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ACCURACY AND RELIABILITY OF TWO BODY WEIGHT ESTIMATORS BASED ON LINEAR MEASUREMENTS IN HORSES

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Abstract

Estimation methods are routinely used to determine the body weight of a horse when a scale is not available. However, it is important to evaluate the accuracy and reliability of these predictions since nutritional management and drug dosage, among others, require knowledge of the animal's weight. The objective of this study was to evaluate the accuracy and reliability of estimated weights of horses using two prediction models, and to discuss the effect of the predictions on animal management. Seventy-one adult male animals (40 mules and 31 horses) were weighed on a precision scale (control weight). Chest circumference and body length were measured and used to estimate body weight using the two models. Accuracy was evaluated by analysis of fit indices, comparison of squared prediction errors, delta Akaike's information criterion, and decomposition of the mean squared error of prediction. For economic evaluation, three production scenarios were established: simple (worming + forage), traditional (worming + forage + concentrate mixture), and traditional with supplementation (worming + forage + concentrate mixture + supplementation). Economic values were collected through a pricing survey carried out in the Midwest region of Brazil and converted to US dollars. Percent differences in costs were evaluated using Fisher's exact test. The most suitable model for the morphometric profile of the animals was that using a combination of chest circumference and body length. The differences in economic values between production scenarios were significant ($P<0.05$). Losses using the inadequate model are 10% higher compared to control; thus, in a facility with 20 equids that uses this model, the losses are ≈ US$ 10,000/year. When investment in a scale is not possible, it is fundamental to evaluate which model is more compatible with the body biotype of the herd since all types of management that depend on the body weight of the animals may result in significant economic losses.

Key words Economic evaluation, zootechnical control, management, linear measures, body weight

ACURÁCIA E CONFIABILIDADE DE DOIS ESTIMADORES DE PESO CORPORAL BASEADOS EM MENSURAÇÕES LINEARES EM EQUÍDEOS

Resumo

Estimativas para determinar o peso corporal de um equino são rotineiramente usadas quando uma balança não está disponível. Todavia, é fundamental realizar um diagnóstico da acurácia e confiabilidade das predições destes estimadores, pois o manejo nutricional, dosificação de fármacos, entre outros, exigem o conhecimento do peso. Assim, objetivou-se avaliar a acurácia e confiabilidade de predições de peso estimado de equídeos utilizando dois modelos de cálculos e discutir o reflexo das predições no manejo dos animais. Foram pesados 71 equídeos machos (40 Muares e 31 Equinos) com idade adulta, em balança de precisão (peso controle). Medidas de perímetro torácico e comprimento corporal foram realizadas e utilizadas para estimar o peso corporal usando os modelos. A acurácia foi avaliada via análise do índice de adequação, comparação entre o quadrado do erro de predição, critério de informação Delta Akaike's e decomposição do erro quadrático médio da predição. Para avaliação econômica, criaram-se três cenários de produção: simples (vermifugação + volumoso), tradicional (vermifugação + volumoso + concentrado) e tradicional com suplementação (vermifugação + volumoso + concentrado + suplementação). Valores econômicos foram verificados em pesquisa de preço na região Centro Oeste do Brasil e convertidos em dólar. Avaliou-se as diferenças de percentagem dos custos utilizando teste de Fisher. O modelo mais adequado para o perfil morfométrico dos animais foi o que usa combinação entre perímetro torácico e comprimento corporal. Foram significativas ($P<0,05$) as diferenças para os valores econômicos nos cenários de produção. Prejuízos usando o modelo inadequado são 10% superiores em relação ao controle, assim em um estabelecimento com 20 equídeos que usa este modelo, os prejuízos são ≈ 10 mil dólares/ano. Na ausência da balança, é fundamental avaliar qual modelo de cálculo será mais compatível com biotipo corporal do rebanho, pois todo tipo de manejo que depende do peso corporal dos animais, pode gerar prejuízos econômicos significativos.

Palavras-chave avaliação econômica, controle zootécnico, manejos, medidas lineares, peso corporal

INTRODUCTION

In Brazil, equid farming is an important segment of agribusiness. This activity is not only related to commercial livestock, but also has a strong interrelationship with sectors linked to leisure, culture, sport, and ecotourism. According to the Food and Agriculture Organization (FAO, 2016), Brazil has the fourth largest population of horses in the world.

According to estimates of the Brazilian Institute of Geography and Statistics (2016), the country has 5,577,539 horses. Furthermore, according to the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA, 2016), this livestock sector accounts for R$ 16.15 billion in transactions every year and generates 610,000 direct jobs and 2,430,000 indirect jobs, thus being responsible for more than 3 million jobs. These numbers possibly reflect the high investment made in the sectors of breed selection and genetic improvement, nutritional management and medical segments, as well as in the training of professionals and trainers. However, despite these expressive values, research in this sector is limited, especially that related to economic aspects.

Knowledge of body weight is extremely important for the rearing and management of horses. Factors such as nutritional management, drug dosage, identification of skills, and the determination of animal growth and development can affect decision-making and the economic revenue of the breeding facility. However, not all equestrian facilities have a precision scale to correctly measure weight and weight estimators have therefore been developed. Within this context, it is important to evaluate the accuracy and reliability of estimated weights obtained with prediction models, mainly because they were developed based on the body morphometry of a given group of animals. Furthermore, these models may not be suitable for application to other body profiles (other groups). In general, the results allow us to define the best model, reducing errors and increasing accuracy and, consequently, the efficiency of animal management.

Ensminger (1977) proposed measurement of the animal's chest circumference as a model to estimate weights. On the other hand, Carroll and Huntington (1988) developed a model that includes measurements of chest circumference and body length. The use of a model based on the animal's morphometric measurements may provide satisfactory results for the development body weight equations (Martinson et al., 2014). However, according to Heinrichs et al. (1992), breed, age, body condition and physiological state of the animal can influence the regression of body weight on body measurements and the prediction accuracy, suggesting adaptation of the prediction equations according to each class.

Several studies have been conducted to establish the accuracy of different methods (MILNER and HEWITT, 1969; WAGNER and TYLER, 2011; Hoffmann et al., 2013). However, the results are usually contradictory. Some studies in the literature have also used weight estimators based on the body morphometry (REZENDE et al., 2015; SOUZA et al., 2015) of equids and researchers may reach a wrong conclusion if they have not tested the most suitable model for the body biotype of the animals present in the dataset.

Within this context, despite decades of research, it is still uncertain which are the most accurate methods and what is the economic impact that the misuse of weight estimators can have on breeding facilities. Therefore, the objective of this study was to evaluate the accuracy and reliability of estimated weights of equids (*Equus caballus* and *Equus asinus*) using two prediction models based on linear measurements, and to discuss the impact of these predictions on animal management and system profitability.

MATERIAL AND METHODS

Data from 71 adult mongrel male animals (40 mules and 31 horses) were evaluated in collaboration with a horse breeding facility located in the State of Mato Grosso do Sul (Brazil). All animals were weighed on a mechanical precision scale and this result was considered the control weight. The chest circumference was measured with a measuring tape and hypometer: the measuring tape was positioned just at the end of the withers between the T8 and T9 spinous processes, passing through the intercostal space of the 8th and 9th ribs to the joint of the last rib with the xiphoid process. Body length was measured as the distance between the cranial part of the greater tubercle of the humerus and the caudal part of the ischial tuberosity (REZENDE et al., 2015). The body weight of the animal was then estimated from these measurements using two models. Model 1, according to Ensminger (1977), consisted of cubic chest circumference multiplied by 80. For model 2 proposed by Carroll and Huntington (1988), the following formula was used: squared chest circumference multiplied by body length and the result divided by 11877.

The following fit indices were used to evaluate the accuracy of the weight predictions: coefficient of determination of a linear regression Y on X; mean squared error of prediction (MSEP); mean deviation; model efficiency factor (MEF); coefficient of determination of the model (CDM); model accuracy; concordance correlation coefficient (CCC), and corrected Akaike's information criterion (AIC). The squared error of prediction of the models was also compared at a level of significance of 5% (P<0.05) by the t-test (WALLACH and GOFFINET, 1989). In addition, the delta AIC (DACI) (BURNHAM and ANDERSON, 2002), behavior of the predicted data in relation to the observed (NETER et al., 1996) and, finally, decomposition of MSEP (BIBBY and TOUTENBURG, 1977) were evaluated. The models were evaluated separately for mules and horses and general comparison was performed considering both models. It is thus possible to identify the most suitable model in relation to the control weight for horses and for mules. All analyses were performed using the SAS software (2018).

Additionally, to investigate the impact of errors in weight estimation on animal management, the average cost of a commercial maintenance ration (containing approximately 10-12% crude protein, 1.5% calcium and 0.8% phosphorus), mineral supplement, bale of hay (Tifton), and deworming drug (ivermectin) was obtained. The diet was based on horses performing moderate work: 3 to 6 hours per day of walking, trotting, and cantering (Table 1). Hay 2.5% of weight; ration 2.0 kg per 100 kg weight; supplement 75 g animal/day (500 kg). The values in the table were adjusted to 10 kg/ animal.

Table 1 – Description of inputs used as a basis in animal management and their respective costs.

Product**	EMV	Quantity	V/kg	MI/10kg	VR	VAR	D/A *
				Health			
Dewormer	9.00	1-600.00 kg	0.01	-	0.15 bim	0.90	0.23
				Nutritional			
Hay	58.00	25.00 kg	2.32	7.50	6.75 mon	81.00	21.03
Ration	62.00	25.00 kg	2.48	6.00	14.88 mon	178.56	46.38
Supplement	168.00	25.00 kg	6.72	0.05	0.38 mon	4.59	1.19

EMV: estimated market value; V/kg: kg value; MI/10kg: monthly intake per 10 kg of weight; VR: value in reais; VAR: annual value in reais; D/A: annual value in dollar; bim: bi-monthly; mon: monthly.
*Exchange rate on 28/07/2019. US$ 1.00 = R$ 3.85. Source: BMeF Bovespa.
** Average value of products collected through a pricing survey carried out in virtual and agricultural stores located in the Midwest and Southern regions of Brazil.

Three scenarios were preestablished:

I - worming + forage [simple system]

II - worming + forage + concentrate mixture [traditional system]

III - worming + forage + concentrate mixture + supplementation [traditional system with supplementation]

The three scenarios were compared between control weight, model 1 (ENSMINGER, 1977) and model 2 (CARROLL and HUNTINGTON, 1988). Based on the average value of the two models and the control weight, an estimate was obtained by simulating annual expenditure converted into dollars among scenarios using the following equations:

(((weight/10) x bi-monthly value dewormer) x 6)/3.85

(((weight/10) x monthly value forage intake) x 12)/3.85

(((weight/10) x monthly value concentrate) x 12)/3.85

(((weight/10) x monthly value supplementation) x 12)/3.85

Subsequently, the equation was applied according to the order of the scenarios: I = worming + forage; II = worming + forage + concentrate, and III = worming + forage + concentrate + supplementation. Differences between models and the control weight were transformed into percentages. Finally, the hypothesis of equality by contrast was tested for percent differences in economic costs per scenario between the two models and the control weight using Fisher's exact test, based on the following contrasts:

[1] Simple system - model proposed by Ensminger (1977) *vs* simple system – model proposed by Carroll and Huntington (1988).

[2] Traditional system – model proposed by Ensminger (1977) *vs* traditional system – model proposed by Carroll and Huntington (1988).

[3] Traditional system with supplementation – model proposed by Ensminger (1977) *vs* traditional system with supplementation – model proposed by Carroll and Huntington (1988).

RESULTS AND DISCUSSION

The results showed that the weights predicted with the model proposed by Carroll and Huntington (1988) were similar to the control weight (Table 2). These results corroborate those of the fit indices (Table 3). The morphometric profile of the animals is more compatible with the model that combines circumference and body

Table 2 – Descriptive analysis of the behavior of predicted data in relation to observed.

	Mule			Horse		
	Model 1	Model 2	Control	Model 1	Model 2	Control
	Predicted	Predicted	Observed	Predicted	Predicted	Observed
Minimum	321.57	285.74	311.00	400.02	361.21	350.37
Maximum	602.36	464.87	468.00	540.10	474.28	353.00
Mean	446.03	376.10	362.73	449.47	402.70	408.55
Median	451.18	390.42	357.00	443.62	402.80	414.00
Variance	3985.70	1750.36	1400.98	2354.67	1056.47	1062.52
Standard deviation	63.13	41.83	37.42	48.52	32.50	32.59
Asymmetry	0.30	-0.31	0.88	0.28	0.86	-.055
Kurtosis	3.26	2.89	3.90	1.37	2.99	1.94
X – Y mean	83.30	13.36	--	50.91	-5.84	--
Covariance	1212.64	1048.18	--	1037.11	623.17	--

	Comparison general model (mules and horses)		
	Model 1	Model 2	Control
	Predicted	Predicted	Observed
Minimum	321.57	285.74	311.00
Maximum	602.36	474.28	468.00
Mean	450.35	384.65	377.46
Median	451.18	391.16	372.50
Variance	3395.63	1640.03	1723.66
Standard deviation	58.27	40.49	41.51
Asymmetry	0.23	-0.25	0.29
Kurtosis	3.27	3.51	2.20
X – Y mean	72.89	7.19	--
Covariance	1290.48	1177.44	--

Table 3 – Model comparison using fit indices.

	General Model			Mule			Horse		
	Control	Model 1	Model 2	Control	Model 1	Model 2	Control	Model 1	Model 2
Mean	377.46	450.35	384.65	362.73	446.03	376.1	408.55	459.47	402.7
SD	41.51	58.27	40.49	37.42	63.13	41.83	32.59	48.52	32.5
Median	372.5	451.18	391.16	357	451.18	390.42	414	443.62	402.8
r^2	-----	0.3	0.52	-----	0.29	0.49	-----	0.54	0.43
MSEP	-----	7668.56	940.37	-----	9616.77	1067.77	-----	3555.67	671.4
MD	-----	-72.89	-7.19	-----	-83.3	-13.36	-----	-50.91	5.84
MEF	-----	-3.61	0.43	-----	-6.24	0.19	-----	-2.76	0.28
CDM	-----	0.19	1.01	-----	0.12	0.72	-----	0.2	0.97
MA	-----	0.46	0.98	-----	0.38	0.94	-----	0.52	0.98
CCC	-----	0.25	0.71	-----	0.2	0.66	-----	0.38	0.65
CAIC	-----	201.89	191.13	-----	134.77	128.23	-----	60.58	62.47

SD: standard deviation; r^2: coefficient of determination of a linear regression Y on X; MSEP: mean squared error of prediction; MD: mean deviation; MEF: model efficiency factor; CDM: coefficient of determination of the model; MA: model accuracy; CCC: concordance correlation coefficient; CAIC: corrected Akaike's information criterion.

length measurements, obtaining a better fit in absolute terms, with a lower MSEP, positive MEF, high coefficient of determination via linear regression (r^2) and high CDM, in addition to a higher value for analysis of model accuracy and CCC. The results agree with Neder et al. (2009) who studied Crioulo horses and also observed better fit of the model proposed by Carroll and Huntington (1988) compared to the model of Ensminger (1977).

Wagner and Tyler (2011) also found differences between estimators for weight prediction and actual weight. The authors identified the most suitable models for the type of animals studied. This reinforces the need to pay special attention to the model that is most compatible with the herd to be studied since the measures may vary depending on the conformation of each individual which, in turn, is directly related the breed to which the animal belongs (NEDER et al., 2009). Commercially, it is possible to find a specific type of "equine measuring tape" for weight determination of animals. Hoffmann et al. (2013) observed no significant differences when weight was determined with a "equine measuring tape" and based on estimators that use combinations of animal measurements. Within this context, the reliability of the weight must be confirmed when a "equine measuring tape" is acquired.

The prediction error of the models was significantly different (Table 4), reinforcing the importance of correctly controlling which model is most suitable for the body biotype of the herd. Considering the DAIC, the model proposed by Carroll and Huntington is the most adequate. The AIC is a measure of the imperfection of model fit, i.e., the higher the AIC value, the lower the probability that the data occur according to that model (GOTELLI and ELLISON, 2011).

Table 4 – Comparison of the squared error of prediction of the models at a significance level of 5% (P<0.05) by the t-test and delta Akaike's information criterion.

	General		Horse		Mule	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Diff.	----------	6728.19	----------	2884.26	----------	8548.99
SDSR	----------	17.04	----------	1236.54	----------	2350.55
P	----------	-0.000	----------	0.048	----------	0.0019
DAIC	----------	-10.76	----------	1.88	----------	-6.54
P	----------	0.99	----------	0.280	----------	0.96

Diff.: difference between mean squared prediction errors; SDSR: standard deviation of the mean squared differences of prediction errors divided by the square root of n; DACI: delta Akaike's information criterion.

Evaluation of the decomposition of MSEP shows that in the model proposed by Ensminger (1977), the error concentrates ≈ 70% on the average, while in the model proposed by Carroll and Huntington (1988), the error is mainly concentrated on random errors, i.e., on the variability of differences between animals (Table 5). The systematic error distribution retained a similar explanation between the models, showing an equal discrepancy between specimens in the data.

Table 5 – Decomposition of the mean squared error of prediction (MSEP).

	General			
	Model 1		Model 2	
Modal	5313.05 (69.28%)		51.70 (5.49%)	
Systematic error	1202.00 (15.67%)		103.21 (10.97%)	
Random error	1153.50 (15.04%)		785.45 (83.52%)	
	Mule		**Horse**	
	Model 1	Model 2	Model 1	Model 2
Modal	6938.89 (72.15%)	178.65 (16.73%)	2592.39 (72.90%)	34.19 (5.09%)
Systematic error	1740.08 (18.09%)	224.43 (21.01%)	535.71 (14.98%)	106.27 (15.82%)
Random error	937.80 (9.75%)	664.68 (62.24%)	430.57 (12.10%)	530.93 (79.07%)

In general, totally disregarding the difference between MSEP of the models, the model proposed by Carroll and Huntington (1988) was found to better predict weight but has a larger random error, i.e., better prediction but less accuracy. The first model has less prediction but higher accuracy, i.e., the predictions are distant from the actual value but close to each other, while the second model makes the precision difficult but is closer to the actual value.

As can be seen, the weight, when estimated, may have results with large differences from what was observed. The consequence of this was demonstrated by the significant difference ($P<0.05$) in the percentage of economic values in the production scenarios between models. The economic losses using the model that is not compatible with the herd's body biotype exceed 10% of costs in relation to the actual value (Table 6).

Considering an equestrian center that uses the traditional system with supplementation, a simulation in a facility that has 20 horses and mules (general scenario) and the model proposed by Ensminger (1977), this loss can reach ≈ US$ 10,000,00 per year. In general, comparing the two models, differences of ≈ US$ 450.00 per animal can be saved annually. When this equestrian facility has only mules, using

Table 6 – Contrast of annual expenditure (US$/year) based on mean weight.

	General	Horse	Mule
	Control weight		
Simple system	801.70	868.60	771.10
Traditional system	2552.40	2763.50	2453.40
Traditional system with supplementation	2597.3	2812.1	2496.60
	Model proposed by Ensminger (1977)		
Simple system[1]	957.50 (≈16% ↑)A*	976.90 (≈11% ↑)A*	948.30 (≈18% ↑)A*
Traditional system[2]	3046.20 (≈16% ↑)A*	3107.90 (≈11% ↑)A*	3017.00 (≈18% ↑)A*
Traditional system with supplementation[3]	3099.80 (≈ 16% ↑)A*	3162.60 (≈ 11% ↑)A*	3070.10 (≈18% ↑)A*
	Model proposed by Carroll and Huntington (1988)		
Simple system[1]	817.70 (≈ 2% ↑)B*	856.20 (≈ 1.45% ↑)B*	799.60 (≈ 3.56% ↑)B*
Traditional system[2]	2601.70 (≈ 2% ↑)B*	2723.90 (≈ 1.45% ↑)B*	2544.00 (≈ 3.56% ↑)B*
Traditional system with supplementation[3]	2647.50 (≈ 2% ↑)B*	2771.80 (≈ 1.45% ↑)B*	2588.80 (≈ 3.56% ↑)B*

(00.00%↑): Percent contrast (%) of the values in US$/year of the models in relation to control weight. Contrasts followed by the same letters do not differ significantly between systems (1-1, 2-2 and 3-3) by Fisher's exact test.
*P<0.0001.

the model proposed by Ensminger (1977), the costs will be 18% higher than the actual cost, exceeding US$ 570.00 per animal per year. Using the model proposed by Carroll and Huntington (1988), the losses are lower, with a maximum difference of 3.56% in relation to the control weight.

The losses gradually increase when the use of concentrate and supplementation is added (items with greater economic weight than a simple system). Thus, when the equestrian breeding facility uses modern feeding systems, it will be more susceptible to losses due to waste. The average investment for the acquisition of a precision scale with a capacity of 1,500 kg (including freight and installation) is ≈ R$ 12,300.00, which is equivalent to US$ 3,194.00. Therefore, considering the possible losses resulting from the use of weight estimators, it is economically viable to invest in a precision scale or to previously study the most suitable model for the herd's body biotype.

Studying horses stabled in the state of Santa Catarina, Anjos and Leme (2014) found that only 6% of the respondents reported that they received professional guidance regarding horse diet formulation. Another 12% followed the instructions of the horse owners, 15% were instructed by a veterinarian with consent from the owners and 21% by handlers, and 46% reported that the persons responsible for diet formulation were the owners of the equestrian facilities. The authors also reported that respondents differentiated the diet based on the level of physical effort required from the animal, weight and activity, weight + activity + age, weight, and activity + age. This further highlights the importance of correct weight assessment of the animals since the costs can even outweigh the losses estimated here when there is no technician capable of formulating the entire nutritional management of the animals.

It is important to emphasize that the scenarios were classified considering the estimates reported by the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA, 2016), which states that 3.9 million horses are engaged in activities on rural properties. Traditionally, these animals do not receive attention in terms of management; they are generally kept on pasture and the care received is limited to the application of deworming medication. It is estimated that the cost of maintaining these animals is about R$ 120.00 per year/head. The other scenarios are the traditional systems seen in equestrian facilities. It is noteworthy that, in all scenarios, hay is maintained because horses need to meet their fiber requirements from forage, which contributes to prevent metabolic disorders (SALAZAR et al., 2019). The forage should form the basis of the animals' meals (HARRIS et al., 2016). Thus, the inclusion of forage in the horse diet is indisputable, especially for animals that are unable to access pasture areas (ANJOS and LEME, 2014).

Drugs such as anthelmintics, antibiotics or anti-inflammatory drugs must be administered under professional guidance according to the animal's body weight. If the weight of the horse is not accurately established, administration of a medication may result in under- or overdosing. Long-term drug resistance of pathogens is a possible consequence of careless and imprecise dosing (MOLENTA et al., 2005). To make the deworming requires accurate weight determination of the animal in order to avoid problems due to underdosing or waste because it can generate the emergence of drug resistance among parasites (BYCZKOWSKA et al., 2019).

A standard deworming program in an equestrian facility should be developed based on the initial infection level, followed by the degree of environmental contamination and coproscopy results, procedures that will allow to reduce or eliminate the parasite burden of horses, thus preventing other serious diseases caused by the passage of parasites through the animal's body.

If the body weight is not accurately established, diets with excess or deficient nutrients can compromise not only the development of the horse but also its performance at work, increasing the risk of a variety of diseases and disorders with consequent economic losses. A poorly balanced diet can also cause obesity in animals, a condition associated with the development of various diseases (OWERS and CHUBBOCK, 2013; JENSEN et al., 2016). Therefore, to obtain the best result for horses, welfare conditions, a balanced diet and adequate management must be offered, as reported by Cintra (2006).

CONCLUSION

When investment in a precision scale for weight determination of horses is not possible, it is fundamental to evaluate which model is most compatible with the body biotype of the animals in the herd. If this is not controlled, all types of management that depend on body weight can be compromised, causing significant losses to equestrian facilities. In general, the best model was that using simultaneous combinations of the animal's length and circumference measurements. When erroneous estimates are used, the loss is five times greater for the model that considers only the animal's chest circumference.

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