Animal Feed Science and Technology 163 (2011) 170–176

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Fecal nitrogen to estimate intake and digestibility in grazing ruminants

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ARTICLE INFO

Article history:
Received 11 February 2010
Received in revised form
15 November 2010
Accepted 16 November 2010

Keywords:
Digestibility
Fecal nitrogen
Forage
Sheep

ABSTRACT

This study aimed at evaluating forage intake and digestibility in ruminants using fecal nitrogen content, as well as validating a non-linear model to estimate digestibility in ruminants. A total of 58 conventional metabolism trials, carried out with sheep fed 27 forages (offered pure or in mixture) used in Rio Grande do Sul (RS) during the period 1969–1989 was analyzed. OM intake and OM digestibility (OMD) results were regressed linearly against fecal N, and OMD was also estimated from fecal crude protein ($N \times 6.25$) content by a non-linear regression model. Fecal nitrogen excretion estimated forage intake in sheep with an $R^2 = 0.73$, whereas a low R^2 value of 0.36 was observed for OMD estimates. The equation obtained using the non-linear model was OMD = 0.7326 − 0.3598 exp [(−0.9052 CP (g/kg OM))/100]. The parameters *a* (0.7326) and *b* (0.3598) estimated by the equation for all forages were significant (P<0.00001) and there was no effect of type of forage (P=0.38). The mean prediction error (MSPE), was 0.2379, indicating that the equation fit well to the data. The difference between estimated and observed organic matter digestibility was mainly caused by random variation (0.9765). The results indicated that the equation using the non-linear model developed with all forages can be used with enough precision to estimate the OM digestibility of forage consumed by sheep in Rio Grande do Sul.

1. Introduction

Voluntary intake is the amount of ingested feed by an animal during a determined period with free access to the feed, and it is the main factor that influences animal performance and production efficiency (Mertens, 1994). These variables are also affected by feed digestibility and energy efficiency, as both variables are positively correlated with feed intake and quality.

Forage nutritional value is characterized by the digestibility of organic matter (OMD) in the diet. In animals under extensive grazing, OMD determination depends on the representativeness of fecal and consumed forage samples; however, this is not easily achieved in heterogeneous pastures due to variations in their composition and to diet selection by the animal. Therefore, indirect methods, such as *in vitro* techniques, internal markers, near infrared reflectance spectrometry (NIRS), and nitrogen concentration in the feces have been used to estimate digestibility.

Abbreviations: CI, confidence interval; CP, crude protein; DF, degrees of freedom; DM, dry matter; OM, organic matter; GE, gross energy; N, nitrogen; OMD, organic matter digestibility; MSPE, mean square prediction error; MPE, mean prediction error; SE, standard error; S^2, residual error variance; S^2u, variance of the random effect parameter.

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0377-8401
doi:10.1016/j.anifeedsci.2010.11.008

The use of fecal nitrogen (N) as a marker is based on one of two assumptions: endogenous fecal N excretion is constant and independent from fecal dry matter excretion, or fecal N excretion is directly related to fecal organic matter excretion. In the first case, fecal N excretion is directly proportional to diet digestibility, while in the second case, fecal N excretion is directly related to the intake of a determined feed (Gallup and Briggs, 1948; Lancaster, 1949; Lukas et al., 2005; Oliveira et al., 2007).

Equation based on fecal nitrogen content is interesting to estimate the digestibility of heterogeneous pastures and selective intake because it allows estimating forage quality with no need of having representative samples of the consumed forage or of imposing restrictions to animals. However, it requires conducting a parallel digestibility experiment with different intake levels to obtain an equation that is specific of that forage.

Considering that the different digestive capacities of animal species and the specific effect of diet type may influence the parameters of fecal N regression equation on organic matter digestibility, Streeter (1969) and Le Du and Penning (1982) recommend determining individual regression equations for each animal species and diet type to estimate digestibility under grazing conditions. However, these individual equations for a specific diet may limit the general use of this method, and thus, a general equation could accurately estimate organic matter digestibility in different forage-based diets (Boval et al., 2003; Lukas et al., 2005; Wang et al., 2009).

The objective of the present study was to test the applicability, under south Brazil (RS) conditions, of two fecal index equations for estimating forage intake and digestibility and to validate the non-linear regression equation proposed by Wang et al. (2009) to estimate digestibility in sheep.

2. Material and methods

2.1. Animals and feeding

Data were compiled from digestibility experiments carried out with sheep fed different forages during the period 1969–1989 (238 observations from 58 experiments, with 28 forages represented – pure or in mixtures: grass and/or legumes) in the Animal Science Lab (Laboratório de Ensino Zootécnico Prof. Geraldo Velloso Nunes Vieira), Department of Animal Science, School of Agronomy, Federal University of Rio Grande do Sul (UFRGS), Brazil. Animals were housed in metabolic cages, and had free access to water and mineral salts. The periods of adaptation to the experimental diets were of at least 10 days, followed by 5–7 days of feed intake and fecal excretion measurements. The number of animals per trial ranged from 3 to 9 and the initial weight ranged from 13.8 to 40.9 kg.

2.2. Chemical analysis

Forage, forage residue, and fecal samples of each experiment were ground and submitted to the Animal Nutrition Lab of UFRGS. Fecal samples were analyzed for dry matter (DM) by toluene distillation (AOAC methods no. 23.005, 1960 and no. 7.005, 1975) and for N were used fresh samples for analysis (AOAC methods no. 2.036, 1960 and no. 2.049, 1975). All other samples were analyzed dried for DM (Easley et al., 1965), organic matter (OM) (AOAC methods no. 22.010, 1960 and no. 7.010, 1975), and nitrogen (AOAC methods 2.036, 1960 and no. 2.049, 1975).

2.3. Biometric analysis

Forages were classified according to: 1. digestibility (low digestibility forages = OMD lower than 0.50; intermediate digestibility forages = OMD higher than 0.50 and lower than 0.60; and high digestibility forages = OMD higher than 0.60); 2. forage type (straws, grass hays and silages, mixture of hay species, all forages except silages and all forages except legumes), and 3. production cycle (cool and warm-season annual forages, and cool and warm-season perennial forages).

Intake was calculated as the daily difference between feed supply and feed residues. Organic matter digestibility was assessed *in vivo* by determining the composition and the amount of feed supply, feed residues, and fecal excretion, which were weighed, and a representative sample was collected.

Intake and OMD results were submitted to linear regression analysis against fecal N excretion (g/d) and fecal N content (g/kg OM) respectively. OMD was also estimated by the non-linear regression model proposed by Wang et al. (2009), $y_{ij} = a - (b + \mu_i) \exp[(-cx_{ij})/100] + e_{ij}$ obtained by the non-linear mixed model procedure (NLMIXED) of SAS (2002) package, which fits the specified non-linear mixed model by maximizing approximation to the likelihood integrated over the random effects and allows the random coefficients to enter the model non-linearly. In that equation, y_{ij} represents the jth organic matter digestibility on the ith forage (i = 1–28); a, b and c are constant effect parameters; μ_i is the random effect parameters of forage; x_{ij} is the corresponding crude protein (N × 6.25) content in fecal organic matter (g/kg), and e_{ij} is the residual error. The prediction accuracy of relationship between the estimated and observed OM digestibility was examined using mean square prediction error (MSPE), according to Rook et al. (1990) and the mean prediction error (MPE, square root of the MPSE), reported on proportion of the mean observed OMD, was used to describe the relative prediction accuracy.

Table 1
Chemical composition of the forages used in digestibility trials with sheep (values are ranges of the variables).

Forage	Forage type	DMI (kg/d)	OMI (kg/d)	Chemical composition (g/kg of DM)			OMD	CP (g/kg of fecal OM)	Cycle[a]
				DM (g/kg)	OM	CP			
Medicago sativa	Hay	0.332–1.601	0.298–1.427	875–935	875–972	170–230	0.529–0.730	18.60–32.16	WSP
Oryza sativa	Straw	0.478–0.648	0.383–0.519	863	800	50	0.555–0.581	9.10–9.47	WSA
Avena sativa	Hay	0.365–0.618	0.313–0.529	828	856	202	0.715–0.781	27.42–29.87	CSA
Lollium multiflorum (Lm)	Straw	0.538–0.777	0.497–0.719	902	924	44	0.438–0.572	12.72–15.47	CSA
Lm + trifolium repens (Tr) + Lotus corniculatus	Hay	0.374–0.853	0.348–0.793	873	930	102	0.654–0.681	19.17–19.90	CSA
Native pasture	Hay	0.305–0.516	0.284–482	914	932	78	0.453–0.474	12.40–13.50	WSP
Holcus lanatus (Hl)	Hay	0.257–0.403	0.236–0.375	851	931	65	0.417–0.444	10.80–11.70	CSA
Hl + Lm + Tr	Hay	0.516–0.704	0.469–0.640	906	990	137	0.428–0.506	15.60–19.14	CSA
Eleusine indica	Hay	0.435–0,821	0.396–0.772	860	911	80	0.587–0.627	10.80–11.70	WSA
Secale cereale	Hay	0.416–0.816	0.364–0.715	806	876	193	0.719–0.790	25.03–30.61	CSA
Lotus corniculatus	Hay	0.397–0.744	0.370–0.694	864–886	932–934	93–144	0.465–0.602	12.20–22.10	CSP
Desmodium spp + Chloris gayana Kunth (CgK)	Hay	0.337–0.517	0.305–0.468	851	905	130	0.594–0.651	19.70–22.40	WSP
Vigna unguiculata (Vu)	Silage	0.484–0.698	0.338–0.487	334	698	185	0.512–0.597	23.70–24.40	CSA
Pennisetum americanum (Pa)	Hay	0.317–0.739	0.284–0.674	861–906	894–926	54–103	0.603–0.684	12.90–23.20	WSA
Pa + Vu	Hay	0.475–0.688	0.425–0.616	833	895	121	0.661–0.682	20.65–23.75	WSA
Zea mays	Silage	0.345–0.670	0.328–0.636	336	949	63	0.627–0.645	13.71–16.17	WSA
Digitaria decumbens (Dd)	Hay	0.882–1.125	0.742–1.015	894	902	108	0.625–0.681	16.24–18.85	WSP
Dd + desmodium spp	Hay	0.304–0.457	0.277–0.417	885	911	156	0.554–0.584	21.70–23.60	WSP
Dd + macroptilium atropurpureum (Ma)	Hay	0.383–0.503	0.347–0.455	859	905	166	0.566–0.588	18.30–21.30	WSP
Chloris gayana Kunth (CgK)	Hay	0.455–0.610	0.418–0.552	871–911	917–925	55–73	0.526–0.650	6.60–16.50	WSP
CgK	Straw	0.212–0.288	0.204–0.271	891–914	935–941	49–56	0.386–0.466	11.90–14.00	WSP
CgK + Ma	Hay	0.282–0.334	0.225–0.302	886	903	127	0.546–0.617	18.70–20.40	WSP
Setaria sphacelata	Hay	0.103–0.932	0.0917–0.825	914–936	886–942	39–64	0.345–0.673	8.62–17.86	WSP
Glicyne max (Gm)	Straw	0.225–0.350	0.213–0.331	867	947	87	0.424–0.471	10.02–11.80	WSP
Gm + Medigaco sativa	Straw/hay	0.226–0.445	0.209–0.412	897	925	137	0.472–0.718	12.41–23.78	WSP
Sudax	Hay	0.414–0.632	0.347–0.572	855–902	854–904	100–167	0.576–0.646	19.10–30.90	CSP
Triticum vulgare Vill.	Straw	0.430–0.568	0.353–0.466	885	821	39	0.374–0.470	9.36–10.17	CSA

Note: DMI, intake of dry matter; OMI, intake of organic matter; DM, dry matter; OM, organic matter; CP, crude protein, OMD, digestibility of organic matter.
[a] Production cycle, where: WSP, warm-season perennial; CSP, cool-season perennial; WSA, warm season annual; CSA, cool-season annual.

3. Results

The extent of dry matter, organic matter, and crude protein concentrations in the forages were 334–936 g/kg, 698–990 g/kg DM, 38–230 g/kg DM, respectively. Average daily dry matter and organic matter intakes varied between 0.103 and 1.601 kg/day and between 0.092 and 1.427 kg/day, respectively. Nitrogen content in organic fecal matter was 41–201 (g/kg OM), fecal nitrogen excretion was 5–79 g/day, and organic matter digestibility was 0.345–0.790 kg/kg OM (Table 1).

Table 2
Relation between organic matter intake (g/day; y) and fecal nitrogen excretion (g/day; x) in sheep.

Groups		Regression equation	R^2	SEM
	All forages	$y = 216 + 11.1x$	0.71	7.3
Digestibility	Low digestibility forages	$y = 110 + 15.6x$	0.78	10.2
	Intermediate digestibility forages	$y = 291 + 8.0x$	0.47	12.8
	High digestibility forages	$y = 233 + 11.0x$	0.72	10.7
Forage type	Straws	$y = 48 + 20.0x$	0.91	9.7
	Grass hays and silages	$y = 204 + 13.4x$	0.52	9.8
	Mixtures of hay species	$y = 62 + 15.6x$	0.83	11.3
	All forages except silages	$y = 209 + 11.5x$	0.75	6.9
	All forages except legumes	$y = 178 + 14.4x$	0.58	8.4
Production cycle	Cool-season annual forages	$y = 148 + 14.2x$	0.72	13.7
	Warm-season annual forages	$y = 355 + 4.6x$	0.23	11.2
	Cool-season perennial forages	$y = 215 + 12.1x$	0.94	11.9
	Warm-season perennial forages	$y = 201 + 11.6x$	0.76	10.6

Table 3
Relation between organic matter digestibility (y) and fecal nitrogen content (g/kg organic matter; x) in sheep.

		Regression equation	R^2	SEM
	All forages	$y = 0.432 + 0.0079x$	0.38	0.0045
Digestibility	Low digestibility forages	$y = 0.390 + 0.0044x$	0.01	0.0053
	Intermediate digestibility forages	$y = 0.537 + 0.0009x$	0.05	0.0037
	High digestibility forages	$y = 0.580 + 0.0034x$	0.26	0.0030
Forage type	Straws	$y = 0.373 - 0.0078x$	0.05	0.0123
	Grass hays and silages	$y = 0.453 + 0.0142x$	0.58	0.0052
	Mixtures of hay species	$y = 0.377 + 0.0103x$	0.21	0.0129
	All forages except silages	$y = 0.414 + 0.0089x$	0.44	0.0045
	All forages except legumes	$y = 0.425 + 0.0162x$	0.60	0.0050
Production cycle	Cool-season annual forages	$y = 0.266 + 0.0153x$	0.81	0.0101
	Warm-season annual forages	$y = 0.626 + 0.0003x$	0.00	0.0051
	Cool-season perennial forages	$y = 0.385 + 0.0082x$	0.60	0.0091
	Warm-season perennial forages	$y = 0.409 + 0.0091x$	0.45	0.0058

There was a linear relation between organic matter intake and fecal nitrogen excretion (g/d) in sheep, when analyzing data of the 58 experiments together (OMI = 216.17 + 11.09x, R^2 = 0.71, Table 2). Forages were also separately analyzed as a function of digestibility, forage type, and production cycle, according to the classification in Table 1, resulting in lower data variation, with higher SEM and higher slope precision for most of the groups, as shown in Table 2.

The first assumption states that metabolic fecal nitrogen excretion is constant and independent from fecal dry matter excretion, and therefore, it is expected that fecal nitrogen is directly proportional to digestibility. However, the results obtained in the present study with data from 58 trials using all forage were below the limit to accept this assumption (OMD = 0.4320 + 0.0079x, R^2 = 0.38, Table 3), and did not produce an adequate digestibility linear estimate when fecal nitrogen excretion (g/d) was used.

Even when forages were analyzed in separate groups, according to digestibility, forage type, or production cycle (Table 3), only cool-season annual forages provided a significant improvement in OMD estimates. In the remaining groups, error variance was more reduced than data variation, but the accuracy continued to be below the acceptable limit of this estimate.

The low accuracy obtained when estimating digestibility using fecal nitrogen excretion is possibly due to the mathematical model used. Therefore, the non-linear regression model proposed by Wang et al. (2009) was tested. This model considers the random effect of forage to estimate organic matter digestibility using fecal crude protein (N × 6.25) concentration (g/kg of MO).

For all forages, the following equation was obtained: OMD = 0.7246 − 0.3598 exp [(−0.9052 CP (g/kg OM))/100]. The probability values (P > t) of the estimated parameters were significant for parameters of the effect constant (a and b) and the residual error variance (S^2), however there were no significant effects of parameter constant effect (c) and type of forage (S^2u) (Table 4). This non-linear equation model was also used to analyze forages grouped according to digestibility, forage type and production cycle. The obtained equations are shown in Tables 5–7. However, the model was not adequate for forages with low digestibility, warm-season annual forages and cool and warm-season perennial forages possibly because the data does not follow the equation model and also due to the low number of replications of some forages.

There were no differences in the mean bias between estimated and observed OM digestibility for the forages and residual variation of the differences was mainly caused by random variation of the regression equation (0.9765 of MSPE). The contribution of the variation of the line bias (0.0235 of MSPE) was relatively low. The prediction error (MPE) was also low (0.0238, Table 8), indicating an acceptable accuracy for the organic matter digestibility estimated by this equation.

In forage groups the probability values (P > t) of the estimated parameters were significant for the constant effect parameter (a) and for residual error variance (S^2) but there was no significant effect of forage (S^2u) (Tables 5–7). The mean bias between OM digestibility estimated and observed for groups of forage was low (−0.282E−0.5 to 0.00107 of MSPE) and the residual variation of the differences was mainly caused by random variation of the regression equation (0.8188–0.9871 of MSPE), while the contribution of the mean bias and deviation of the slope of the regression on residual variation were

Table 4
Parameters estimated by the non-linear regression equation of Wang et al. (2009) for prediction of organic matter digestibility in sheep.

Estimated parameter				
Parameter	Estimated	SE	DF	P=t
All forages				
a	0.724	0.0694	25	<0.0001
b	0.360	0.0551	25	<0.0001
c	0.905	0.4762	25	0.0689
S^2	0.0023	0.0002	25	<0.0001
S^2u	0.0073	0.0082	25	0.3817

SE, standard error; DF, degrees of freedom; a, b, and c are constant-effect parameters; S^2, residual error variance; S^2u, variance of the random effect parameter.

Table 5
Parameters estimated by the non-linear regression equation of Wang et al. (2009) for prediction of organic matter digestibility in sheep.

Estimated parameter					
Groups	Parameter	Estimated	SE	DF	P=*t*
Digestibility	Intermediated digestibility forage				
	a	0.627	0.1301	13	0.0003
	b	0.112	0.1100	13	0.3248
	c	0.456	0.9286	13	0.6312
	S^2	0.00047	0.0001	13	0.0006
	S^2u	−111E−14	0.0007	13	1.0000
	High digestibility forages				
	a	0.773	0.0477	12	<0.0001
	b	0.209	0.0232	12	<0.0001
	c	0.588	0.2249	12	0.0226
	S^2	0.000844	0.0001	12	<0.0001
	S^2u	−111E−14	0.0083	12	1.0000

SE, standard error; DF, degrees of freedom; *a*, *b*, and *c* are constant-effect parameters; S^2, residual error variance; S^2u, variance of the random effect parameter.

relatively low (Table 8). The mean prediction error (MPE) for forage groups was also low (0.0065–0.0281), indicating that this equation can be used with high accuracy for predicting the OM digestibility of forages.

4. Discussion

In the study carried out by Boval et al. (1996), fecal nitrogen excretion (g/day) was the best indicator for the prediction of organic matter intake in ruminants. In the present study the accuracy degree of the slope obtained between fecal nitrogen excretion (g/day) and organic matter intake (g/day) can be considered high ($R^2 = 0.71$), clearly demonstrating the possibility of the use of fecal nitrogen methodology to estimate intake in heterogeneous pastures, which is consistent with Boval et al. (1996). Nevertheless, this means conducting a parallel digestibility study with different intake levels to obtain a specific

Table 6
Parameters estimated by the non-linear regression equation of Wang et al. (2009) for prediction of organic matter digestibility in sheep.

Estimated parameter					
Groups	Parameter	Estimated	SE	DF	P=*t*
Forage type	Staws				
	a	0.506	0.1198	3	0.0242
	b	0.885	3.3216	3	0.8071
	c	4.381	8.7025	3	0.6493
	S^2	0.0017	0.0058	3	0.0575
	S^2u	0.7172	7.2801	3	0.9327
	Grass hays and silages				
	a	0.653	0.0268	11	<0.0001
	b	0.832	0.6161	11	0.2041
	c	2.911	1.2910	11	0.0455
	S^2	0.00186	0.0003	11	<0.0001
	S^2u	0.2049	0.3767	11	0.5972
	Mixtures of hay species				
	a	0.700	0.0993	5	0.0009
	b	0.762	0.4649	5	0.1622
	c	1.649	1.1951	5	0.2262
	S^2	0.0006	0.0002	5	0.0291
	S^2u	0.1016	0.2940	5	0.7439
	All forages except silages				
	a	0.659	0.0401	24	<0.0001
	b	0.525	0.2733	24	0.0666
	c	1.917	1.0576	24	0.0825
	S^2	0.00243	0.0002	24	<0.0001
	S^2u	0.04161	0.0723	24	0.5701
	All forages except legumes				
	a	0.708	0.1156	15	<0.0001
	b	0.383	0.0898	15	0.0007
	c	1.174	1.1772	15	0.3345
	S^2	0.00289	0.0004	15	<0.0001
	S^2u	0.00976	0.0270	15	0.7226

SE, standard error; DF, degrees of freedom; *a*, *b*, and *c* are constant-effect parameters; S^2, residual error variance; S^2u, variance of the random effect parameter.

Table 7
Parameters estimated by the non-linear regression equation of Wang et al. (2009) for prediction of organic matter digestibility in sheep.

Estimated parameter					
Groups	Parameter	Estimated	SE	DF	P=*t*
Production cycle	Cool-season annual forages				
	a	0.885	0.1391	5	0.0014
	b	0.892	0.1530	5	0.0021
	c	1.013	0.5300	5	0.1142
	S^2	0.001	0.0003	5	0.0216
	S^2u	0.007	0.0177	5	0.7042

SE, standard error; DF, degrees of freedom; a, b, and c are constant-effect parameters; S^2, residual error variance; S^2u, variance of the random effect parameter.

equation for that particular forage, as the fecal nitrogen content used in that estimate is expressed in grams per day, which is difficult to determine under extensive grazing conditions without the use of external markers or feces collection bags.

In a similar evaluation, Oliveira et al. (2007) compiled data from eight *in vivo* digestibility experiments with sheep at *ad libitum* intake and obtained an R^2 value = 0.48 between organic matter intake (g/day) and fecal nitrogen excretion (g/day). On the other hand, that same study obtained an R^2 value = 0.96 when animals were fed a single type of diet at different intake levels.

David et al. (2008), working with sheep fed different ryegrass allowance levels determined an R^2 value = 0.65 between organic matter intake (g/day) and fecal nitrogen excretion (g/day).

Equations obtained in present study show good precision, and hence, can be used to estimate OM intake in forages produced in the state of Rio Grande do Sul.

The first assumption suggests that lower organic matter digestibility of a determined food would result in lower fecal nitrogen content, as feces production would be higher, therefore, in the present study relation between forage organic matter digestibility and fecal nitrogen concentration was found only for cool-season annual forages (R^2 = 0.82, Table 3).

Oliveira et al. (2007) found R^2 values = 0.24 and 0.020 between fecal nitrogen content (g/kg OM) and organic matter digestibility in data compiled from eight *in vivo* digestibility experiments with sheep at *ad libitum* intake and from another *in vivo* digestibility experiment at different intake levels of a single type of diet. David et al. (2008) obtained an R^2 value = 0.07 for sheep fed different ryegrass allowances.

The low accuracy of the digestibility estimated using fecal nitrogen content determined in the present study and by the aforementioned authors is possibly caused by the inaccureted fit of linear regression models since relationship between fecal CP concentration and OM digestibility is not linear (Lukas et al., 2005). Variation of animals feed intake also increased variability in fecal nitrogen excretion, leading to a low relationship between organic matter digestibility and fecal nitrogen content, as the two basic assumptions of using fecal nitrogen as an indicator are acting simultaneously.

The reliability of the fecal nitrogen method depends on the number of observations in the *in vivo* digestibility studies, as well as on the applied regression model. Boval et al. (2003) used an inverse and quadratic function to describe the relation between forage OMD and fecal N content, whereas Lukas et al. (2005) observed that a factorial exponential model was more accurate to predict OMD than inverse and quadratic models.

Table 8
Comparison between estimated (by the Wang et al., 2009 equation) and observed organic matter digestibility in sheep using mean square prediction error (MSPE) and mean prediction error (MPE) methods (Rook et al., 1990).

Groups	OM digestibility		MPE	Proportion of MSPE		
	Estimated	Observed		Mean bias	Line bias	Random variation
Digestibility	All forages					
	0.593	0.593	0.0238	0	0.023	0.977
	Intermediate digestibility forage					
	0.555	0.555	0.0130	0	0.140	0.860
	High digestibility forages					
	0.660	0.659	0.0193	0.003	0.010	0.987
Forage type	Straws					
	0.467	0.467	0.0207	0	0.085	0.915
	Grass hays and silages					
	0.596	0.596	0.0184	0	0.069	0.931
	Mixtures of hay species					
	0.592	0.592	0.00646	0	0.181	0.819
	All forages except silages					
	0.592	0.592	0.0237	0	0.034	0.966
	All forages except legumes					
	0.577	0.577	0.0281	0	0.026	0.974
Production cycle	Cool-season annual forages					
	0.569	0.569	0.00742	0	0.065	0.935

Ospina and Prates (2000), using 161 individual organic matter digestibility observations in forages consumed by sheep in the state of Rio Grande do Sul, fitted organic matter digestibility (OMD) and fecal nitrogen (FNg/kgOM) data to an hyperbolic model type $Y = a + b/X$, generating the equation: OMD = 0.8163 − 0.4097/FN (R^2 = 0.73; SEE = 0.044). The estimates obtained with this equation were shown to be accurate for the estimation of organic matter digestibility, suggesting its possible utilization under practical conditions.

The equation OMD = 0.7236 − 0.3598 exp [(−0.9052 CP (g/kg OM))/100] estimates the OMD with good prediction. The difference between estimated and observed OM digestibility was mainly caused by random variation of the equation (0.9765 of MSPE), indicating that the equation developed can be used quite accurately to estimate the OMD of forage ingested by ruminants in Rio Grande do Sul.

In the equations obtained by forage groups, the mean bias between estimated and observed organic matter digestibility was low ranging for −0.28E−0.5 to 0.00107, and the residual variation of the differences between estimated and observed OM digestibility was also mainly caused by random variation of the equation (0.8188–0.9871 of MSPE), whereas the contribution of the mean bias and the deviation of the slope were relatively low. The mean prediction error (MPE) in forage groups was also low (0.0065–0.028), indicating that these equations for each group of forage can also be used with high accuracy for predicting the organic matter digestibility of forages.

Wang et al. (2009) using data obtained from *in vivo* digestibility trials (721 observations of nine types of diets) with sheep, found that the estimated parameters in the equation were significant ($P<0.05$), and there was no random effect of type of diet. The mean prediction error was low (0.071) and the difference between estimated and observed OMD was mainly caused by random variation (0.899), which indicated that the equation was suitable to predict the OMD of forage ingested by sheep grazing on heterogeneous pasture.

The equations obtained in the present study were better in relation to aforementioned authors, due to the greater variability in the digestibility data used in this work, including different types of forage with digestibility and production cycle with enough variation, grown in Rio Grande do Sul and used for sheep.

Therefore, the general equation, obtained with all forages can be used with great precision to estimate organic matter digestibility of forage ingested by sheep in Rio Grande do Sul conditions.

5. Conclusions

Fecal nitrogen excretion (g/d) and fecal nitrogen content (g/kg OM) can provide high-accuracy estimates of forage intake and digestibility in sheep.

The linear regression model was adequate to estimate forage intake, whereas the non-linear regression model gave better estimate of digestibility of forages used to feed grazing sheep in the state of Rio Grande do Sul.

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