A general faecal nitrogen model for estimating intake in cattle and sheep fed multi-species native forage

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Abstract

The Rio de la Plata grassland ecoregion in southern America, which includes Uruguay, south of Brazil and part of Argentina, plays a crucial role in providing feed to livestock in outdoor extensive production systems due to its high plant species richness, chemical composition and annual production. Estimating animal intake in this heterogeneous grassland environment poses a significant challenge. Therefore, our goal was to develop a general linear regression model based on faecal nitrogen excretion (FNe) to estimate organic matter (OM) intake in cattle and sheep fed multi-species native forage using data from different zones of the Rio de la Plata region. We collated data from previous studies conducted based on the same protocol in Brazil and Uruguay, comprising 219 individual observations (72 from cattle and 147 from sheep); 15 data points from sheep in Uruguay remain unpublished. The trials were conducted using metabolism cages and animals were fed fresh or hay native forage. Mixed linear models were developed using R software. The best-fitting model was selected based on the Bayesian information criterion (BIC) and Akaike information criterion (AIC). The predictive accuracy of the fitted OM intake model was evaluated using 5-fold cross-validation. The resulting linear regression model revealed a positive relationship between FNe and OM intake ($p < 0.001$; $R^2 = 0.851$) across the entire dataset [Intake (g OM/kg BW/day) = 3.335 + 106.321 × FNe (g N/kg BW/day)]. The animal species effect was not significant ($p = 0.337$). Pearson correlation between predicted and observed values of the animal forage OM intake model was 0.957, with a root mean square error (RMSE) of 1.598, a mean absolute error (MAE) of 1.241 and a concordance correlation coefficient (CCC) of 0.937. In conclusion, our findings highlight that a general linear regression model, developed using combined data from both cattle and sheep, can be used to precisely estimate OM intake using FNe for animals fed multi-species native forage from the Río de la Plata region.

Introduction

In the Rio de la Plata region of South America, which includes all of Uruguay, the central-eastern part of Argentina, and a portion of southern Brazil (Baeza and Paruelo 2020), most ruminants graze on native grasslands. These grasslands are characterised by highly diverse native vegetation (Andrade et al. 2018), with a rich variety of plant species that create a heterogeneous environment. Therefore, estimating animal forage intake in this grazing environment is challenging. To address this, several studies have focused on developing specific linear regression models using faecal nitrogen excretion (FNe) to estimate organic matter (OM) intake in beef cattle and sheep fed native forage in Brazil (Kozloski et al. 2018; Azevedo et al. 2024) and Uruguay (Tafernaberry et al. 2024). These studies indicated that it is possible to develop accurate models for estimating OM intake in cattle and sheep

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separately or together for southern Brazil forage based on FNe. Given that faecal nitrogen is a well-established proxy for estimating intake in ruminants (Lancaster 1949; Peripolli et al. 2011), an important question arises: can a single model reliably estimate OM intake for both sheep and cattle fed native forages with similar vegetation across different zones of the Rio de la Plata region? We hypothesize that a general linear regression model can accurately predict OM intake for both species using data from different zones of the Rio de la Plata region. The objective of this study was to develop and validate a general linear regression model using FNe to estimate OM intake in cattle and sheep fed multi-species native forage from the Río de la Plata region.

Methods

This study was conducted using a comprehensive database compiled by researchers from Uruguay and Brazil. The database included data from previous experiments performed between 2014 and 2022 with beef cattle and sheep housed in metabolism cages and fed fresh or hay-preserved multispecies native forages typical of the Rio de la Plata region in South America ($n = 219$). Most of the data in this database ($n = 204$) have been previously published in peer-reviewed scientific articles (Kozloski et al. 2018; Azevedo et al. 2024; Tafernaberry et al. 2024). However, 15 data points from sheep in Uruguay remain unpublished. Of the 219 individual observations, 72 were from steers (Angus and Hereford breeds) and 147 were from male sheep (Corriedale and Texel × Corriedale crosses). The body weight (BW) of the animals was 273 ± 73 kg for steers and 38 ± 9 kg for sheep, respectively.

All experiments adhered to a consistent methodology as described by Rymer (2000). Briefly, in all experiments, all animals had a 5-day acclimatisation period in metabolism cages before starting the 10-day adaptation period to the different amounts of forage offered, followed by a 5-day period for forage and faeces sampling. During the first 5-day acclimatisation period, the same amount of forage (*ad libitum*) was offered to all the animals, while during the following 10-day adaptation period to the treatments and the 5-day sampling, they received different amounts of forage, which corresponded to their treatment. The treatments in each trial differed, but in general, animals were receiving forage in daily amounts ranging between 15 and 25 g of dry matter (DM) per kg BW or *ad libitum*. When forage was offered fresh, every day, the forage required to feed the animals was harvested using a mower and stored overnight in a refrigerator. For the trial in which animals were fed hay, native forage was cut 3 cm above the ground, dried in the field, and stored in a shed for later feeding. Fresh forage or hay was offered twice a day (at 8 and 17 h) to animals individually according to their BW and treatment. Every morning, prior to feeding the animals, forage refusals of each animal from the previous day were removed and weighed. During the 5-day sampling period, samples of offered and refused forage were collected, oven-dried at 55°C, and ground (1 mm) for subsequent analysis of DM and OM; these data were used to determine OM intake. To estimate daily faecal excretion, each animal was equipped with a harness and bag. Dung bags were emptied once daily for sheep and twice daily for cattle before feeding. The total daily fresh faecal excretion of each animal was weighed and homogenized. A sub-sample representing 20% and 10%, for sheep and cattle, respectively, was taken from the total and oven-dried at 55°C for subsequent analysis of DM, OM, and nitrogen.

The analysis, performed in R software, aimed to develop and validate a predictive mode for OM intake using FNe as a predictor in linear mixed-effects models. Five candidate models, each including animal species (sheep and cattle) as a fixed effect and differing in random effects structures, were compared using Akaike information criterion (AIC) and Bayesian information criterion (BIC). The coefficient of determination (R^2) and Pearson correlation (r) were calculated to assess the model's explanatory power, while ANOVA was used to test the significance of fixed effects. The predictive accuracy of the fitted OM intake model was evaluated using 5-fold cross-validation (James et al. 2014), where the dataset was randomly split into 80% training and 20% testing subsets for each fold. Performance metrics included mean absolute error (MAE), root mean squared error (RMSE), concordance correlation coefficient (CCC), and Pearson correlation (r), ensuring a comprehensive evaluation of predictive accuracy.

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Results

Figure 1a shows the representation of the best model developed to estimate OM intake in sheep and beef cattle fed native forage. The resulting linear regression model revealed a positive relationship between FNe and OM intake ($p < 0.001$; $R^2 = 0.851$) across the entire dataset [Intake (g OM/kg BW/day) = 3.335 + 106.321 × FNe (g N/kg BW/day)]. The best model was identified as having animal species as a fixed effect and random effects structured as ~1|Trial, and showed the best predictive performance, with the lowest AIC (945.7) and BIC (962.5). The animal species effect was not significant ($p = 0.337$).

The cross-validation using the model developed in this study is shown in Figure 1b. Pearson correlation between predicted and observed values of the animal forage OM intake model was 0.957, with an RMSE of 1.598, an MAE of 1.241 and a CCC of 0.937.

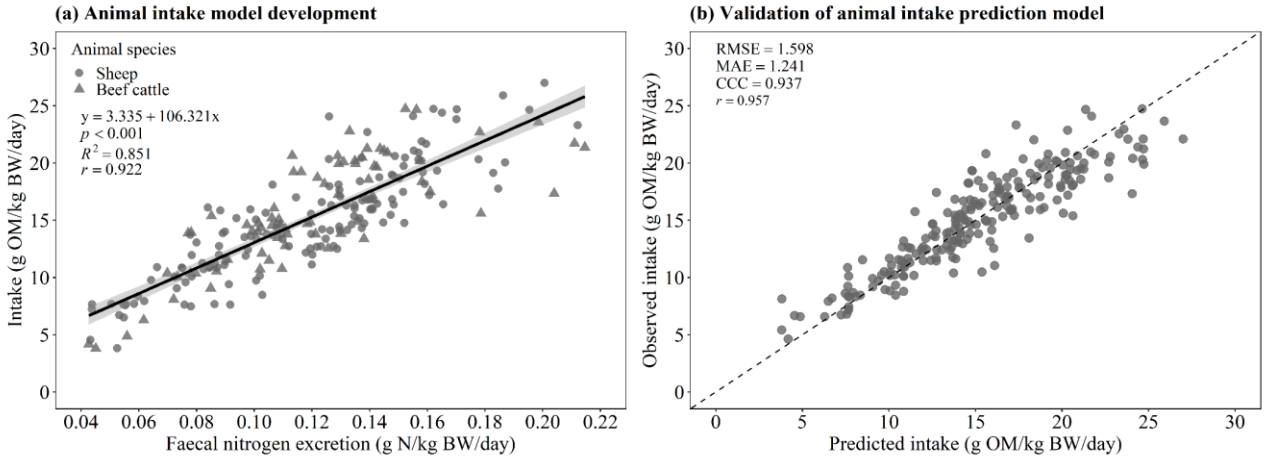

Figure 1. Relationship between faecal nitrogen excretion and organic matter intake in beef cattle and sheep (a) and predicted and observed animal organic matter intake validation using the developed model (b).

Discussion

This is the first study to utilize a database comprising 219 individual observations (72 from cattle and 147 from sheep) from two countries within the Rio de la Plata region to develop a general model for estimating forage intake in both beef cattle and sheep fed native forage, using FNe. The previous studies using sheep and cattle fed native forage in this region proved that the FNe can be precisely used to estimate intake in those animals (Kozloski et al. 2018; Azevedo et al. 2024; Tafernaberry et al. 2024). Nevertheless, the primary goal was to develop a single linear model using combined data from both beef cattle and sheep to estimate their intake. Our hypothesis was that this approach would be feasible. The results confirmed this hypothesis: FNe has a strong relationship with OM intake, regardless of the animal species. This finding demonstrates that a single general model can precisely ($r = 0.922$; Figure 1a) and accurately ($r = 0.957$; Figure 1b) estimate intake in both sheep and cattle consuming this multispecies native forage. Therefore, this represents a significant advancement in pasture and animal science in our region, particularly within the context of heterogeneous environments such as multispecies native grasslands. In conclusion, our findings support the hypothesis that a general linear regression model, developed using combined data from both beef cattle and sheep, can be used to precisely estimate OM intake using FNe for animals fed multi-species native forage from the Río de la Plata region in South America.

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