Predicting of Maximum Forage Intake Capacity in Cattle from Degradability Characteristics, Passage Rate and Rumen Pool Size of NDF

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Abstract

An experiment (5 x 5 Latin Square) was conducted to estimate the physical fill of tropical forages and maximum intake capacity of five mature non-pregnant crossbred dairy heifers kept under zero grazing system. Five (5) forages [Brachiaria brizantha hay (BH), Maize (Zea mays) silage (MS), Lucerne (Medicago sativa) hay (LH), Lucerne and grass hay (LGH) and urea-treated rice straw (UTRS)] were used. The forages were fed as sole diets ad libitum with only minerals and vitamins supplements. Water was provided all the time and measured daily. Voluntary feed intake (VFI) and faecal output were measured for seven days. Degradability characteristics were obtained in situ using the nylon bag technique. Rumen pool size of NDF was measured by rumen evacuation technique. Passage rates were calculated based on faecal output and rumen pool size of NDF. There was a marked difference ($P<0.0001$) between the rate and extent at which NDF for tropical forages was degraded. The rate of passage (% h^{-1}) was different ($P<0.03$) between forage diets with values ranging from 1.4 to 1.8 for MS and UTRS, respectively. Rumen pool sizes of NDF were different ($P<0.01$) between forage diets and weighed 4.8, 3.8, 4.7, 5.2 and 4.5 kg for BH, MS, LH, LGH and UTRS, respectively. Fill (days) also varied between forage diets and ranged from 1.4 for UTRS to 1.8 for MS. The intake capacity of animals for NDF were different ($P<0.01$), highest in animals fed LGH (5.0 kg d^{-1}) and lowest in animals fed MS (3.1 kg d^{-1}). Using predicted NDF intake (PNDFI) based on NDF degradability characteristics and passage rates derived from faecal output and rumen pool size of NDF, good prediction of dry matter intake was obtained ($R^2 = 0.70$). It was concluded that a system of describing the physical fill of NDF in tropical forages could be used to predict VFI in cattle.

Key words: *Prediction of intake, tropical forages, NDF kinetics.*

Introduction

Forage contributes a substantial proportion of energy intake in dairy cattle. Knowledge of the amount of forage that an animal can consume is a fundamental aspect of nutrition since it accounts for the inputs of all nutrients that determine the efficiency of livestock production. This information can be obtained by either actual measurements of VFI or by use of prediction models.

Prediction of VFI using degradability characteristics (Shem *et al.*, 1995) and assumed rumen DM pool of 9 kg and passage rate of 1% h^{-1} (Kimambo *et al.*, 1994) has been reported. Work done by Kimambo *et al.* (1996) that measured rumen pool size of DM in steers was rather inconclusive because intake was carried out in different animals (heifers) and therefore it was not possible to test the precision of the estimates. Further work by Mgheni *et al.* (1998) measured rumen pool of DM and degradability characteristics as predictors of VFI in heifers was limited by the fact that rumen DM pool includes a

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microbial fraction and a constant passage rate of 2 % h^{-1} used to calculate fill values led to poor correlation (R^2 = 0. 28). This was due to high associated with rumen digesta. In this study, measured passage rates and rumen pool size of NDF (Stensig *et al.*, 1994b) and Fill (days) (Madsen *et al.*, 1994) were used as predictors of VFI as NDF is distinct from microbial matter. This is likely to improve the precision of the VFI prediction models. In this study, Fill (days) is considered to be the average rumen NDF content expressed as a proportion of daily NDF intake.

Materials and methods

Animals and experimental design

Voluntary dry matter intake (VDMI) of five forages was measured in five rumen fistulated mature non-pregnant cross- bred heifers weighing 268 ± 6 kg in a 5 x 5 Latin Square. Five forage based diets formed five treatments namely, T1=*Brachiaria brizantha* hay (BH), T2 = Lucerne (*Medicago sativa)* hay (LH), T3= Lucerne/grass mixture hay (LGH), T4 = Maize (*Zea mays)* silage (MS) and T5 = Rice (*Oryza sativa* var. SUPA) straw, that was urea treated (UTRS) as described by Mgheni *et al.* (1993). The experiment lasted for 30 days including 14 days of preliminary period. The animals were weighed three times at the beginning of the preliminary period (Day 1 to 3) and the average was the initial body weight.

Feeding protocol

The animals were fed *ad libitum.* Chopping of the feeds (10-15 cm) was carried out to minimise selection but not too fine to affect digestibility. Minerals and vitamins were provided sufficient for optimum microbial activity (ARC, 1990). This was to establish maximum quantity of the forage that could be eaten by the animal when fed *ad libitum* as a sole diet. Hence the animals were fed individually *ad libitum.* Feeding was adjusted everyday using the previous day level of intake to be 10-15% in excess of the *ad libitum* intake to avoid selective feeding. Fresh feeds were provided twice per day at 0900 and 1500 h. All feeds and refusals were weighed daily, sampled, and prepared for subsequent analyses. Determination of DM was carried out everyday in both feeds and refusals. Water intake was measured daily by water flow meters that were connected to the main water supply lines for each stall and connected to automatic drinkers. The amount of water was recorded everyday before morning feeding time.

In situ NDF degradability characteristics

Degradability characteristics of the five forages were determined in situ using the nylon bag technique (Mgheni *et al.*, 1996). The study was also carried out simultaneously with actual intake study. The feed samples were incubated on Day 15 and taken out before rumen evacuations started. Feeding regime and water supply were therefore similar to the intake experiment. Samples were air dried and milled to pass through a 2.5 mm screen. Rumen incubation time of 0, 2, 4, 8, 16, 24, 48, 96, 144, and 192 h were used to develop degradation profiles. Approx. 1 g of each sample was incubated into nylon bags (measuring 7.5 x 10 cm and pore size 36 μ) per animal in each incubation time for DM degradation. All bags were inserted at the same time during morning feeding time of Day 15 and taken out as scheduled. The samples were rinsed and frozen to arrest microbial activity. After the longest incubation time (192 h) all samples were machine washed in cold water for 20 min and stored for subsequent analysis of NDF according to the procedure described by Van Soest *et al.* (1991).

Measure of NDF pool size

The rumen pool size of NDF was measured by complete evacuation of rumen contents as described by Stensig *et* (1994b). Evacuation was done on Day 24 at 1700 h (evening), on Day 27 at 0700 h (morning) and on Day 29 at 1300 h (mid-day). Minimum time interval of 48 h was allowed to avoid any effect that might occur on subsequent measurements. The rumen mat was removed from the rumen manually by hand and the material not removable by hand was removed by scooping with a cup that is small enough to pass through the rumen fistula. The mat fraction was separated from the available liquid and both fractions weighed. About one litre of the liquid was sampled and the rest immediately returned to the rumen to avoid nutrient losses that may affect microbial activity. The mat was weighed and thoroughly mixed in a big pot and about 5% by weight sampled and the rest returned into the rumen immediately. The two samples were

composited into their proportional weights to form two samples of 500 g each of the rumen digesta and the remaining portions returned into the rumen. The samples were oven dried at 60°C to constant weight to determine DM and for subsequent analysis. The procedure was repeated for 3 days.

Chemical analysis

Dry matter (DM), ash and nitrogen in feeds (Macro-Kjeldahl) analyses were carried out using the procedure as outlined by the AOAC (1990). The NDF contents in feeds, rumen contents, faeces and residues from *in situ* nylon bag and long incubation for 30 days was determined according to the procedures described by Van Soest *et al.* (1991).

Calculations

Calculation of rumen degradability characteristics

Rumen degradability characteristics (RDC) of NDF for forage samples were calculated using the exponential equation by Ørskov and McDonald (1979) with lag time as suggested by Dhanoa (1988): $Y(t) = a$ for $t \leq t_{oo}$

$$Y(t) = a + b\,(1 - e^{-c\,(t-t_0)}) \text{ for } t > t \quad \text{.....(Model 1)}$$

where,

$Y(t)$	=	the degraded feed fraction at time t.
a	=	soluble feed fraction (the intercept) for DM. For NDF it will be near zero, as NDF is not soluble in water.
b	=	insoluble but potentially degradable fraction.
c	=	rate constant (h^{-1}).
t	=	incubation time (h).
t_0	=	lag time (h).

The parameters were estimated by PROC NLIN (SAS, 1996). Parameters of all the models where lag time was included were bound only to accept $t_0 \geq 0$.

Calculation of passage rate ($k_p h^{-1}$)

$$(k_p h^{-1}) = \frac{\text{NDF faecal output (kg / 24 h)}}{\text{Rumen pool size of NDF in kg}} \quad \text{(Model 2)}$$

Calculation of physical fill

Fill (day) was calculated based on the RDCs and passage rates in the following equation:

$$Fill = \frac{1-a}{k_p} \times \left(1 - e^{-kt_0}\right) + \frac{1-a-b}{k_p} \times e^{-kt_0} + \frac{b}{c+k_p} \times e^{-kt_0}$$

.....(Model 3)

where, *Fill* divided by 24 is the physical fill with the unit (day), ***a***, ***b***, ***c***, and t_o were parameters from Model 1, k_p is the passage rate (h^{-1}) obtained from Model 2.

Prediction of intake

Predicted NDF intake (PNDFI) of feedstuff ascribed to a limitation of the physical capacity of the reticulo-rumen and corrected microbial matter was calculated as:

$$\text{PNDFI (kg d}^{-1}) = \frac{\text{Rumen pool size of NDF (kg)}}{\text{Fill (day)}} \quad \text{.....(Model 4)}$$

Finally the potential DM intake (PDMI) of the forages assuming physical limitation and corrected microbial matter was predicted as:

$$\text{PDMI (kg d}^{-1}) = \frac{1}{\text{NDF in the forage DM}} * \text{PNDFI. (Model 5)}$$

where, PNDFI = predicted NDF intake by Model 4

Statistical analysis

Statistical analysis was executed by the General Linear Model (GLM) of SAS (1996) to test the differences between forage diets in all the parameters measured. The difference between treatments least square means was compared by PDIFF of the same software (GLM).

Results

Chemical composition

The chemical composition of all the forages is given in Table 1. As expected all nutrients concentration analysed varied substantially among the forages studied.

Table 1. Chemical composition of tropical forages used in the experiment[1]

Type of feedstuff	Feed DM as fed (g kg^{-1})	On DM basis (g kg^{-1} DM)		
		Ash	CP	NDF
Forages:				
Brachiaria brizantha hay (BH)	819	93	64	748
Maize (*Zea mays*) silage (MS)	222	101	63	737
Lucerne (*Medicago sativa*) hay (LH)	815	110	151	615
Lucerne /grass hay (LGH)	817	116	111	750
Urea-treated rice (*Oryza sativa*) straw (UTRS)	784	180	74	770

[1]In this and subsequent tables and figures, **DM** = Dry matter, **CP**= Crude protein, **NDF**= Neutral detergent fibre, Digestible NDF= **DNDF, INDF**,= Indigestible NDF, **N** = Nitrogen, **NA** = not analysed, **BH** =*Brachiaria brizantha* hay, **MS** = Maize silage, **LH** = Lucerne hay, **LGH** = Lucerne grass mixture hay, and **UTRS** = Urea-treated rice straw.

Intake and in vivo digestibility of feed components

Table 2 gives the intake of total DM, OM and protein and the forage intake of the same feed fractions including the NDF. Apparent digestibility coefficients and water intake are also given in Table 2. There were differences ($P<$ 0.01) in total DM intake (TDMI) and forage DM intake (FDMI) between the sole forage diets. The MS was consumed the least (4.2 kg d^{-1}), whereas LGH was consumed the highest (6.7 kg d^{-1}) amount. The total OM intake (TOMI), forage OM intake (FOMI) and forage NDF were significantly ($P<$ 0.01) different between the forage diets. The crude protein (CP) intake and water intake were also different ($P<0.0001$) between the forage diets. The extent at which the forages were digested (*in vivo*) in the sole forage diets was different for OM ($P<$ 0.03) and not different ($P>0.32$) for NDF between forages diets.

Table 2. Feed and water intake, OM and NDF digestibility by dairy heifers

	Diet					SEM	*P*-value forage
	BH	MS	LH	LGH	UTRS		
Intake							
Total DM[1] (kg d^{-1})	5.10^{b}	4.20^{c}	6.52^{a}	6.70^{a}	6.34^{ab}	0.46	0.0093
Total OM[1] (kg d^{-1})	4.60^{bc}	3.75^{c}	5.79^{ab}	5.91^{a}	5.17^{ab}	0.40	0.0143
Forage DM (kg d^{-1})	5.06^{b}	4.16^{c}	6.48^{a}	6.66^{a}	6.31^{ab}	0.46	0.0093
Forage OM (kg d^{-1})	4.59^{bc}	3.73^{c}	5.77^{ab}	5.89^{a}	5.16^{ab}	0.40	0.0143
Forage NDF (kg d^{-1})	3.79^{b}	3.06^{b}	4.02^{a}	5.00^{a}	4.86^{a}	0.35	0.0106
Forage CP (kg d^{-1})	0.32^{cd}	0.26^{d}	0.98^{a}	0.74^{b}	0.47^{c}	0.06	0.0001
Water intake (l d^{-1})	21.7^{b}	10.1^{c}	29.9^{a}	30.5^{a}	22.6^{b}	1.7	0.0001
Digestibility: (%)							
OM	56.3^{bc}	60.6^{ab}	62.9^{a}	55.7^{c}	60.2^{abc}	1.5	0.0260
NDF	54.6	61.2	57.7	59.4	60.6	2.3	0.3181

[abc]Means within rows with different superscript are significantly different (P<0.05).
[1]Minerals and vitamins DM intake were 0.0368 kg d^{-1} for all diets

In situ rumen degradability

Table 3 gives the values for the forage rumen degradability characteristics (RDCs). Between forages, there was a marked difference in the rate ($P<$ 0.005) and extent ($P<$ 0.0004) at which these forages were degraded. The lag time was observed in some forage but not different ($P>0.05$) between forages. Fig. 1 illustrates the degradability profile of NDF and proves the assumption that NDF for the degradability constant "**a**" is near zero, as NDF is not soluble in water as assumed in Model 1.

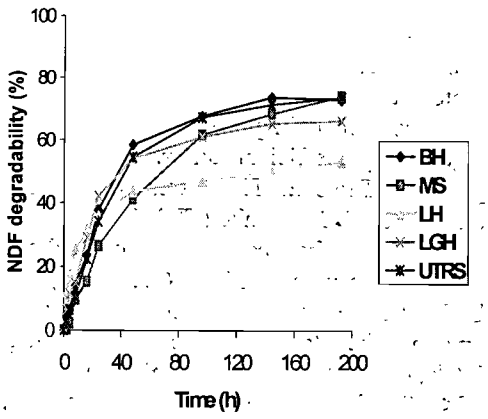

Fig. 1: Degradability profile of NDF for tropical forages incubated in four forage diets

Table 3. Degradability constants of neutral detergent fibre (NDF) for tropical forages incubated in five forage diets

Diet	Degradability constants			Lag time (h)
	Type of forage incubated	b (% DM)	c (% h^{-1})	
BH	BH	69.9[a]	3.8[bc]	2.39
MS	MS	76.1[b]	2.0[c]	3.26
LH	LH	49.9[c]	6.9[a]	0.00
LGH	LGH	61.7[a]	5.0[ab]	1.25
UTRS	UTRS	70.3[a]	3.2[bc]	2.70
SEM		2.8	0.7	0.82
P-value diet		0.0004	0.0051	0.11

[abc]Means within columns with different superscript are significantly different (P<0.05).

Rumen pool sizes

Least square means of rumen pool sizes of total wet digesta, its DM content, dry digesta, NDF, digestible NDF (DNDF) and indigestible NDF (INDF) as a mean of the three evacuations are shown in Table 4. The pool sizes of wet digesta, DM and NDF were higher in animals fed LGH and UTRS and lowest in MS forage diet. Animals fed on LH had the highest INDF pool followed by those fed UTRS, BH and LGH and lowest in those fed on MS. Animals fed LGH had the highest pool size of NDF, followed by those fed on BH, LH and UTRS and lowest in those fed on MS. There was no significant difference (P>0.05) in NDF pool between the animals fed on LGH, BH, LH and UTRS. The difference observed was only between pool sizes of NDF in fed on MS and those on other forage diets. Animals fed on LH had the least DNDF pool, and those fed on BH showed the highest DNDF pool, whereas LGH was close to LH, followed by MS and UTRS that had the lowest pool size of DNDF. Approximately more than 50 % of the rumen pool size of NDF in animals fed on LH was indigestible.

Table 4. Intake for NDF fractions, rumen pool sizes, and faecal output determined in five forage diets

Parameter	Diet					SEM	*P*-value diet
	BH	MS	LH	LGH	UTRS		
Intake (kg d^{-1})							
NDF	3.79[b]	3.06[b]	4.02[ab]	5.00[a]	4.86[a]	0.35	0.0106
[1]DNDF	3.22[a]	2.63[b]	2.95[a]	3.90[a]	4.62[a]	0.30	0.0043
[2]INDF	0.58[b]	0.43[bc]	1.06[a]	1.10[a]	0.24[c]	0.07	0.0001
Mean rumen pool sizes (kg) of:							
Wet digesta	48.7[ab]	43.3[b]	51.8[ab]	59.5[c]	53.0[a]	2.1	0.0020
DM content (%)	13.1[a]	11.3[b]	11.9[b]	11.8[b]	13.3[a]	0.3	0.0040
Dry digesta	6.3[a]	4.9[b]	6.2[a]	7.1[a]	7.1[a]	0.3	0.0010
NDF	4.8[a]	3.8[b]	4.7[a]	5.2[a]	4.5[ab]	0.2	0.0123
DNDF	3.9[a]	3.2[bc]	2.0[d]	2.9[c]	3.6[bc]	0.2	0.0001
INDF	1.0[a]	0.6[a]	2.7[b]	2.3[c]	0.8[a]	0.1	0.0001
Faecal output (kg d^{-1}):							
NDF	1.73[a]	1.20[b]	1.67[a]	2.01[a]	1.88[a]	0.12	0.0019
DDNF	1.16[b]	0.77[c]	0.61[d]	0.91[bc]	1.65[a]	0.10	0.0001
[3]INDF	0.58[b]	0.43[bc]	1.06[a]	1.10[a]	0.24[c]	0.07	0.0001

[abc]Means within rows with different superscript are significantly different (P<0.05).
[1]DNDF = Digestible NDF.

[2]INDF = Indigestible NDF was determined by long time (30 days) nylon bag incubation *in vivo*.
[3]INDF = Assumed that INDF intake is equal to faecal output INDF as INDF is not digestible and rate of digestion is therefore zero.

Table 5. Derived NDF kinetics (% h^{-1}) and calculated Fill (day) of animals fed on different tropical forage diets

Parameter	Diet					SEM	*P*-value diet
	BH	MS	LH	LGH	UTRS		
Derived NDF kinetics (% h^{-1}):							
Rate of intake (k_i):							
NDF	3.47	3.65	3.69	4.11	4.58	0.34	0.2024
DNDF	3.66^{b}	3.77^{b}	6.87^{a}	5.77^{a}	5.38^{ab}	0.66	0.0220
[1]INDF	2.70^{b}	3.48^{a}	1.64^{c}	2.06^{bc}	1.17^{c}	0.23	0.0001
Rate of passage (k_p):							
NDF	1.54^{ab}	1.36^{b}	1.53^{b}	1.63^{ab}	1.78^{a}	0.08	0.0323
DNDF	1.28^{b}	1.04^{b}	1.41^{b}	1.30^{b}	1.93^{a}	0.13	0.0058
INDF	2.70^{b}	3.48^{a}	1.64^{c}	2.06^{bc}	1.17^{c}	0.23	0.0001
Rate of digestion (k_d):							
NDF (k_d)	1.93	2.29	2.16	2.16	2.80	0.29	0.3143
DNDF (k_d)	2.37^{c}	2.74^{b}	5.46^{a}	4.46^{ab}	3.46^{b}	0.60	0.0192
c NDF (*in situ*)	3.8^{bc}	2.0^{c}	6.9^{a}	5.0^{ab}	3.2^{bc}	0.7	0.0051
Calculated Fill (day):							
[2]Fill-1	1.55^{ab}	1.84^{a}	1.77^{a}	1.41^{b}	1.35^{b}	0.12	0.0400
[3]Fill-2	1.25	1.38	1.35	1.20	1.23	0.07	0.3400

[abc]Means within rows with different superscript are significantly different (P<0.05).
[1]INDF rate of intake is in theory, equal to INDF rate of passage (See Table 4)
[2]Fill - 1 = Fill (day) calculated from k_p estimated from rumen evacuation technique (RET) using derived k_p for total-NDF.
[3]Fill - 2 = Fill (day) calculated using an assumed passage rate (k_p) of 2 % h^{-1}

Derived NDF kinetics

The passage and digestion rates are given in Table 5. The passage rates (k_p) for the forages were different (P<0.03) between the forage diets for total-NDF, for DNDF (P<0.01) and for INDF (P<0.0001). The rate of digestion (k_d) of NDF and DNDF derived from NDF kinetics were lower than those obtained from direct method *in situ* (Table 3) but highly comparable (Table 3 and 5).

Physical fill in the rumen

The physical fill of the forages given with the unit Fill (days) is given in Table 5. The results showed significant differences (P<0.04) in Fill (days) between the different forages when calculated using passage rate obtained using rumen evacuation technique-total NDF (RET-total NDF), whereas Fill (days) calculated using a constant passage rate of 2 % h^{-1} did not show any difference (P>0.05) between the forage diets.

Predicted intake

The predicted NDF intake (PNDFI) using rumen pool size of NDF (kg) and Fill (days) estimated using passage rates measured either by using RET or a constant weight of 2 % h^{-1} is given in Table 6. Measured NDF intakes for different forages are also given for comparison. The PNDFI across forages were under-estimated when passage rate obtained from RET was used to calculate Fill except for UTRS. Table 6 also gives the predicted DM intake (PDMI) of the forages estimated from the PNDFI (Models 4 and 5). Similar trend to that obtained for PNDFI was observed for PDMI for all forage diets. The accuracy of predicting DM intake from PNDFI from NDF parameters and measured passage rates tested by simple regression analysis and their linear relationships are given in Table 7. The best relationship (R^2 = 0.70) was obtained when DM intake was predicted using pool size of NDF and Fill calculated from RET-total NDF (P<0.0001),

whereas poor relationship (R^2 =0.36) was obtained when a constant passage rate of 2 % h^{-1} was used. The predicted values were calibrated using the measured values in the equation **DMI (kg d^{-1}) = 1.19 + 1.1 PDMI ± 0.83 RMSE,** when passage rates from RET-total NDF was used and **DMI (kg d^{-1}) = 2.59 + 0.63 PDMI ± 1.21 RMSE** when a constant passage rate of 2 % h^{-1} was used.

Table 6. Predicted NDF intake (PNDFI) in (kgd^{-1}) estimated from rumen pool sizes of NDF and Fill calculated from passage rates (k) measured using rumen evacuation technique (RET) and assumed passage rate of 2 % h^{-1}

PNDFI (kg d^{-1})	Diet					SEM	R^2	*P*-value diet
	BH	MS	LH	LGH	UTRS			
Predicted NDFI:								
MNDFI[1]	3.79[b]	3.06[b]	4.02[a]	5.00[a]	4.86[a]	0.35	0.75	0.011
PNDFI[2] (RET) Total-NDF	3.12[ab]	2.09[c]	2.75[b]	3.65[a]	3.32[ab]	0.22	0.83	0.005
PNDFI[3] **k = 2% h^{-1}**	3.81[ab]	2.78[c]	3.57[b]	4.29[a]	3.63[b]	0.21	0.89	0.111
Predicted DMI:								
MDMI[4]	5.06[b]	4.16[c]	6.48[a]	6.66[a]	6.31[ab]	0.46	0.76	0.009
PDMI[5] (RET) Total-NDF	4.16[a]	2.85[b]	4.44[a]	4.86[a]	4.32[a]	0.28	0.84	0.003
PDMI[6] **k = 2% h^{-1}**	5.07[ab]	3.79[c]	5.78[a]	5.72[a]	4.73[b]	0.25	0.92	0.001

[ab]Means within rows with different superscript are significantly different (P<0.05).
[*1]Measured or actual NDFI as given in Table 2 for comparison
[2]Predicted NDF intake using Fill calculated from k_p estimated from rumen evacuation technique (RET) -total NDF.
[3]Predicted NDF intake using Fill calculated from assumed k_p of 2% h^{-1}.
[4]Measured or actual DMI as given in Table 2 for comparison
[5]Predicted DM intake using Fill calculated from k_p estimated from rumen evacuation technique (RET) -total NDF.
[6]Predicted DM intake using Fill calculated from assumed k_p of 2% h^{-1}.

Table 7. The accuracy of predicting forage DM intake (FDMI) using rumen pool size of NDF and Fill calculated from passage rates estimated using rumen evacuation technique (RET) and assumed passage rate of 2 % h^{-1}

PFDMI from:	Equation	R^2	RMSE	SE of estimate[1]		P>value	
				β	α	β	α
Fill-1	**DMI (kg d^{-1}) = 1.19 + 1.10X**	**0.70**	**0.83**	**0.15**	**0.64**	**0.0001**	**0.079**
Fill-2	**DMI (kg d^{-1}) = 2.59 + 0.63X**	**0.36**	**1.21**	**0.17**	**0.91**	**0.002**	**0.009**

Fill - 1 = Fill (days) calculated from k_p estimated from rumen evacuation technique (RET) -total NDF.
Fill - 2 = Fill (days) calculated using an assumed passage rate (k_p) of 2 % h^{-1}.
[1] The symbols β and α are the coefficients of regression and the intercept respectively, whereas X is the predicted dry matter intake.

Discussion

Apparent digestibility coefficients

The apparent digestibility coefficients showed high variations between forage diets (Table 2) for OM digestibility (OMD) of 7 % units and NDF digestibility (NDFD) of 6 % units. Such results suggest that if the energy value of tropical forages is to be estimated correctly then it is necessary to estimate each of the forage separately as routine analysis to be included in the Feed Tables and/or development of Feeding Systems. The OMD is preferred to DMD because of variations in ash content in tropical forages (Table 1). The digestibility coefficients of OM and NDF obtained in this study, are close to those reported by Tuen *et al.* (1991) by goats at 85 % *ad libitum*. The little difference observed, therefore may suggest differences in animal species, level of feeding and variations between rice straws varieties and other forage species.

Rumen degradability characteristics of NDF

The observed variability between forages on rumen degradability characteristics (RDCs) of NDF could be due to differences in chemical composition, particularly CP and NDF (Table 1). High CP favours microbial protein synthesis, whereas high NDF (depending on the degree of lignification) decrease the extent and rate at which the NDF is degraded in the rumen (Table 2 and 3). Variation in RDCs between forages has been reported in the tropics (Kimambo *et al.*, 1994; Shem *et al.*, 1995; Mgheni *et al.*, 1996) and in the temperate (Stensig *et al.*, 1994a). The problem of microbial contamination in the present study was not observed in the RDCs for NDF as reported for DM and N by Mgheni *et al.* (1998), suggesting that the NDF solution removed microbial and endogenous materials. Similar findings were reported by Stensig *et al.* (1994a) who reported that the NDF fraction is preferred for the estimation of RDCs for calculation of physical fill because it is distinct from microbial and endogenous material.

Passage rates

Variation in the passage rates observed for the different forages was possibly due to various reasons. Passage rates increase with increased level of feeding, the extent and rate of digestibility. The higher the level of feeding the higher the passage rates and vice versa. Forages that are digested at faster rates, were degraded and passed out of the rumen at a faster rate (Table 3) than those degraded or passed at a slower rate. Of interest to note here was the exceptionally higher passage rate of UTRS than other forages (Table 5). This trend could be caused by high silica content in rice straw (Mgheni *et al.*, 1993). Silica is a heavy element that will always have the tendency of sinking down through the rumen mat into the reticulum or cranial sac where passage is facilitated. Review by Van Soest (1994) showed that high silica content in forages reduce NDF digestibility. This can be explained by the fact that silica has high specific gravity that accelerates passage of digesta out of the rumen and results in reduced NDF digestibility.

The differences in passage rates found in these forage diets (Table 5) suggest that it is important to estimate the passage rates accurately for each individual forage if the parameter is to be used to calculate Fill (day) as a predictor of DMI (Models 3, 4 and 5). Passage rates derived from parameters obtained from RET is closer to the "true " passage rate than that obtained by using a constant passage rate of 2 % h^{-1}. The values obtained in the present study, however, are lower than those reported by Shem *et al.* (1995) and Mgheni *et al.* (2002) when passage rates for tropical forages were estimated using chromium-mordanted fibre. The values are also lower than those assumed by other feed evaluation systems (Jarrige *et al.*, 1986; ARC, 1990; Madsen *et al.*, 1995).

Rumen pool sizes

Feeds can also be described in terms of their pool sizes in the rumen. Although rumen pool size of NDF can also be animal characteristics as described by Mould *et al.* (1982), the greatest variation was observed between forages (Table 4). The difference in pool size of NDF was related to the level of intake. It was highest in LGH, which had also the highest intake of NDF (Table 2) and lowest in MS that had the lowest intake (Table 2). This high pool size of LGH relative to other forages can be explained by high intake of this forage compared to other forages (Table 2). Similarly low pool size of MS can also be related to the level of intake caused by sub-optimal quality of MS. Less optimal preservation

method caused by high water content (Table 1) and probably high heat condition in the silo produced silage of low quality and resulted into low intake, that consequently lowered the rumen pool size. Low intake observed in BH and MS forage based diets can also be explained by low CP contents (Table1). Forages of less than 70 g kg^{-1} DM depress intake due to physical limitation in the reticulorumen (Madsen *et al.*, 1994). In this study, INDF (Table 4) creates further a physical limitations to intake until when it is passed out of the rumen.

Physical fill

The major objective of this study was to describe tropical feeds in terms of their physical fill. The calculated Fill (days) using passage rates obtained from RET methods and assumed passage rate of 2 % h^{-1} (Table 6) was quite variable between forages due to differences observed in RDCs (Table 3) and passage rates (Table 5). A small change in RDCs and passage rates showed a big change in Fill (days) values ascribed to each forage. The accuracy of Fill (days) value therefore depend on the accuracy of estimated RDCs and passage rates and hence the importance of estimating each parameter in order to make the prediction model as accurate as possible.

Physical fill can be understood as mean retention time of NDF in the rumen. Hence the higher the fill the more the rumen is going to be occupied and give no room for more intake by the animal. However, intake will depend on the rate of digestion and passage of the feed. This may imply that high fill is an indication of high feed intake as in the case of LH and low intake as in the case of MS (Table 5). This may suggest other reasons limiting intake other than physical fill. Hence, fill is equal to the average rumen NDF content expressed as a proportion of daily NDF intake and therefore equal to maximum daily intake that express a physical limitation in VFI. Similar suggestions have been made by Madsen *et al.* (1994). This may support the reasons why physical limitations of feed intake have been accepted as a major parameter in various feed evaluation systems in France (Jarrige *at al.*, 1986) and Nordic countries (Madsen *et al.*, 1995).

Intake parameters

Variability in feed intake of different forage diets has in this study, been attributed to physical limitations caused by digestion and passage rates that give variation in the physical fill. However, it has been difficult to use a single parameter to explain differences obtained in intake. For practical purposes it has been necessary to study those parameters believed to mostly limit VFI under specified feeding situation. Forages used in this study were expected to be eaten to maximum rumen fill for one to assume a physical limitation of VFI. However, due to various feed characteristics the levels achieved were highly variable between the forage diets, even though all forages were fed *ad libitum*. The reason for this variation may be different for each forage diet because of the variations observed in all parameters measured, such as chemical composition, digestibility coefficients, RDCs, digestion and passage rates of NDF fractions.

Prediction of intake

Prediction models on intake have always been different in accuracy and precision depending on the parameters put into the model. In this study, the NDF-total NDF kinetics parameters have been found to have the best relationship when used to predict intake. In feed evaluation the best prediction model is one, which can give the amount of food the animal can consume at an expected level of production with a reasonable degree of accuracy and least error. Accuracy, however, seems to make models more complicated. For example, when the farmer (end user) wants to understand the model, then complicated models can be unpopular to the farmer, but if the farmer wants to understand the outcome of the model then it does not matter how complicated the model is. The goal, therefore, should be to be as precise as possible. The prediction model (Models 4 and 5) used in this study, predicted forage DM intake with variable degree of accuracy. This may suggest that degree

of accuracy with which the variables used to predict VFI were estimated was very important.

The most important parameter in this study was the NDF in the feeds, passage rates and rumen pool sizes of NDF. As shown in Table 8 the standard error of the PDMI was within the acceptable level. This may suggest that if the NDF analysis procedure and passage rates procedure were improved upon for better accuracy the models could also be improved. The parameters can be used to predict voluntary feed intake with an accuracy of R^2 = 0.70 (RMSE = 0.83). This degree of accuracy can be acceptable under small-scale dairy farmers planning for how much forage to feed their animals. For the system to be used in practice, however, it is necessary to have accurate estimates of the important input factors to the model, that is the RDCs, rumen pool size and passage rates of NDF (Stensig *et al.*, 1994 b).

In this study, measured passage rates and constant passage rate of 2 % h^{-1} gave variable degree of accuracy of prediction in terms of the R^2, the root mean square error (RMSE), the intercept and the coefficient of regression (Table 7), and the standard error of difference between treatments means (Table 6). This may suggest that the best model to be used is one that can explain most of the variation in the model (highest R^2) with the least and reasonable errors (RMSE and standard error of estimate of other constants (the intercept and the coefficient of regression). In this study, the prediction model that used the Fill (days) calculated from passage rate estimated from RET- total NDF gave the higher R^2 = 0.70 and least RMSE and standard error of estimate compared to when a constant value of 2 % h^{-1} passage rate was used (R^2 = 0.36). This may suggest that for the system to be used in practice all the inputs to the model have to be measured as accurately as possible and the model obtained cannot be used as a general model but only useful to the condition in which it was developed. Similar findings were reported by Stensig *et al.* (1994 b) using similar techniques, where improved R^2 and low error of estimate were reported for total-NDF compared to when DM parameters were used to predict intake. This may suggest a more precise estimate of the inputs to the model, because NDF parameters were corrected for microbial DM.

Conclusions

The results have shown that the most important limitation to tropical forage intake is the physical fill of NDF in the rumen. Thus, Fill (day) can adequately be used to describe the limitation of intake in tropical forages based on RDCs obtained from the nylon bag technique, rumen pool size and passage rate of NDF measured by rumen evacuation technique. The parameters can be used to predict voluntary feed intake with an accuracy of R^2 = 0.70 (RMSE = 0.83). For practical purposes the predicted values were calibrated using the measured values in the equation DMI (kg d^{-1}) = 1.19 + 1.1 x PDMI when passage rates from RET was used and DMI (kg d^{-1}) = 2.59 + 0.63 x PDMI when a constant passage rate of 2 % h^{-1} was used.

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