 3).

A negative energy balance (ATE value is negative) occurs when the intake of energy is less than the energy required for reproductive and productive purposes and leads to a mobilization of reserve energy. On the other hand, in a positive energy balance (when the ATE value is positive), the intake of energy is greater than the energy intake required for reproduction and production, which leads to an addition to the energy reserves that is available for later mobilization.

Efficiency of Energy Use. Moe et al. (1970) used a multiple regression analysis of data from 126 lactating dairy cows in a negative energy balance and 224 lactating dairy cows in a positive energy balance. They reported an 84% efficiency in the conversion of NE to NEl, a 64.4% efficiency in the conversion of ME to NEl, and a 72.6% efficiency in the conversion of ME to NE available for reserves (NEr). At present, efficiency of use of dietary energy for milk production is difficult to determine accurately in horses. Differences in attempts to compute such efficiencies have been caused either by differences in the value chosen for efficiency of use or by differences in the estimation of milk energy output in horses. In the late 1970s, scientists in Norway and the United States estimated efficiency of use to be 60% (Nedkvitne, 1976; NRC, 1978) whereas in France efficiency was estimated to be 66% (Meyer, 1979). These comparisons show that there are only small differences in lactating energy requirements formulated in different countries and are similar to the efficiencies derived for dairy cattle (Doreau et al., 1988). In addition, similar studies conducted around the same time in the United Kingdom estimated efficiency in the use of ME for DE to be 85% (Abrams, 1984). Because scarce information is presently available for horses, the coefficients of energy interconversion proposed by Tedeschi et al. (2006) were used to compute ME from NE and the 85% was used to compute DE from ME.

A negative energy balance (ATE < 0) in lactating mare indicates energy reserves are being used for milk production. As noted before, there is an 84% efficiency in the mobilization of NEr into NEl and a 64.4% efficiency in ME use for lactation, and the amount of ME available from the mobilization of reserves is computed using Eq. [10] (Table 3). On the other hand, a positive energy balance (ATE > 0) indicates that the intake energy exceeds the energy requirements, and therefore, the dietary energy is deposited for reserves rather than milk production. As stated before, a 72.6% efficiency of ME use for to NEr is assumed. The calculated amount of milk from a lactating animal in a positive energy balance is shown in Eq. [11] (Table 3). When the animal is not lactating, a 60% efficiency of ME use for NEr is assumed.

The ATE is variation in total tissue energy (Mcal NE/d), and ΔME is variation in ME (Mcal/d).

Then DE is computed assuming an efficiency of 85% as shown in Eq. [12] (Table 3), and the change in DMI (ADMI) is computed based on the dietary DE content as shown in Eq. [13] (Table 3). If ADMI is positive, then additional amounts of the diet have to be consumed; if the ADMI is negative, then this amount of diet would have to be withdrawn to obtain the desired BCS.

Model Application

An independent dataset was used to evaluate the developed horse model. Nonlactating Quarter Horse mares (n = 20; 4 to 18 yr of age; mean = 7 yr) with initial BW ranging from 376 to 553 kg (mean = 458 kg) and initial BCS of 3.5 to 7 were used in the model evaluation. Mares were individually housed (3.6 by 4.3 m stalls) at the Texas A&M University Equestrian Center. Individual housing of each mare was needed to precisely manage DEI throughout the study, but all mares were rotated to individual turn out pens every other day to provide free exercise. A 1-wk acclimation period was used to allow mare adaptation to the housing environment and all mares were treated with a dose of anthelmintic (Equimectrin Oral Paste, 1.87%; Merial Limited, Duluth, GA), before the start of the study.

The BCS, RF thickness, and BW values were obtained for each mare once before the commencement of the feeding trial and once per week thereafter for the duration of a 30-d feeding trial. The BCS were obtained for each mare by 3 experienced, independent appraisers and then averaged together to determine the BCS of each mare. It was assessed using the equine BCS system established by Henneke et al. (1983) with a 9-point scale including quarter-point increments. Each judge conducted scoring of BCS independently but
concurrently with the other judges, so all horses were scored at the same time of the day. Each of the 6 body areas (neck, withers, shoulders, ribs, loin, and tailhead) was assessed using both physical palpation and visual appraisal to evaluate the amount of fat present.

The RF thickness measurements were gathered via ultrasonic scanning equipment with a 5 MHz transducer (MicroMaxx Ultrasound System; SonoSite, Inc., Bothell, WA). Rump scanning site was determined by measuring 5.08 cm from the midline and 10.16 cm from the point of the hip. Body fat content was then calculated using an equation previously published (Westervelt et al., 1976). Measurement points were consistent from week to week via pictures of RF measurement site produced by ultrasound at each sampling time. Mares were individually weighed on a livestock weighbridge scale (Paul Livestock Scale; Adrian J. Paul Co., Inc., Duncan, OK) to determine BW.

**Treatments.** Pretrial BCS was used to assign mares to 1 of 4 treatment groups and fed to alter BCS by 1 unit as follows: from 4 to 5 (Group 1), 5 to 4 (Group 2), 6 to 7 (Group 3), and 7 to 6 (Group 4). After initial scoring, the data for each mare was placed into the model. Mares were then fed according to the reparameterized model predictions.

**Diet.** Hay samples were obtained randomly by core sampling and concentrate samples were obtained by random grab sampling. Hay samples were submitted for nutrient analysis to a commercial laboratory (Soil, Water, and Forage Testing Laboratory, Texas A&M University, College Station, TX). Each mare was individually fed forage and concentrate twice per day, 12 h apart in individual stalls outfitted with hay and grain combined stall feeders. Forage was offered first with the concentrate being offered immediately afterward. Forage consisted of Coastal Bermudagrass hay (95.3% DM, 9.7% CP, 36.3% ADF, 65.9% NDF, 57.1% estimated TDN, 0.18% P, 0.4% Ca, 1.3% K, 0.2% Mg, 82 mg/kg Na, 23 mg/kg Zn, 161 mg/kg Fe, 89 mg/kg Cu, and 105 mg/kg Mn) and concentrate consisted of a commercially pelleted horse feed (Brazos County Producer’s Co-Operative Association, Bryan, TX; 12.0% CP, 10.0% crude fiber, 2.9% fat, 0.7% Ca, 0.5% P, 32.5 mg/kg Cu, 115.1 mg/kg Zn, 0.4 mg/kg Se, and 4,586 IU vitamin A/kg). Clean water was available ad libitum. During the 1-wk adaptation period, mares were fed 70 to 30 forage to concentrate intake ratio (2.5% of BW) in an attempt to maintain a constant energy status during the pretrial period. Any refusals were collected daily after each feeding, weighed, and recorded. Initial and target BCS, percent BF, and BW data collected from each mare were inputted into the reparameterized nutrition model. Feeding regimen was manipulated so that mares were individually fed according to the DE predicted by the horse model to achieve the designed gain or loss of 1 BCS within a 30-d period depending on the treatment protocol. The proposed DEI values were calculated to maintain the 70 to 30 forage to concentrate intake ratio.

**Model Evaluation and Statistical Analyses**

Final BCS, BF, and BW values were compared with the model-predicted values to assess the reparameterized nutrition model adequacy. The model adequacy was assessed using several statistics as discussed by Tedeschi (2006) and it was obtained with the model evaluation system (http://nutritionmodels.tamu.edu). Briefly, the $r^2$ was used to determine the model precision, which represents the proportion of variability in a given data set. Maximum error (MAE) statistic represents the maximum amount, by which the observed values differ from the model-predicted values. Mean bias (MB) is based on the mean deviance between the observed and model-predicted values (Cochran and Cox, 1957). A positive MB statistic indicates the model underpredicted the final values whereas a negative MB statistic means the model overpredicted the final values. Accuracy is a measure of how closely model-predicted values are to the observed values (Tedeschi, 2006). It was assessed via the mean square error of prediction (Bibby and Toutenburg, 1977). All regression and correlation analyses were performed with SPSS (SPSS, Inc., Chicago, IL).

**RESULTS**

The exact DE increase in for the mares in Group 1 ranged from 4.95 to 7.63 Mcal DE/d with an average of 6.41 Mcal DE/d to improve 1 BCS (BCS 4 to 5). For mares in Group 2, a range of 2.37 to 4.23 Mcal DE/d was subtracted from the diet with an average decrease of 3.0 Mcal DE/d in dietary intake for a mare to decrease 1 BCS (5 to 4). Mares in Group 3 that were fed to increase BCS from a 6 to 7 required an average of a 6.91 Mcal DE/d increase. The range was 2.37 to 4.23 Mcal DE/d. Conversely, an average decrease of 5.36 Mcal DE/d was needed for mares in Group 4 to go from BCS 7 to 6. The range was 3.33 to 6.94 Mcal DE/d decrease. The model adequacy statistics are shown in Table 4.

**Evaluating BCS.** Final observed BCS values were compared with the final BCS values predicted by the model. Mare data points ($n = 20$) were used for the evaluation of the predictability of the model in regards to BCS and resulted in an $r^2$ of 0.907 ($P < 0.001$) with a MAE of 0.5. This means the model accounted for 90.7% of the observed BCS variation, with a maximum BCS variation of 0.5 of a BCS between final observed and model-predicted values. Figure 1 shows the scatterplot
of the final observed BCS values vs. the final model-predicted values.

**Evaluating Body Fat.** The ability of the model to predict changes in BF was analyzed and the observed final BF values were compared with the model-predicted final BF values for all mares \((n = 20)\). This resulted in an \(r^2\) of 0.607 \((P < 0.001)\) with a MAE of 2.96% BF units. A scatterplot of the observed final BF values vs. the model-predicted final BF values is depicted in Fig. 2.

**Evaluating BW.** The BW evaluations were conducted using EBW values. Figure 3 depicts a scatterplot of the observed final EBW values vs. the model-predicted final EBW values on the \(y = x\) line. The \(r^2\) value was 0.94 \((P < 0.001)\) with a MAE of 31.9 kg of BW.

Correlation analyses were completed to determine the strength of correlation between BCS and BF, specifically the expected percent change in BF per 1 BCS change. Two sets of data were analyzed: initial BCS/percent BF and final BCS/percent BF. If a strong correlation between BCS and percent BF exists, then in theory, both sets of data should reveal similar results. The initial set of data resulted in a Pearson correlation of 0.808 whereas the final set of data had an \(r\) of 0.788 and both correlations were statistically significant \((P = 0.01)\). Although both correlation statistics are less than 2.5% different, the mean correlation was calculated to be 0.798. It indicates that for every change in 1 BCS (either increasing or decreasing), a change in the same direction of 1.054% units of BF can be expected.

### DISCUSSION

**Model Development**

**Body Composition.** Coefficients of variation are normally greater than 16% for BF but only 6% for BWa and BP (Lohman, 1971). The relative consistency in FFM body composition has spurred research in the estimation of whole-body composition through indirect methods (Lohman, 1971). Variability in BF content has been correlated to both genetics and environmental factors and such differences among breeds, planes of nutrition, age, gender, and type of diet affect fat deposition in every horse (Lohman, 1971; Kearns et al., 2002). The majority of variation in FFM body composition takes place in the early years of life of the animal. During development, decreases in BWa and increases in BP and BA occur simultaneously until a plateau is reached, after which point the fat-free body composition remains relatively constant for the duration of the life of the animal (Lohman, 1971). This concept of “chemical maturity” was first defined by Moulton (1923, p. 80) as “the point at which the concentration of water, proteins, and salts becomes comparatively constant in the fat-free cell.” Moulton (1923) estimated the point of chemical maturity to be about 4.5% of total life expectancy. Therefore, although different animals reach chemical maturity at different ages, the ages are relative to a part of the total life cycle (Moulton, 1923). Because the reparameterized

![Figure 1. Linear regression between observed and model-predicted BCS \((r^2 = 0.907; P < 0.001)\).](image1)

![Figure 2. Linear regression between observed and model-predicted body fat (BF; \(r^2 = 0.607; P < 0.001)\).](image2)

![Figure 3. Linear regression between observed and model-predicted BW \((r^2 = 0.94; P < 0.001)\).](image3)
nutrition model for horse depends on accurate estimates of body composition and the prediction of BF was devised from a linear relationship between RF and BF (Eq. [1]; Table 3), further studies should focus on the improvement of these measurements. New techniques have been used in cattle (Ribeiro et al., 2008, 2011) and their use in horses has not been tested yet.

**Energy System.** The horse is a nonruminant herbivore naturally apt to digesting diets high in fiber via microbial fermentation. The need for better formulation of diets in horses has led to an increasing interest in the research of energy partitioning within the equine body. Energy systems have been developed to define and quantify the energy content of feeds and the energy use in the horse. The energy system for cattle is based on the NE system (NRC, 2000, 2001) whereas the energy system for horse is based on the DE system (NRC, 2007). The model conceptualized by Tedeschi et al. (2006) was based on the NE system and Eq. [10] to [13] were used to convert it back to DE basis. It was possible that these interconversions may have added uncertainties to the predictions as shown by the relatively low precision in predicting BF.

Nutrient supply of feeds of similar DE varies depending on its chemical composition (for example, starch vs. cell wall carbohydrates) and varies depending on the site and type of digestion (for example, enzymatic digestion in the small intestine vs. fermentation in the large intestine). Therefore, it has been noted the DE system overestimates the DE value of forages and protein-rich feeds whereas it underestimates the DE value of starch-rich feeds (Vermorel and Martin-Rosset, 1997). Such discrepancies led to the development of a NE system. Although the DE system of estimating energy content is based on digestibility as the discriminating factor between feeds, the NE system is based on the ability to use the end product, as it takes into consideration the energy costs of mastication, movement of ingesta through the digestive tract, and heat of fermentation (Cuddeford, 2004). The NE system has the potential to predict energy content and requirements more accurately; however, it requires more information and, therefore, is more complicated than the DE system (NRC, 2007). The NE system for horses was not initiated until the early 1980s in France. The French system (Vermorel et al., 1984) is the most developed NE system for horses to date. Also known as the Unite Fourragere Cheval (UFC) system, it relates NE requirements to a standard horse feed unit derived from the NE value of 1 kg of barley (1 UFC = NE of 1 kg barley). Although Hintz and Cymbaluk (1994) found the calculated amount of feed required by broodmares as estimated by the French NE system was similar to that estimated by the DE system, others found that DE requirements exceeded the NE requirements by 19% (Martin-Rossett and Vermorel, 2004). Because the DE system is more widely accepted, it was the basis of unit of caloric intake in our work.

**Model Relevancy**

Results suggested the predictability of the current horse model was most precise in predicting BW and then BCS, with the least predictable measurement being percent BF; however, percent BF still provides an \( r^2 \) of approximately 0.61. It was hypothesized that final percent BF values would be difficult to predict because BF deposition and metabolism trends vary per individual animal and rely heavily on genetics. However, it should be noted that the observed final percent BF values of all mares finished with less than a 20% variation from the model-predicted values. Almost half of the observed final percent BF values of the mares (\( n = 9 \)) varied less than 10% from the model-predicted values, and the observed final percent BF values of 5 mares varied less than 5% from model predicted values.

In regards to BCS, all mares finished the model application period at a BCS that was at least 90% of the final model-predicted BCS. A larger amount of DE is needed to increase BCS above, as opposed to below, 5 perhaps because mares in a BCS below 5 are receiving less than 100% of the maintenance requirements for DE and any increase in DE, no matter how small, can greatly enhance the nutrition status for that animal as opposed to an animal that is already at an acceptable state of nutrition.

In regards to BW, the observed final EBW values of all mares veered no more than approximately 32 kg from the model-predicted final values. Thirty-two kilograms accounts for an 8% difference from model-predicted values. Eighteen mares had observed final values with less than a 5% difference (<17 kg), 16 mares had less than 3% difference (<12 kg), 12 mares had less than 2% difference (<6 kg), and 7 mares had less than 1% difference (<3 kg) from predicted final values. Therefore, of the data inputted into the model, 90% of mares inputted into the model will end with observed final values that differed by no more than 5% from the model-predicted final values in regards to BW.

**Model Application**

We believe the developed model is more accurate and reliable than visual appraisal alone and can be used by any horse owner, breeder, trainer, equine nutrition specialist, or farm owner seeking to maximize profitability and production. This model can enhance animal feeding systems and provide insight on nutrition status of the animal, providing a much needed tool for the
equine industry. The economic benefit the mare owner will gain from more precise feeding regimens will lead to greater profit and business potential. The developed model will also provide a foundation on which to build more complex equine models in the future, including models tailored to growing or working horses, lactating broodmares, breeding stallions, geriatric horses, and others. This model can also be used by rescue facilities to calculate more precise costs of feeding abused and malnourished horses in hopes of being able to house a larger number of animals. Along with the economic benefits possible with the use of the developed model, other benefits to the equine industry include the ability to minimize the amount of resources (such as trained personnel and equipment) spent on a mare not yet at an optimum state for reproduction.

In conclusion, knowledge of equine body composition, intake, and digestion can be used to develop accurate mathematical nutrition models that can aid in estimating nutrient requirements. This study developed a computer model to predict DE needed to support changes in BCS but it is important to point out that the program was tested using midrange BCS (BCS 4 to 7). The current approach is novel in idea but further development and testing is needed. Further research should focus on a sensitivity analysis of the coefficients assumed for efficiency of use of NE (including efficiencies used by swine), the relationship between changes of BCS and EBW, and the relationships among BCS, BF, and RF. This computer model may enhance equine feeding systems, concomitantly reducing the costs of unnecessary overfeeding and maintaining broodmares at an optimum level of reproductive efficiency.

LITERATURE CITED
