In vivo nutrient digestibility in sheep, and rumen dry matter degradability in cattle fed crop by-product based diets

Safiétou Touré Fall[1], Maïmouna Cissé[1], D. Ditaroh[1], D. Richard[2], N'Dèye Salane Ndiaye[1] and B. Diaw[1]

*[1]ISRA Senegalese Institute of Agricultural Research,
National Laboratory of Animal Breeding and Veterinary Research
BP 2057 Dakar, Sénégal
[2]CIRAD International Center for Agronomic Research and Development – EMVT,
Department of Animal Breeding and Tropical Veterinary Medicine
BP 5035 Montpellier, Cedex 01, France*

ABSTRACT

Nutrient *in vivo* digestibility in sheep and rumen dry matter degradability in cattle fed cereal straw and concentrate-based diets were determined in two experiments. In Experiment 1, a conventional *in vivo* balance trial was conducted with six Peul-peul sheep to evaluate apparent digestibility of 3 diets. Diet 1 consisted of (g/kg DM): rice straw 560, molasses 115, rice bran 180, peanut cake 130 and mineral supplement 15; diet 2 contained (g/kg DM): millet straw 580, molasses 115, millet bran 175, peanut cake 113 and mineral supplement 15; diet 3 was a mixture of (g/kg DM) peanut hulls 180 and cake 50, molasses 200, maize grain 95, senal* 200, cotton seeds 250 and mineral supplement 25. In Experiment 2, the rumen degradation pattern of the feed ingredients was evaluated using the nylon bag technique in three fistulated Gobra zebu bulls successively fed the same diets.

In vivo dry matter and organic matter digestibility were significantly (P<0.05) influenced by diet type and particularly cell wall digestion was higher (P<0.01) in the straw based diets (1 and 2) when compared with the mixed feed (diet 3). The animal did not influence (P<0.05) feed degradation profiles which were strongly (P<0.001) modified by diet and feed type. It was possible to classify different feed types according to their theoretical DM degradability (Dt) in low (Dt < 50% DM) and medium quality roughages (50<Dt>55 % DM) and concentrates (Dt>55 % DM). Treatment of straws with molasses (17%) significantly (P<0.01) improved their DM degradation. The feed average de-

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* Senal: manufactured concentrate made up of wheat bran, molasses, urea and minerals

gradation profile was influenced by fibre content, especially lignocellulose (R= – 0.76). Feed Dt can also be predicted by dry matter disappearance at 24 h incubation time (R=0.90) and from individual ingredients in the case of mixed feeds.

KEY WORDS: cereal straws, *in vivo* digestibility, rumen degradation, cattle, sheep

INTRODUCTION

Optimization of the rumen function is of major importance for the digestion of diets based on low quality roughages (Sundstøl and Owen, 1984; Galyean and Goetsch, 1993). There are strong relationships between diet composition and digestibility. Rumen microbial ecosystem and activity are influenced by the supplement type and level in the diet which determine the availability of minerals, nitrogen and glucogenic precursors. Special attention is given to cell wall concentration in the ration as it is related to feed efficiency (Van Soest, 1982). Thus, inter-ingredient relationships determine the occurrence of associative effects (Frederiksen, 1973; Kromann, 1973; Sauvant and Giger, 1989; Berge and Dulphy, 1991; Archimede et al., 1996). Rations should then be formulated not only to meet ruminant nutrient requirements but also to stimulate positive interactions among ingredients. The latter interactions may improve the feed value by enhancing feed intake, microbial synthesis and fibre degradation. The extent and rate of feed dry matter intraruminal degradation are valid criteria for assessing the feed value of fibrous feeds for ruminants and the efficiency of the rumen (Ørskov et al., 1980; Preston and Leng, 1987).

The main objective of this study was to assess *in vivo* dry matter, organic matter, crude protein and fibre digestibility of three diets based on rice straw (diet 1), millet straw (diet 2) and peanut hulls (diet 3) and to study rumen efficiency of zebu cattle fed those diets by measuring dry matter degradation of different ingredients using the nylon bag method. The influence of animal, feedstuffs and diet type on the *in sacco* degradation pattern was studied by comparison of three diets with different levels of concentrates.

MATERIAL AND METHODS

In vivo digestibility trials – Experiment 1

Animals and diets

Conventional *in vivo* balance trials were performed with six young male Peulpeul sheep for evaluation of diet dry matter digestibility. The animals of 25 kg

TABLE 1

Diets composition and nutritive value, % of DM

Composition	Diets		
	1	2	3
Rice straw	56	–	–
Rice bran	18	–	–
Peanut cake	13	11.5	5
Peanut hulls	–	–	18
Cotton seeds	–	–	25
Millet straw	–	58	–
Molasses	11.5	11.5	20
Millet bran	–	17.5	–
Maize grain	–	–	9.5
Senal[1]	–	–	20
Mineral mixture	1.5	1.5	2.5
Feed unit[2]/kg DM	0.64	0.6	0.80
Digestible crude protein, g/kgDM	72	67	90
Calcium	5	4.5	5
Phosphorus	3	3	3

[1] Senal: manufactured concentrate made up of wheat bran (90% DM) + molasses (10% DM)
[2] Feed unit: Net Energy unit (INRA, 1978)

body weight were housed in individual pens equipped for measurement of feed intake and faecal output.

Three diets were studied (Table 1). Two of them contained the test crop residues while the third contained more concentrates and served as a high quality control diet. In straw-based diets, molassed rice straw and molassed millet straw (17:63 w/w) were given as a basal diet while the other ingredients were mixed and given as supplement 1 and 2 in diets 1 and 2, respectively. For diet 3 all ingredients were mixed and given as a total compound feed.

Experimental procedures

Sheep were maintained in individual pens for 15 days of adjustment followed by 6 days of measurement periods. During the latter period, feed offered and refused as well as total faecal output were measured daily and samples were ovendried at 60°C for dry matter evaluation. The pooled faecal sample, each feed ingredient, supplement 1, supplement 2 and mixed diet 3 were collected for chemical analysis.

Chemical analysis

Feed ingredients, mixtures and faecal output were analyzed for dry matter, crude protein, phosphorus and calcium (AOAC, 1975) and cell wall components: NDF, ADF and lignin (Goering and Van Soest, 1979).

In sacco degradation trials – Experiment 2

Three young Gobra zebu bulls fitted with rumen cannulae were successively fed diet 1, 2 and 3 (Table 1), each during 15 days of adjustment followed by a 3 day measurement period. Feed ingredients and total rations were sampled, oven dried (60°C) and ground through a 1 mm screen for incubation in the rumen. Bags with an internal dimension of 6 x 11 cm and made of Blutex nylon material (Tripette et Renaud, France) with 46 μm pore size were each filled with 3 g ground sample and heat sealed. One bag of each sample was withdrawn at 2, 4, 24, 48 and 72 h, washed with running water until clear, then beaten with a stomacher to reduce bacterial contamination (Michalet-Doreau and Ould-Bah, 1989), washed again and oven dried at 60°C. For each sample six replications were run from two trials with 3 animals.

Calculations and statistical analysis

The significance of differences in dry matter and nutrient digestibilities were assessed by variance analysis using GLM procedures. Animal and diet effects were separated by the Duncan test (SAS, 1988).

Degradation parameters were calculated according to the model of Ørskov and McDonald (1979): $D = a + b (1-e^{-ct})$;

where D is the DM degraded at a given time t; a represents the readily degradable fraction; b is the slowly degraded fraction and c the degradation rate of the b fraction.

Rumen DM degradability (Dt) was calculated according to the equation:

$Dt = a + (bc / c+k)$;

in which k represents the rumen outflow rate of 4% h^{-1} (Lechner-Doll et al., 1992).

To check the existence of lag time (to), the model modification proposed by Dhanoa (1988) was also applied:

$D = a + b(1- e^{-(ct-to)})$ and $Dt = a + (bc / c+ke^{-kto})$

To calculate degradation parameters, degradation profiles were fitted to NLIN procedures (Marquardt Methods; SAS, 1988). Analysis of variance using the GLM

procedure (SAS, 1988) was applied to examine animal, diet and feed effects on degradation parameters. The influence of feed chemical composition on these parameters was examined by regression analysis.

DM degradability (Dt) of supplements 1 and 2 and diet 3 was evaluated from degradability of different ingredients by the following relation:

$$Dt = Dt_1 L_1 + Dt_2 L_2 + \ldots\ldots + Dt_x L_x$$

where Dt_1 = degradability for ingredient 1; L_1 = ingredient 1 content in the mixture
Dt_2 = degradability for ingredient 2; L_2 = ingredient 2 content in the mixture
Dt_x = degradability for ingredients x; L_x = ingredient x content in the mixture
Estimated Dt was then compared to that measured.

RESULTS

In vivo digestibility – Experiment 1

Chemical composition of feed ingredients and diets. The composition of feed ingredients is given in Table 2. The results are consistent with the usual ranges of tropical feed chemical composition (Kearl, 1982; Richard et al., 1989; Pond et al., 1995). Silica levels were high in cereal straws, peanut hulls and rice bran and also in supplement 1 made in part of rice bran. This is due to soil contamination occurring during processing for agro-industrial by products, or late harvesting in the case of cereal straws.

TABLE 2

Chemical composition of feed ingredients, g/kg DM

Ingredients	Cellulose	Crude protein	NDF	ADF	Si	P	Ca
Rice straw	350	41	680	393	152	1.1	2.8
Millet straw	380	65	714	453	122	1.3	4.2
Peanut hulls	348	61	831	708	46	0.4	0.6
Rice bran	76	51	655	440	164	3.4	0.8
Millet bran	20	139	475	14	65	5.1	1.1
Senal	123	228	527	177	5.9	3.8	15.0
Peanut cake	50	485	376	202	8.6	4.6	1.2
Cotton seeds	241	240	466	327	3.9	5.0	1.3
Supplement 1	218	175	674	331	122	4.5	4.1
Supplement 2	73	232	795	121	53	5.5	7.3
Maize grain	19	88	678	47	5.5	1.3	0.9
Diet 3	184	162	607	290	23	4.9	0.6
Molasses	0	6	-	-	-	0.7	7.3

TABLE 3

Average chemical composition of feed consumed

Diets	DM intake	OM	CP	NDF	ADF	ADL
	g/kg BW$^{0.75}$			% DM		
1	64	81.6	11.6	55.3	33.3	6.4
2	59	81.0	11.2	42.3	24.6	5.5
3	88	88.3	16.0	36.6	26.4	10.5

Average chemical composition of total diet intake is shown in Table 3. OM content was similar from one diet to another while ration 2 was higher in CP compared with cereal by-product based diets which had a higher fibre concentration.

TABLE 4

In vivo digestibility of nutrients in tested rations, % of DM

Diets	DM*	OM*	CP*	NDF**	ADF**	ADL**
1	52.0[a]	58.7[a]	68.1[a]	51.9[a]	49.5[a]	12.1[a]
2	56.0[b]	63.6[b]	57.3[b]	52.9[a]	53.5[a]	17.3[a]
3	56.9[b]	57.6[a]	69.8[a]	24.6[b]	17.2[b]	5.5[b]

means with different superscripts are significantly different ; * P<0.05 ; ** P<0.01

In vivo digestibility of diets. Table 4 shows the *in vivo* apparent digestibility of tested diets. Variations between animals were not significant (P<0.05). Average dry matter (DMD), organic matter (OMD) and crude protein digestibility (CPD) were significantly influenced by the diet type (P<0.05). Those differences were more pronounced in cell wall components which were better (P<0.01) digested in straw based rations. NDF digestibility (NDFD) averaged 52 % in diets 1 and 2 against 25 % DM only in diet 3. The same tendency was observed in ADF and lignin digestibility. Thus, the low fibre content in diet 3, appeared to have a negative effect on cell wall digestibility.

In sacco degradability – Experiment 2

DM degradation profiles of tested feeds are presented in Table 5 and Figures 1, 2 and 3. Table 6 shows calculated degradation parameters. The two applied models gave similar results in concentrate feeds while degradation parameters differed in low quality roughage. With the Dhanoa model it was possible to select the slowly degraded feedstuffs with a lag time varying from 3 to 4.9 h in cereal straws.

Degradation kinetics varied within a wide range from rice straw (dt=47 % DM) to Senal (dt=70 % DM). Differences among feeds were highly significant

TABLE 5

Dry matter degradability of feeds (% DM): influence of the diet type

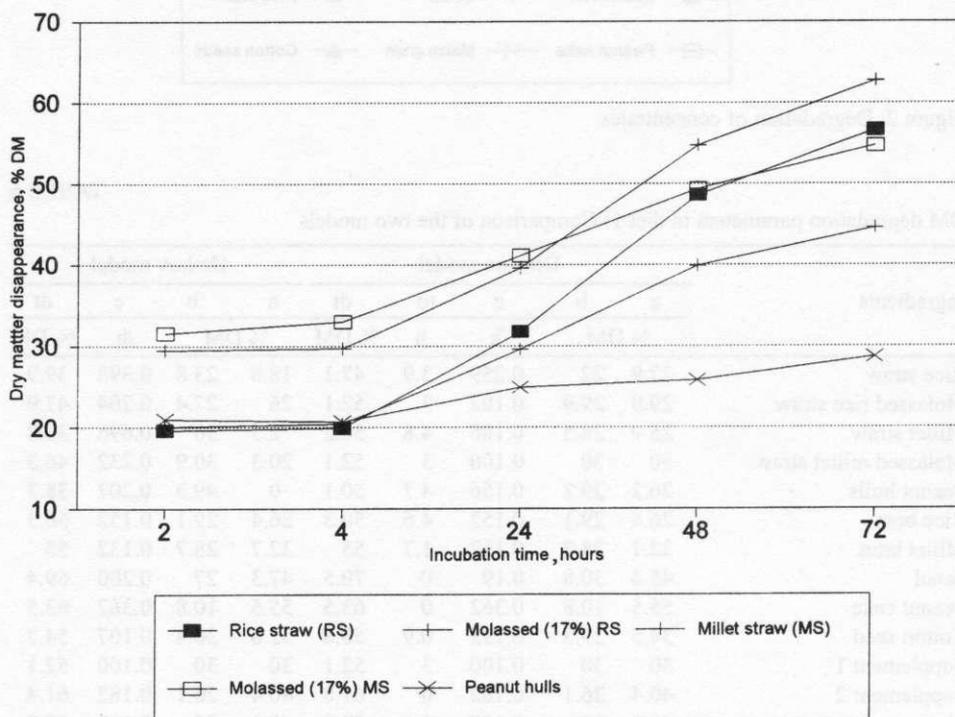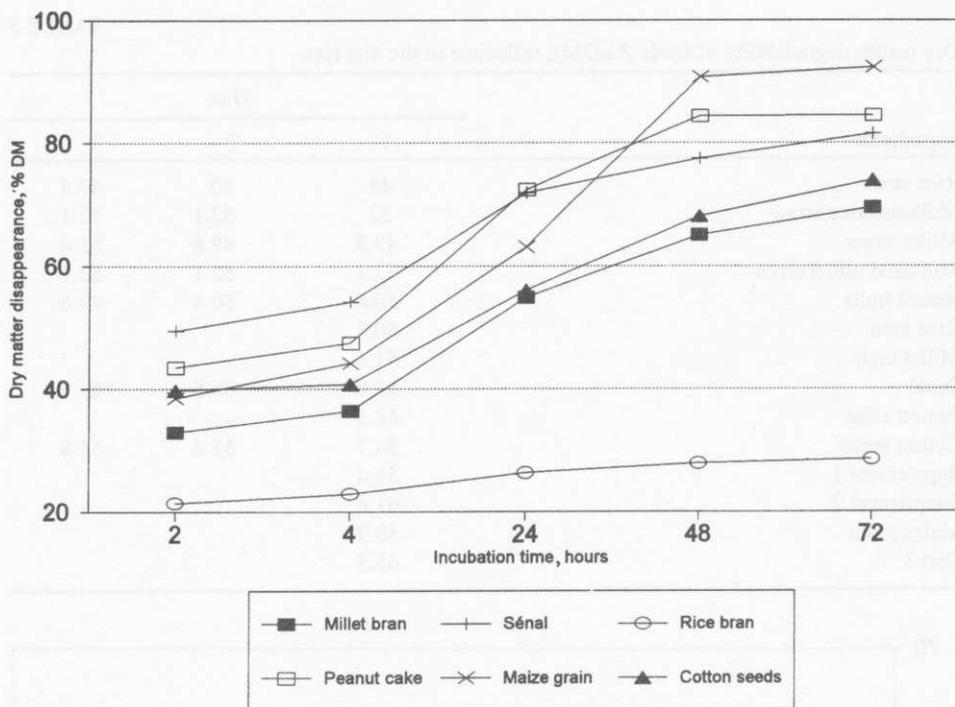| Ingredients	Diet		
	1	2	3
Rice straw	44	50	47.4
Molassed rice straw	52	52.1	52.1
Millet straw	49.5	49.6	51.4
Molassed millet straw	52.1	52.1	52.1
Peanut hulls	50.4	50.4	49.6
Rice bran	50.3		
Millet bran	51.4		
Senal	69.8	68.8	69.7
Peanut cake	68.5		
Cotton seeds	54.7	55.8	53.8
Supplement 1	52.4		
Supplement 2	61.8		
Maize grain	68.9		
Diet 3	65.5		

Figure 1. Degradation of basal diets

Figure 2. Degradation of concentrates

TABLE 6

DM degradation parameters in diet 1: Comparison of the two models

| Ingredients	Dhanoa model					Ørskov model			
	a	b	c	to	dt	a	b	c	dt
	% DM		/h	h	% DM	% DM		/h	% DM
Rice straw	27.9	22	0.259	3.9	47.1	18.8	23.8	0.398	39.9
Molassed rice straw	29.9	29.9	0.102	3	52.1	26	27.4	0.204	47.9
Millet straw	25.9	28.5	0.186	4.8	50.2	2.5	30	0.696	30.8
Molassed millet straw	30	30	0.100	3	52.1	20.3	30.9	0.232	46.3
Peanut hulls	26.2	29.2	0.156	4.7	50.1	0	49.3	0.207	38.3
Rice bran	26.4	29.1	0.152	4.6	50.3	26.4	29.1	0.152	50.3
Millet bran	32.7	28.7	0.132	1.7	55	32.7	28.7	0.132	55
Senal	45.4	30.8	0.19	0	70.5	47.3	27	0.200	69.4
Peanut cake	55.5	10.8	0.362	0	63.5	55.5	10.8	0.362	63.5
Cotton seed	34.5	29.3	0.193	0.9	58.8	32.6	30.4	0.107	54.7
Supplement 1	30	30	0.100	3	52.1	30	30	0.100	52.1
Supplement 2	40.4	26.1	0.182	0	61.8	40.4	26.1	0.182	61.8
Maize grain	40.9	25	0.107	0	59.2	40.9	25	0.107	59.2
Diet 3	35.6	38.8	0.168	0.2	66.9	37.7	31.9	0.276	65.5
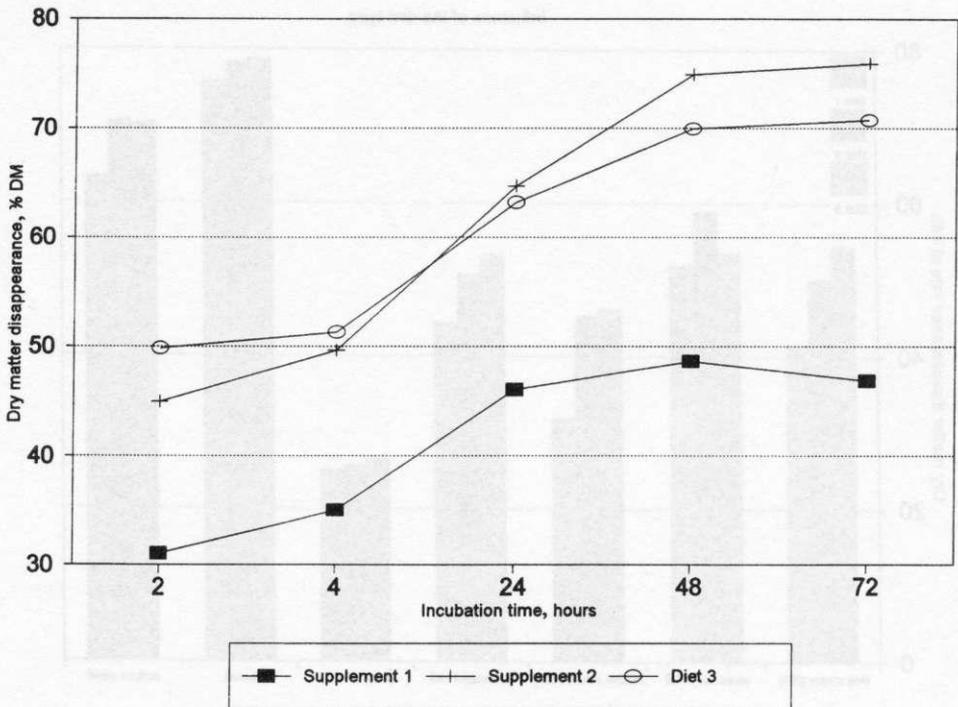
Figure 3. Degradation of feed mixtures

(P<0.0001). Three groups could be distinguished. Low quality feeds like straws fed alone, peanut hulls and rice bran (dt<50 %DM), medium quality forage like molassed cereal straws (50<Dt<55 %DM) and concentrates (Dt>55 %DM). There was a significant (P<0.01) beneficial effect when cereal straws where treated with molasses.

Differences in feed degradability were related to fibre content. ADF and crude fibre (CF) were the best predictors of DM degradability.

$Dt = 66.8 - 0.046 ADF$ $R = 0.76$ $P < 0.001$ $SE = 7.1$ $N = 14$

$Dt = 63.7 - 0.057 CF$ $R = 0.76$ $P < 0.001$ $SE = 7.1$ $N = 14$

Among concentrate feeds, whole cotton seeds which have the highest fibre content, were less degraded than Senal; the same for millet straw among the fibrous feeds. Silica (R= – 0.65) and NDF (R= – 0.57) may also play a negative role in DM degradation profile.

The animal did not influence the degradation profiles of different diets significantly (P<0.05) while diet type was a major variation factor (P<0.001). Compared with a high concentrate diet, straw based diets (1 and 2) offered higher dry matter degradability at 48 h incubation time (Figure 4). The applied calculation model
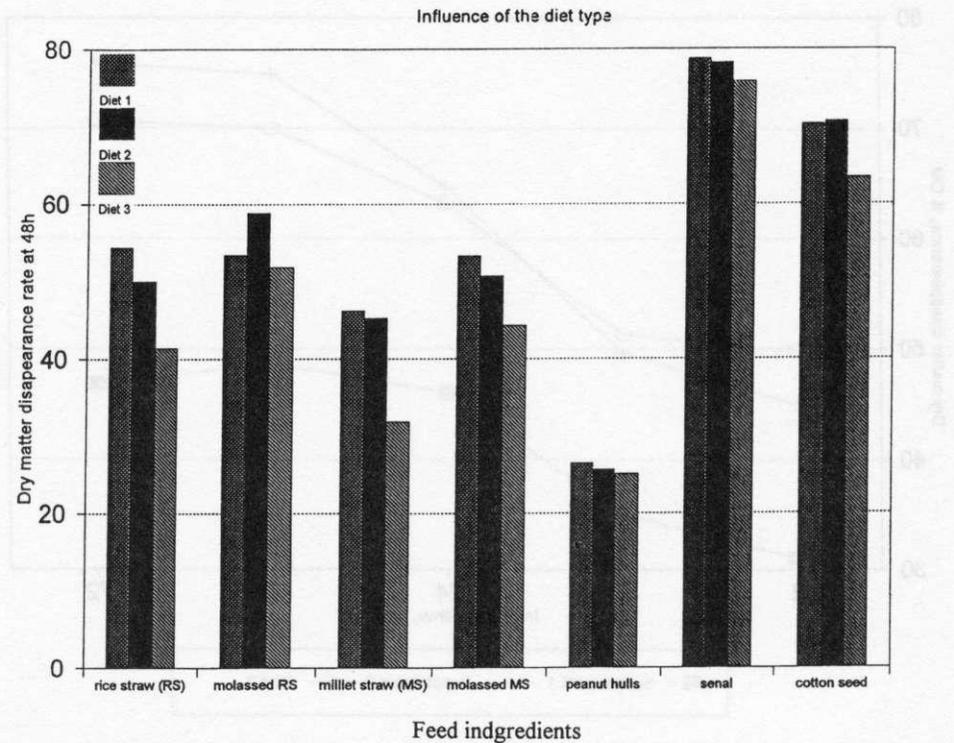
Figure 4. Degradation of feedstuffs

influences the extent of between-diet variation; in the Ørskov model strong variation profiles were observed among diets while those differences were not important when the Dhanoa model was used (Table 5).

Measured and calculated Dt values were closely similar for Supplement 2. A difference of 5 points was observed in supplement 1 and diet 3 (Table 7).

Dt could also be predicted from dry matter disappearance at 24 h incubation time (Deg24h)

$Dt = 24.4 + 0.563*Deg24h$ R = 0.90   P<0.001 SE = 5.0 N=14

In vivo digestibility (DMD) was close to dry matter degradability (Dt): 56.9 vs 54.9 % DM in diet 3.

TABLE 7
Estimation of mixed feeds Dt (% DM) from individual ingredients

	Supplement 1	Supplement 2	Diet 3
Calculated	57.6	60.4	71.5
Measured	52.1	61.8	66.2
Difference	– 5.5	– 1.4	– 5.3

DISCUSSION

OMD was comparable to our previous results (Fall et al., 1989; Richard et al., 1989) in the rice straw based diet while it was superior to the millet straw based one. That may be due to better forage quality with good leaf preservation. The concentrate mixture (diet 3) had low DM and OM digestibility because of low cell wall digestion. The NDF content of that diet was 61% DM and only 25, 17 and 5% of NDF, ADF and lignin was digested, respectively. A lower retention time because of its fine texture might also depress total OMD of the concentrate mixture.

DM degradation profiles were quite different from one feedstuff to another. In general, the feed classification made on the Dt basis gave the usual ranking of feedstuffs except for rice bran which, expected to be a concentrate, was classified among the lowest quality feeds. This may be due to soil contamination of rice bran and peanut hulls during processing as indicated by high NDF and silica contents (Table 2).

Rice and millet straw degradation profiles (a + b = 30 to 60%DM) were close to those of Ørskov (1988) for different wheat straw varieties. They differed from those reported for Mediterranean countries in which the a+b value varied from 60 in triticale to 70% DM in wheat straw (Chermiti et al., 1996). They were also lower than the barley straw DM degradability (a + b = 66% DM) described by Bhargava et al. (1986), but higher than that reported by Hvelplund (1989) (a + b = 24). These differences can be explained by drought stresses and poor harvesting conditions leading consequently to large leaf losses, soil contamination and digestibility depression. The heterogeneity of straws is well known to depend on plant species and variety, year, harvesting period and methods (Bhargava et al., 1988; Cappers et al., 1988; Ørskov, 1988).

As expected, the Dt values of concentrates were high in general except for that of rice bran which was of low quality with high NDF and silica contents (Table 2).

Feed degradability was well predicted by fibre content and strong relationships between ADF and Dt (R = − 0.76) were found. The negative effect of lignocellulose (ADF) on feed digestibility in general, and particularly in low quality roughages is well known (Van Soest, 1982; Akin et al., 1990). So processing fibrous feeds and supplementation strategies should be directed to improve cell wall digestion.

Having in mind that nylon bag studies are not always easy to carry out, estimation of feed degradability from chemical composition and ingredient proportions in the diet could help simplify the method. Estimates of the mixed feed Dt from the Dt of individual ingredients were in agreement with the findings of Stallings et al. (1991) regarding the protein degradation profile of diets containing barley silages. That method can be a useful tool for estimating the degradability of mixed feed diets.

Measurement of *in vivo* DMD of three diets based on crop by-products available in Senegal showed comparable value regarding DM and OM digestibility between millet and rice straw based diets compared to a high concentrate mixture. Cereal straw based diets showed a higher tendency to digest fibre.

In vivo observations were confirmed by *in sacco* results which showed significant (P<0.001) influence of the ration type on DM degradation profiles for the 14 incubated feeds. In general, better fibre digestion in straw-based diets compared with high concentrate diets was observed.

The diet influence in the rumen DM degradation profile demonstrates the occurrence of associative effects. The different diet components, the fibrous feeds/concentrates ratio in particular, affect energy digestion. Such digestive interactions between feeds has been widely reported (Galyean and Goetsch, 1993).

Interrelationships between ruminal ecosystems and straw digestion have been reviewed in detail by Durand (1989) and Galyean and Goetsch (1993). Diets 1 and 2 were characterized by high straw levels (concentrate/straw ratio = 43/57) and low readily fermentable carbohydrate content. These types of feeds have a high buffering capacity probably linked to greater salivary secretion and higher rumen residence time. The rumen ecosystem stimulates cellulolytic microorganisms which degrade fibre (Chamberlain and Choung, 1995). In contrast, diet 3 had a high concentrate proportion (82% of the diet) with a predominance of readily fermentable carbohydrate through molasses and maize grains. This diet may develop rumen microbial population that degrades starch and simple sugars rather than low quality fibres. The two diet types may also be differentiated by texture. Straw based diets were coarser than that based mainly on concentrates; this may stimulate intake and rumen outflow rate and thus decrease DM degradability. This is in agreement with Ørskov (1983) and Preston and Leng (1987) who reported better degradability of high fibre content feedstuffs in straw based diets compared with compounded concentrate ones. The latter are rich in soluble and readily degraded carbohydrates which are preferred by microorganisms to complex sugars like cellulose or hemicellulose to satisfy their energy requirements. In addition, concentrate diets give lower rumen pH and hence inhibit fibre digestion.

CONCLUSIONS

Marked influence of diet type on the dry matter digestion profile of feed ingredients demonstrates the occurrence of negative interactions when the concentrate proportion is greater than the level of low quality forages. The latter should be restricted for optimal stimulation of cellulolytic bacteria. Therefore, utilization of expensive concentrates should be minimal to avoid low rumen pH and related fibre digestion inhibition and ensure proper utilization of fibrous feeds.

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STRESZCZENIE

Strawność składników pokarmowych przez owce i rozkład suchej masy w żwaczu bydła dawek zawierających uboczne produkty roślinne

W dwóch doświadczeniach oznaczono na owcach strawność składników pokarmowych oraz rozkład suchej masy w żwaczu bydła dawek zawierających słomę zbożową i paszę treściwą. W doświadczeniu 1, przeprowadzonym na sześciu owcach Peul-peul, oznaczono strawność pozorną 3 dawek. Dawka 1 składała się z (g/kg s.m) słomy ryżowej 580, melasy 115, otrąb ryżowych 180, makuchu arachidowego 130 i dodatku mineralnego 15; dawka 2: słoma z prosa 580, melasa 115, otręby z prosa 175, makuch arachidowy 113 i mieszanka mineralna 15; dawka 3: mieszanka łusek 180 i makuchu arachidowego 50, melasa 200, ziarno kukurydzy 95, senał 200, nasiona bawełny 250 i dodatek mineralny 25. W doświadczeniu 2 oznaczono rozkład s.m., stosując metodę woreczków nylonowych, na 3 buchajkach Gobra zebu, otrzymujących te same pasze.

Na strawność s.m. i substancji organicznej, oznaczonej *in vivo*, istotnie wpłynął ($P<0,05$) rodzaj skarmianej dawki; strawność błon komórkowych dawek zawierających słomę (1 i 2) była większa ($P<0,01$) niż dawki 3. Stopień rozkładu s.m. zależał od rodzaju dawki i typu paszy ($P<0,001$). W oparciu o te wyniki autorzy proponują podział różnych rodzajów pasz na podstawie ich teoretycznego rozkładu (Dt) s.m.: nisko (Dt$<$50% s.m.) i średniej jakości pasze objętościowe (50$<$ Dt $>$ 55% s.m.) i pasze treściwe (Dt $>$ 55% s.m.). Traktowanie słomy melasą (dodatek 17% melasy do słomy) istotnie ($P<0,01$) zwiększało jej rozkład. Stopień rozkładu s.m. paszy zależał od zawartości włókna, a szczególnie lignocelulozy (R$=-0,76$). Dt paszy może być także oszacowane na podstawie ubytku s.m. w czasie 24 godzinnej inkubacji (R$=0,90$) lub w przypadku mieszanek paszowych ubytku s.m. poszczególnych składników dawki.