Recent advances in evaluation of roughages as feeds for ruminants

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SUMMARY

A method of evaluating fibrous feeds is proposed and discussed. The method is based on determination of degradation characteristics of roughages from experiments in which the roughages are incubated in the rumen for different periods of time (t) and the relationship of time (t) to degradation (p) described by a mathematical description $p = a + b(1 - e^{-ct})$. Further improvements to this expression are suggested and the relationship to animal performance, and in particular feed intake, is discussed.

INTRODUCTION

Feed evaluation systems developed in Europe and the USA during the past century are based on either total digestible nutrients (TDN), metabolisable energy (ME), starch equivalents (SE) or other systems of net energy (NE). While for some feeds measurements are obtained in respiration chambers the values are most often based on measurements of digestibility at maintenance energy intake and the ME or NE calculated from established factors. These systems have served their purpose reasonably well particularly production systems in which the animals have been rationed to receive less than *ad libitum* intake. The systems have also provided reasonably good comparative values of feeds.

The greatest weakness of all the systems developed so far is that they give no information on the amount of each feed the animals are likely to consume. While as mentioned before this is not so important when animals are rationed below their potential *ad libitum* intake, or are given high quality feeds which induce little or no physical limitation to intake, it is a serious weakness when the animals are fed *ad libitum* on roughage based diets. The poorer the quality of the feeds and the more the production systems are based on *ad libitum* intake the greater the problems with present feed evaluation systems. While digestibility of roughages is usually positively correlated with intake it generally accounts for less than 50% of the variation.

Recognizing that the characteristics of feeds which influence rumen fill and thus voluntary intake relate to rate and potential extent of fermentation several attempts have been made to describe these characteristics of feeds (see for instance Van Soest, 1982; Ellis *et al.*, 1988; Kennedy, 1988). In this paper an approach used by our group will be discussed in some detail and some suggestions will be made as to how future feed evaluation systems for roughage based diets may be developed.

The objective of the work was therefore to identify those characteristics of roughages which had implications as far as rumen fill was concerned and to determine how these characteristics contributed to the accuracy of predicting intake and growth rate.

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CONTENT OF SOLUBLE MATERIAL

Almost all roughages contain a variable fraction of soluble materials or cell content. This material will generally not intrude appreciably on space in the rumen and so it is an important characteristic.

CONTENT OF INSOLUBLE BUT FERMENTABLE MATERIALS

The potential fermentation of the insoluble material is important as it determines the potential amount which could be extracted by the animal and also the minimum of materials which will pass through the gut as completely indigestible and thus occupy space all the time.

RATE OF DEGRADATION

The rate of degradation is also an important characteristic as it determines the amount of energy that will be extracted during the time the material is retained in the rumen and also the time during which the fermentable material occupies space in the rumen.

RATE OF REDUCTION OF LONG TO SMALL PARTICLES

The rate at which long particles are reduced to particles which will leave the rumen could also be an important characteristic determining rumen retention time and thus voluntary intake.

EXPERIMENTAL APPROACHES

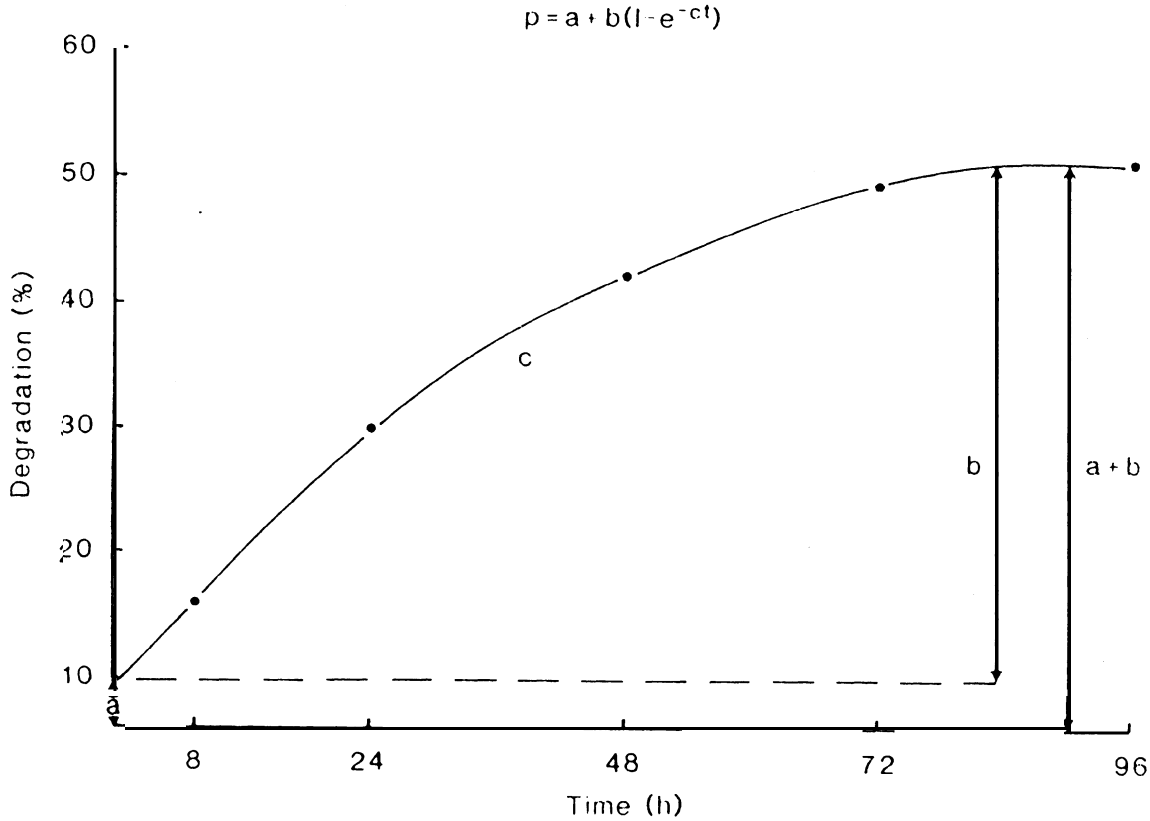
In order to determine some of the factors referred to and test the extent to which these factors could predict intake and performance a large experiment carried out in our laboratory, and published by Orskov et *al.*, 1988 and Reid et *al.*, 1988 will be discussed in some detail. Based on these observations some suggestions as to future descriptions of feeds will be made.

The technique we used consisted of describing the degradation characteristics using nylon bags incubated in the rumen and withdrawing bags at different intervals of time. In the case described only disappearance of dry matter with determined. Subsequently the data were treated mathematically using the same procedure as originally used for description of protein degradability (Ørskov and McDonald, 1979) namely the exponential equation of the form $p = a t b (1 - e^{-ct})$. The meaning of these factors are shown in Fig. 1. In this instance a represents the extrapolated zero value which was taken to be the immediate soluble material, b the insoluble but potentially fermentable material, and c the rate constant of b.

Five types of straw which varied in rate and extent of degradation were used. A portion of each straw was subsequently treated with ammonia. The untreated straws were supplemented with urea to ensure that N deficiency did not impair voluntary intake. Each type of straw was subsequently given *ad libitum* to 8 individually fed steers for periods of 2 months. In order to ensure no live weight loss the steers were also given daily 1.5 kg of concentrate.

The straws were also fed to sheep in respiration chambers for determination of the metabolisability at the maintenance level of intake. In Table 1 the results are given for the description of the straws using the values of a, b and c from the exponential equation and the performance of the animals. It can be seen that there was a great deal of variation between the straws which was seen in

Fig. 1 Description of degradability of fibrous residues



their a, b and c values. It is of interest that ammonia treatment consistently increased the b value but had little effect on the rate constant. It can also be seen that the varieties of barley straws varied considerably in degradability.

Table 1. Description of straws according to the exponential equation relating degradation (p) to time (t) according to p = a t b (1 − l^{-ct}). Also dry matter intake and growth rate of steers.

Type of straw	Variety	Ammonia treatment	Constant a	Constant b	Constant c	Dry matter intake kg/d	Growth rate g/d
Winter barley	Gerbel	−	6.0	32.9	0.0337	3.43	106
	"	+	7.9	54.4	0.0258	4.70	359
	Igri	−	5.1	38.2	0.0391	3.56	126
	"	+	7.9	45.2	0.0351	4.82	332
Spring barley	Corgi	−	3.4	48.7	0.0483	5.16	400
	"	+	6.4	60.4	0.0457	5.86	608
	Golden	−	7.5	48.0	0.0303	4.43	198
	Promise	+	9.3	52.1	0.0376	4.93	602
Winter wheat	Norman	−	7.7	40.9	0.0345	4.57	273
	"	+	9.0	51.9	0.0364	5.81	516

In Table 2 the factors of the exponential equation have been used to predict performance and intake. Initially the total potential (a t b) was used then the rate constant c was added and finally a, b and c were separated. It can be seen that the accuracy of predicting intake and growth rate was impressive. It is most important that addition of the rate constant c always improved accuracy of prediction. Digestibility alone gave a correlation of 0.70 with intake similar to metabolisability.

Table 2. Prediction of intake of dry matter and digestible dry matter and of growth rate in cattle from degradation characteristics generated from the equation $p = a + b\ (1 - e^{-ct})$.

Factors	*Y* variable	Formulae	*R*	Residual s.d.
$(a + b)$	Dry matter intake (kg/day)	$0.572 + 0.0766(a + b)$	0.83	0.452
$(a + b) + c$		$-0.822 + 0.0748(a + b) + 40.7c$	0.89	0.375
$a + b + c$		$-1.56 + 0.159a + 0.0658b + 56.4c$	0.88	0.383
$(a + b)$	Digestible dry matter intake (kg/day)	$1.258 + 0.0642(a + b)$	0.86	0.33
$(a + b) + c$		$-2.595 + 0.06244(a + b) + 39.0c$	0.96	0.195
$a + b + c$		$-2.576 + 0.0554a + 0.0640b + 37.7c$	0.95	0.204
$(a + b)$	Growth rate (g/day)	$-0.595 + 0.0175(a + b)$	0.84	99
$(a + b) + c$		$0.922 + 0.0170(a + b) + 9.55c$	0.91	77
$a + b + c$		$-1.267 + 0.0571a + 0.0126b + 17.02c$	0.95	54

The use of the equation above assumes that the extrapolated value a gives some measure of solubility. This applies generally to protein supplements but for many fibrous feeds there is often a negative value for a, due to the fact that there is sometimes a lag phase during which microbes colonize the particles so that for a period there is no apparent loss of dry matter. It is possible to overcome the problem of lag phase by determining solubility and use this value as the zero time incubation. However, such procedure reduces the accuracy of the equation and also obscures the meaning of the rate constant.

In another approach described by McDonald (1981) the solubility is determined and denoted a'. The b' value is then (a t b)-a' while the rate constant c is the same. The principle of this approach is given in Fig. 2, which allows calculation of the lag phase L which also contributes to rumen retention time. The improvement in accuracy of determining production parameters using this approach is given in Table 3 in terms of correlation coefficients. Here it can be seen that the accuracy of predicting dry matter intake was substantially and significantly improved by separating a', b' and c, so that about 90% of variation in intake could be accounted for by the degradation characteristics compared to only about 50% from information on digestibility and metabolisability. The required information was also obtained at a much lower cost. Inclusion of lag phase in the equation did not further increase accuracy of prediction as shown by no significant change in the correlation coefficients.

Fig. 2 Description of degradability of fibrous residues $p = a' + b'(1 - e^{-ct})$ using solubility a' and lag phase L

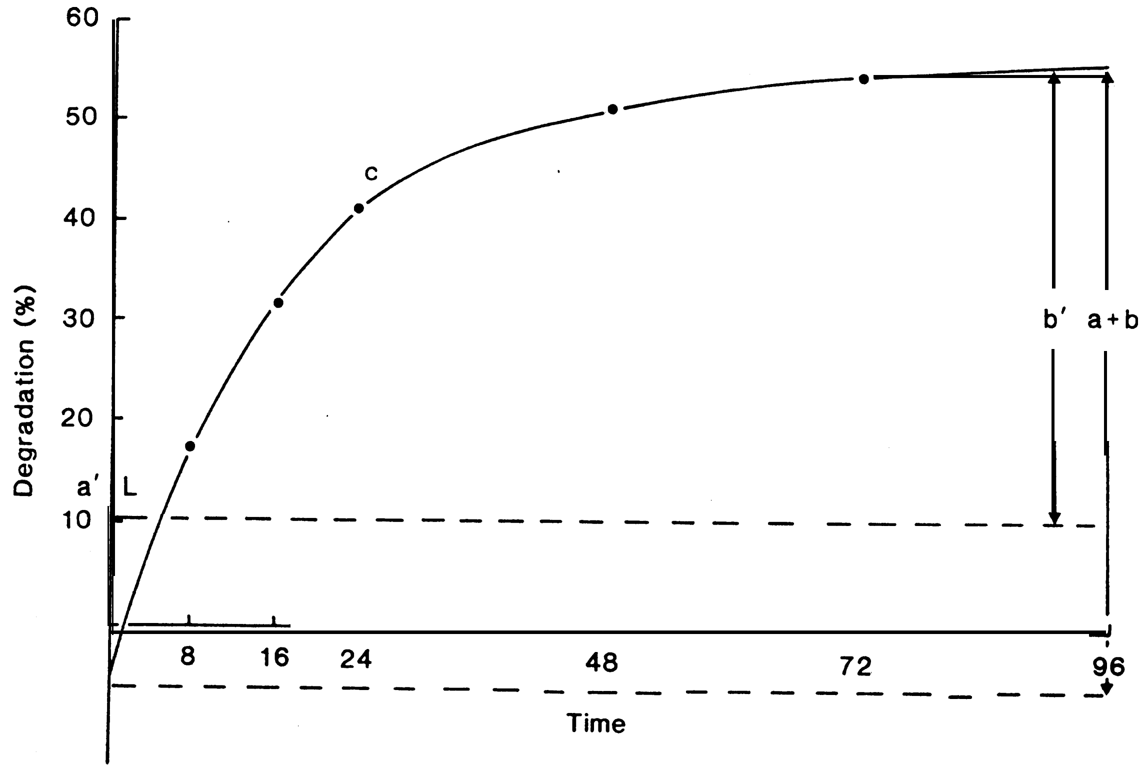


Table 3. Accuracy *(R)* of estimating digestibility, dry matter intake, digestible dry matter intake and growth rate from feed degradation characteristics, as indicated by the multiple correlation coefficients.

Degradation characteristics	Digestibility	Dry matter intake	Digestible dry matter intake	Growth rate
(a + b)	0.77	0.83	0.86	0.84
(a + b) + c	0.85	0.89	0.96	0.91
a' + b' + c	0.90	0.93	0.96	0.95
a' + b' + c + L	0.91	0.93	0.95	0.95
Index	0.74	0.95	0.94	0.96

a' = solubility *b'* = *(a + b) − a'* *L* is the lag phase

The values for a', b' and c for some feeds are given in Table 4 which represent a possible way in which future description of roughage feeds can be made. Such values can be improved by describing organic matter disappearance and even energy disappearance which may be important in feeds with a high ash or lipid contents.

In some circumstances it may be desirable to represent the feed by a single value such as an index which could be used to indicate the level of production which can be achieved from the amount the animals could consume. A possible approach to generate an index value here was to use the regression equation which related voluntary dry matter intake to a', b' and c and which

Table 4. Description of roughages using the modified equation of $p = a' + b' (1 - e^{-ct})$ where a' is the solubility. For index value see text.

Feedstuff	a'	b'	c	Lag phase h	Index value
Spring barley straw (Cent)	10.3	33.8	0.0466	4.8	33.1
Spring barley straw (Corgi)	12.8	37.1	0.0580	6.7	39.2
Winter barley straw (Gerbel)	6.6	39.1	0.0247	3.3	27.2
Oat straw	11.4	38.2	0.0240	2.7	31.5
Rice straw	17.1	36.0	0.0399	4.2	39.2
Barley leaf blade	15.6	70.2	0.0672	5.0	57.1
Barley stem	13.5	36.4	0.0406	7.3	26.2
Oat leaf	11.3	49.4	0.0352	3.9	38.1
Oat stem	12.4	29.8	0.0152	1.5	27.1
Hay	21.5	49.6	0.0377	3.2	59.0

gave a multiple correlation coefficient of $r = 0.93$. Since the basis of this calculation is to find the coefficients to the factors which result in the lowest residual standard deviation it follows that the regression coefficients for each factor will indicate their respective importance. In order to simplify, each coefficient was divided by the coefficient for a so that the coefficient for a was 1 Using this approach the coefficient for b was 0.4 and for c 200. The index values for the feeds in Tables 2 and 4 have calculated using this approach. In Table 3 it can be seen that the correlation with intake was high which of course was to be expected but a correlation of $r = 0.96$ with the independent parameter of growth rate was impressive. It is also possible using this approach to calculate the minimum index value which enables the animal to achieve a defined level of production. For instance it was calculated that an index value of at least 36 was required for the steers to meet their maintenance energy need. It should be pointed out of course that such index values have no biological meaning but it may be a useful number to give to roughage feeds.

While in the work here about 90% of variation in intake was accounted for by degradation characteristics, this of course needs to be tested with a wider range of feeds of different types. While the rate at which long particles are reduced to small particles may also restrict intake it was possible to achieve a high accuracy of prediction without that information. It cannot be assumed that it is not important but the results here suggest that either the rate constant for reducing particles is greater than passage rate or it was similar for the feeds considered. For some feeds with very tough fibrous components such as banana leaves or sisal pulp, this is likely to be important. The rumen retention times of long and small straw particles were found to be 53 and 48 h respectively by Ørskov, Ojwang and Reid, 1988. In other words the difference was quite small.

The description of feeds here, of course, assumes that the rumen fermentation proceeds at an optimal rate and not impeded by lack of N or by a rumen environment which results in less than optimal rumen fermentation. Our approach is not considered to be the final answer to future feed evaluation systems. It does, however, seem to be a possible route to a system which has a greater relevance to ruminant production than conventional evaluation systems. Laboratory methods need to be developed to generate the characteristics required.

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