Release of Mineral Elements from Tropical Feeds during Degradation in the Rumen

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ABSTRACT : The proportion of dry matter (DM) and mineral elements (Ca, Mg, P, Na, K, Zn) released from eight feeds (2 rice straws, RS1 and RS2; 2 grasses, NB21 and guinea; 2 leguminous fodders, glyricidia and erythrina; jak leaves 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.

Both the type of feed and the incubation time in the rumen significantly influenced ($p < 0.01$) the proportion of minerals released. In legumes, jak leaves and rice bran about 80% of the potentially degradable DM fraction was solubilized within 24 h in the rumen, and with the grasses, rice straws and jak leaves a considerable proportion of DM was released between 48 and 240 h in the rumen. During the early hours of incubation (up to 24 h) there were distinct differences between and within the feed classes in their ability to release all mineral elements studied. In all test feeds, high proportions of Mg and K were released within 24 h. Some feeds showed a tendency to ad/absorb Ca (grasses, rice straws and rice bran), P (jak leaves, rice straws), Na (glyricidia and rice bran) and Zn (jak leaves) from water and rumen fluid, and this was partly related to the low initial concentration.

In terms of absolute quantity of mineral released, legumes (erythrina is superior to glyricidia) are a good source of Ca, Mg, P and Zn, and jak leaves a good source of Ca and Na. Within grasses, guinea contains appreciable quantity of available Mg and P. Rice bran is rich in available Mg, P and Zn.

(Key Words: Tropical Feeds, Minerals, Solubility)

INTRODUCTION

In tropical developing countries animals are often given diets consisting of unfertilized improved or natural grasses, tree leaves and shrubs, crop residues and wastes. In such diets the mineral content is generally low and also their availability to the host is not know. Also, in many of these countries ruminants to a large extent depend on roughages to meet their mineral requirements. Wide ranges in mineral concentration in tropical roughages were reported by McDowell et al. (1983), Vijchulata et al. (1983) and Ibrahim et al. (1987). It was concluded that over 50% of the grasses contained deficient levels of calcium, and over 50% of the Sri Lanka roughages analyzed (131 feeds) contained border line or deficient concentration of phosphorus, sodium, copper and zinc (Ibrahim et al., 1987).

Minerals to be available for host animal and its rumen microbes have to be solubilized in the digestive tract. In this aspect the rumen has been considered to be a very important site. More importantly mineral requirements of the microbes could only be met by recycling via saliva and those that are solubilized in the rumen. Factors that affect the potential availbility of minerals from roughages are; the distribution of the minerals within the plant cell (soluble cell material or cell wall matrix), the form in which they are present (Ca as oxalates and P as fytin; Blaney et al., 1982; Ward and Harbers, 1982), their association with cell wall components (Zn-cellulose binding; Bremner and Knight, 1970), their association with protein (Cu; Snedeker and Greger, 1983), their association or interaction with other minerals (Al with Mg and Ca; Robinson et al., 1984). Other factors such as pH, osmolality of the media and interactions with other minerals in the rumen environment also determine its biological availability. As such, it is rather important to know not only the concentration of mineral elements in feeds, but also the extent to which they are solubilised in

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the rumen.

In vitro (Todd, 1961; Edwards et al., 1977; Kincaid and Cronrath, 1983; Ibrahim et al., 1990), *in sacco* (Playne et al., 1978; Rocke et al., 1983) and *in vivo* (Ivan and Viera, 1981; Ibrahim et al., 1990) methods have been used to assess the solubility of mineral elements in feeds. The objective of the present study is to assess the extent to which mineral elements present in various feeds are released in the rumen.

MATERIALS AND METHODS

Animals and diet

Two Dutch Friesian cows, 500 kg liveweight fitted with large rumen cannula (10 cm inside diameter) were used. The cows were fed a maintenance ration (8 kg dry matter (DM) day^{-1}) which consisted of 50% wheat straw [*in vitro* organic matter digestibility (IVOMD) 50.4%; N 0.42%] and 50% hay (IVOMD 71.2%; N 2.37%). This was fed in equal meals per day at 06:00 and 17:00 h.

Test feeds

The eight test feeds used in this study were selected from of batch of 131 feed samples (grasses, leguminous fodders, tree leaves and shrubs, rice straws, concentrates) which were brought to the Metherlands from Sri Lanka to study the variation in chemical composition and nutritive (Ibrahim et al., 1987). Based on their importance for ruminant feeding in Sri Lanka, two grasses: *Pennisitium purpureum* (NB 21, 4-wks cut) and *Panicum maximum* ecotype Guinea A (guinea, 3-wks cut); two types of leguminous tree leaves: *Glyricidia maculata* (glyricidia, 4-wks regrowth) and *Erythrina varigata* (erythrina, 7-wks regrowth); one species of tree leaves: *Artocarpus heterophyllus* (jak leaves); two varieties of rice straw (RS1, BW 297-2 and RS2, BG 745); and one concentrate feed: rice bran from a commercial mill, were selected. For bag incubation studies the roughages were ground to pass through a 5-mm sieve.

Incubation procedure

Five gram of air-dry material (5 mm sieve) was weighed into 18 × 9 cm bags made out of nylon cloth with pore size of 41 microns (Nybolt, Switzerland) 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, Holland) was applied (0.5 cm width) on the inner side of the heat sealed lines. 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. The bags were incubated for 6, 12, 24, 48 and 240 hours in the rumen. Bage 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). The 0 hour incubation (control) were also washed in the same manner. The bags were dried at 70℃, weighed and the residues were ground to pass through a 1 mm sieve in a laboratory mill.

Chemical analysis

The test feeds were analyzed for dry matter and ash by the method of the Association of Official Analytical Chemists (1980), for neutral detergent fibre (NDF) by the method of Goering and Van Soest (1973), and for IVOMD by the method of Tilley and Terry (1963). The test feeds and the bag residues were analyzed for dry matter and for Ca, Mg, P, Na, K, and Zn by the method of the International Organization for Standardization (1987).

Statistical analysis

The data on the proportion of minerals remaining in the residue was tested as a factorial study, taking into account the effects due to cow, test feed and incubation time (Statistical Analysis Systems, 1982).

RESULTS

Chemical composition

The chemical composition of the feeds is presented in table 1. The leguminous fodders and jak leaves contained high levels of Ca (>16 g kg^{-1} DM) as compared to other feeds (<6 g kg^{-1} DM). The straws, NB21 and jak leaves was low in Mg (<2.6 g kg^{-1} DM) as compared to the other feeds (≥ 5 g kg^{-1} DM). P content in rice bran (9.5 g kg^{-1} DM) was more than twice as that in leguminous fodders (3.7-4.4 g kg^{-1} DM). Jak leaves contained appreciable quantity of Na (1.3 g kg^{-1} DM) as compared to other feeds (<0.5 g kg^{-1} DM), and the K content in the feeds ranged from 6.9 g kg^{-1} D (rice bran) to 32.8 g kg^{-1} DM (NB21). The Zn content in jak leaves was low (15.6 g kg^{-1} DM) and that in erythrina was more than twice as that in glyricidia (67 vs 26 g kg^{-1} DM). IVOMD of RS1 was 20 digestibility units more than RS2, but there was no difference in the crude protein (CP) content (42 g kg^{-1} DM). IVOMD of guinea grass was 6 units lower than that of NB21, but the CP content in the former was higher (126 vs 86 g kg^{-1} DM). Rice bran not only had a low IVOMD (45%), but also the ash content was high (208 g kg^{-1} DM).

Table 1. Organic matter digestibility *in vitro* (IVOMD) and chemical composition of the test feeds

Feed	IVOMD	Total ash	Crude protein	Neutral detergent fibre	Ca	Mg	P	Na	K	Zn
	%	....	....	....	g kg^{-1} DM	....	....	....	....	mg kg^{-1} DM
Rice straw										
RS1	53	144	42	704	3.0	1.5	0.6	0.2	26.9	58.8
RS2	36	183	42	734	3.8	2.5	0.9	0.3	17.6	58.9
NB21	63	124	86	647	4.3	1.9	2.3	0.1	32.8	39.6
Guinea grass	57	118	126	686	6.0	5.8	3.7	0.5	15.0	35.5
Glyricidia	70	102	302	331	15.6	5.3	3.7	0.1	25.6	25.8
Erythrina	72	117	383	399	19.2	5.1	4.4	0.2	28.1	66.6
Jack leaves	52	88	126	391	16.3	2.1	1.5	1.3	11.4	15.6
Rice bran	45	208	107	455	1.3	5.0	9.5	0.2	6.9	77.3

Degradation of dry matter (DM)

The pattern of DM disappearance in the test feeds studied is shown in figure 1. Except for the two grasses and rice straws, with the other feeds about 80% of the potentially degradable DM fraction was solubilized within 24 h of incubation. It is also evident that with the legumes and rice bran, there is little or no difference in the DM solubilized between 48 and 240 h. With the grasses, rice straws and jak leaves a considerable proportion of the DM is solubilized between 48 and 240 h in the rumen.

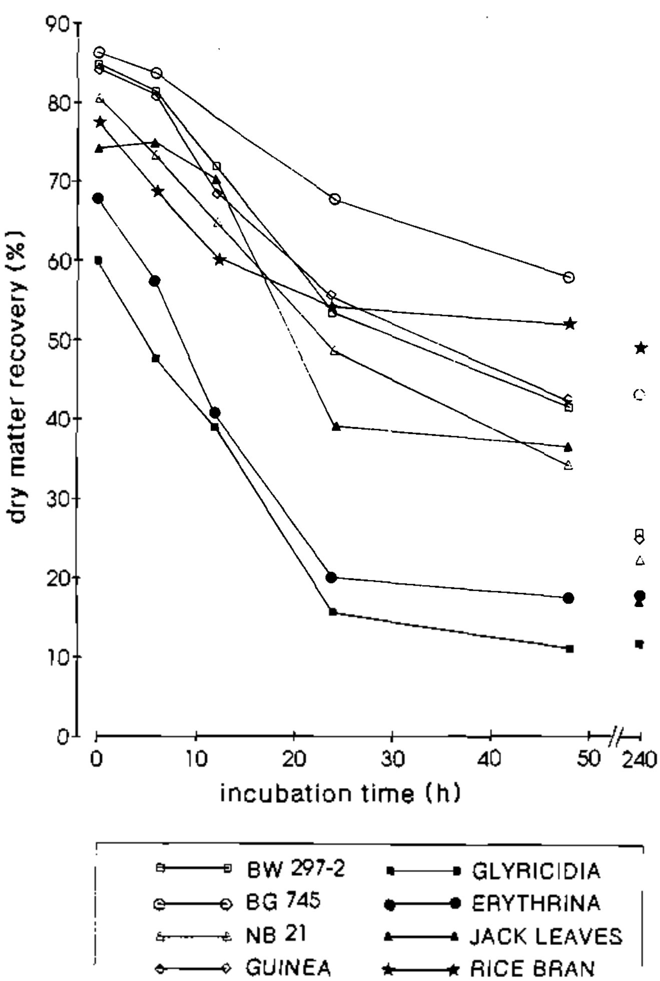

Figure 1. Variation in rumen degradability DM of feeds.

Release of mineral elements in the rumen

Comparison between the recoveries (expressed as a % of the initial amount) of mineral elements from the test feeds between 0, 48 and 240 h in the rumen are presented in table 2. The pattern of mineral release between the different feed classes (pooled according to feed class) is shown in figure 2.

Ca

There is distinct difference in the pattern of Ca released within the feed classes studied. For example after 48 h of rumen incubation, RS1 was significantly ($p < 0.01$) better than RS2 (48 vs. 106%); NB21 was significantly ($p < 0.01$) better than guinea grass (47 vs. 88%); erythrina was better than glyricidia (13 vs. 24%). In five (rice straws, grasses and rice bran) of the 8 feeds, washing with water (0 h incubation) resulted in Ca recoveries > 100%, but with the residues left after 48 h incubation only rice bran showed recoveries over 100%. Although rice bran released part of the Ca sorbed during incubation in the rumen, recovery in the residue DM after 240 h was nearly two fold (177% of the initial amount).

Mg

Although there was differences within the two straws (recovery of 44 and 34% for RS1 and RS2, respectively) and the grasses (recovery of 45 and 22% for NB21 and

Table 2. Proportion of minerals remaining in feed residues (% of amounts initially present) after washing with water (0 h) and incubation in the rumen for 48 and 240 h

	Ca			Mg			P			Na			K			Zn		
	0	48	240	0	48	240	0	48	240	0	48	240	0	48	240	0	48	240
Rice straw																		
RS1	170	84^{d}	46^{c}	44	8^{d}	5^{bc}	37	115^{e}	56^{c}	93	56de	39^{c}	1.5	0.3	0.2	111	54^{d}	9^{ab}
RS2	197	106^{e}	73^{d}	31	7^{d}	6^{c}	47	62^{d}	53^{c}	68	56de	44^{c}	1.9	0.4	0.4	91	70^{e}	15^{bc}
NB21	178	47^{c}	25^{b}	45	4^{bc}	3^{ab}	32	14^{c}	12^{b}	23	9^{ab}	17^{ab}	1.1	0.1	0.0	6	4^{a}	4^{a}
Guinea grasss	315	88^{d}	42^{c}	22	2^{ab}	1^{a}	52	14^{c}	9^{ab}	55	40^{cd}	19^{b}	2.9	0.6	0.4	54	51^{d}	20^{c}
Glyricidia	92	24^{b}	20^{b}	15	1^{a}	1^{a}	41	12^{bc}	7^{ab}	300	72^{e}	76^{d}	1.1	0.2	0.2	100	40^{c}	18^{c}
Erythrina	74	13^{ab}	7^{a}	14	1^{a}	1^{a}	15	3^{a}	4^{a}	97	25^{bc}	20^{b}	0.7	0.1	0.1	16	6^{a}	6^{a}
Jack leaves	26	10^{a}	5^{a}	94	6^{cd}	2^{a}	253	16^{c}	6^{a}	31	5^{a}	2^{a}	3.7	0.6	0.3	246	57^{d}	54^{d}
Rice bran	455	190^{f}	177^{e}	8	2^{ab}	2^{a}	5	6^{ab}	8^{ab}	314	235^{f}	220^{e}	4.1	0.5	0.5	13	16^{b}	16^{bc}

Within columns figures followed by different superscripts are significantly different ($p < 0.01$).

guinea, respectively) in their ability to release Mg in water, there was hardly any difference in Mg release between them after 48 h in the rumen. About 85-90% of the Mg present in legumes and rice bran was soluble in water as compared to only 5% with jak leaves. The grasses and the straws were in between releasing 50-60%. Nevertheless all test feeds released > 90% after 24 h incubation in the rumen.

P

Although rice straws released P in water (recoveries of 37 and 47% for RS1 and RS2, respectively) the recoveries gradually increased with the time spent in the rumen, and the P content in residues incubated for 24 h was twice the amount initially present. Also, the high quality straw (RS1) sorbed more P as compared RS2 (recoveries of 115 and 62% for RS1 and RS2, respectively, after 48 h). But there was no significant difference difference between them after 240 h in the rumen. Erythrina released 85% of its P in water, while glyricidia released only 60%. The difference between the two legumes was narrow after 48 h incubation, nevertheless erythrina was significantly ($p < 0.01$) superior to glyricidia (release of 97 and 88%, respectively). Between grass species, release of P in water from NB21 was higher than guinea (68 and 48, respectively), but there was no difference between them in the rumen incubated samples. Washing with water increased the P content in jak leaves more than two fold, but after 24 h in the rumen the recovery was 25%. Rice bran released 95% of its P in water and thereafter the value remained unchanged with rumen incubation.

Na and K

In glyricidia and rice bran the Na recovery in DM of 0 and 6 h rumen incubated residues was > 300%, but after 24 h in the rumen glyricidia released almost all the sorbed Na (recovery 105%) while the recovery from rice bran was 217%. Erythrina did not sorb Na from water nor did it release Na after 6 h in the rumen (recovery 113%), but with the increase in rumen incubation time it steadily released Na (released 67% after 24 h in the rumen). The recovery of Na from glyricidia, erythrina and rice bran after 240 h in the rumen was 76, 20 and 220%, respectively. As with the legumes, there was distinct differences between the two grasses in their ability to release Na. Although the Na content of guinea grass was higher than NB21 (0.5 vs 0.5 g kg^{-1} DM), the latter released 77% in water as compared to 45% for guinea, and the corresponding values after 48 h in the rumen were 91 and 60%, respectively. Na content in jak leaves was the highest among the feeds studied, out of which 69% was released in water and 94% after 24 h rumen incubation.

All feeds released > 95% of K in water and > 99% after 6 h in the rumen. There was no significant difference within straws, grasses and legumes in the pattern of K release.

Zn

Washing with water increased the Zn content in the residue DM of jak leaves more than two fold (recovery 246%), whereas with RS1 and glyricidia the recoveries were 111 and 100%, respectively. Although RS1 did not release Zn when washed with water, release of Zn in the rumen was significantly ($p < 0.01$) greater than from RS2. NB21 released 94% in water and 96% after 48 h rumen incubation, the corresponding values for guinea grass are

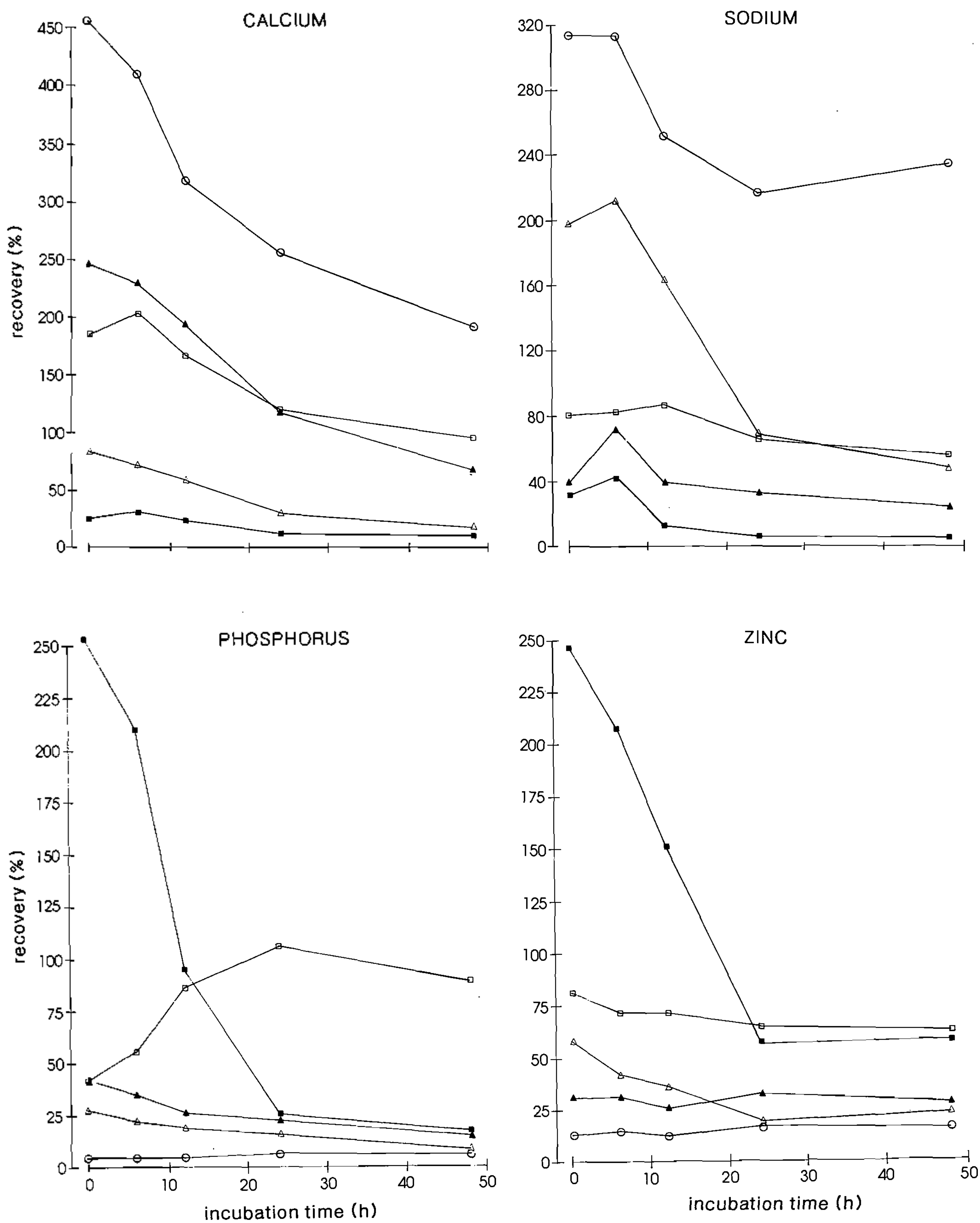

Figure 2. Recovery of mineral elements after incubation of feeds in the rumen.

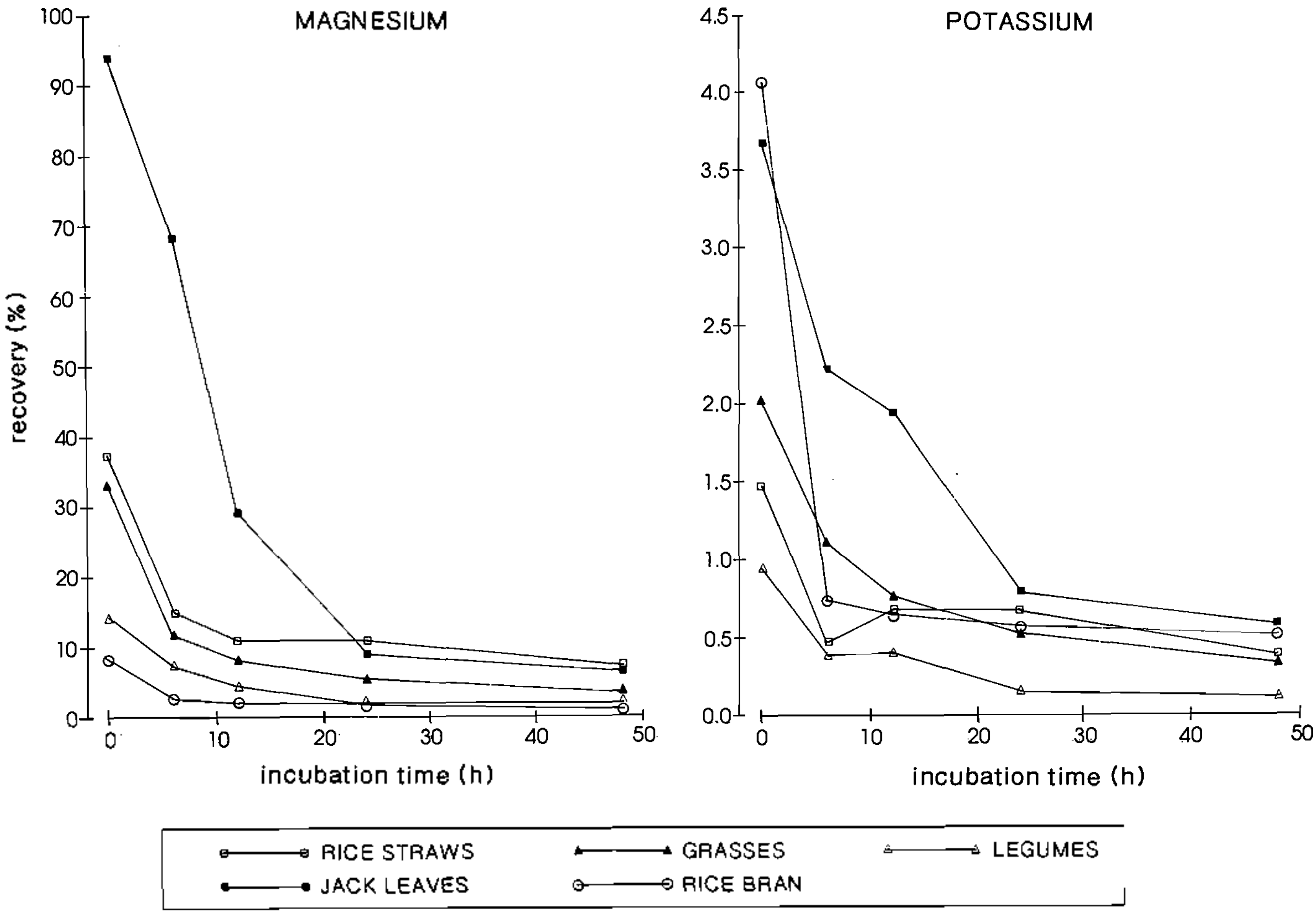

Figure 2. CONT.

46 and 49%, respectively. Similarly, erythrina released 84% in water and 94% after 48 h in the rumen and the corresponding values for glyricidia are 0 and 60%, respectively. Washing with water increased the Zn content in jak leaves by 246%, but in the 24 h rumen incubated residues the recovery was 60%. Rice bran released > 80% of its Zn in water and in the rumen.

DISCUSSION

Both the quantity of minerals in feeds and their biological availability need to be considered in assessing mineral requirements. Although the mineral content in feeds could be determined chemically, their availability to the animal and micro organisms is much more difficult to assess. According to Kincaid and Conrath (1983), mineral in roughages may be present in (a) fast released, soluble fraction of high availability, (b) potentially available fraction which could be released after fibre or protein digestion, and (c) complexed or bound fraction of low availability. Minerals associated with the fibre may be solubilized more slowly and may be less biologically available. Other factors arising from the rumen environment are changes in pH, mineral concentration gradient and interactions. The extent and release of mineral elements in the digestive tract is rather a neglected field of study. The obvious site is the rumen where most of the OM is digested and possibly some elements may become available when undigested residue move to the acid conditions in the abomasum (eg. Ca, Mg).

In the present study the data indicate wide differences between and within species in their ability to release or ad/absorb the mineral elements studied. Solubility of K in water was high (95-99%), but the release or sorption of other mineral elements was highly variable. This could be attributed to the difference in mineral concentration, extent of DM solubilized and the inherent ability of the plant fibres to adsorb cations. In another study with rice straw, guinea grass, glyricidia, jak leaves and rice bran, Ibrahim et al. (1990) found that soaking in demineralised water for 6 h removed 4-39% of Ca, 51-96% of Mg, 64-89% of P, 84-97% of Na, 91-99% of K and 27-88% of Zn. Although the use of demineralized water would have created a concentration gradient for flow minerals from the feed DM, there was distinct difference between the feeds studied. In the present study, except the legumes and jak leaves which were high in Ca (15.6 - 19.6 g kg^{-1} DM), the other six feeds absorbed Ca from water to varying extent; this was most pronounced with guinea grass (recovery of 315%) and rice bran (recovery of 455%). Influx of mineral elements from the water used for washing (which contained 45 mg l^{-1} Ca), formation of calcium oxalate due to the presence of oxalates in rice by-products, and the differences in cation exchange capacity (CEC) of the fibres may be possible causes for these high recoveries.

Todd (1961) working with perennial ryegrass and white and red cloer, reported that 60-70% of Mg in these species was water soluble. Similar values (64-74%) were reported for perennial ryegrass by Whitehead et al. (1986). In the present study, the values obtained for rice straws (56-69%), grasses (55-78%) and legumes (85-86%) are within the ranges reported by the above authors. But in the other two feeds, Mg solubility ranged from 6% (jak leaves) to 92% (rice bran). In spite of the extreme difference in Mg solubilities between these two feeds the amount of DM solubilized in water was similar (26 and 23%, respectively).

Bromfield and Jones (1972) studied the leaching of P from hay and intact pasture plants and reported that 60-85% of the P in ground hay was water soluble and that 62% was leached under normal rainfall conditions from intact plants. Whitehead et al. (1985) studied the release of Zn from grasses (perennial rye grass and tall fescue) and legumes (white clover and lucerne) and reported that 18-52% was water soluble. In similar studies (Ivan et al., 1979; Ivan and Viera 1981), Zn solubilities of 83-95% were found. In the present study RS1 and jak leaves absorbed Zn from water, while with the other 6 feeds solubilities ranged from 0% (glyricidia) to 94% (NB21). Also, there are distinct differences within the straws (RS1 better than RS2), grasses (NB21 better than guinea) and legumes (erythrina better than glyricidia) in their ability to release Zn in water or during rumen incubation.

In four tropical hays (2 grasses and 2 legumes), Playne et al. (1978) reported that 35-67% of Ca, 29-86% of P and 80-90% of K and Mg was released within 48 h in the rumen. Also, in grass silage 63, 84, 51, 86, 72 and 62% of Ca, Mg, P, Na, K and Zn, respectively, was released within 5 h in the rumen (Rooke et al., 1983). In the present study, although the feeds used covered a much wider range of plant species of contrasting chemical composition, the high solubility values found for Mg (92-99%) and K(> 99%) after 48 h in the rumen is in agreement with the above authors. It is of interest to note that the Mg in jak leaves was released more slowly as compared to other feeds and 90% was released after 24 h in rumen, whereas the other feeds released 90% in 12 h (figure 2). The main site of absorption of Mg seems to be the reticulo-rumen (Field, 1981), therefore its release in the rumen is also important for the host animal.

With the legumes and rice bran much of the potentially degradable DM was solubilized within 24 h in the rumen, whereas with the other feeds digestion continued up to 240 h. If the concentration of an element was high, the proportion of the element solubilised was usually high and it was often selectively solubilised and was removed faster than the removal of DM (figure 2; Ca and Na in jak leaves and Ca in legumes). On the other hand, increases in element concentration concomitant with continuing digestion of DM indicates that the elements is not associated with the digesting cell walls or there is an influx of mineral elements from the solvent (water, rumen fluid). Also, increases in element concentration could be due to the presence of bacteria strongly attached to the residues and which were not removed during washing. In an *in vitro* study using neutral detergent solution (without EDTA), Ibrahim et al. (1990) reported that the cell walls of rice straw, guinea grass, jak leaves and rice bran retained 62-87% of Ca and 18-69% of Mg. In similar studies with acid detergent solution, it was found that 23 to 80% of Zn in *Cynodon dactylon* (Edwards et al., 1977), lucerne (Kincaid and Cronrath, 1983) and jak leaves (Ibrahim et al., 1990) was within the ligno-cellulose complex. This indicates that these minerals and those absorbed by the plant fibres would become available with degradation of cell wall. In the present study, solubility of Zn in the 48 h rumen incubated samples ranged from 96% (NB21) to 30% (RS2). Also, rice straws contained 50% more Zn initially as compared to NB21 (58.9 vs 39.6 mg kg^{-1} DM), but the latter released 97% within 24 h in the rumen as compared to 38% with the straws. These differences could be attributed to the difference in cell wall contents (which ranged from 331 g kg^{-1} DM for glyricidia to 734 g kg^{-1} DM for RS2), the extent and rate of cell wall degradation, and also the CEC of these different cell wall types. It has been demonstrated that the CEC of NDF and that of rumen digested residues can range widely depending on the type of fibre and presence of silicified cells (Van Soest, 1982).

CONCLUSIONS

In terms of absolute amounts released (g or mg kg^{-1} DM incubated in the rumen), both legumes seems a good source of Ca (12-15 g), Mg (5 g) and P (3-4 g), while erythrina for Zn (63 mg). Jak leaves is a good source of Ca (15 g) and Na (1.2 g), while rice bran is rich in fast soluble P (9 g) and Zn (65 mg).

Although the results of the present study and those reported in literature indicate that solubility of Mg present in roughages is more than 60%, the net availbility of dietary Mg for adult cattle and sheep is about 20% (ARC, 1965). The affinity of microbial cell walls for Ca and Mg (Fitt et al., 1974) would reduce the availability of these minerals for the animal and thus result in low net availability. As such, it is important to realise that the release of minerals during digestion in the rumen is only indicative that it may be potentially available for the rumen microbes or to the animal.

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REFERENCES

Association of Official Analytical Chemists, 1980. Official Methods of Analysis of the Association of Official Analytical Chemists. 13th Edition, Washington, D.C.

ARC, 1965. The nutrient requirements of farm livestock, No 2. Ruminants. Agricultural Research Council (ARC), Commonwealth Agricultural Bureau, London, UK.

Blaney, B. J., R. J. W. Garther and T. A. Head. 1982. The effects of oxalate in tropical grasses on calcium, phosphorus and magnesium availability to cattle. J. Agric. Sci. (Cambridge), 99:533-539.

Bremner, I. and A. H. Knight. 1970. The complexes of zinc, copper and manganese present in rye grass. Brit. J. Nutr., 24:279-289.

Bromfield, S. M. and O. L. Jones. 1972. The initial leaching of hayed-off pasture plants in relation to the recycling of phosphorus. Austr. J. agric. Res., 23:811-824.

Edwards, J. H., W. A. Jackson, E. R. Beaty and R. A. McCreery. 1977. Element concentration of forage and non-soluble cell wall fraction of coastal Bermuda grass. Agron. J., 69:617-619.

Field, A. C. 1981. Some thoughts on dietary requirements of macro-elements for ruminants. Proc. Nutr. Soc., 40:267-272.

Goering, H. K. and van P. J. Soest. 1970. Forage fiber analysis. (apparatus, reagents, procedures and some applications). Agric. Res. Serv. Agric. Handbook No. 379, Washington, DC. p. 20.

Ibrahim, M. N. M., S. Tamminga and G. Zemmelink. 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.

Ibranhim, M. N. M., van der, A. Kamp, G. Zemmelink and S. Tamminga. 1990. Solubility of mineral elements present in ruminant feeds. J. Agric. Sci. (Cambridge), 114:265-274.

International Organization for standardization, 1987. Animal Feeding Stuffs, Determination of Calcium, Copper, Iron Magnesium, Manganese, Potassium, Sodium and Zinc contents - AAS method. Publication TC/34/ION 333, Geneva : IOS.

Ivan, M., P. Jui and M. Hidiroglou. 1979. The effects of nitroilotriacetic acid on solubilities of zinc, copper, manganess and iron in the stomach of sheep. Can. J. Physiol. Pharmacol., 57:369-374.

Ivan, M. and D. M. Veira. 1981. Effect of dietary protein on the solubilities of manganese, copper, zinc, iron in the rumen and abomasum of sheep. Can. J. Anim. Sci., 61:955-959.

Kincaid, R. L. and J. D. Cronrath. 1983. Amount and digestion of minerals in Washington forages. J. Dairy Sci., 66:821-824.

McDowell, L. R., J. H. Conrad and G. L. Ellis. 1983. Mineral deficiencies and imbalances, and their diagnosis. In: F. M. C. Gilchrist and R. I. Mackie (Editors), Herbage Nutrition in the Subtropics and Tropics. Proceedings of the International Symposium of Herbivore Nutrition in the Subtropics and Tropics, The Science Press (Pty) Ltd. South Africa.

Playne, M. J., M. G. Echevarria and R. G. Megarrity. 1978. Release of nitrogen, sulphurm, phosphorus, calcium, magnesium, potassium and sodium from four tropical hays during their digestion in nylon bags in the rumen. J. Sci. Fd. Agric., 29:520-526.

Robinson, D. L., O. J. Hemkes and A. Kemp. 1984. Relationships among forage aluminium levels, soil contamination on forages and availability of elements to dairy cows. Neth. J. Agric. Sci., 32:73-80.

Rooks, J. A., A. O. Akinsoyinu and D. G. Armstrong. 1983. The release of mineral elements from grass silages incubated in *in sacco* in the rumens of Jersey cattle. Grassl. and For. Sci., 38:311-316.

Snedeker, S. M. and J. L. Greger. 1983. Metabolism of zinc, copper and iron as affected by dietary protein, cysteine and histidine. J. Nutr., 113:644-652.

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

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

Todd, J. R., 1961. Magnesium in forage plants. II. Magnesium distribution in grasses and clovers. J. Agric. Sci. (Cambridge), 57:35-38.

Van Soest, P. J. 1982. Nutritional Ecology of the Ruminant. Corvallis, Oregon, O and B Books, Inc.

Vijchulata, P., S. Chipadpanich and L. R. McDowell. 1983. Mineral status of cattle raised in the villages of central Thailand. Trop. Anim. Prod., 8:131-137.

Ward, G. M. and L. H. Harbers. 1982. Technical note: Effect of pH on extractability of calcium and oxalate from alfalfa leaflets. J. Dariy Sci., 65:154.

Whitehead, D. C., K. M. Goulden and R. D. Hartley. 1985. The distribution of nutrient elements in cell wall and other fractions of the herbage of some grasses and legumes. J. Sci. Fd. Agric., 36:311-318.

Whitehead, D. C., K. M. Goulden and R. D. Hartley. 1986. Fractions of nitrogen, sulphur, phosphorus, calcium and magnesium in the herbage of perennial ryegrass as influenced by fertilizer nitrogen. Anim. Feed Sci. Technol. 14:231-242.