ELSEVIER

Animal Feed Science and Technology 54 (1995) 81-92

ANIMAL FEED SCIENCE AND TECHNOLOGY

Degradation of tropical roughages and concentrate feeds in the rumen

M.N.M. Ibrahim[a,*], S. Tamminga[b], G. Zemmelink[a]

[a]*Department of Animal Production Systems, Agricultural University, P.O. Box 338, 6700 AH Wageningen, The Netherlands*

[b]*Department of Animal Nutrition, Agricultural University, P.O. Box 338, 6700 AH Wageningen, The Netherlands*

Received 15 June 1994; accepted 17 November 1994

Abstract

Degradation characteristics of four grasses, three leguminous fodder species, jack leaves, coconut meal and rice bran were studied using the nylon bag procedure. Bag incubations up to 10 days were performed in the rumen of cows fed on a ration consisting of 50% wheat straw and 50% hay.

Degradation characteristics for organic matter (OM), neutral detergent fibre (NDF) and nitrogen (N) were evaluated using a two fraction model with a fixed undegradable fraction (U) and lag time. Among the grasses, the degradable fractions (D) of OM and NDF in NB21 and guinea grass were significantly higher ($P<0.05$) than in the other two grasses. Guinea grass not only had the highest N content (20.3 g kg^{-1} dry matter (DM)), but also its D fraction was significantly higher ($P<0.05$) than that of the other grasses. The rate of degradation (k_d) for all components studied did not differ significantly between grasses. Unlike in grass species, the D and U values obtained for OM, NDF, and N in legumes species did not differ significantly, but the k_d values were significantly ($P<0.05$) different.

Except for the long lag phase in jack leaves, which ranged from 10.4 h for NDF to 11.5 h for N, all other degradation characteristics were significantly higher ($P<0.05$) than for grasses and rice bran. The poor nutritive value of rice bran obtained from a commercial mill was reflected in the extremely high U fraction (47%, 66% and 22% for OM, NDF and N, respectively). Nevertheless, the degradation characteristics (D and k_d) for N were significantly better than for grasses. Coconut meal had the highest potentially degradable fraction (D + water soluble fraction).

Rumen degradable N content in grasses ranged from 41% (guinea) to 60% (ruzi), and in legumes from 69% (leucaena) to 79% (glyricidia). About 67% of the N present in jack leaves and rice bran was rumen degradable.

Keywords: Tropical feedstuffs; Nylon bag technique

0377-8401/95/$09.50
SSDI 0377-8401(94)00758-6

1. Introduction

In tropical areas of the world, ruminants rely on year-round grazing of natural pastures or are hand-fed cut grass, crop residues, and leaf material from trees and shrubs. Most of these areas suffer from seasonal dry periods during which the available grass drops in quality, especially in its content of energy and nitrogen. As a consequence, feed intake declines and animal productivity is curtailed.

Under most existing tropical ruminant livestock production systems there is considerable scope for improving production through better feeding. The main feeding constraints are: low herbage availability, physical limitation of intake of tropical forages, nutrient deficiencies limiting rumen microbial digestion of fibrous feeds, and an imbalance between nutrients extracted from feeds and nutrients required by the animal. Tropical forages have a large proportion of lignified cell walls with low fermentation rates and digestibility, leading to low rates of disappearance through digestion or passage and limited intake.

Supplementation of limiting nutrients to the rumen microorganisms to enhance their growth and increase utilisation of fibrous feeds has received much attention in recent years as a way to improve tropical feeding systems. Emphasis has been given in recent studies to the timing and supply of degradable N to meet the continuous demand of the rumen microorganisms. Rumen NH_3 concentration required to achieve maximum fermentation, which results in maximum intake and digestibility in low quality forages, is far greater than that suggested earlier for maximum efficiency of microbial protein production (Satter and Slyter, 1974; Hoover, 1986). There is evidence which indicates that if crude protein (CP) falls below 6–8% of dietary dry matter (DM) intake the appetite of the animal is depressed. A large proportion of tropical grasses, particularly native pastures have values below this range (Minson, 1990).

The nutritive value of a feed is assessed by the amount of nutrients it contains (chemical composition), digestibility and level of voluntary intake. It is difficult to build meaningful relationships between chemical components and digestibility. Moreover, these measurements do not provide information on achievable intakes. However, the degradation characteristics of a feed, particularly rate of degradation, provide an estimate of its rumen digestibility, which to a large extent influences intake.

There is very little information available on degradation characteristics of tropical grasses, legumes and concentrate. Many of the comparisons between and within these feed classes is based on in vitro digestibility estimates (Ibrahim et al., 1987; Minson, 1990). The objective of the present study was to assess differences in the extent and rate of degradation between some commonly used forages and concentrate feeds in Sri Lanka.

2. Materials and methods

2.1. Test feeds

The ten test feeds used in this study were selected from a batch of 73 feed samples (grasses, leguminous fodders, tree leaves and shrubs, concentrates) which were brought to

* Corresponding author: Tel. +31 (0)8370 83186; Fax. +31 (0)8370 85006.

the Netherlands from Sri Lanka to study the variation in chemical composition and nutritive value (Ibrahim et al., 1987). Based on their importance for ruminant feeding in Sri Lanka the following were selected: four grasses, *Brachiaria ruziziensis* (ruzi, 4-week cut), *Pennisitium purpureum* (NB21, 4-week cut), *Brachiaria brizantha* (signal, 4-week cut), and *Panicum maximum* ecotype Guinea A (guinea, 3-week cut); three types of leguminous tree leaves, *Glyricidia maculata* (glyricidia, 4 weeks regrowth), *Leucaena leucocephala* (leucaena, 4 weeks regrowth), and *Erythrina varigata* (erythrina, 7 weeks regrowth); one species of tree leaves, *Artocarpus heterophyllus* (jack leaves); two types of concentrate feeds, coconut meal and rice bran. For bag incubation studies the roughages were ground to pass through a 5 mm sieve.

2.2. Animals and diet

Two Dutch Friesian cows, 500 kg liveweight fitted with large rumen cannula (10 cm inside diameter) were used. Cows were fed a maintenance ration (8 kg DM day^{-1}) which consisted of 50% wheat straw (in vitro organic matter digestibility OMD (IVOMD) 50.4%, CP 2.6%) and 50% hay (IVOMD 71.2%, CP 14.8%), and fed in equal meals per day at 06:00 and 17:00 h.

2.3. Incubation procedure

Five grams of air-dry material (5 mm sieve) were weighed into 18 cm × 9 cm bags made out of nylon cloth with pore size of 41 μm (Nybolt, Zürich) formed by folding the cloth and heat sealing one end and the side (Seal Boy, Audion-Elektro, Amsterdam). As an extra precaution, glue (Quick Repair, Griffon, Amsterdam) was applied (0.5 cm width) on the inner side of the heat sealed lines. In total 160 bags were filled, 80 bags per cow. The bags were tied and attached by a 25 cm nylon cord (1.5 mm diameter) to a 750 g polypropylene block suspended by a 70 cm nylon cord (3 mm diameter) to the inside of the cannula cap. Bags were incubated for 3, 6, 12, 18, 24, 48 and 240 h in the rumen.

Bags were immediately plunged into an ice bath after removal from the rumen, rinsed in tap water, and subsequently washed for 20 min in a washing machine (wool wash programme, V360-Bosch), which included three rinses and three centrifugations in the cycle. The 0 h incubation (control) bags were also washed in the same manner. The bags were dried at 70°C, weighed and the residues were ground to pass through a 1 mm sieve in a laboratory mill.

The DM of the test feeds was determined by drying at 100°C and the organic matter (OM) calculated as weight lost upon ashing at 500°C. The test feeds were also analysed for N and crude fat by the standard method of the Association of Official Analytical Chemists (AOAC, 1980), and for neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) by the method of Goering and Van Soest (1970). IVOMD values of the test feeds were measured by the method of Tilley and Terry (1963).

Bag residues were analysed for DM, OM, N and NDF.

2.4. Calculations and statistical analysis

The residue (R) of a particular component (OM, NDF, N) remaining at any time of incubation was calculated as the dry weight (70°C) of the bag, and residues corrected for bag tare divided by duplicate zero-time values.

The OM, NDF and N residue disappearance was fitted individually by cow and test feed to the models described by Robinson et al. (1986), by Genstat least square analysis (Alvey

Table 1
Chemical composition (g kg^{-1} DM) and in vitro OMD (IVOMD) of the test feeds

	Total ash	Nitrogen	Crude fat	NDF	ADF	ADL	IVOMD (%)
Grasses							
Ruzi	80	12.3	18	615	322	33	65.5
NB 21	124	13.8	19	647	364	32	63.4
Signal	98	12.5	17	686	377	57	53.2
Guinea	118	20.3	12	686	368	38	56.7
Legumes							
Glyricidia	102	48.3	32	331	197	43	70.0
Leucaena	101	60.8	33	354	164	60	61.4
Erythrina	117	61.3	26	399	216	55	72.0
Jack leaves	88	20.2	38	391	279	72	52.1
Coconut meal	59	38.1	103	475	247	41	86.1
Rice bran	208	17.1	–	455	303	97	45.2

NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin.

Table 2
Water soluble fraction (S) and parameters of the model[a] used to describe degradation of organic matter in the rumen (mean of two cows)

Feed	S (%)	D (%)	U (%)	k_d (% h^{-1})	L (h)	R-SD	RDOM (g kg^{-1} DM)
Grasses							
Ruzi	24.7	52.4bc	22.9cd	4.1e	2.2bc	2.24	471
NB21	15.8	61.4a	22.8cd	3.9e	1.9bc	2.87	405
Signal	15.1	53.0bc	31.9b	3.1e	1.7bc	2.49	345
Guinea	13.5	60.9a	25.3c	3.1e	3.1bc	2.60	354
Legumes							
Glyricidia	38.3	48.6c	12.1e	10.8b	4.0bc	3.00	663
Leucaena	32.9	54.3bc	12.9e	6.3d	2.8bc	2.20	594
Erythrina	28.7	51.4bc	18.2de	13.9a	4.6bc	2.54	606
Jack leaves	25.4	56.9ab	17.1de	7.1d	10.7a	2.55	564
Coconut meal	38.1	56.0ab	5.7f	11.0b	4.9b	2.71	745
Rice bran	22.4	30.9d	46.7a	8.6c	1.0c	2.43	344

[a]D, degradable fraction; U, undegradable fraction; k_d, rate of degradation of D; L, degradation time lag.
Within a column, means with dissimilar letters are significantly different ($P < 0.05$).
RSD, residual standard deviation; RDOM, rumen degradable organic matter.

et al., 1982). The simplest model that fitted the data with minimal bias was the exponential model. This model supposes two fractions, one undegradable (U) and one degradable (D) at an exponential rate ($-k_d$). Data were fitted separately to the four options available with this model; namely, with fixed or free U and with or without a discrete degradation time lag (L) to describe delay in initiation of degradation. The data were best fitted when U was fixed (240 h incubation period residue) and a degradation time lag was included

$$R = De^{[-k_{d(t-L)}]} + U$$

where R is residue, D is the size of the degradable fraction (% total), U is the size of the undegradable fraction (% total), k_d is the rate of degradation of D (% h^{-1}), L is the time lag before degradation begins (h) and t is time (h).

The parameters of the model were analysed as a factorial study with cow, feed, and the cow × feed interaction as factors (Statistical Application Systems, 1982).

Rumen degradable organic matter (RDOM) and nitrogen (RDN) in feeds was estimated using a presumed rate of particle passage (k_p) of 4% h^{-1} and the equation

$$S + D[k_d/(k_d + k_p)]$$

where S and D represent the amount of soluble and degradable material, respectively, in the feeds.

3. Results

3.1. Chemical composition

The chemical composition and OM digestibility of the test feeds are given in Table 1. The N content (g kg^{-1} DM) in grasses ranged from 12 (ruzi/signal) to 20 (guinea), and

Table 3

Parameters of the model[a] used to describe degradation of NDF and N in the rumen (mean of two cows)

Feed	NDF				N				
	D (%)	U (%)	k_d (% h^{-1})	L (h)	S (%)	U (%)	k_d (% h^{-1})	L (h)	RDN (g kg^{-1} DM)
Grasses									
Ruzi	65.7d	30.3c	4.3bc	3.7	35.9	18.7b	4.3d	1.1	7.3 (60)
NB21	75.2b	24.8d	3.9bc	1.1	19.2	21.7b	3.6d	3.8	6.5 (47)
Signal	56.0e	43.5b	4.1bc	3.3	40.2	28.3a	4.9d	5.6	7.2 (58)
Guinea	72.4bc	26.5cd	3.1c	3.1	8.9	17.1b	3.1d	0.0	8.4 (41)
Legumes									
Glyricidia	66.7cd	23.5d	10.9a	6.5	40.7	6.0cd	10.3b	7.3	38.2 (79)
Leucaena	71.6bc	23.2d	4.4bc	2.5	36.6	7.4c	5.3d	3.9	41.7 (69)
Erythrina	70.5bcd	26.0cd	11.1a	4.5	36.4	10.1c	13.0a	4.9	46.9 (77)
Jack leaves	70.5bcd	27.9cd	6.6b	10.4	14.2	11.4c	10.2b	11.5	13.7 (68)
Coconut meal	81.1a	11.1e	11.1a	3.8	28.9	1.8d	7.4c	6.7	28.2 (74)
Rice bran	24.1f	66.6a	5.3bc	1.2	38.9	22.0b	10.3b	0.9	11.5 (67)

[a]D, degradable fraction; U, undegradable fraction; k_d, rate of degradation of the degradable fraction; L, degradation time lag.

Within a column, means with dissimilar letters are significantly different ($P < 0.05$).

S, water soluble fraction; RDN, rumen degradable nitrogen.

Figures in parentheses are expressed as a percentage of total N in feed DM.

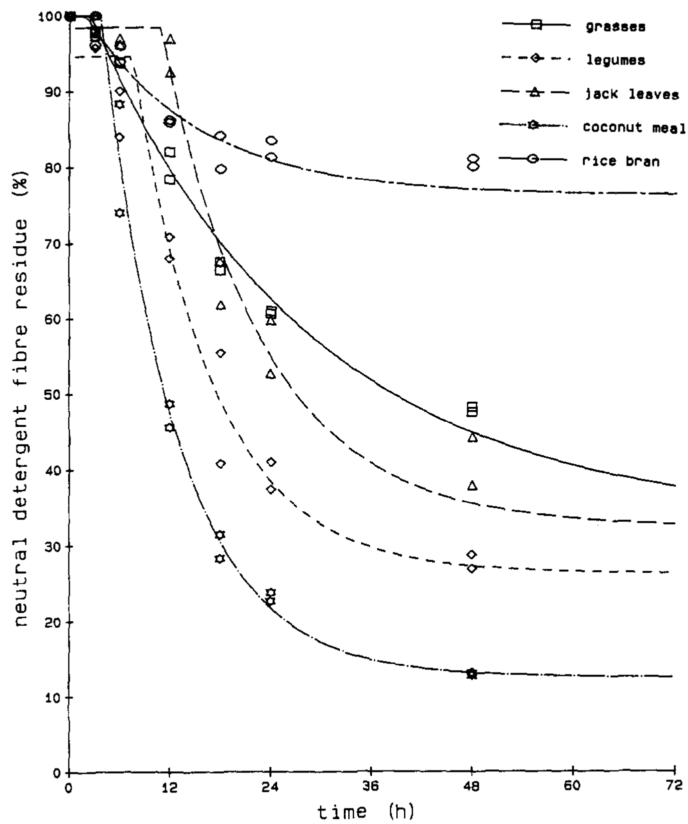

Fig. 1. Variation in rumen degradability of NDF of tropical forages and concentrate feeds.

that in legumes from 48 (glyricidia) to 61 (leucaena/erythrina). The comparatively high lignin content in signal (57) is reflected by a low IVOMD (53%). Compared with the other two legumes, leucaena had a higher lignin content (5–7 units) and a lower IVOMD value (9–11 units). The IVOMD values for guinea grass and jack leaves were similar (52%), but the latter had a higher lignin (57 vs. 72) and N (12.5 vs. 20.2) content. The low IVOMD value obtained for rice bran (45%) is reflected in its high ash (silica) and lignin content.

3.2. Degradation of organic matter (OM)

The parameters of the model used to describe the degradation of OM residue are presented in Table 2. The low residual standard deviation (RSD) values indicate that the model fitted the data satisfactorily. Among the grasses, the *D* fraction in NB21 and guinea was significantly ($P<0.05$) higher than that in signal and ruzi, and the *U* fraction in signal was significantly higher than that of the other three grasses studied. Except for k_d, which significantly differed between the three legumes, the other degradation parameters did not differ significantly. Erythrina had the highest k_d value (13.9% h^{-1}) compared with all other feeds studied. Compared with grasses, jack leaves had a lower *U* fraction (17.1%) and a signif-

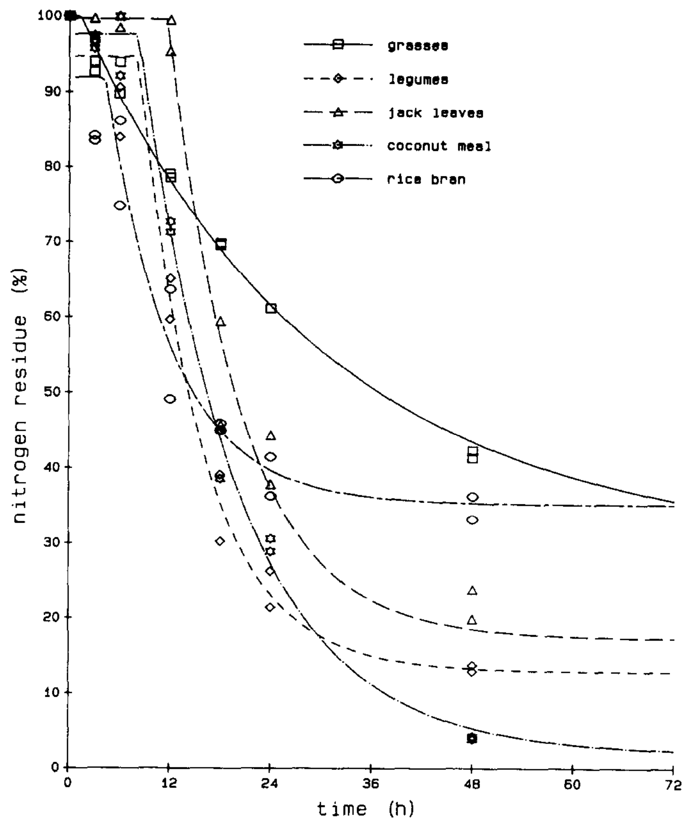

Fig. 2. Variation in rumen degradability of nitrogen of tropical forages and concentrate feeds.

icantly higher k_d value (7.1% h^{-1}). The lag phase for jack leaves was the highest among the feeds studied (10.7 h). The *U* fraction in coconut meal was significantly lower (5.7%), and that in rice bran was significantly higher (46.7%) compared with all other feeds.

3.3. Degradation of neutral detergent fibre (NDF) and nitrogen

Within grasses and legumes, the degradation characteristics for NDF were similar to those for OM (Table 3). The *U* fraction in signal (43.5%) was significantly higher than the other grass species, but there was no significant difference between the k_d and *L* values. Similarly within legumes, the parameters *D*, *U* and *L* did not differ significantly, and the k_d value obtained for leucaena was significantly low compared with glyricidia and erythrina.

The degradation curves, as fitted by the model, indicate that at early stages of degradation (less than 18 h), the NDF residue in grasses was lower than in jack leaves, but after 18 h the jack leaves residues was about 10 units lower than that of grasses (Fig. 1). With coconut meal and rice bran, there are distinct differences in the pattern of degradation and among the feeds studied, they represent the extremes.

For N, the k_d and L values did not significantly differ among grasses. However, the D fraction significantly ($P<0.05$) differed among grasses with guinea having the highest (71.6%) and signal the lowest (31.3%). Also, the U fraction in signal was significantly higher than in the other three grasses (28.3%). The S fraction for the three legumes ranged between 36 and 41, and the D, U and L values did not differ significantly. However, the k_d value differed significantly between the three legumes. The k_d value obtained for erythrina (13.0) was significantly higher than that found for all other feeds (range 3.1–10.3). The U fraction and the k_d value found for jack leaves differed from the grasses, and the L value obtained for jack leaves was higher than that found for all other feeds (11.5 h). Compared with all feeds, coconut meal had the lowest U fraction (1.8%), and the D fraction in rice bran was lower (39.1%).

The RDN in grasses ranged from 6.5 g (NB21) to 8.4 g (guinea), and in the legumes it ranged from 38.2 g (glyricidia) to 46.9 g (erythrina). About 67% of the N present in jack leaves and rice bran was rumen degradable.

The N degradation curves, as fitted by the model, show no distinction between the feeds in their ability to release N at early hours of degradation (less than 18 h), but after 24 h there are distinct differences between the feed classes (Fig. 2). For example, at 15 h the amount of N released from grasses and jack leaves was similar ($\pm$25%), but at 24 h the N released from these feeds was 40% and 60%, respectively.

4. Discussion

The natural or unfertilised grasses harvested by farmers from common grazing grounds, road sides and paddy field bunds are of low digestibility at least partly because of low N contents, and high NDF and lignin contents (Ibrahim et al., 1987). Of the four grass species used in the study, guinea grass, and to a lesser extent signal grass, are the most common species growing wild in Sri Lanka. The three leguminous species are also commonly seen in all parts of the island, and jack leaves are traditionally fed to goats. Coconut meal and rice bran form the bulk of the concentrate feed available, with the latter more commonly used by farmers.

In developing countries, in vitro digestibility estimates are commonly used as an index of feeding value because of difficulties associated with conducting animal feeding trials. While, this measurement might be of use to compare between feeds, it does not provide information on intake. Voluntary intake is governed by the amount of material in the reticulo-rumen (both degradable and undegradable), the rate of digestion and the rate of passage of digesta out of the reticulo-rumen. In this regard the data obtained from in sacco rumen degradation studies provides information on both degradable and undegradable fractions of the feed, and also on the rate of degradation. The potentially degradable ($S+D$) OM fraction between grasses ranged from 68 to 77%. Signal grass not only falls in the lower range, but also had a lower k_d value for the degradable fraction (3.1% h^{-1}) and a higher U fraction. However, the degradation parameters obtained for guinea grass are comparable to those of the two improved grasses (ruzi and NB21). Differences between guinea and signal grass are much greater for the degradation characteristics for NDF than for OM. Information available in the literature on evaluation of tropical grasses based on degradation characteristics is scarce to make meaningful comparisons with the data obtained in the present study. Generally, at the optimal stage of harvesting, the extent of digestion of legume OM is greater than for grasses, largely because of differences in cell wall (CW) level; however, the extent of legume CW degradation is usually less than for grass because of greater lignin content in the former (Galyean and Goetsch, 1993). Differences in degradation patterns of grasses and legumes (Fig. 1) could be a function of more restricted or localised deposition of lignin in legumes (Buxton and Fritz, 1985). Localised deposition of lignin in legumes would minimise its physical restriction to NDF digestion (Moore and Cherney, 1986). Jack leaves not only had a higher potentially degradable OM fraction (82.3%) compared with grasses (74.2%), but also had a higher rate of degradation and a lower U fraction. The degradation pattern of NDF in jack leaves falls between grasses and legumes. The significantly higher lag phase observed for jack leaves, with all components studied, could be due to the presence of latex or resins which inhibits initial colonisation of cell walls by rumen microbes. The degradation characteristics obtained for both OM and NDF indicate that the average quality rice bran used in the study is inferior (higher U fraction) to grasses. Feeding experiments conducted in Sri Lanka with cattle using rice bran of similar quality (Ghebrehiwet et al., 1988) indicate that animals fail to ingest more than 1.2 kg day^{-1} even when offered ad libitum. In a more elaborate study conducted in Sri Lanka (Ibrahim, 1986) it was shown that the chemical composition and digestibility of rice bran varies among varieties, threshing procedure (machine/tractor/buffalo), pre-milling conditions (raw or parboiled) and type of machinery (bran/husk contamination) used for milling. The higher U fraction and high total ash content (20.8%) observed in our study is a clear indication of the extent to which contamination with hulls could reduce the quality of rice bran. In another batch of rice bran comparable values for the size of the U fraction and k_d were observed (Tamminga et al., 1990). Except for high fat content (10.3%) in coconut meal, its degradation characteristics for OM and NDF were superior to all feeds tested.

Nitrogen is considered the limiting factor in livestock production in the tropics (Egan, 1985). Whatever the characteristics of the N source, the concentration of ammonia in the rumen fluid is raised by N addition, which presumably allows a build-up in the population of cellulolytic bacteria and a fully functional biomass, thereby increasing plant degradation and allowing increased forage intake by the cattle. There is evidence to show that there is a considerable amount of error involved in measuring N release from rumen incubated feeds. Also, the extent of microbial colonisation of plant residues to a great extent depends on the quality of the feed (Kennedy et al., 1984; Varvikko and Lindberg, 1985). The ideal forage supplement has been thought of as one which releases N and other growth factors into the rumen environment to maintain optimum conditions for microbial growth and yet contain significant quantities of protein capable of escaping rumen digestion.

The attractive feature of legumes is primarily the high N content. Minson (1990) found that CP in a range of tropical legumes varied from 6 to 30%, but only 10% of the species studied contained less than 12%. One important difference between legume species is the considerable variation in the solubility of protein in the rumen fluid (Aii and Stobbs, 1980). In the present study, the k_d values were significantly different even though there was no significant difference in D, U and L values among the three legume species studied. Under situations where there is sufficient rumen ammonia to optimise fibre digestion, the slower rate of breakdown of N in leucaena may be of practical significance, since legumes are retained in the rumen for a shorter time than grasses (Thornton and Minson, 1973). As such, considerable quantities of undegradable N could leave the rumen to be hydrolysed in the small intestine and absorbed with greater benefit to animal productivity. This suggestion is supported by the observation of Flores et al. (1979) that leucaena increased milk yield in a similar manner to formaldehyde treated casein. Among the feeds with low N contents (less than 20 g kg^{-1} DM), and in spite of the long lag phase, the release of N from jack leaves is much faster and greater than from grasses and rice bran. Although the disappearance of degradable N from rice bran and jack leaves was similar (60%) at 24 h, at 36 h jack leaves released a further 20% compared with 5% from rice bran. Also, the RDN content in jack leaves is higher than in the grasses and rice bran and this might be of practical significance in situations where N content in the basal roughage is insufficient to maintain optimum rumen ammonia levels to maximise fibre digestion. However, 39% of the N present in rice bran is water soluble, compared with 14% with jack leaves. Protein meals which contain 400 g kg^{-1} DM protein, of which at least half escapes rumen degradation have increased productivity of cattle in pens (Hennessy et al., 1983). In this respect, the protein content of coconut meal is low (238 g kg^{-1} DM) and highly degradable in the rumen (74%).

Chenost et al. (1970) and Hovell et al. (1986) reported that the degradability of roughage incubated in sacco in the rumen gave better predictions of voluntary intake ($r=0.82$) than in vivo digestibility. With barley straw, Ørskov et al. (1987) found that better predictions of intake ($r=0.88$) and animal performance ($r=0.95$) could be made by including the degradable fraction and its rate constant in the regression. One useful application of the potential degradable characteristics of a roughage (feed) can be made. The Agricultural Research Council (1984) recommendations relate rumen degradable nitrogen (RDN) requirements of the rumen microorganisms to OM digested in the rumen. This is a complicated measurement to make in vivo. The relatively simple method of determining the degradable fraction using in sacco procedure will define the maximum amount of degradable OM potentially available to the rumen microorganisms from a given feed, and hence the optimal RDN concentration. For optimum microbial yield, the RDN/RDOM ratio should be between 20 and 25 g RDN kg^{-1} RDOM (Tamminga et al., 1990). The ratio based on RDOM and RDN indicates that ruzi (15.5) and NB21 (16.0) remain below this range; signal (20.9), guinea (23.7) and jack leaves (24.3) are on the borderline, and the legumes (57.6–77.4), coconut meal (37.8) and rice bran (33.4) have a surplus of RDN.

Acknowledgements

The authors wish to thank H.G.D. Perera and R.S. Ketelaar for assisting with the bag incubations, and Ir. B. Brouwer for assisting with statistical analyses of the data. The assistance provided by the technical staff (laboratories and metabolism unit) of the Institute for Livestock Feeding and Nutrition Research (IVVO), the Netherlands is gratefully acknowledged. Financial assistance was provided by Commission of the European Communities under contract no. TSD-A-301-NL (N).

References

Agricultural Research Council, 1984. The Nutrient Requirements of Ruminant Livestock. ARC, Commonwealth Agricultural Bureaux (CAB).

Aii, T. and Stobbs, T.H., 1980. Solubility of the protein of tropical pasture species and the rate of its digestion in the rumen. Anim. Feed Sci. Technol., 5: 183–192.

Alvey, N., Galweg, N. and Lane, P., 1982. An Introduction in Genstat. Academic Press, London, 152 pp.

Association of Official Analytical Chemists, 1980. Official Methods of Analysis, 13th edn. AOAC, Washington, DC.

Buxton, D.R. and Fritz, J.O., 1985. Digestibility and chemical composition of cell walls from grass and legume stems. In: Proc. of the 15th Int. Grassland Congress, Kyoto, Japan, 24–31 August 1985.

Chenost, M., Grenet, E., Demarquilly, C. and Jarrige, R., 1970. The use of nylon bag technique for the study of forage digestion in the rumen and for predicting feeding value. In: Proc. XI Int. Grassland Congress, Queensland, Australia. University of Queensland Press, St. Lucia, Qld., pp. 697–701.

Egan, A.R., 1985. Principles of supplementation of poor quality roughages with nitrogen. In: R.M. Dixon (Editor), Ruminant Feeding Systems Utilizing Fibrous Agricultural Residues. IDP, Canberra, Australia, pp. 49–57.

Flores, J.F., Stobbs, T.H. and Minson, D.J., 1979. The influence of the legume *Leucaena leucocephala* and formal-casein on the production and composition of milk from grazing cows. J. Agric. Sci., 92: 351–357.

Galyean, M.L. and Goetsch, A.L., 1993. Utilization of forage fibre by ruminants. In: H.G. Jung, D.R. Buxton, R.D. Hatfield and J. Ralph (Editors), Forage Cell Wall Structure and Digestibility. United States Agricultural Research Service, Madison, WI, pp. 33–72.

Ghebrehiwet, T., Ibrahim, M.N.M. and Schiere, J.B., 1988. Response of growing bulls diets containing untreated or urea treated rice straw with rice bran supplementation. Biol. Wastes, 25: 269–280.

Goering, H.K. and van Soest, P.J., 1970. Forage Fibre Analyses (Apparatus, Reagents, Procedures and some Applications). Agriculture Handbook No. 379, US Department of Agriculture, Washington, DC.

Hennessy, D.W., Williamson, P.J., Nolan, J.V., Kempton, T.J. and Leng, R.A., 1983. The role of energy or protein-rich supplements in the sub-tropics for young cattle consuming basal diets that are low in digestible energy and protein. J. Agric. Sci., 100: 657–666.

Hoover, W.H., 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci., 69: 2755–2766.

Hovell, F.D. DeB., Ngambi, J.W.W., Barker, W.P. and Kyle, D.J., 1986. The voluntary intake of hay by sheep in relation to its degradability in the rumen as measured in nylon bags. Anim. Prod., 42: 111–118.

Ibrahim, M.N.M., 1986. Rice bran as a supplement for straw based rations. In: R.M. Dixon (Editor), Ruminant Feeding Systems Utilizing Fibrous Agricultural Residues. IDP, Canberra, Australia, pp. 139–144.

Ibrahim, M.N.M., Tamminga, S. and Zemmelink, G., 1987. Nutritive value of some commonly available ruminant feeds in Sri Lanka. In: R.M. Dixon (Editor), Ruminant Feeding Systems Utilizing Fibrous Agricultural Residues. IDP, Canberra, Australia, pp. 137–150.

Kennedy, P.M., Hazlewood, G.P. and Milligan, L.P., 1984. A comparison of methods for the estimation of the proportion of microbial nitrogen in duodenal digestion, and the correction for microbial contamination in nylon bags incubated in the rumen of sheep. Br. J. Nutr., 52: 403–417.

Minson, D.J., 1990. Forage in Ruminant Nutrition. Academic Press, San Diego, CA.

Moore, K.J. and Cherney, J.H., 1986. Digestion kinetics of sequential extracted cell wall components of forage. Crop Sci., 26: 1230–1235.

Ørskov, E.R., Kay, M. and Reid, G.W., 1987. Prediction of intake of straw and performance by cattle from chemical analysis, biological measurements and degradation characteristics. Paper presented at the workshop on Methods of Evaluation of Straws in Ruminant Feeding, INRA, Theix, France, 2–4 June 1987.

Robinson, P.H., Fadel, J.G. and Tamminga, S., 1986. Evaluation of mathematical models to describe neutral detergent residue in terms of its susceptibility to degradation in the rumen. Anim. Feed Sci. Technol., 15: 249–271.

Satter, L.D. and Slyter, L.L., 1974. Effect of ammonia concentration on rumen microbial protein production in vitro. Br. J. Nutr., 32: 199–208.

Statistical Application Systems, 1982. SAS User's Guide: SAS Institute Inc., Carey, NC, 956 pp.

Tamminga, S., van Vuuren, A.M., van der Koelen, C.J., Ketelaar, R.S. and van der Togt, P.L., 1990. Ruminal behaviour of structural carbohydrates, non-structural carbohydrates and crude protein from concentrate ingredients in dairy cows. Neth. J. Agric. Sci., 38: 513–526.

Thornton, R.F. and Minson, D.J., 1973. The relationship between apparent retention time in the rumen, voluntary intake and apparent digestibility of legume and grass diets in sheep. Aust. J. Agric. Res., 24: 809–819.

Tilley, J.M.A. and Terry, R.A., 1963. A two-stage technique for in vitro digestion of forage crops. J. Br. Grassl. Soc., 18: 104–111.

Varvikko, T. and Lindberg, J.E., 1985. Estimation of microbial nitrogen in nylon-bag residues by feed ^{15}N dilution. Br. J. Nutr., 54: 473–481.