Predicting the Steady-state Attainability of Faecal Excretion in Ruminants when related to Length of Preliminary Period and Flow Rate of Digesta

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Predicting the Steady-state Attainability of Faecal Excretion in Ruminants when related to Length of Preliminary Period and Flow Rate of Digesta

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The steady-state attainment of faecal excretion in ruminants given a new feed was predicted by the attainability coefficient calculated using the Blaxter's compartmental model containing three parameters : length of preliminary period, outflow rate from rumen (k_1) and flow rate through hind-gut (k_2) of digesta. It was theoretically predicted that the faecal excretion approached a steady-state closer when the length of adaptation period was longer and/or the rate of digesta movement was higher. After the change of feed, the coefficient calculated for the faecal excretion derived from a previous feed showed a decrease to approach a zero-state closer when the longer period had passed and/or the digesta moved faster. Taking 28-day preliminary period led to the attainability coefficient higher than 0.99 irrespective of flow rate, meaning that a steady-state was attained for faecal excretion. Seven-day adaptation gave a value higher than 0.96 to the steady-state attainability provided both k_1 and k_2 were higher than 0.03. The application of the steady-state attainability to several published studies of various feeding conditions showed that the coefficient higher than 0.99 was given to almost all the cases in which 7-32 day adaptation was taken and flow rate was 0.014-0.085 for k_1 and 0.031-0.503 for k_2. The prediction was also applied to several other published studies with tropical forages where only k_1 was estimated to be 0.019-0.085 and 7-day adaptation gave a value higher than 0.94 to the steady-state attainability of most cases.

It is suggested that the steady-state attainment of faecal excretion in ruminants may be predicted by the attainability coefficient calculated using the Blaxter's model.

INTRODUCTION

Feeding experiments with ruminants require long periods to attain a steady-state of faecal excretion before commencing the measurement (Blaxter et *al.,* 1956 ; Minson *et al.,* 1976 ; Minson, 1990 ; Mertens, 1993). The excretion of faeces is closely related to the flow of digesta through the digestive tract and this has been studied using various mathematical models describing the digestive system compartmentally (Warner, 1981; Mertens, 1993 ; Faichney, 1993). A model proposed by Blaxter *et al.* (1956) is probably the pioneering one that described kinetically the flow of digesta from rumen to abomasum, from abomasum to duodenum and the excretion of faeces. The clear interpretation of this model was made later (Grovum and Phillips, 1973 ; Grovum and Williams, 1973, 1977) and the method of measuring flow rate was improved (Grovum and Williams, 1973 ; Udén *et al.,* 1980). The Blaxter's model is a simple one

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based on a fundamental concept of digesta movement, and thus this has influenced the construction of various models which are more complex in from (Faichney and Griffiths, 1978 ; Ellis et al., 1979 ; Faichney and Boston, 1983 ; Dhanoa et al., 1985 ; France et *al., 1985* ; France *et al.*, 1988 ; Pond et al., 1988 ; Cruickshank et al., 1989).

Using the Blaxter's model whether a steady-state was attained for a new feed was estimated indirectly by predicting the residual amount of previous feed excreted in faeces (Blaxter *et al.*, 1956). However, this was limited to only a few cases and it is also necessary to study the direct prediction of steady-state attainability under various lengths of preliminary adaptation and rates of digesta flow.

This study was designed, using the Blaxter's model, to predict the steady-state attainablility of faecal excretion in ruminants given a new feed and the decrease in residual digesta derived from a previous feed in the alimentary tract when related to length of preliminary period and flow rate of digesta, and followed by applying the attainability of steady-state to published studies to evaluate this prediction.

DESCRIPTION OF FAECAL EXCRETION

Differential equations for the flow of a single digesta

To describe the flow of a single digesta Blaxter et al. (1956) proposed three differential equations, and this was clearly explained (Grovum and Phillips, 1973 ; Grovum and Williams, 1973, 1977).

$$\frac{dA}{dt}=-k_1A \quad (1)$$

$$\frac{dB}{dt}=k_1A-k_2B \quad (2)$$

$$\frac{dC}{dt}=k_2B_{(t-TT)} \quad (3)$$

where A, B and C denote amounts of a unit of digesta in rumen, hind-gut and faeces respectively, k_1 and k_2 are rate constants (hr^{-1}) with $k_1 \leqq k_2, 0 \leqq t(hr) < \infty$ for equations [(1), (2)] and $TT \leqq t < \infty$ for equation (3), and TT (hr) being transit time through intestines.

Description of the faecal excretion derived from a single digesta

Blaxter *et al.* (1956) solved equations [(1), (2), (3)] to describe the faecal excretion derived from a single digesta [C(t)].

$$C(t)=1-\frac{1}{k_2-k_1}[k_2e^{-k_1(t-TT)}-k_1e^{-k_2(t-TT)}] \quad for \quad k_1<k_2 \quad (4)$$

$$C(t)=1-[k(t-TT)+1]e^{-k(t-TT)} \quad for \quad k_1=k_2 \quad (5)$$

where $TT \leqq t < \infty$, $C(TT)=O$ and when $t \to \infty$ $C(t) \to 1$.

Description of the faecal excretion that approaches and attains a steady-state

The preliminary adaptation is taken to annul the effect of a previous feed and to attain a steady-state for a new feed. In this study the approach of faecal excretion to a steady-state is described using the flow rate for a new feed obtained from a steady-state. This may be supported by a work of Blaxter et *al.* (1956) who used k_1 and k_2 of a previous diet to describe the decrease in faecal output that occurred after the break of a steady-state caused by the change of diet.

Hence, when the animal is kept on the same feeding conditions, the faecal excretion approaching a steady-state $[Cn(t)]$ may be obtained by summing the ordinates at time t.

$$Cn(t) = \sum_{i=0}^{n-1} \{ C(t + 24i) - C(TT + 24i) \} \tag{6}$$

where $TT \leqq t \leqq TT + 24$ and i (day) is numbered $0,1,2\ldots,n-1$.

Then, the faecal excretion that attains a steady-state $[Cs(t)]$ is obtained by calculating $Cn(t)$ when $n \to \infty$.

$$Cs(t) = \lim_{n\to\infty} Cn(t)$$

$$= \frac{1}{k_2 - k_1}\left[\frac{k_2 e^{24k_1}}{e^{24k_1}-1}(1 - e^{-k_1(t-TT)}) - \frac{k_1 e^{24k_2}}{e^{24k_2}-1}(1 - e^{-k_2(t-TT)})\right] \quad \text{for } k_1 < k_2 \tag{7}$$

$$Cs(t) = \frac{e^{24k}}{e^{24k}-1}\left[\left\{\frac{24k}{e^{24k}-1}+1\right\} - \left\{\frac{24k}{e^{24k}-1} + k(t - TT) + 1\right\} e^{-k(t-TT)}\right] \quad \text{for } k_1 = k_2 \tag{8}$$

where $TT \leqq t \leqq TT + 24$, $Cs(TT) = 0$ and $Cs(TT + 24) = 1$ irrespective of the length of TT.

Calculating the coefficient that predicts the steady-state attainability of faecal excretion when given a new feed

A steady-state of faecal excretion is shown by $Cs(TT + 24) = 1$. When $n \to \infty$ $Cn(TT + 24) \to Cs(TT + 24)$, therefore, $Cn(TT + 24)$ may be proposed as a coefficient that predicts the steady-state attainability of faecal excretion.

Preliminary feeding period (n) varies from 0 to 30 days (Minson, 1990). The flow rate (k_1, k_2) of digesta is usually not less than 0.01 hr^{-1}, that is, the mean retention time $(1/k_1, 1/k_2)$ is not more than 100hr (Warner, 1981). Thus, in this study the calculation of $Cn(TT+24)$ was done when taking [28, 21, 14, 7] for n, [0.01, 0.02, $\cdots$, 0.05] *for* k_1 and [0.01, 0.02, $\cdots$, 0.10] for k_2 with satisfying $k_1 \leqq k_2$. This was followed by omitting the figures below the second decimal place to satisfy a theoretical requirement of $Cn(TT+24) < 1$.

Calculating the coefficient that predicts the decrease in output of faeces derived from a previous feed following the change of diet

After changed to a new diet, there occurs a decrease in output of faeces derived from a previous diet and this will continue until reaching a zero-state (Blaxter et *al.*, 1956). Provided a steady-state has already been attained for the previous diet its amount in the alimentary tract $[D(t)]$ is described by,

$$D(t) = \frac{1}{k_2 - k_1}\left[\frac{k_2 e^{24k_1}}{e^{24k_1}-1} e^{-k_1(t-TT)} - \frac{k_1 e^{24k_2}}{e^{24k_2}-1} e^{-k_2(t-TT)}\right] \quad \text{for } k_1 < k_2 \tag{9}$$

$$D(t) = \frac{e^{24k}}{e^{24k}-1}\left[\frac{24k}{e^{24k}-1} + k(t - TT) + 1\right] e^{-k(t-TT)} \quad \text{for } k_1 = k_2 \tag{10}$$

where $TT \leqq t \leqq TT + 24$, and corresponding faecal excretion is described by $[D(TT) - D(t)]$.

Then, the faecal excretion occurring after the cessation of feeding $[Dn(t)]$ is obtained by,

$$Dn(t) = D(TT + 24n) - D(24n + t) \quad (11)$$

where $TT \leqq t \leqq TT + 24$ and n is the number of days following the last feeding of previous diet.

When $n \to \infty$ $Dn(TT + 24) \to 0$, therefore, $Dn(TT + 24)$ may be proposed as a coefficient that predicts the zero-state reachability of faecal excretion derived from the previous diet. The calculation of $Dn(TT + 24)$ was done when taking [28, 21, 14, 7] for n, [0.01, 0.02, ⋯, 0.05] for k_1 and [0.01, 0.02, ⋯, 0.10] for k_2 with satisfying $k_1 \leqq k_2$, the same conditions as those taken for the adaptation to a new diet. This was followed by taking any figures of the third decimal place up to the second decimal place to satisfy a theoretical requirement of $Dn(TT + 24) > O$.

THE STEADY-STATE ATTAINABILITY COEFFICIENT OF FAECAL EXCRETION AND THEORETICAL CONSIDERATIONS

The steady-state attainability coefficient calculated using the Blaxter's model (Blaxter *et al.*, 1956) is shown in Table 1. The theoretical prediction is that the faecal excretion of ruminants given a new feed approaches a steady-state closer when the length of preliminary period is longer and/or the rate of digesta movement is higher. After the change of feed, it is theoretically predicted that the faecal excretion derived from a previous feed approaches a zero-state closer when longer period has passed and/or the digesta moves faster (Table 2).

When n, k_1 and k_2 are the same between the new and previous diets adding their coefficients makes 1 (Tables 1 and 2). Therefore, the steady-state attainability of the new diet can be predicted indirectly by the zero-state reachability of the previous diet. Where the two diets are different in characteristics both indirect and direct predictions may be accepted for a new diet with a small bias provided the preliminary period is longer than 14 days. However, as shown in Tables 1 and 2, seven-day preliminary adaptation causes the occurrence of two typical cases which each requires direct or indirect prediction as follows. (1) The direct prediction is required where the steady-state attainability for a new diet is only 0.66 due to lower rate of flow ($k_1 = 0.01, k_2 = 0.02$) even when the effect of a previous diet is less than 0.01 caused by higher rate ($k_1 = 0.04$, $k_2 = 0.06$). *(2)* Where the reverse occurs a steady-state of a new diet is not attained yet by the presence of a residual portion of the previous diet and so this case requires an indirect prediction to annul the effect of a previous diet, Consequently both these two cases require a preliminary period longer than seven days to attain a steady-state.

The three parameters (n, k_1, k_2) determine the coefficient of steady-state attainability $[Cn(TT + 24)]$. However, when $Cn(TT + 24)$ appears after the feeding on the last day of preliminary period depends on the length of TT that usually does not exceed 48 hours. For the range $0 < TT \leqq 24$ that is found in most feeding condi-

Table 1. The attainability coefficient of steady-state of faecal excretion derived from a new feed when related to length of preliminary period and flow rates [k_1 and $k_2(h^{-1})$] of digesta.

a) 28days

k_1 \ k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
0.01										
0.02	—									
0.03	—				0.99 $\leqq$ attainability coefficient < 1					
0.04	—									
0.05	—									

b) 21days

k_1 \ k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
0.01	0.96	0.98								
0.02	—									
0.03	—				0.99 $\leqq$ attainability coefficient < 1					
0.04	—									
0.05	—									

c) 14days

k_1 \ k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
0.01	0.84	0.93	0.94	0.95	0.95	0.95	0.95	0.96	0.96	0.96
0.02										
0.03	—				0.99 $\leqq$ attainability coefficient < 1					
0.04	—									
0.05	—									

d) 7days

k_1 \ k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
0.01	0.50	0.66	0.72	0.75	0.76	0.77	0.78	0.78	0.79	0.79
0.02	—	0.84	0.90	0.93	0.94	0.94	0.95	0.95	0.95	0.95
0.03	—		0.96	0.97	0.98	0.98	0.98	0.98		
0.04	—					0.99 $\leqq$ attainability coefficient < 1				
0.05	—									

tions, $Cn(TT+24)$ can appear until the second day of measurement period when the first faecal sample is collected. However, for the range $24 \leqq TT \leqq 48$ occurring sometimes, there is a possibility of appearing on the third day and this causes a reduction in the coefficient when collecting the first faecal sample on the second day. A comparative calculation showed that the reduction was not more than 0.01, 0.01, 0.03 and 0.08 for 28, 21, 14 and 7 days of preliminary adaptation, respectively. Hence, the decrements can be negligible or overcome by extending the measurement period following the usual adaptation.

Table 2. The reachability coefficient of zero-state of faecal excretion derived from a previous feed when related to length of period after changed to a new feed and flow rates [k_1 and $k_2 (h^{-1})$] of previous digesta.

a) 28days

	k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
k_1	0.01										
	0.02	—									
	0.03	—									
	0.04										
	0.05	—									

0 < reachability coefficient ≦ 0.01

b) 21days

	k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
k_1:	0.01	**0.04**	**0.02**								
	0.02	—									
	0.03	—									
	0.04	—									
	0.05	—									

0 < reachability coefficient ≦ 0.01

c) 14days

	k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
k_1:	0.01	0.16	0.07	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.04
	0.02	—									
	0.03	—									
	0.04	—									
	0.05	—									

0 < reachability coefficient ≦ 0.01

d) 7days

	k_2:	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
k_1:	0.01	0.50	0.34	0.28	0.25	0.24	0.23	0.22	0.22	0.21	0.21
	0.02	—	0.16	0.10	0.07	0.06	0.06	0.05	0.05	0.05	0.05
	0.03 / 0.04	=		0.04	0.03	0.02	0.02	0.02	0.02		
	0.05	—	—	—	—						

0 < reachability coefficient ≦ 0.01

THE APPLICATION OF THE STEADY-STATE ATTAINABILITY TO PUBLISHED STUDIES AND EVALUATING THE PREDICTION

Applying the steady-state attainability to several published studies of various feeding conditions shows that the attainability coefficient is higher than 0.99 for almost all the cases (Table 3).

By taking 28-day preliminary period 0.99 ≦ attainability coefficient < 1 is

Table 3. Applying the steady-state attainability coefficient of faecal excretion to several published studies in which k_1, k_2 *and* TT were measured.

Animals	Feeds and level of feeding (F) or intake (I) / head / day	Preliminary period (day)	$k_1(hr^{-1})$	$k_2(hr^{-1})$	$TT(hr)$	Coefficient	Source
Sheep	Grass (pelleted) 1210g (F) ; reared under 1.3°C	32	0.072	0.288	14.0	>0.99	1
Sheep	Grass (pelleted) 121Og (F) ; reared under 21.2°C	32	0.052	0.325	15.1	>0.99	1
Sheep	Brome grass (pelleted) 1420g (F) ; reared under 2-5°C	21	0.085	0.152	8.4	>0.99	2
Sheep	Brome grass (pelleted) 1420g (F) ; reared under 22-25°C	21	0.056	0.128	7.7	>0.99	2
Sheep	Lucerne 800g (F)	21	0.065	0.175	12.9	>0.99	3
Sheep	Lucern 100g + wheat 500g : (F)	21	0.047	0.069	22.4	>0.99	3
Sheep	Steam-treated larch (1)+concentrate (9) : 2% of BW (F)	20	0.014	0.068	29.7	>0.99	4
Sheep	Steam-treated larch (3)+concentrate (7) : 2% of BW (F)	20	0.024	0.034	31.8	>0.99	4
Sheep	Orchard grass (7)+concentrate (3) : 2% of BW (F)	20	0.038	0.104	19.3	>0.99	4
Deer	Red top+Fescue : 46.3g/kg $BW^{0.75}$ (I) ; feeding in January	14	0.059	0.357	9.0	>0.99	5
Sheep	Red top+Fescue : 23.1g/kg $BW^{0.75}$ (I) ; feeding in January	14	0.040	0.081	16.0	>0.99	5
Deer	Red top+Fescue : 70.0g/kg $BW^{0.75}$ (I) ; feeding in April	14	0.043	0.476	6.9	>0.99	5
Sheep	Red top+Fescue : 24.6g/kg $BW^{0.75}$ (I) ; feeding in April	14	0.036	0.081	14.9	>0.99	5
Sheep	Rice straw (7)+concentrate (3) : 2% of BW (F)	14	0.032	0.065	23.5	>0.99	6
Sheep	Ammonia-treated rice straw (7)+concentrate (3) : 2% of BW (F)	14	0.038	0.067	22.7	>0.99	6
Sheep	Orchard grass (7)+concentrate (3) : 2% of BW (F)	14	0.040	0.067	24.0	>0.99	6
Sheep	Grass (long) 600g (F)	10	0.031	0.031	36.0	>0.99	7
Sheep	Grass (long) 1500g (F)	10	0.037	0.064	25.0	>0.99	7
Sheep	Grass (finely ground and cubed) 600g (F)	10	0.034	0.235	17.0	>0.99	7
Sheep	Grass (finely ground and cubed) 1500g (F)	10	0.045	0.503	9.0	>0.99	7
Sheep	Lucerne 400g (I)	10	0.038	0.097	16.7	>0.99	8
Sheep	Lucerne 1300g (I)	10	0.080	0.322	8.5	>0.99	8
Sheep	Italian ryegrass (chopped) 800g (I)		0.043	0.097	20.7	>0.99	9
Sheep	Italian ryegrass (pelleted) 800g (I)	7	0.048	0.174	17.4	>0.99	9
Sheep	Lucerne (cob) 800g (I)	7	0.037	0.045	17.5	>0.99	9
Sheep	Lucerne (chopped) 800g (I)	7	0.036	0.068	13.8	>0.99	9
Goat	Lucerne (8) + concentrate (2) : 50g/kg $BW^{0.75}$ (F) ; marker (Cr-paper)	7	0.026	0.044		0.96	10
Goat	Lucerne (8) + concentrate (2) : 50g/kg $BW^{0.75}$ (F) ; marker (Cr-NDF)	7	0.022	0.031		0.92	10

Source : 1 (Westra and Christopherson, 1976), 2 (Kennedy et al., 1977), 3 (Grovum and Williams, 1973), 4 (Nakashima et al., 1992), 5 (Milne et al., 1978), 6 (Nakashima, 1994), 7 (Blaxter *et al.*, 1956), 8 (Grovum and Williams, 1977), 9 (Milne and Campling, 1972), 10 (Zhao *et al.*, 1992) obtained for a new diet irrespective of the rate of digesta movement, meaning that a steady-state is attained for the faecal excretion (Table 1). The previous diet shows 0 < reachability coefficient $\leqq$ 0.01 and so its faecal excretion reaches a zero-state (Table 2). This prediction is in agreement with the fact that the steady-state of faecal excretion is usually attained within 30 days (Minson, 1990). The preliminary adaptation longer than 30 days is often taken when environmental temperature is a major factor affecting the feed digestion and related problems (Westra and Christopherson, 1976).

Reducing the adaptation period to 21 days causes only a small reduction in the coefficient of steady-state attainability. Even when the flow rate is very low ($0.01 \leqq k_1 \leqq k_2 \leqq 0.02$), the steady-state attainability for a new diet is 0.96-0.98 and a previous diet shows 0.04-0.02 for the zero-state reachability (Tables 1 and 2). The steady-state attainability higher than 0.99 is given to a work of Nakashima et *al. (1992)* who fed sheep with a mixed diet containing a concentrate plus steam-treated larch or orchard grass, and also to sheep eating brome grass (Kennedy et *al.*, 1977) and eating lucerne only or lucerne plus concentrate (Grovum and Williams, 1973).

Fourteen-day preliminary adaptation leads to the steady-state attainability showing 0.93 or higher when both k_1 and k_2 are not less than 0.02 (Table 1). Corresponding zero-state reachability of a previous diet is not more than 0.07 (Table 2). Even with the lower flow rates varying from 0.01 to 0.02 the steady-state attainability is not less than 0.84. It is predicted that the steady-state attainability is higher than 0.99 when deer and sheep were given a mixture of red top and fescue (Milne *et al.*, 1978) and when fed sheep with rice straw (untreated or ammonia-treated) or orchard grass that was each mixed with a concentrate (Nakashima, 1994). Fourteen-day adaptation is recommended where the change of diet is a major one (Minson *et al.*, 1976), and in a study with poor quality hay it took 12-15 days to establish stable intake by sheep (Blaxter *et al.*, 1961).

When 10-day preliminary period is taken the steady-state attainability higher than 0.99 is given to sheep eating different physical forms and amounts of a grass (Blaxter *et al., 1956)* and different amounts of lucerne (Grovum and Williams, 1977). Blaxter *et al.* (1956) reported that 10 days appeared sufficient to annul any effects of a previous diet. Provided k_1 and k_2 are 0.02 or higher it is predicted that the effect of previous diet is decreased to 0.05 or lower.

By taking 7 days for the adaptation to a new feed, the steady-state attainability shows a value not less than 0.96 (0.84) when both k_1 and k_2 are 0.03 (0.02) or higher (Table 1). Corresponding zero-state reachability of a previous diet is not more than 0.04 (0.16) as shown in Table 2. The prediction gives a value higher than 0.99 to the steady-state attainability when sheep were fed different physical forms of Italian ryegrass or lucerne (Milne and Campling, 1972). The coefficient 0.96 or 0.92 is shown when chromium-mordanted paper or NDF was used as a marker for goats eating a mixed diet of lucerne hay-cubes and a concentrate (Zhao et *al.*, 1992).

The attainability coefficient of steady-state may also be estimated even when only k_1 is measured. This is because $k_1 \leqq k_2$ and calculating when $k_1 = k_2$ gives a coefficient which is slightly lower than that calculated when $k_1 < k_2$, provided k_1 is 0.03 or higher (Table 1). This calculation was applied to several published studies with tropical forages in which 7-day adaptation was taken to measure the reticulo-ruminal reten-

Table 4. Applying the steady-state attainability coefficient of faecal excretion to several published studies in which k_1 was estimated from the mean retention time measured for rumen $(1/k_1)$.

Animals	Feeds and level of feeding (F) or intake (I) / head / day	Preliminary period (day)	Retention time $[1/k_1(hr)]$	$k_1(hr^{-1})$	Coefficient	Source
Sheep	Rhodes grass 300g (F)		21.8	0.046	>0.99	1
Sheep	Rhodes grass 624g (F)		17.0	0.059	>0.99	1
Sheep	Dallis grass+white clover : 298g (F)	7	23.2	0.043	>0.99	1
Sheep	Dallis grass+white clover : 638g (F)	7	17.7	0.056	>0.99	1
Sheep	Kikuyu grass (immature leaf) 63.1g/kg $BW^{0.75}$ (I)	7	18.9	0.053	>0.99	2
Sheep	Kikuyu grass (mature leaf) 44.3g/kg $BW^{0.75}$ (I)	7	20.8	0.048	>0.99	2
Sheep	Kikuyu grass (immature stem) 45.9g/kg $BW^{0.75}$ (I)	7	29.5	0.034	>0.97	2
Sheep	Kikuyu grass (mature stem) 29.0g/kg $BW^{0.75}$ (I)		51.1	0.020	>0.84	2
Sheep	Setaria (chopped leaf) 40.7g/kg $BW^{0.75}$ (I)	7	21.2	0.047	>0.99	3
Sheep	Setaria (pelleted leaf) 59.5g/kg $BW^{0.75}$ (I)	7	16.2	0.062	>0.99	3
Sheep	Setaria (chopped stem) 26.9g/kg $BW^{0.75}$ (I)	7	27.7	0.036	>0.98	3
Sheep	Setaria (pelleted stem) 37.5g/kg $BW^{0.75}$ (I)	7	22.0	0.045	>0.99	3
Sheep	Pangola grass (calcium-unfertilized) 39.4g/kg $BW^{0.75}$ (I)	7	33.3	0.030	>0.96	4
Sheep	Pangola grass (calcium-fertilized) 43.2g/kg $BW^{0.75}$ (I)	7	27.4	0.036	>0.98	4
Sheep	Pangola grass (sulphur-unfertilized) 44.0g/kg $BW^{0.75}$ (I)	7	29.7	0.034	>0.97	5
Sheep	Pangola grass (sulphur-fertilized) 48.6g/kg $BW^{0.75}$ (I)		24.2	0.041	>0.99	5
Cattle	Rhodes grass (mature leaf) 28.5g/kg $BW^{0.9}$ (I)	7	35.7	0.028	>0.94	6
Cattle	Rhodes grass (mature stem) 20.4g/kg $BW^{0.9}$ (I)	7	51.4	0.019	>0.82	6
Sheep	Rhodes grass (mature leaf) 28.2g/kg $BW^{0.9}$ (I)	7	28.0	0.036	>0.98	6
Sheep	Rhodes grass (mature stem) 19.0g/kg $BW^{0.9}$ (I)	7	39.4	0.025	>0.92	6
Cattle	Rongai dolichos (leaf) 36.5g/kg $BW^{0.9}$ (I)	7	23.6	0.042	>0.99	7
Cattle	Rongai dolichos (stem) 20.4g/kg $BW^{0.9}$ (I)		43.2	0.023	>0.89	7
Sheep	Rongai dolichos (leaf) 51.2g/kg $BW^{0.9}$ (I)	7	11.7	0.085	>0.99	7
Sheep	Rongai dolichos (stem) 31.8g/kg $BW^{0.9}$ (I)	7	17.7	0.056	>0.99	7
Cattle	Green panic (leaf) 18.7g/kg BW (I)	7	23.9	0.042	>0.99	8
Cattle	Green panic (stem) 8.5g/kg BW (I)	7	33.4	0.030	>0.96	8
Cattle	Rongai dolichos (leaf) 23.9g/kg BW (I)	7	17.3	0.058	>0.99	8
Cattle	Rongai dolichos (stem) 10.5g/kg BW (I)	7	35.6	0.028	>0.94	8

Source : 1 (Minson, 1966), 2 (Laredo and Minson, 1973), 3 (Laredo and Minson, 1975), 4 (Rees and Minson, 1976), 5 (Rees and Minson, 1978), 6 (Poppi *et al.*, 1981), 7 (Hendricksen *et al.*, 1981), 8 (McLeod *et al.*, 1990) tion time ($1/k_1$), and it was found that in most cases $k_1 \geq 0.028$ (retention time $\leq$ 35.7 hr) and so the steady-state attainability 20.94 (Table 4). These studies dealt with sheep and/or cattle fed tropical forages which were different in species, growth stages, fertilizer managements, plant fractions, chopping sizes and amounts eaten (Minson, 1966 ; Laredo and Minson, 1973, 1975 ; Rees and Minson, 1976, 1978 ; Poppi *et al.*, 1981 ; Hendricksen et *al.*, 1981; McLeod et al., 1990). Tropical forages, compared with temperate forages, appear to show lower k_1 probably due to the more lignified plant tissue that requires longer time retained in rumen to reduce the size of digesta particles before leaving the rumen (Minson, 1990). Hence, this prediction is not contrary to the accepted practice of taking seven-day adaptation that is usually considered sufficient to attain a steady-state when forages are given to ruminants (Minson et al., 1976 ; Minson, 1990).

It is suggested that the steady-state attainment of faecal excretion in ruminants may be predicted by the attainability coefficient calculated using the Blaxter's model when applied to the data from published studies.

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