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Prediction of water intake in hair sheep: development of a new model

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The objective of this study was to establish equations for the prediction of the water intake (WI) of hair sheep. The data set used was derived from eight studies containing 185 individual observations of hair sheep: 120 non-castrated males, 22 castrated males, and 43 females in a feedlot. A stepwise procedure was used, with a significance level of $P < 0.05$, to determine which variables would be included in the prediction model. Then, a random coefficient model was used, considering the random study effect and including the possibility of covariance between the intercept and slope. Furthermore, sex classes were considered a fixed effect and tested in the model parameters. To validate the model, the comparison between predicted and measured values was performed using the Model Evaluation System. The correlation between WI and metabolizable energy intake (MEI), body weight (BW), dry matter (DM), dry matter intake (DMI), and temperature-humidity index (THI) was significant ($P < 0.001$), assuming values of 0.35, 0.37, 0.43, 0.54, and 0.57, respectively. The stepwise analysis indicated that DM and DMI were significant variables ($P < 0.001$) for predicting WI in hair sheep. Sex classes did not affect ($P = 0.3340$) the model predicting WI in hair sheep; therefore, a single equation was generated: $WI \text{ (kg/day)} = 0.1282 (\pm 0.5861) + 2.4186 (\pm 0.5842) \times DMI$ ($R^2 = 0.70$, $MSE = 0.1631$, $AIC = 297.6$). The validation suggests that the model accurately predicts the water intake of sheep. In conclusion, the proposed model should be used to more accurately predict WI in hair sheep and contribute significantly to improving the rational use of water.

KEYWORDS

feed intake, multi-study approach, small ruminants, tropical environments, water requirements

1 Introduction

As society debates the relevant issues of climate change and the sustainable use of natural resources, including land and water, it is crucial to understand the nutrient requirements of sheep raised in hot environments (Cannas et al., 2019). It is pertinent to continue refining and discussing nutrient utilization and requirements to enhance the efficiency of production systems, maximize resource economy, and other related objectives (Tedeschi, 2023).

Water is the most important nutrient for animals with physical properties that make it critical to numerous metabolic functions such as regulating body temperature, digestion, lactation, general metabolism, and excretion of metabolic waste (NASEM, 2016) being the main constituent of the animal's body, amounting to 50 - 80% of body weight depending on age and degree fatness (CSIRO, 2007).

The water requirements are met by voluntary intake, water contained in the feed, and water formed within the animal's body because of metabolic oxidation (NRC, 2007). However, voluntary water intake can be the best approximation to total water requirements (ARC, 1980). Therefore, the accuracy of estimates of the volume of water ingested by animals is a critical point for applicability.

International nutrient requirement committees (NRC, 2007; CSIRO, 2007) contribute significantly to suggestions on the nutritional requirements of sheep. These Committees adopted the prediction equations for water intake from the studies by Forbes (1968) and Luke (1987), respectively. However, in tropical environments, the water requirements for hair sheep may be different from those suggested by the Committees because water intake is affected by multiple factors such as individuality, genetics, climate, diet, age, and physiological stages (CSIRO, 2007). The equation suggested by Luke (1987) and adopted by CSIRO (2007) model used mainly Australian Merino animals in its data set. These animals have a high tolerance to prolonged exposure to thermal stress, maintaining homeostasis patterns even when exposed to high temperatures (Alhidary et al., 2012), mainly due to the external part of their wool being composed of small dark blocks (Macfarlane et al., 1966) causing the surface of its wool to become heated and the hot surface radiates a large part of the solar energy (Macfarlane et al., 1956) which helps control body temperature and reduces the effect of thermal stress in these animals. Hair sheep may appear to be more tolerant to heat stress than woolly sheep, however tolerance is not determined solely by coat type (wool/hair). Instead, adaptation to severe scenarios, which includes modifications in critical pathways such as energy metabolism and body size, dictates the animal's ability to withstand heat stress (McManus et al., 2020).

Continuous update of knowledge is essential. Furthermore, the equations adopted in these Committees were derived from independent studies or without considering individual information on water intake, which may limit the use of their estimates. Thus, the use of a multi-study approach to integrate information from studies and generate more precise and accurate models, since differences in the experimental conditions of each study are incorporated into the model as a random effect, which results in less bias in the model parameters.

We hypothesized that the water intake prediction models adopted by International Committees may not be adequate for hair sheep raised in tropical regions. Our objective was to develop a model for predicting water intake in hair sheep raised using a multi-study approach.

2 Materials and methods

2.1 Inclusion criteria for studies

Only studies carried out with growing hair sheep raised in tropical and semi-arid regions that had at least one of the following individual information were included in the data set: water intake (WI), body weight (BW), dry matter content of diets (DM), dry matter intake (DMI), total digestible nutrients intake (TDNI), average temperature and relative humidity. Thus, the data set was compiled from eight studies (Perazzo et al., 2017; Pereira et al., 2018a; Morais et al., 2021; Silva et al., 2021a; Soares et al., 2022; Santos, 2023; Brito Neto, 2024; Herbster et al., 2025) containing 185 individual observations of hair sheep with three sex classes (120 non-castrated, 22 castrated males, and 43 females) in a feedlot system. It is important to highlight that few studies reporting water intake by hair sheep have raw data sets available. Therefore, this study used only data from feedlot animals due to a lack of information on animals in the pasture system. In all studies, animals were individually fed with total mixed rations with individual and *ad libitum* water supply. The average roughage: concentrate ratio in this data set was 538.1 ± 157 (g/kg): 461.8 ± 157 (g/kg), and the average dry matter (DM) content of the diets was 730 ± 260 (ranging from 260 to 910 g/kg of DM). The description of the studies is presented in Table 1. The descriptive analysis of the variables used in the development of the equations is shown in Table 2.

2.2 Dry matter, water intake, and climatic variables

In all studies, animals were fed diets in the form of total mixed ration (TMR, kg/day) *ad libitum* twice daily (08:00 h and 4:00 h.), allowing 100 to 200 g/kg of refusals. Every day before providing the TMR, the refusals from each animal were removed and weighed for daily control. The DMI (kg/day) was determined by the difference between the amount of TMR (kg/day) offered and the amount of refusals (kg/day) collected. In all studies, water was provided *ad libitum* individually in buckets of known volume. Twice a day (08:00 h and 16:00 h), the residual water content present in the buckets was weighed on a digital scale. Then, the water was renewed, and the amount of water supplied was weighed on a digital scale to control intake. To measure water losses due to evaporation, buckets containing the amount of water like those used to supply the animals were distributed near the individual. After 24 h, the buckets were weighed again, with the difference in weight considered evaporation losses. Water intake (kg/day) was then

TABLE 1 Description of studies used to predict water intake in hair sheep raised in tropical regions.

Study	n	Age (days)	Genotype	Sex classes	Roughage	R: C (g/kg)	DM (g/kg)	CP (g/kg DMI)	ME (Mcal/kg DMI)	T (°C)	RH (%)
Perazzo et al. (2017)	27	220	Crossbred	NC	Tifton hay	520:480	834	128	-	-	-
	3			NC							
Pereira et al. (2018a)	4	240	Morada Nova	C	Tifton hay	600:400	910	169	2.29	28.83	69.42
	4			F							
Morais et al. (2021)	34	257	Santa Ines	NC	Tifton hay	500:500	910	184		29.05	67.32
Silva et al. (2021a)	27	240	Crossbred	NC	Palm/Bufel hay	440:560	260	128	2.57	-	-
Soares et al. (2022)	18	210	Crossbred	NC	Palm/Tifton hay	410:590	805	145	2.56	-	-
Santos (2023)	28	254	Santa Ines	NC	Sorghum Silage	300:700	562	151	2.59	-	-
Brito Neto (2024)	24	280	Santa Ines	F	Tifton hay	500:500/ 750:250	903	136	2.38	27.72	71.95
Herbster et al. (2025)	16	270	Dorper x Santa Ines	F	Tifton hay	600:400	900	160	2.41	27.92	69.58

NC, Non-castrated males; C, Castrated males; F, Females; R: C, roughage: concentrate ratio; RH, relative humidity.

determined by the difference between the amount of water supplied and the sum of residual water in the buckets and daily water loss by evaporation, according to Equation (1):

WI (kg/day) = WS – (RW + WLE) (1)

where WS = water supplied (kg/day); RW = residual water (kg/day); WLE = water losses by evaporation (kg/day).

In the studies of Herbster et al. (2025) and Brito Neto (2024), climate variables were collected by the Automatic Meteorological Station of the National Institute of Meteorology (INMET) installed 600 m from the experimental feedlot. For the study by Pereira et al. (2018a), these variables were collected by data loggers installed in the experimental feedlot. In the study by Morais et al. (2021), these variables were obtained using a digital hygrometer thermometer with an external sensor.

The temperature-humidity index (THI)was calculated in all studies according to the Equation (2) recommended by Kelly and Bond (1971):

THI = Tair – 0.55 × (1 – RH) × (Tair – 58) (2)

where THI = temperature-humidity index; Tair = air temperature (°F), being that temperatures were converted before calculation using (Tair °C × 1.8) + 32, and RH = relative humidity in decimals. The studies by Perazzo et al. (2017); Silva et al. (2021a); Soares et al. (2022), and Santos (2023) were not included in the THI calculation due to a lack of information on air temperature and relative humidity.

2.3 Metabolizable energy intake

In all studies, metabolizable energy intake (Mcal/day) was estimated from TDN intake (Total nutrients digestible, kg/day), considering that 1 kilogram of TDN contains 4.409 Mcal of digestible energy and that metabolizable energy corresponds to 85% of digestible energy (Brito Neto et al., 2023). More information about estimating the digestibility of diets and TDN can be found in previously published studies (Perazzo et al., 2017; Pereira et al., 2018a; Morais et al., 2021; Silva et al., 2021a; Soares et al., 2022; Santos, 2023; Brito Neto, 2024; Herbster et al., 2025).

2.4 Statistical analysis

For the development of the WI prediction equation, the variables body weight (BW), dry matter content of diets (DM), dry matter intake (DMI), metabolizable energy intake (MEI), and temperature-humidity index (THI) were adopted as possible predictor variables. A Pearson correlation analysis was performed to evaluate the relationship between water intake (WI) and the other variables adopted as possible predictors. In the second stage, the variables that showed a significant correlation were submitted to the stepwise procedure using an ordinary least squares regression with a significance of P<0.05 to determine which variables would be included in the prediction model (Table 3).

TABLE 2 Descriptive statistics of the data used to develop models to predict the water intake of hair sheep.

Variable	n	Mean	SD	Minimum	Maximum
BW (kg)					
Non-castrated males	93	27.20	2.98	18.15	36.73
Castrated males	22	31.23	6.60	19.64	41.00
Females	43	23.83	3.86	17.64	32.10
DMI (kg/day)					
Non-castrated males	120	1.12	0.188	0.636	1.69
Castrated males	22	1.07	0.166	0.681	1.40
Females	43	0.841	0.162	0.615	1.23
DM (g/kg)					
Non-castrated males	120	656	258	259	908
Castrated males	22	824	116	639	908
Females	43	903	3.00	900	908
WI (kg/day)					
Non-castrated males	120	2.88	0.954	0.675	5.52
Castrated males	22	2.62	0.792	1.40	4.12
Females	43	2.13	0.720	1.20	3.90
MEI (Mcal/day)					
Non-castrated males	93	2.75	0.53	1.64	4.22
Castrated males	21	2.88	0.67	1.59	4.18
Females	43	2.20	0.39	1.51	3.11
THI					
Non-castrated males	37	79.56	0.008	79.54	79.57
Castrated males	4	79.54	0.000	79.54	79.54
Females	43	78.33	0.392	78.20	79.54

BW, body weight; DMI, dry matter intake; DM, dry matter content of the diets; MEI, metabolizable energy intake; THI, temperature-humidity index; WI, water intake.

TABLE 3 Results of stepwise analyses, including the coefficient of determination (R^2), and regression coefficients.

Step	Regression coefficients			R^2	P-value
	Intercept	DMI	DM		
1	-1.71	4.68		0.73	<0.0001
2	39.78	3.30	-44.75	0.79	<0.0001

After choosing the predictive variables, as the data set was composed of different studies, it was necessary to quantify the variance associated with the studies (St-Pierre, 2001). A random

coefficient model was used, considering the random study effect and including the possibility of covariance between the intercept and slope. Furthermore, sex class was considered a fixed effect and tested in the model parameters, and when differences were significant ($P < 0.05$), an equation was adjusted for each sex class. The effect of sex classes was tested on the intercept and slope coefficients of all models. The covariance matrices were tested, and matrix selection was based on each matrix's Akaike information criterion (AIC), with the lowest value of AIC being chosen. Nine types of variances covariance structures were tested: variance components (VC), unstructured (UN), heterogeneous autoregressive (ARH(1)), Ante-dependence (ANTE), Autoregressive (AR(1)), Compound Symmetry (CS), Heterogeneous Toeplitz (TOEPH(2)), and Factor Analytic (FA(1)).

Individual observations with Student residuals greater than 2.5 or less than -2.5 were considered outliers (Tedeschi, 2006) and excluded from the data set. Furthermore, when Cook's distance was greater than 1, the study was considered an "outlier" and removed from the data set for that specific analysis (Cook, 1979). For all statistical procedures, a significance level of 0.05 was adopted for fixed effects and 0.20 for random effects. All statistical procedures were performed using the MIXED procedure of the SAS Studio 3.1.0 (SAS® OnDemand for Academics, SAS Institute Inc., Cary, NC, USA).

2.5 Validation of the model

An independent data set was used to validate the equations with the same inclusion criteria established in this study. We used 11 studies with a total of 36 means of treatments, totaling 264 animals (Table 4). The comparison between predicted and observed values was performed using the Model Evaluation System (MES) (Tedeschi, 2006). To validate the equation, the observed and predicted WI values were compared using Equation (3):

$$Y = \beta_0 + \beta_1 \times X \quad (3)$$

where Y = observed values; X = predicted values; β_0 = intercept; and β_1 = slope. Regression was evaluated with the following statistical hypotheses (Neter et al., 1996): $H_0: \beta_0 = 0$ and $\beta_1 = 1$; H_a : not H_0 . The slope and intercept of the curve were evaluated separately to identify possible errors in the equations. After validation, the equations of prediction errors were determined using the estimated mean squared error of prediction (MSEP) and its components (squared bias, SB; component relative to the magnitude of random fluctuation, MaF; and component relative to the model of random fluctuation, MoF (Bibby and Toutenburg, 1977). The root squares mean prediction error (RMSEP) was used to evaluate model precision, being that the smaller the RMSEP values the better the model precision. The concordance correlation coefficient (CCC) and model accuracy (Cb) were used to assess the equation's accuracy and precision (Deyo et al., 1991; Nickerson, 1997; Liao, 2003), and values closer to +1 were better.

The same validation procedure and determination of model prediction errors were performed using the equation of Forbes (1968) suggested by the NRC (2007): $TWI = 3.86 (\pm 0.75) DMI -$

TABLE 4 Description of the studies used to validate the water intake prediction models for hair sheep.

Study	n	Genotype	Sex classes	Roughage	R:C (g/kg)	Temperature (°C)	RH (%)
Neiva et al. (2004)	40	Santa Ines	Non-castrated males	Elephant grass hay	500:500	29.57	79
Costa et al. (2012)	36	Santa Ines	Non-castrated males	Palm	1000:0	26	–
Souza et al. (2013)	21	Santa Ines	Castrated males	Palm	1000:0	28.54	–
Souza et al. (2018)	20	Santa Ines	Non-castrated males	Sisal silage/Tifton hay	500:500	26	–
Araújo et al. (2019)	32	Morada Nova	Non-castrated males	Buffel hay	500:500	27	–
Albuquerque et al. (2020)	16	Santa Ines	Non-castrated males	Buffel hay	500:500	27.65	–
Araújo et al. (2021)	35	Santa Ines	Non-castrated males	Tifton hay/brewery residue	600:400	25.71	–
Mendes et al. (2021)	10	Dorper x Santa Ines	Non-castrated males	Tifton hay	600:400	27.90	80
Silva et al. (2021b)	40	Crossbred	Non-castrated males	Palm silage	560:440	29.47	–
Souza et al. (2022)	8	Santa Ines	Non-castrated males	Tifton hay	500:500	27.65	60.52
Nobre et al. (2023)	6	Santa Ines	Non-castrated males	Palm silage/Tifton hay	600:400	26.56	–

R:C, roughage: concentrate ratio; RH, relative humidity.

0.99 (± 0.41), where TWI was total water intake and DMI was dry-matter intake, both expressed as kg per head/day, respectively. In addition, graphical analysis was also used to define the best prediction model for hair sheep.

3 Results

The correlation between WI and MEI, BW, DM, DMI, and THI was significant (P<0.001), assuming values of 0.35, 0.37, 0.43, 0.54, and 0.57, respectively. The stepwise analysis indicated that DM and

DMI were significant variables (P<0.001) for predicting WI in hair sheep (Table 3). Sex classes did not affect (P = 0.3340) the intercept and the slope of the model predicting water intake in hair sheep. Furthermore, the DM variable did not present a significant effect (P = 0.3496) on the prediction model. Therefore, only the DMI showed a significant effect (P=0.0063), and an Equation (4) was generated for all sex classes (Figure 1):

WI = 0.1282 (± 0.5861) + 2.4186(± 0.5842) × DMI (4)

R2 = 0.70; MSE = 0.1631; AIC = 297.6

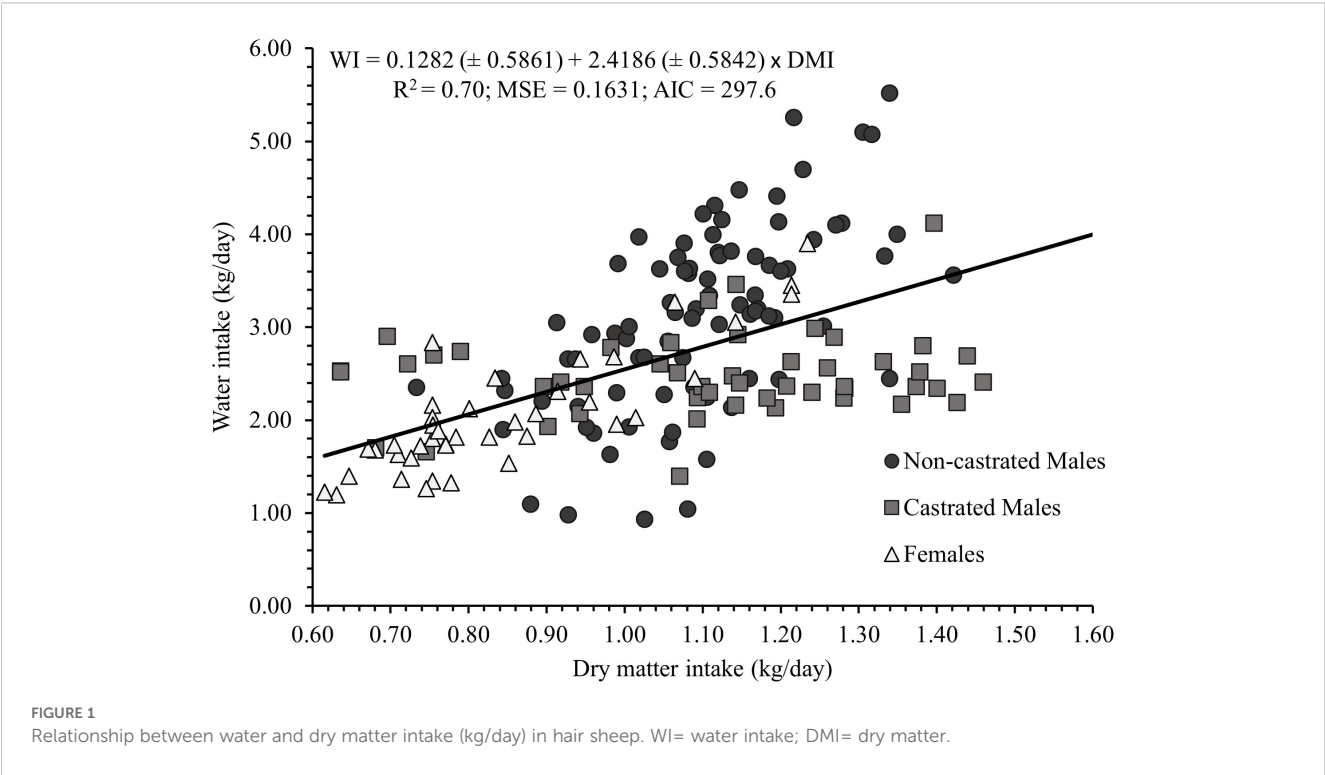


TABLE 5 Regression parameters and accuracy between water intake predictions and observed water intake values for hair sheep in tropical conditions.

Item	Observed	New model	Model Forbes (1968)
Mean	2.68	2.80	3.28
Standard deviation	0.842	0.605	0.965
Minimum	1.40	1.85	1.76
Maximum	4.90	4.09	5.34
Regression Parameters			
Intercept	–	0.936	1.39
P-Value	–	0.1369	0.004
Slope	–	0.6145	0.388
P-Value	–	0.084	0.00006
CCC	–	0.415	0.359
Cb	–	0.932	0.807
MSEP			
SB	–	0.018	0.373
MaF	–	0.051	0.338
MoF	–	0.554	0.563
RMSEP	–	0.789	1.12

CCC, concordance correlation coefficient; Cb, model accuracy; MSEP, mean squared error of prediction; SB, square bias; (MaF), magnitude of random fluctuation; MoF, model of random fluctuation; RMSEP, root mean squared error of prediction.

Where WI is the water intake (kg/day), and DMI corresponds to dry matter intake (kg/day).

The results of the validation indicated that the equation suggested in this study accurately predicts the water WI of hair sheep [$P > 0.05$ for the intercept ($\beta_0 = 0$) and slope ($\beta_1 = 1$)]. Table 5

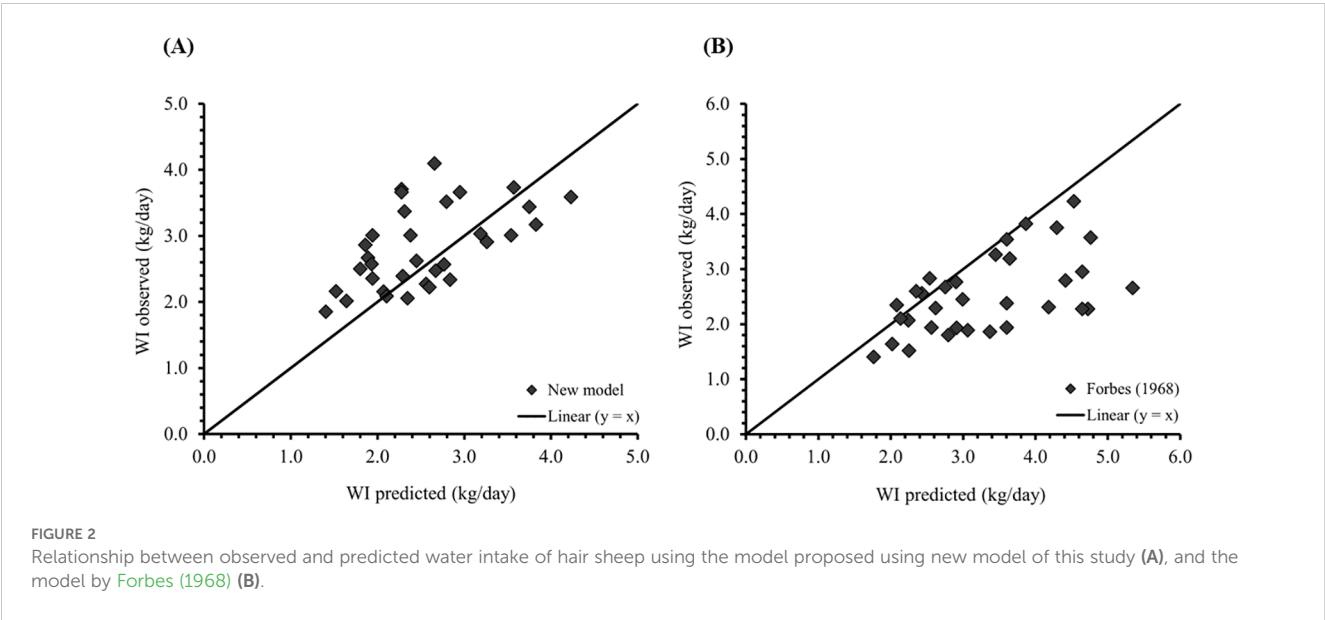
shows the regression parameters and accuracy between water intake predictions and observed water intake values for hair sheep in tropical conditions in which the results of the validation also indicated that the model recommended by Forbes (1968) could not accurately predict the WI of hair sheep [$P < 0.05$ for the intercept ($\beta_0 = 0$) and slope ($\beta_1 = 1$)]. The graphical evaluation of the models indicated a good adjustment of the equation suggested in this study (Figure 2). Furthermore, in our study, the MSEP partitioning demonstrated low participation of SB and MaF, showing the accuracy of the equation.

However, the model suggested by Forbes (1968) overestimated WI. Considering the distance between the predicted and observed values, the residuals of the predictions were plotted as a function of the observed WI (Figure 3). The visual evaluation of residuals' behavior reinforces the hypothesis of a lack of adjustment of the models for hair sheep in Forbes (1968). On the other hand, residues were less dispersed with the equation in this study, which indicates a smaller possibility of error in the prediction.

4 Discussion

In regions where water supply is limited, quantitative information on water intake is as important as information on the animals' other nutritional requirements. Thus, mathematical models that predict water intake by drinking are useful in understanding the water supply needed by animals on farms. The trial data assembled in this study included variables that allow for the development of the model, which can capture the true associations and have a sound extrapolation capacity. The random-effect multi-study approach used to construct the model also supports extrapolation as it assumes the data to be a random sample of the total population.

In our study, only dry matter intake (DMI) was identified as a significant predictor variable for estimating water intake in hair sheep. The estimated water intake per kilogram of dry matter



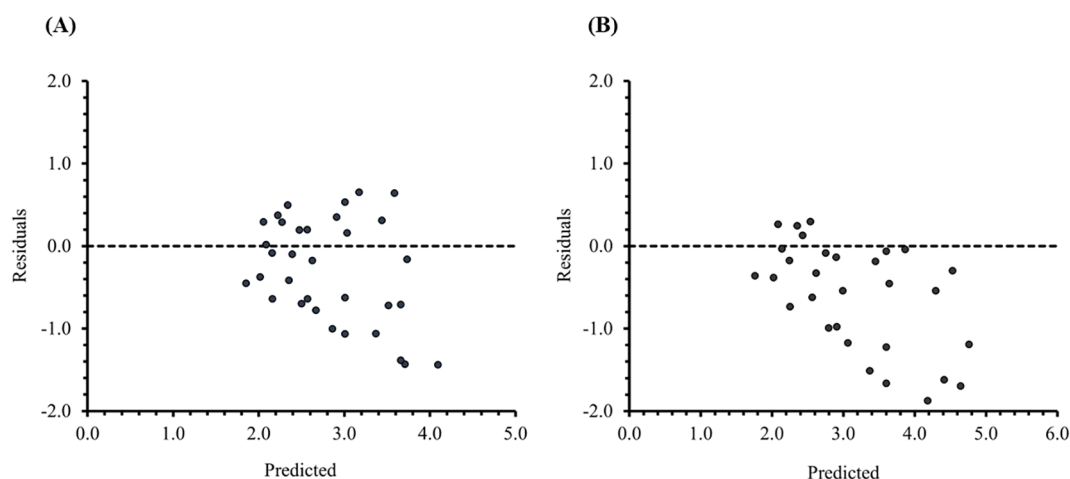


FIGURE 3
Distribution of prediction residuals using new model of this study (A) and using model by Forbes (1968) (B) in function of predicted water intake.

consumed was 2.55 liters. Water requirements for ruminants are generally expressed as kilograms per unit of dry matter intake (ARC, 1980; NRC, 1985; NRC, 2000), following the prediction model proposed by Forbes (1968). This model, which utilizes DMI as a predictor variable, has been widely adopted by international committees for sheep (ARC, 1980; NRC, 2007). It is important to note that increased dry matter intake is typically associated with increased voluntary water intake, as was the case in our study, confirming that these variables are closely related. In fact, many studies have reported reductions in DMI and performance when water supply was restricted (Santos et al., 2019; Freitas et al., 2021). The increase in WI related to DMI could be explained by the increased caloric input due to the heat of fermentation and digestion (NRC, 1981). Microbial metabolic activity dissipates free energy as heat during fermentation in the digestive tract, primarily in the rumen. Heat loss during the fermentation process ranges from 3.0 to 12.0% of gross dietary energy in ruminants (Ferrell, 1993). Thus, the relationship between body thermal control and water intake can be attributed to the temporary reduction in ruminal temperature immediately after water intake (Bewley et al., 2008).

It is important to highlight that for a given body size, the water intake per unit of dry matter consumed tends to be higher when dry matter intake is low compared to when it is high. It appears that the "estimated water intake" of animals fed on dry diets agrees more closely with prediction than that of animals fed on low dry matter diets, when total water intake may often be more than apparent needs. This discrepancy can partly be attributed to increased water loss through feces at higher feed intakes (Forbes, 1968). Additionally, it may be influenced by a higher metabolic rate, increased respiratory water losses, or the need to excrete greater quantities of waste products in the urine.

In our findings, water intake correlated well with dry matter intake, resulting in a more precise and accurate prediction equation for estimating the water intake of hair sheep when compared to Forbes' (1968) model. The direct relationship between DMI and WI explains the fact that the Forbes (1968) model presents an overestimate in the

WI from hair sheep, approximately 22% (estimated average WI was 3.28 kg/d vs. an observed WI of 2.68 kg/d values, according to comparative analysis in MES). Several factors can influence DMI, such as body weight and genetic group (BR-CORTE, 2023), and consequently, water intake. The Forbes (1968) equation adopted by the NRC (2007) was generated from a study involving data from seven crossbred ewes (Border Leicester x Cheviot) and two Speckle Faced Welsh, which are considered large breeds (CSIRO, 2007). Animals with greater body mass within a certain limit tend to have greater dry matter intake (Van Soest, 1994) and, consequently, greater water intake. In our study, BW showed a significant correlation with WI ($P < 0.05$); however, after the stepwise procedure, this variable was not statistically significant ($P > 0.05$) and was not included in the variables for the prediction model. This may be attributed to the high correlation between BW and DMI (Van Soest, 1994), thus linking them to WI and nullifying the effect of BW on WI.

Hair sheep are animals with smaller body masses, being classified as medium and small breeds (Sousa et al., 2003). Therefore, proportionally, dry matter intake about body mass is lower when compared to animals with larger masses, which justifies the overestimation of values when the Forbes (1968) equation is used to predict water intake in small breeds such as hair sheep. In addition, according to comparative analysis in MES, the equation in the current study has better accuracy and precision, as the CCC and Cb are closer to 1, these parameters indicate the efficiency and reproducibility of the equation tested (Tedeschi, 2006).

Body water has an important thermoregulatory function, maintaining homeothermia, especially in animals raised in hot areas (CSIRO, 2007). Water intake prediction models include climate variables such as solar radiation, average temperature, and THI in their estimates, due to this thermoregulatory function of water (Arias and Mader, 2011; Ahlberg et al., 2018; Zanetti et al., 2019). In our study, this index showed a very significant correlation with WI (0.57), but in the stepwise procedure, it was not significant ($P > 0.05$). This may have occurred due to the lower variability in the THI in different studies, assuming average values of 78. Furthermore, hair

sheep are more adapted to thermal stress than wool breeds from temperate climates (McManus et al., 2020). Sheep raised in harsh scenarios tend to present physiological adaptations to adapt to these areas, such as the reduction of metabolic rates (Silanikove, 2000; Chedid et al., 2014). When animals are exposed to an environmental temperature that exceeds the upper critical temperature of the thermoneutral zone (i.e., heat stress), physiological changes occur, mainly in the secretion of thyroid hormones (Starling et al., 2005). The decreased thyroid activity promotes a reduction in metabolism and consequently reduces heat production and heat stress (Pereira et al., 2018b). In addition, Marai et al. (2007) report the THI value that indicates thermal stress in sheep is greater than 82, which indicates that in this study, the animals were in thermal comfort, therefore, this variable was not significant.

It is necessary to continually develop new studies to obtain information on water intake in the various production systems, which will allow the refinement of the proposed model. Sheep farming is generally divided into extensive, semi-intensive, and intensive (industrial/confinement). This division hides enormous variability in productive and environmental aspects within and between systems. Therefore, estimating water intake in sheep should be continuous, especially in tropical regions with greater variability in roughage, agro-industrial residues, and feed types. Our study was conducted based on data of feedlot sheep with growing animals, in scenarios with temperatures between 25–30°C. Therefore, to improve the knowledge of water intakes for livestock raised in tropical regions, it's necessary to increase studies of water intake for sheep in pasture-based systems, in different physiological states (i.e., pregnancy and lactation), and these data must be incorporated into data sets, which will allow a better understanding of water intake and how water efficiency can be improved.

5 Conclusion

Finally, in conclusion, our study makes a significant contribution because the proposed model can help to predict the water intake precisely and accurately in hair sheep raised in tropical areas. Therefore, the proposed model $WI = 0.1282 (\pm 0.5861) + 2.4186 (\pm 0.5842) \times DMI$ may provide a more accurate prediction for sustainable usage of water in the hair sheep production systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional

requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

CH: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft. AB: Formal analysis, Investigation, Methodology, Writing – original draft. JC: Formal analysis, Methodology, Writing – original draft. MM: Conceptualization, Formal analysis, Methodology, Writing – original draft. EJ: Conceptualization, Formal analysis, Methodology, Writing – original draft. AR: Conceptualization, Formal analysis, Methodology, Writing – original draft. LS: Conceptualization, Formal analysis, Methodology, Writing – original draft. LB: Conceptualization, Formal analysis, Methodology, Writing – original draft. AC-C: Conceptualization, Formal analysis, Methodology, Writing – original draft. SS: Conceptualization, Formal analysis, Methodology, Writing – original draft. RO: Conceptualization, Formal analysis, Methodology, Writing – original draft. EP: Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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