

Methods for Determination of Passage Rates of Fibre in Tropical Forages in Mature Non-pregnant Dairy Heifers

¹Mgheni, D.M*, M. R. Weisbjerg², A.E. Kimambo¹, T. Hvelplund², J. Madsen³ and L.A. Mtenga¹

¹Department of Animal Science and Production, Faculty of Agriculture, Sokoine University of Agriculture, P.O. Box 3004, Morogoro, Tanzania.

²Danish Institute of Agricultural Sciences, P.O. Box 50, DK-8830 Tjele, Denmark.

³Department of Animal Science and Health, The Royal Veterinary and Agricultural University, Grønnegårdsvej 2, DK-1870, Frederiksberg C, Denmark

Abstract

Passage rates were estimated *in vivo* using five rumen fistulated non-pregnant dairy heifers. Rumen evacuation technique (RET) and chromium mordanted fibre (CR-MF) method were used to estimate passage rates in 5 x 5 Latin Square experiment. Passage rates measured using CR-MF and RET showed high variability between forages and between the two methods. The passage rates derived from parameters obtained from RET differed ($P < 0.03$) between the forage diets. The values were 1.78, 1.63, 1.54, and 1.36 % h⁻¹ for urea treated rice straw (UTRS), Lucerne/*(Medicago sativa)* grass mixture hay, *Brachiaria brizantha* hay (BH), Lucerne alone (LH) and Maize (*Zea mays*) silage (MS) respectively. The passage rates obtained from CR-MF method were also different ($P < 0.42$) between the forage diets and were 3.24, 2.98, 2.79, 2.56 and 2.26 % h⁻¹ for MS, LH, UTRS, LGH and BH respectively. The values were higher in CR-MF method ranging from 2.26 – 3.24 h⁻¹ compared to those obtained from RET which ranged from 1.36 – 1.78 h⁻¹. The results further showed that the passage rates were estimated with different accuracy when compared with the precision with which the passage rates were used to calculate fill values for prediction of dry matter intake (DMI). Fill values calculated from RET predicted DMI with a precision of $R^2 = 0.70$ compared to $R^2 = 0.46$ obtained from CR-MF. It was concluded that CR-MF give higher values of passage rates in tropical forages than RET method of estimating passage rates and the later method is recommended as it predicted DMI with higher precision.

Keywords: Rumen evacuation technique (RET), chromium mordanted fibre (CR-MF), flow rate

Introduction

Several methods are available for estimating passage rates of fibre. The use of markers to estimate passage rates of fibre using particulate markers such as chromium is the most popular method among the rare earth markers (Uden *et al.*, 1980). In this method the natural log of faecal

marker concentration is plotted against time. Passage rate is then calculated as a coefficient of regression of the linear descending portion of the line (Robinson *et al.*, 1987).

Despite this acceptable mathematical approach, the use of rare earth markers to estimate passage rate of fibre has been criticised by several authors (Uden *et al.*, 1980; Ramazin *et al.*,

*Corresponding author

1991; Stensig *et al.*, 1994). In these and other publications (Ehle, 1984; Stensig *et al.*, 1998) there is a general agreement that there are several criteria for an ideal marker, yet not a single marker has fulfilled all of them. Migration of the rare earth markers from particulate phase to the liquid phase and to other feed particles result into estimation of combined liquid and particles passage rates and not that originally marked. The problem can be avoided or reduced by mordanting the fibre with chromium (Udén *et al.*, 1980; Ehle, 1984). The technique creates a much stronger linkage between the marker and the fibre (Ramazin *et al.*, 1991). The method however, has also some problems such as altering digesta kinetics (Moore *et al.*, 1992) and that concentration of chromium on the fibre affects density and hence the passage characteristics of the marked fibre (Ehle, 1984; Ramazin *et al.*, 1991).

Alternative to markers, passage rate can also be estimated directly *in vivo* using rumen evacuation technique that involves direct measurements of rumen pool sizes in combination with daily rumen outflow and faecal output (Robinson *et al.*, 1987; Stensig *et al.*, 1998). This method (RET) compared to markers, does not alter the particle density and hence likely to give the true values of passage rates. The method, however, requires fistulated animals and hence can limit the number of animals used during the experiment.

In the tropics, assumed passage rates have been used to calculate Fill (day) that is an important input to prediction model of intake (Kimambo *et al.*, 1996) a practice that may lead to inaccurate prediction values. This experiment was conducted to evaluate and compare rumen evacuation technique (RET) and chromium mordanted fibre (CR-MF) methods of estimating passage rates in mature, non-pregnant dairy heifers using sole forage diets.

Materials and methods

Animals, feeding and experimental design

Five rumen fistulated mature non-pregnant heifers (Friesian x Boran) were used in a 5 x 5 Latin Square experiment for 30 days to estimate dry matter intake (DMI), faecal output, passage rates and rumen pool size of Neutral Detergent Fibre (NDF). The first 14 days were used as preliminary period. The animals were fed sole forage

diets and supplemented with 20g of commercial minerals and 20g of vitamin supplements per day to form four diets as:

Diet 1 = *Brachiaria brizantha* hay (BH) =BH

Diet 2 = Maize silage (MS) =MS

Diet 3 = Lucerne hay (LH) =LH

Diet 4 = Lucerne (20%) and grass mixture hay =LGH

Diet 5 = Urea-treated rice straw (UTRS) =UTRS

Measure of dry matter intake (DMI)

Dry matter intake (DMI) was estimated for 7 days after 14 days of preliminary period. Chopping of the feeds was carried out to minimise selection but not too fine to affect the physical structure. The animals were fed individually *ad libitum*. Feeding was adjusted everyday to be 10-15% in excess of the *ad libitum* intake using the previous day level of intake. Fresh feeds were provided twice per day at 0900 and 1500 h. All feeds and orts were weighed daily, sampled and prepared for subsequent analyses. The DM determination was carried out everyday in both feeds and orts. Fresh and clean water was provided from the automatic drinkers all the time.

Preparation of chromium mordanted fibre (CR-MF)

Determination of passage rate was carried out in the same experiment as that of estimating faecal output and intake. Passage rate of NDF was estimated using chromium mordanted fibre (CR-MF) as described by Udén *et al.* (1980). Chromium-mordanted fibre was prepared using a modified method of Udén *et al.* (1980). Air equilibrated sample (0.5 kg) of each forage was washed and drained several times until when the water drained was clear or colourless. Sodium dichromate (355 g) was made into a solution (1 l) and added to the fibre while stirring vigorously. The material was then returned into stainless steel pots covered with distilled hot water to 15 to 20 cm below the top and covered with aluminium foil. The pots were placed in an oven at 105°C for 24 h. After cooling the solution was drained, the pots filled with distilled cold water and repeated several times until when the water drained was clear. Ascorbic acid (500 g) was dissolved in 2 l distilled cold water. All the CR-MF

was poured into a 20 l bucket and filled about half with cold distilled water. Ascorbic acid solution was added and the bucket filled to 10 to 15 cm below the top. The material was stirred vigorously on and off for 1 h. The material was rinsed several times until when the water was clear, with 2 h interval between each rinse. The CR-MF was spread on top of trays covered with aluminium foil and dried in an oven at 60°C until dry. The CR-MF was air - equilibrated before dosing to the animals.

Dosing the animals with CR-MF and measure of faecal output

The animals were dosed once with 120 g of air equilibrated CR-MF on Day 16 of the experiment. The animals were dosed by placing the CR-MF on the cranial sac of the rumen where the food enters the rumen from the oesophagus. Faecal samples were collected 24 h after rumen dose of CR-MF followed by sampling after every 12 h up to 96 h after CR-MF dose (Udén *et al.*, 1980) to monitor the decline of chromium with time. After each collection time, samples were put in polythene bags and stored in a deep freezer (-5°C) before being dried for subsequent analysis.

Measure of rumen pool size of NDF

Rumen pool size of NDF was measured by rumen evacuation method (Stensig *et al.*, 1998) for 3 days during the last seven days of the experiments. Evacuation protocols were such that a minimum time interval of 48 h between two evacuations was allowed to avoid any effect that might occur on subsequent measurements. Rumen evacuations were performed at 1700 h (evening) on Day 24, at 0700 h (morning) on Day 27, and at 1300 h (mid-day) on Day 29. 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 liquid and both fractions weighed. About 1 l of the liquid was sampled and the rest was immediately returned to the rumen. The mat was weighed and thoroughly mixed in a big pot. About 5 % by weight were sampled, and the rest was returned into the rumen immediately. Finally the two samples were composted into their proportional weights of 500 g each of the rumen digesta in duplicate and the left over returned to

their respective animal. The samples were oven dried at 80°C (1st Day) and 60°C (2nd Day) to constant weight to determine DM that was used to calculate the dry digesta (DM pool) from wet digesta. The samples were then ground through a 1.0 mm sieve for subsequent analysis.

In situ determination of indigestible NDF

After termination of the intake, faecal output and NDF rumen pool size experiment, three heifers were fed on *Brachiaria* hay (BH) supplemented with 200 g fishmeal and urea 20 g/100 kg live body weight. After 14 days of preliminary feeding period, determination of indigestible NDF (INDF) was done *in situ* using long time incubation. Approximately 3 g of feed, rumen digesta and faecal samples ground to pass through 2.5 mm sieve were weighed into nylon bags measuring 10 x 20 cm with a pore size of 36 x 36 µm. The bags were incubated into the rumen of three fistulated heifers for 30 days. The bags were removed from the rumen, washed in tap water to remove feed particles then machine-washed in cold water for 20 min. The residues were transferred into a beaker and boiled in 100 ml of NDF solution to remove microbial contamination to obtain the indigestible NDF (INDF) residue. The residue was ashed to obtain ash free INDF that was also used to calculate the digestible NDF (DNDF).

Chemical analysis

Dry matter and ash analysis of the samples was carried out using the procedure as outlined by the AOAC (1990). All the samples analysed for NDF were done according to the methods described by Van Soest *et al.* (1991). Chromium concentration in faeces was extracted according to a modified procedure as described by Jeng and Bergeseth (1992). The samples were dried and ground to pass through a sieve size of 1.0 mm. Samples (3 g) were weighed into clean crucibles and ashed at 450°C for 12 h. The ash was left to cool and 5 ml of concentrated Nitric acid (HNO₃) was added and left to soak for 4-6 h while covered. The residue was transferred into 50 ml volumetric flask and diluted with distilled water up to the 50 ml meniscus mark. The material was then filtered into 50 ml bottles through filter paper (medium speed and average pore size

of 1.4–2.9 μm). Chromium concentration in the filtrate was determined using Atomic Absorption Spectrophotometer (UNICAM 919).

Calculations

Calculation of passage rate using CR-MF

Assuming one compartment model with first order kinetics, chromium concentration can be described using a single exponential equation:

$$Cr_t = Cr_0 e^{-(k_p)t} + \varepsilon_t \quad (\text{Model 1})$$

where, $Cr_t = [\text{Cr}]$ of faeces measured at time t

$Cr_0 = [\text{Cr}]$ at time t_0

$k_p =$ rate constant for $[\text{Cr}]$ decline (h^{-1})

$T_{\text{coll}} =$ time of sample collection (h)

$\varepsilon_t =$ random error term

Model 1 was transformed to a linear relationship by the natural logarithm (\ln) in the model:

$$\ln[Cr_t] = \ln[Cr_0] - kt + \varepsilon_t \quad (\text{Model 2})$$

where, $k =$ passage rate (h^{-1}) and the rest are as Model 1.

Passage rate was then estimated as the regression coefficient (k) using PROC REG (SAS, 1996).

Calculation of rumen pool size of NDF

The rumen pool size of NDF was calculated as: Pool size of NDF (kg) = DM pool in the rumen (kg) X proportion of NDF in the rumen digesta (Model 3)

Calculation of passage rate using rumen evacuation technique (RET)

The kinetics of NDF intake, passage and digestion were calculated using the models presented by Robinson *et al.* (1987). Rates of intake (k_i), passage (k_p) and digestion (k_d) were calculated as:

Rates of intake (k_i):

$$k_i (\text{h}^{-1}) = \frac{\text{NDF intake in kg d}^{-1}/24 \text{ h/day}}{\text{rumen pool size of NDF, kg}} \quad (\text{Model 4})$$

Rate of passage (k_p):

NDF faecal output in $\text{kg d}^{-1}/24 \text{ h/day}$:

$$k_p (\text{h}^{-1}) = \frac{\text{NDF faecal output in kg d}^{-1}/24 \text{ h/day}}{\text{rumen pool size of NDF, kg}} \quad (\text{Model 5})$$

Rate of digestion (k_d):

$$k_d (\text{h}^{-1}) = \frac{\text{NDF intake in kg d}^{-1}/24 \text{ h/day}}{\text{rumen pool size of NDF, kg}} \quad (\text{Model 6})$$

Digestion kinetics for digestible NDF (DNDF)

and indigestible NDF (INDF) were calculated in a similar way (Model 4, 5 and 6).

Calculation of Fill (day) and predicted DMI

Fill (day) and predicted dry matter intake (PDMI) were calculated according to the method described by Mgheni *et al.* (1999). The PDMI values were used to compare passage rates obtained from RET and CR-MF in relation to their ability to explain the accuracy of the model for predicting DMI of forages.

Statistical analysis

The values obtained were subjected to the General Linear Model (GLM) of SAS (1996) to test difference between forages on all the parameters measured. The precision with which the parameters used as input to the prediction model was tested using simple linear regression.

Results

Parameters used in deriving passage rates

Forage NDF content, rumen pool of NDF, DNDF and INDF and faecal output for the same are given in Table 1. The NDF varied from 615–770 g kg^{-1} DM for LH and UTRS respectively. The rumen pool of INDF was found to be lowest in UTRS compared to other forages, whereas LH with the lowest NDF content had the lowest DNDF pool size. The rumen pool size of NDF was found to be high in forages that were consumed in large quantity compared to those forages that were of low intake.

Table 1: Forage dry matter (as fed); Neutral Detergent Fiber (NDF); intake for dry matter (DMI), NDF, digestible NDF, and indigestible NDF; rumen pool sizes and faecal output in tropical forage diets

Diets	Diets					SEM	P-value ¹ /diet
	BH	MS	LH	LGH	UTRS		
Chemical composition:							
DM as fed (g kg ⁻¹),	819	222	815	817	784		
NDF (g kg ⁻¹),	748	737	615	750	770		
Intake:							
DM (kg d ⁻¹),	5.06 ^b	4.16 ^c	6.48 ^a	6.66 ^a	6.31 ^{ab}	0.46	0.0143
NDF (kg d ⁻¹),	3.79 ^b	3.06 ^b	4.02 ^{ab}	5.00 ^a	4.86 ^a	0.35	0.0106
DNDF (kg d ⁻¹),	3.22 ^a	2.63 ^b	2.95 ^a	3.90 ^a	4.62 ^a	0.30	0.0043
INDF ² (kg d ⁻¹),	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:							
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 ^c	0.6 ^c	2.7 ^a	2.3 ^b	0.8 ^c	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
DNDF	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

¹In this and subsequent tables, DM= Dry matter, NDF = Neutral detergent fibre DNDF = Digestible

NDF, INDF=Indigestible NDF, BH= *Brachiaria brizantha* hay, MS=Maize (*Zea mays*) silage,

LH=Lucerne (*Medicago sativa*) hay, LGH=Lucerne grass mixture hay, and UTRS = Urea - treated rice (*Oryza sativa*) straw.

^{abc} Means within rows with different superscript are significantly different ($P < 0.05$).

² INDF was determined by long time (30 days) nylon bag incubation.

³ Assumed that INDF intake is equal to faecal output INDF.

Passage rates either by using CR-MF or RET methods are given in Table 2. The results showed that passage rates measured using CR-MF were higher than the values obtained using RET.

In addition the passage rates measured using CR-MF method and RET did not show any marked pattern or trend in relation to the level of NDF intake.

Table 2: Measured passage rates using CR-MF and derived kinetics for NDF, DNDF and INDF obtained from RET in tropical forage diets

	Diets					SEM	P-value diet
	BH	MS	LH	LGH	UTRS		
Passage rates (% h⁻¹):							
CR-MF ¹	2.26	3.24	2.98	2.56	2.79	0.37	0.4201
Derived NDF kinetics (% h⁻¹)-RET²:							
<i>Rate of intake (kj):</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
INDF ³	2.70 ^b	3.48 ^a	1.64 ^c	2.06 ^{bc}	1.17 ^c	0.23	0.0001
<i>Rate of passage (k_p):</i>							
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
<i>Rate of digestion (k_d):</i>							
NDF (k _d) ⁴	1.93	2.29	2.16	2.16	2.80	0.29	0.3143
DNDF (k _d) ⁵	2.37 ^c	2.74 ^b	5.46 ^a	4.46 ^{ab}	3.46 ^b	0.60	0.0192

^{abc} Means within rows with different superscript are significantly different (P<0.05).

¹ Passage rate estimated using chromium mordanted fibre (CR-MF)

² Passage rate estimated using rumen evacuation technique (RET)

³ Assumed that INDF is not digestible and therefore rate of digestion is zero

Prediction of DMI and calculated Fill (day) values

Table 3 gives calculated Fill (day) estimated from passage rates (k_p) measured using rumen evacuation technique (RET), chromium

mordanted fibre (CR-MF) and assumed passage rate of 2% h⁻¹. Predicted DMI using Fill (day) values calculated from passage rates obtained from either CR-MF or RET is given in Table 4.

Table 3: Calculated Fill (day) estimated from passage rates (k_p) measured using rumen evacuation technique (RET), chromium mordanted fibre (CR-MF) and assumed passage rate of 2% h⁻¹

	Forage diet					SEM	P-value diet
	BH	MS	LH	LGH	UTRS		
MDMI ¹ (kg/day)	5.06 ^b	4.16 ^c	6.48 ^a	6.66 ^a	6.31 ^{ab}	0.46	0.009
¹ Fill-1	1.19	0.99	0.98	1.00	1.08	0.12	0.6839
² Fill-2	1.55 ^{ab}	1.84 ^a	1.77 ^a	1.41 ^b	1.35 ^b	0.12	0.0447
³ Fill-3	1.25	1.50	1.64	1.24	1.74	0.14	0.0992
⁴ Fill-4	1.25	1.38	1.35	1.20	1.23	0.07	0.3364

^{ab} Means within rows with different superscripts are significantly different (P<0.05).

¹ Fill-1 values calculated from k_p estimated from CR-MF.

² Fill-2 Values calculated from k_p estimated from RET- total NDF

³ Fill-3 Values calculated from k_p estimated from RET-total NDF, DNDF and INDF.

⁴ Fill-4 values calculated from assumed k_p of 2% h⁻¹.

⁵ Measured DMI

The general trend is that CR-MF fibre over-estimated DMI in all forages except UTRS, whereas the RET method under-estimated the

in digesta kinetics studies; chromium concentration in feeds affect density, and hence the passage characteristics of the marked feedstuff.

Table 4: Predicted DMI (kg/day) estimated from rumen pool sizes of NDF and Fill calculated from passage rates (kp) measured using rumen evacuation technique (RET), chromium mordanted fibre (CR-MF) and assumed passage rate of 2%h⁻¹

	Forage diet					SEM	R ²	P-value diet
	BH	MS	LH	LGH	UTRS			
Predicted DMI ¹								
MDMI ¹ (kg/day)	5.06 ^b	4.16 ^c	6.48 ^a	6.66 ^a	6.31 ^{ab}	0.46	0.76	0.009
PDMI ¹ (CR-MF)	5.38 ^b	5.16 ^b	8.09 ^a	6.85 ^{ab}	6.22 ^{ab}	0.63	0.79	0.040
PDMI ² (Total -NDF)	4.16 ^c	2.85 ^b	4.44 ^a	4.86 ^a	4.32 ^a	0.28	0.84	0.003
PDMI ³ (All fractions)	5.18 ^a	3.52 ^b	4.80 ^a	5.54 ^a	3.42 ^b	0.33	0.85	0.002
PDMI ⁴ (Kp=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).

¹PDMI Using Fill-1 Values calculated from kp estimated from CR-MF.

²PDMI Using Fill-2 values calculated from kp estimated from RET-total NDF.

³PDMI Using Fill-3 values calculated from kp estimated from RET-total NDF, DNDF and INDF

⁴PDMI Using Fill-4 values calculated from assumed kp of 2% h⁻¹

⁵Measured DMI

DMI in all forages. The accuracy of prediction was tested in the present study as given in Table 5.

It was observed that RET -total NDF method was more accurate (2= 0.70 and RMSE= 0.83) in prediction of DMI compared to CR-MF method (R = 0.47 and RMSE= 1.10).

This may explain why CR-MF gave higher passage rates compared to RET. In the present study the two methods RET and CR-MF assumed a steady state that the mass of feed digested or passed per unit time is proportional to mass in the rumen. This concept is not true in practice as feed particles have tendency to float

Table 5: Accuracy of forage DMI prediction using passage rates estimated from RET or CR-MF

PDMI ¹ Equation	R ²	RMSE	SE estimate ¹ of p-value			
			β ₁	β ₂	α	σ
Fill-1 DMI (kg d ⁻¹) = 2.81 - 0.46X	0.47	1.10	0.10	0.68	0.0002	0.004
Fill-2 DMI (kg d ⁻¹) = 1.19 + 1.10X	0.70	0.83	0.15	0.64	0.0001	0.079
Fill-3 DMI (kg d ⁻¹) = 3.04 + 0.60X	0.28	1.26	0.19	0.88	0.0002	0.004
Fill-4 DMI (kg d ⁻¹) = 2.59 - 0.63X	0.36	1.21	0.17	0.91	0.0020	0.009

¹The symbols β and α are the coefficient of regression and the intercept respectively, whereas X is the PDMI.

² Fill - 1 to 4 are described in Table 3 and 4

Discussion

Although CR-MF has been a popular marker

in the beginning of a meal. This is because large particles are of low density and passage rates at

first instance when the food enters the rumen is low. At the later stage the particles are broken down into smaller particles resulting in high density and increased passage rates (Mertens, 1987; Robinson *et al.*, 1987).

In a similar study Stensig *et al.* (1998) showed that where simple one-compartment rumen model with assumed first-order kinetics was used, selective retention of large and light particles is not accounted for and has the tendency to over-estimate rumen outflow of particles at early rumen residence times. Hence from the results of the present study, it was observed that CR-MF has the tendency to over-estimate passage rates compared to RET. However, with two compartment models as described by Moore *et al.* (1992) that take into consideration factors that function to free potentially escapable particles from floating fibrous mat, the tendency to overestimate passage rate could have been reduced. Similarly RET could also have the tendency to over-estimate the passage rates as it is also based on one-compartment model with assumed first order kinetics.

In this study, the two methods (CR-MF and RET) are based on one-compartment model with assumed first order kinetics. This makes the two methods to have the shortcoming of not being able to simulate the actual state in fibre kinetics, as digestion is a dynamic process. This may suggest that the use of two-compartment model to describe the digestion process would have been more appropriate as described by Moore, *et al.* (1992). In this study, however, the sampling interval for faecal collection was not phased to facilitate fitting of the data into a two-compartment model that would have simulated the actual digestion process. Unlike the CR-MF method, the RET, however, has the advantage of being well defined, as both the NDF pool size and the faecal output were obtained from actual intake and outflow data (Table 1 and 2). Thus the technique may give passage rates values that are closer to the true values compared to CR-MF method.

Although both methods have the advantage that they are simple and therefore easy to understand, on the other hand biological interpretation of passage rates can be difficult. For example the methods were not able to rank the passage rates of different forages in a similar trend (Table 2). This is because unlike in two-compartment model (Stensig *et al.*, 1998) the

model used in the two methods does not account for selective retention of feed particles at early residence times. On the other hand, the higher passage rates observed (Table 2) when using CR-MF compared to RET could be due to the migration nature of the chromium from the mordanted fibre to other feed particles in the rumen. Similar migration problems of rare earth markers have been reported by Udén *et al.* (1980). Also the higher passage rates observed for MS when CR-MF was used compared to RET (Table 2) suggest that migration of chromium from MS particles to the liquid phase was higher than other forages.

It has also been reported that the RET (Stensig *et al.*, 1998) and CR-MF (Moore *et al.*, 1992) has the limitation that passage rates cannot be estimated in diets with more than one fibre source. In the present study, this problem was avoided by using sole forage diets and hence no confounding effect was observed or expected. In practice, however, this is not always the case as animals are fed diets of different fibre sources.

In this study, INDF was used to calculate DNDF that was used to derive digestion rates (Model 6). The method for determination of INDF, however, needs to be further evaluated, as the result could not fit to the theoretical assumptions. In theory INDF intake is supposed to be equal to INDF in faeces, as INDF is indigestible. In the present study, differences of more than 50% in some forages like LH and MS was observed and such differences were found unacceptable and were consequently omitted in subsequent calculations. This was possibly due to the presence of high resistant starch in MS, as the use of α -amylase and use of sulphite in LH that is high in CP content was omitted as suggested by Van Soest *et al.* (1991). This is contrary to other findings (Stensig and Robinson, 1997; Stensig *et al.*, 1998) who reported no discrepancies and the INDF obtained between the feed and faeces were within the acceptable range. To avoid further errors INDF in faeces was assumed to be equal to INDF intake (Table 1). Passage rates for DNDF and INDF may be flawed in this case due to inaccurate recovery of INDF post-ruinally.

Long time incubation and rumen evacuation techniques are not only important in estimation of passage rates but also important in studies of

quantitative information about specific characteristics (Table 1 and 2) of various fibre sources to improve the inputs to models on prediction of intake. In the present study it was observed that LH had high INDF and low DNDF, but the rate of DNDF was high compared to other forages. This may explain why LH intake was high compared to other forages (Table 1 and 4) despite having high INDF. This can also be explained by the fact that food will always be passed out of the rumen when digested and absorbed or indigestible and allow more intake. Stensig and Robinson (1997) reported similar findings in Lucerne hay based diets in dairy cattle.

The costs for the two methods for estimation of passage rates were not estimated in the current study. However, taking into consideration the amount of chemicals used in the analysis and mordanting the fibre (CR-MF), the method seems to be relatively more expensive than RET. Apart from being expensive, its accuracy has been criticised by several workers (Ehle, 1984; Robinson *et al.*, 1987; Ramazin *et al.*, 1991; Moore *et al.*, 1992; Stensig *et al.*, 1998). Both methods, however, have been reported to be highly labour intensive (Robinson *et al.*, 1987; Stensig *et al.*, 1998).

Conclusion

The results showed that passage rates obtained from CR-MF method were higher than that obtained from RET. The results further showed that the passage rates were estimated with different accuracy when compared with the precision with which the passage rates were used to calculate fill values for prediction of dry matter intake (DMI). Fill values calculated from passage rates obtained from RET predicted DMI with a precision of $R^2 = 0.70$ compared to $R^2 = 0.46$ when passage rates obtained from CR-MF were used. Therefore RET method could be recommended for estimation of passage rates in cattle fed on tropical forage based diets.

Acknowledgement

The authors are grateful for the financial support from the Danish International Development Agency (DANIDA) under the SUA/MU/RVAU/DIAS - ENRECA Project.

References

- AOAC (1990) Association of Official Agriculture Chemists. Official Methods of Analysis. 15th Edition. AOAC Washington D.C. Volume 1: 62 pp.
- Ehle, F.R. (1984) Influence of feed particles density on particle passage from the rumen of Holstein cow. *Journal of Dairy Science* 67: 693-697.
- Jeng, A.S. and H. Berghseth. (1992) Chemical and mineralogical properties of Norwegian alum shale soils, with special emphasis on heavy metal content and availability. *Acta Agriculture Scandinavia, Sect. B, Soil and Plant Science* 42, 88-93.
- Kimambo, A.E., D.M. Mgheni, F.H. Maeda and L.J. Ngingo. (1996) Voluntary dry matter intake and rumen load of cattle fed different tropical forages. In: Ndikumana, J. and de Leeus, P. (Editors). Sustainable and Feed Production and Utilisation for Smallholder Livestock Enterprises in Sub-Saharan Africa. Proceedings of the 2nd Biennial Conference of African Feed Resource Network (AFRNET). Harare - Zimbabwe. AFRNET (African Feed Resources Network), Nairobi, Kenya: 73-76.
- Mertens, D.R. (1987) Predicting intake and digestibility using mathematical models of ruminal function. *Journal of Animal Science* 64, 1548-1558.
- Mgheni, D.M., R.M. Weisbjerg, A.E. Kimambo, T. Hvelplund, J. Madsen, and L.A. Mtenga. (1999) A system of predicting maximum intake capacity using degradation characteristics and rumen capacity of mature cross bred dairy heifers. In: Proceedings of the 26th Scientific Conference. Tanzania Society of Animal Production. LITI-Tengeru, Arusha, Tanzania, August 2-5, 1999: 80 - 94.
- Moore, J.A., K.R. Pond, M.H. Poore and T. G. Goodwin. (1992) Influence of model and marker on digesta kinetic estimates for sheep. *Journal of Animal Science* 70, 3528-3540.
- Ramazin, M., G. Bittante and L. Bailoni. (1991) Evaluation of different chromium mordanted wheat straws for passage rate studies. *Journal of Dairy Science* 74: 2989-2996.
- Robinson, P.H., S. Tamminga, S. and A.M. Van Vuuren. (1987) Influence of declining ingesta quantity composition and kinetics of ingesta turnover in dairy cows. *Livestock Production Science* 17, 37-62.
- SAS (1996) Statistical Analysis Systems. SAS Institute INC, SAS Language Reference Version 6. Cary, NC. 6.12 Release: pp 1043.

- Stensig, T., M.R. Weisbjerg and T. Hvelplund. (1994) Estimation of ruminal digestibility of NDF from *in sacco* degradation and rumen fractional outflow rate. *Acta Agriculturae Scandinavica, Section A. Animal Science* 44, 96-109.
- Stensig, T. and P.H. Robinson. (1997) Digestion and passage kinetics of forage fibre in dairy cows as affected by fibre-free concentrate in the diet. *Journal of Dairy Science* 80, 1339-1351.
- Stensig, T., Weisbjerg, M.R., and Hvelplund, T. (1998) Evaluation of different methods for the determination of digestion and passage rates of fibre in the rumen of dairy cows. *Acta Agriculturae Scandinavica, Section A. Animal Science* 48, 141-154.
- Udén, P., E. Pablo, E. Colucci and J.P. Van Soest. (1980) Investigation of chromium, cerium and cobalt as markers in digesta. Rate of passage studies. *Journal of the Science of Food and Agriculture* 31, 625-632.
- Van Soest, P.J., J.B. Robertson and B.A. Lewis. (1991) Methods for dietary fibre, neutral detergent fibre and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74, 3583-3597.