The Nutritive Value of Rice Straw in Relation to Variety, Urea Treatment, Location of Growth and Season, and its Prediction from in Sacco Degradability

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ABSTRACT : Ten rice varieties were planted at two locations (lowland and highland), during the wet and dry seasons of different years. *In vivo* digestibility and voluntary intake of the straw, were determined in groups of fat-tail sheep, supplemented with 18 $g \cdot kg^{-0.75}$ concentrate DM, containing ~20% crude protein. Voluntary intake of digestible straw organic matter (DOMI) consistently varied from 15.2 to 20.9 $g \cdot kg^{-0.75}$ between straw varieties, averaged over locations, years and seasons, despite considerable variation between individual batches. This variation in the nutritive value of the straw was independent of straw and grain yield, so it would seem that there is scope for selection of rice varieties with straw of higher nutritive value. The variation in DOMI of straw among location of growth, year and season, was of a magnitude similar to the improvement brought about by urea-ammoniation. The *in sacco* degradation characteristics and digestibility of rice straw residues were superior to those of the offered straw. This can be attributed to a preference for rice straw leaves relative to stems. Averaged over location of growth, year and season, characteristics of *in sacco* degradation, i.e. the rate of fermentative degradation and the truly undegradable fraction, emerged as accurate predictors of the nutritive value of rice straw.
(Key Words: Fibrous Agro-Industrial By-Products, Supplement, Selection, Leaves, Stems)

INTRODUCTION

Ruminant livestock production is essential for the smallholder integrated farming systems of the Asian tropics. Small and large ruminants provide high-quality human consumable food, clothing and/or draught power. In addition, livestock is kept for savings. However, in densely populated regions such as the island of Java in Indonesia, first priority is usually given to primary crop production because of its efficiency in the conversion of solar energy and nutrients into human consumable food. Ruminant livestock production is therefore either restricted to marginal lands, or is largely based on fibrous crop residues such as rice or wheat straw, and maize stover.

The time of harvesting is primarily determined by the maturity of the grain. Because the vegetative material of these grains lignifies during maturation, straw is highly lignified. Moreover, rice straw has a high silica content, the fractional rate of degradation in and the rate of passage of undegraded fibrous particles from the rumen are low (Chuzaemi, 1994). Voluntary intake and digestibility of these highly fibrous and lignified materials are also low (Oosting et al., 1994), amongst others due to the physical restrictions imposed by rumen holding/processing capacity and turnover (Van Bruchem et al., 1994). Consequently, the nutritive value, i.e. the resultant of voluntary intake and digestibility, of crop residues rarely exceeds maintenance requirements for energy and, more in particular, protein.

Significant variation in nutritive value of straw among cereal varieties has been reported (Capper et al., 1987; 1992). Most of these results, however, are based on *in vitro* incubations according to Tilley and Terry (1963). It is questionable whether these results can be extrapolated to the *in vivo* situation, where nutritive value of fibrous feeds is determined by digestibility and voluntary intake. With low-quality fibrous feeds, the latter constitutes a

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constraint, particularly. Besides, adequate supplementation may induce a positive associative effect on straw intake and utilization, and if selection of the more palatable plant parts is possible, the nutritive value may increase considerably (Zemmelink, 1986).

Soebarinoto et al. (1989) described the *in vivo* nutritive value of rice straw, grown in East-Java, Indonesia, showing that the variation among varieties, in terms of their digestible organic matter intake, was of a magnitude about similar to the increase brought about by urea-ammonia treatment. The current study was designed to further examine this phenomenon. Besides, the following objectives were considered. Costs for improvement of low-quality feeds should be kept to a minimum (Schiere and Nell, 1993), although how this is to be achieved may depend on the type and level of production, local market prices, and alternative feed costs. Also costs for the transport of bulky fibrous feeds must be avoided wherever possible. Therefore, considering the prevailing types of large ruminant livestock production systems, i.e. swamp buffaloes and beef cattle under lowland conditions, and dairy cattle at higher altitudes; soil type and altitude were investigated for their impact on straw nutritive value. Straw of rice grown in the wet season becomes available in May to June, at the onset of the dry season, when forages are still abundantly available and so are often stored. The dry season paddy is harvested in September-October when the dry season has almost come to an end and roughage availability has become quite restricted. Thus, straw from wet and dry season was also investigated as it is known that the nutritive value of rice straw may deteriorate substantially during storage.

Moreover, this paper describes the accuracy of *in sacco* degradation characteristics as predictors of the nutritive value of rice straw in terms of voluntary intake of digestible organic matter. Based on the same substrates, the accuracy of prediction by parameters of cumulative *in vitro* gas production is described by Williams et al. (1996).

Various options are available to improve performance of ruminants fed diets based on fibrous crop residues. The present paper describes the potential of the variation of rice straw nutritive value under conditions that the requirements of the rumen microbes in terms of nitrogenous substances and minerals are met. In companion experiments alternative options were explored: (1) the effect of selecting the more palatable parts on voluntary intake, digestibility and gain performance, (2) the effect of supplementation on volatile fatty acid production and microbial protein synthesis in the rumen in relation to gain, (3) the impact of feed quality restriction, subsequent realimentation on compensatory feed intake and growth, and (4) on amino acid availability from the small intestine. These various aspects have been described by Chuzaemi (1994).

MATERIALS AND METHODS

Ten rice varieties : IR 36, Batang Pane, IR 54, IR 64, Citandui, Progo, Cisadane, Krueng Aceh, Kapuas and Tuntang were planted at two locations in the province of East-Java: Mojosari (lowland, regosol, 28 m above sea level) and Malang (highland, alluvial soil, 435 m above sea level). The first transplanting was in early March, 1988 during the wet season (WS1) and harvesting was in May/June at the onset of the dry season. Transplanting was repeated in the wet season of 1989 (WS2), followed by a last transplanting in early July 1989 (dry season, DS). Harvesting was in October at the onset of the wet season. Before transplanting, the irrigated land was fertilized with 87 kg urea and 100 kg TSP ($\sim$8 kg P) per hectare. Twenty days later, 87 kg urea ($\sim$40 kg N) and 100 kg KC*l* ($\sim$52 kg K) per hectare were given, followed again 20 days later, by a final urea dose of 87 kg/ha.

After harvesting, the sun-dried straw was stored and hand-chopped to a length of 5-10 cm. Intake and digestibility of the rice straws were evaluated with young fat-tailed sheep with a body weight that gradually increased from approximately 20 to 30 kg. They were kept in metabolism cages with free access to water. Rice straw was offered at a level of 10-20% excess, and was supplemented with about 18 g DM $kg^{-0.75}$ of concentrates (according to the manufacturer: maize 20-25%; rice bran 25-30%; wheat bran 15-20%; coconut meal 10-15%; soya bean meal 10-15%; molasses 5%; and 3-3.5% mineral/vitamin mix; quantities were varied to give a least cost formulation of $\sim$20% crude protein). The WS1 *in vivo* digestibility trials were run from September 1988 to June 1989, those of WS2 in the period December 1989 to April 1990; and those of the DS rice straws in the period April to September 1990. The WS1 rice straws, both treated with urea-ammonia (ratio urea : water : straw = 4 : 50 : 50, 7-14 days) and untreated, were evaluated for *in vivo* digestibility and voluntary intake with groups of three sheep. The WS2 and DS rice straws were evaluated with groups of five sheep. Adaptation and collection periods were observed, of 10 and 15 days, respectively. Straws were randomly allocated to groups of sheep.

Representative samples were taken of the rice straw and concentrates offered, the rice straw refusals, and the faeces, and oven-dried at 70℃. Subsequently, the air-dry samples were ground with a hammer mill to pass a 1 mm screen and stored pending analysis. Dry matter (DM) was determined at 101℃ and ash at 550℃. Crude protein (CP) was determined according to Kjeldahl, using K_2SO_4 and $CuSO_4$ as catalysts. Silica and cell wall constituents {cellulose (C), hemicellulose (HC) and lignin (L)} were determined according to the method of Goering and Van Soest (1970). The C and HC fractions were calculated from the fibre fractions NDF, ADF and ADL.

In addition to the *in vivo* parameters, the rice straws were also evaluated for *in sacco* degradation (Robinson et al., 1986). The *in sacco* degradation of the 1988 straw samples was carried out at the Rowett Research Institute (Aberdeen, UK) in sheep fed barley straw and grass cubes, whereas the *in sacco* degradation of the 1989 straw samples was also determined in Malang in cattle fed urea-ammoniated rice straw *ad libitum* and concentrates (~2 kg/d). *In sacco* degradation of straw organic matter (OM) was analyzed by non-linear regression according to the following model:

$$R_{t,OM} = U_{OM} + (100 - S_{OM} - U_{OM}) * EXP\{-k_{d,OM} * (t - LT_{OM})\}$$

where:

$R_{t,OM}$: organic matter (OM) residue at time t (%)
U_{OM} : truly undegradable OM fraction (%)
S_{OM} : water soluble OM fraction (%)
$k_{d,OM}$: fractional rate of OM degradation ship %/h (1R)
LT_{OM} : lag phase (h)
t : time

The data were analyzed by DBSTAT (Brouwer, 1990), with results expressed as least squares means, using the general model for statistical analysis of a three pactorial design (Snedecor and Cochran, 1967):

$$Y_{ijk} = \mu + \alpha_i + \beta_j + T_k + e_{ijk}$$

where:

μ : general mean
α_i : effect of variety i (1..10)
β_j : effect of location j (1..2)
T_k : effect of season/treatment/year k (1..4; table 1) or season k (1..2; table 2)
e_{ijk} : error term

Corrected for animal and period effects, the differences between diets were tested by the two-tailed Student t-test based on the LS means (df = 66). Some of the results are based on the WS2 and DS data only (df = 28).

RESULTS

A summary of the chemical composition of the WS2 and DS rice straws is presented in table 1. Crude protein (CP) content was the lowest in Progo, slightly though significantly ($p < 0.05$) lower than in Tuntang. No significant differences were found for the cell wall constituents cellulose, hemicellulose and lignin. Silica content was the lowest in IR 54, significantly ($p < 0.05$) lower than in Batang Pane, Citandui and Progo. Except for CP, no differences were found between locations. Dry season straw showed lower values for CP, lignin and silica, but slightly higher contents of (hemi) cellulose.

An analysis of the variation in DOMI, including the chemical components as factors in a regression model resulted in the following equations (*italics different from 0, p < 0.05*):

straw offered: DOMI = *18.8* (0.4) − 0.01 CP (0.47) − 0.09 C (0.20) + 0.07 HC (0.14) − 0.34 L (0.37) − 0.27 Si (0.26) (R^2 = 0.12, r.s.d. 2.3)

Table 1. Chemical composition of rice straw in relation to variety, location and transplanting season

		OM	CP	C	HC	L	Si[1]
IR 36[2]		783	58	290	255	77	172
Batang Pane		772	54	300	272	67	188
IR 54		794	52	308	264	67	156
IR 64		787	58	300	240	64	162
Citandui		768	57	287	267	67	188
Progo		761	50	293	243	68	188
Cisadane		791	56	297	261	69	166
Krueng Aceh		775	55	284	252	75	169
Kapuas		768	57	299	250	75	168
Tuntang		773	60	276	254	76	172
LSD[2]		23.8	9.5	42.1	43.4	18.2	22.4
Highland[3]		775	59	298	250	71	172
Lowland		779	52	288	261	70	176
Wet season		767	60	285	235	77	183
Dry season		788	51	302	276	64	165
LSD[3]		10.6	4.2	18.8	19.4	8.1	10.0
Mean		777	56	293	256	70	174
SEM[4]		2.6	1.0	4.6	4.7	2.0	2.5
Residues[R]	mean	772	52	306	251	82	159
	SEM	2.1	0.8	4.7	4.0	1.6	2.4

[1] Organic Matter, Crude Protein, Cellulose, Hemi Cellulose, Lignin, Silica (g/kg DM).
[2,3] Least Significant Difference (mean of 2 and 20, $p < 0.05$).
[4] Standard Error Mean.
[R] Straw residue.

straw refused: DOMI = *18.8* (0.3) − 0.79 CP (0.55) − *0.49* C (0.20) + 0.23 HC (0.17) − *1.00* L (0.43) − *0.71* Si (0.23) (R^2 = 0.39, r.s.d. 1.9)

Grain and straw yield, straw voluntary intake and *in sacco* degradability of the rice straw cultivars, are presented in table 2.

Table 2. Grain/straw yield (YG/YS), voluntary OM intake (OMI), digestibility (dOM), intake digestible OM (DOMI), *in-sacco* characteristics water soluble OM (S_{OM}), potentially degradable though water insoluble OM (D_{OM}), rate of OM degradation ($k_{d,OM}$), lag time (LT_{OM}), and the truly undegradable OM (U_{OM})

	YG[1)]	YS[1)]	OMI[2)]	dOM[3)]	DOMI[2)]	S_{OM}[3)]	D_{OM}[3)]	$k_{d,OM}$[4)]	LT_{OM}[5)]	U_{OM}[3)]
IR 36[6)]	4.35	4.40	39.5	47.9	19.2	17.2	47.8	3.32	5.25	35.0
Batang pane	4.86	4.60	38.0	48.9	18.6	15.6	49.8	3.15	5.06	34.5
IR 54	4.23	5.67	32.9	46.1	15.2	17.5	46.7	2.52	4.66	35.8
IR 64	4.55	5.62	35.3	48.3	17.1	17.7	44.3	3.05	4.62	38.0
Citandui	4.45	4.99	34.3	46.4	15.9	16.5	43.0	3.08	4.69	40.6
Progo	3.88	6.89	35.8	48.2	17.3	17.9	45.1	2.78	4.80	37.0
Cisadane	3.88	7.18	35.6	48.2	17.2	17.0	46.7	2.85	5.68	36.3
Krueng Aceh	5.09	5.21	39.0	50.9	19.9	18.0	48.2	3.34	5.04	33.8
Kapuas	4.94	5.25	39.0	50.2	19.6	20.1	46.6	3.04	4.79	33.3
Tuntang	4.66	4.60	41.3	50.3	20.9	18.3	46.2	3.21	4.51	35.6
LSD[6)]	0.976	0.714	3.36	2.96	2.15	3.61	4.60	0.524	1.350	3.10
Highland[7)]	4.45	5.39	36.9	48.7	18.1	16.8	45.7	3.05	5.20	37.5
Lowland	4.52	5.50	37.2	48.4	18.1	18.4	47.1	3.02	4.62	34.5
LSD[7)]	0.435	0.319	1.51	1.33	0.96	1.62	2.06	0.234	0.604	1.39
Wet season 1988[8)]	4.57	4.42	33.4	45.5	15.3	21.3[A]	36.7[A]	2.67[A]	6.13[A]	42.1[A]
1988 ammoniation			38.7	50.0	19.4	19.3[A]	47.5[A]	3.38[A]	6.03[A]	33.3[A]
Wet season 1989	4.24	5.55	36.9	48.1	17.7	18.7[M]	47.9[M]	2.88[M]	3.44[M]	35.2[M]
Dry season 1989	4.65	6.36	39.4	50.6	19.9	11.1[M]	53.7[M]	3.38[M]	4.03[M]	33.3[M]
LSD[8)]	0.535	0.393	2.13	1.88	1.36	2.28	2.91	0.331	0.853	1.96
Mean	4.49	5.44	37.1	48.6	18.1	17.6	46.4	3.03	4.91	36.0

[1)] ton air dry matter per ha; [2)] g/kg$^{0.75}$; [3)] g/kg; [4)] %/h; [5)] h; [6,7,8)] LSD (mean resp. 4, 40 and 20; $p < 0.05$).
[A)] Aberdeen; [M)] Malang.

Straw yield showed a more pronounced variation between years and season than grain yield. No consistent differences were observed in the nutritive value of rice straw between lowland and highland sites. The *in sacco* parameters, however, showed a slight shift in favour of the lowland straws in terms of the values for S_{OM} and U_{OM}. The variation in straw nutritive value (DOMI) was similar to that brought about by urea-ammonia treatment DOMI was slightly though significantly higher for the DS straws, despite a lower value for S_{OM}, but with lower lignin and silica contents and a higher $k_{d,OM}$.

A summary of the overall variation among straw varieties is presented in figure 1. In this figure, the *in sacco* characteristics expressed in relative percentage units (mean 100%), are plotted against the nutritive value of the straw of the various varieties. Although the predictive accuracy of the nutritive value was poor for individual batches of straw, averaged over years, locations and seasons, straw DOMI was highly significantly related to the *in sacco* degradation characteristics. More specific, the potentially degradable fraction (D), the truly undegradable fraction (U) and the rate of degradation (k_d) were significantly related to straw nutritive value (DOMI). No significant relation emerged with the water soluble fraction (S) and lag time (LT).

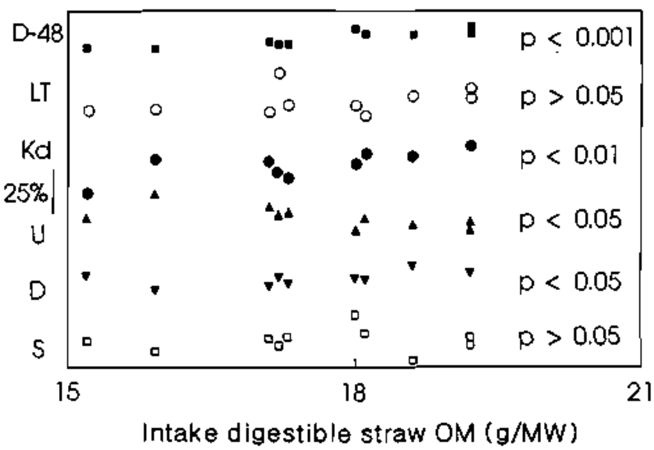

Figure 1. Voluntary intake of digestible straw organic matter ($MW = kg^{0.75}$) relative to *in sacco* degradation characteristics (sliding Y scale in percentage units; vertical bar indicates 25% deviation from mean).

Figure 2 shows the relation between voluntary intake and the straw and grain yields of rice varieties. No significant relationships were found. Grain yield showed a tendency to relate positively with DOMI.

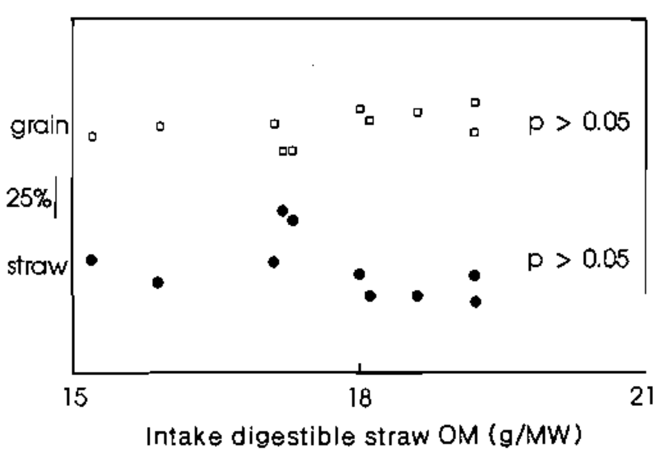

Figure 2. Voluntary intake of digestible straw organic matter ($MW = kg^{0.75}$) from straw in relation to straw and grain yield (sliding Y scale in percentage units; vertical bar indicates 25% deviation from mean).

For the assessment of *in vivo* parameters, the straw was fed in excess of intake, thus allowing selection by the sheep. The straw residues showed significantly lower values for CP and silica but slightly higher values for cellulose and lignin, indicating a positive selection for leaves (table 1). In figure 3, *in sacco* degradation curves of the untreated and urea-treated straws are compared with that of the straw refusals. Although lower in palatability, the refusals were more easily degraded by the rumen microbes than the untreated straw. This illustrates a preference for the leafy fraction. The urea-ammoniation (ARS) seems mostly to lead to an increased rate of fermentative degradation ($k_{d,OM}$), and secondly to a decreased truly undegradable residue (U_{OM}).

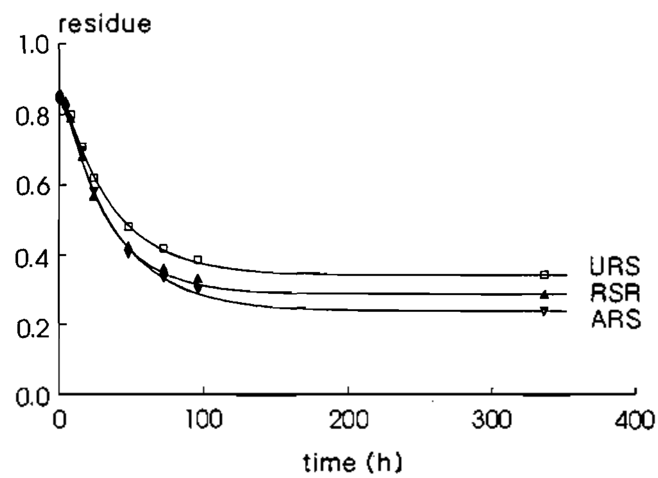

Figure 3. *In sacco* degradation of untreated rice straw (URS), rice straw refusals (RSR) and urea-ammoniated rice straw (ARS).

DISCUSSION

Despite all research, e.g. Sundstøl and Owen (1984), Doyle et al. (1986), Singh and Schiere (1988), Chenost and Reiniger (1989) and Ibrahim et al. (1992), and extension efforts in the field of straw treatment, the rate of adoption of this technique is still low. This may be related to the labour required or the economic return. Hence, it is relevant to explore alternative low-cost options for improving the nutritive value of low-quality fibrous feeds.

The results of the experiment reported here, showed a variation in nutritive value of straw between years and seasons of a magnitude similar to that brought about by urea treatment. Digestibility and intake of dry-season straw was slightly superior to straw grown in the wet season. Voluntary intake and digestibility differed significantly ($p < 0.01$) between varieties. However, no difference was established between locations. In comparison with the wet season, the dry season dOM and DOMI were, on average, 5.6 and 12.4% higher, concomitant with lower lignin and silica, but with increased hemicellulose contents. Further, the regression analysis identified cellulose as a negative factor.

The *in sacco* degradation characteristics of the 1988 straw samples carried out at the Rowett Research Institute (Aberdeen, UK) were slightly different from those of the 1989 straw samples which had been analyzed in Malang. This can probably in part be attributed to the difference in procedures followed. In Malang, the truly undegradable fraction U was determined by 2-week incubation, whereas in the Aberdeen *abc* model (Mehrez and Ørskov, 1977), U was estimated as the asymptote. This resulted in higher U values and consequently lower values for b (D) and c (k_d). Moreover, these differences may have been due to the different microbial populations that could be expected to exist under the different dietary conditions.

For all rice straws, irrespective of location and season of growth, DOMI was not sufficient to meet maintenance requirements. However, in combination with the concentrate supplements of approximately 12 g DOM $kg^{-0.75}$, most diets did support growth, since the sheep gained weight steadily.

The finding that rice straw refusals had *in sacco* degradation characteristics superior to those of the offered straw, is presumably largely attributable to selective consumption. It has been reported that sheep (Chuzaemi, 1994) and goats (Phang and Vadiveloo, 1992) selectively consume leaves and leaf sheaths even though for rice straw this botanical fraction may be less digestible than the stems (Hermanto et al., 1992). This can partly be attributed to differences in resistance to physical degradation (Blümmel et al., 1996), and possibly also to taste and the physical segregation between the botanical fractions.

For individual batches of straw the accuracy of prediction of intake and digestibility from *in sacco* degradation characteristics was poor. This may in part be attributed to variation in feed intake behaviour among individual sheep. However, based on the data averaged over locations, years, seasons and treatments, rumen degradable organic matter (RDOM) was not significantly related to S_{OM} nor lag time LT_{OM}. However, it was positively related to D_{OM} and the *in sacco* rate of degradation (k_{dOM}), and negatively to U_{OM}. The mean derived value for rumen degradable organic matter was significantly related to DOMI (figure 4).

In mixed crop-livestock production systems, priority is usually given to the type, quality and quantity of grain produced for human consumption. Hence, the nutritive value of rice straw can only be regarded as a second priority. Therefore, judging the scope for breeding varieties with a higher nutritive value of straw, requires knowledge of the relationship with grain yield. From figure 2, it could be concluded that opportunities may exist to select varieties with higher nutritive straw since DOMI was not negatively related to grain yield nor to straw yield. This latter aspect would be relevant under conditions, unlike Indonesia (Kossila, 1988), that straw is available in limited amounts, relative to the ruminant livestock population.

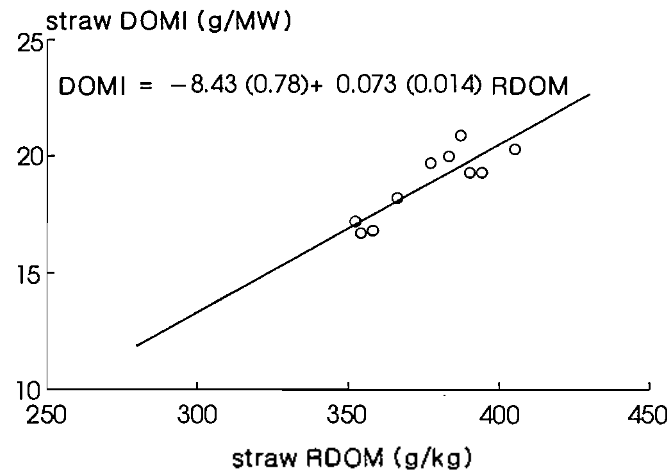

Figure 4. Relationship between digestible straw organic matter (DOMI, $g \cdot kg^{-0.75}$) and *in sacco* rumen degradable organic matter (RDOM, $g \cdot kg^{-1}$) ($R^2 = 0.76$).

Although considerable variation was observed within varieties between years, seasons, and locations, on average the variation among genotypes was at least comparable to that induced by urea ammonia treatment (Soebarinoto et al., 1989). Supplementation with limiting nutrients can also improve straw utilization. The responses to supplements are likely to be higher with good quality straw than with poorer quality. Moreover, maintaining live weight, or even growth, become less dependent on the availability of supplements. Moreover, the strategy of feed-quality restriction with a diet of sole straw during the lean season, and realimentation with forage/foliage supplements during the lush season, can more successfully be implemented (Chuzaemi, 1994). Therefore, in mixed crop-livestock production systems, it is of utmost importance to select varieties with a favourable nutritive value.

The nutritive value of straw batches showed considerable variation. *In sacco* degradation characteristics seem insufficiently accurate for identifying such variation for individual samples. However, averaged over years, seasons and locations, the *in sacco* characteristics were closely related to the nutritive value of rice straw. Since the selection and introduction of new rice cultivars usually requires several years and is meant for extended regions, the *in sacco* degradation procedure would seem to constitute a valuable tool for selection in the process of breeding new rice varieties.

In conclusion, there is consistent variation in the nutritive value of rice straw associated with location of growth, year and season, for different rice cultivars. This variation is of a similar magnitude to the incremental voluntary intake of straw digestible organic matter, brought about by urea-ammoniation. It should therefore be possible to select rice cultivars with straw of higher nutritive value, while avoiding any adverse whole system effect in terms of grain or straw yield.

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