Effect of Plant Fibre on the Solubility of Mineral Elements

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ABSTRACT : Eight feeds and their residues left after washing with tap water (water residue) or incubation in the rumen (rumen residues) were treated with hydrochloric acid, neutral detergent solution without EDTA (NDS) or both, and the release or sorption of minerals (Ca, Mg, P, Na, K, Cu and Zn) assessed. Six of the feeds were from Sri Lanka (*Panicum maximum* ecotype Guinea A, *Glyricidia maculata, Artocarpus heterophyllus* (jak leaves), untreated and urea-treated rice straw, and rice bran) and two from the Netherlands (maize silage and wheat straw). The initial concentration of mineral elements, the concentration of neutral detergent fibre (NDF) and the type of feed significantly influenced ($p<0.01$). The proportion of the mineral elements released or sorbed. In general, feeds with high NDF content (straws and guinea grass) sorbed Ca from tap water, or released less in the rumen, and within these feeds the extent of sorption varied with source of fibre. Acid or NDS treatment removed little of the sorbed Ca, but they removed much of the Mg from both water and rumen residues. Fibres of wheat straw and jak leaves showed an affinity for Mg in the rumen. All feeds and their water and rumen residues sorbed P and Na from NDS, and the extent of sorption varied with the initial concentrations of these elements and with the type of fibre. Acid treatment removed part of the sorbed Na, but not the P. The solubility of K was not affected by the content of NDF, the type of fibre or the initial concentration of K. All feeds and their residues, except for the rumen residues of rice bran, sorbed Cu from tap water and in the rumen. The recovery of Cu in rumen residues declined from 353% to 147% after NDS treatment, and with some feeds (glyricidia and jak leaves) the recovery was below 100%. Acid treatment removed part of the Zn sorbed by the water and rumen residues, but the capacity of residues to retain Zn varied with the type of feed. (*Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 8 : 1277-1284*)

Key Words : Plant Fibre, Mineral Elements, Solubility

INTRODUCTION

Mineral elements in roughages may be present in the following forms; (i) readily-released soluble fraction of high availability (ii) potentially available fraction which could be released after fibre or protein digestion and (iii) complexed or bound fraction which is of low availability. Factors that affect the potential availability 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) and their association with cell wall components (Zn-cellulose binding; Bremner and Knight, 1970), their association with protein (Cu; Snedeker and Greger, 1983) and 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.

The solubility of minerals present in feeds can be studied *in vitro* (Kincaid and Cronrath, 1983; Ibrahim et al., 1990), *in sacco* (Playne et al., 1978; Rooke et al., 1983; Ibrahim, 1994) or *in vivo* (Ivan and Viera, 1981). In an attempt to develop appropriate methods to assess the solubility of minerals present in feeds, a range of *in vitro* methods (Ibrahim et al., 1990) and the *in sacco* method (Ibrahim, 1994) were tested. Although these techniques provided valuable information on comparative solubility of minerals within and between feeds, the interference due to the capacity of some feeds to sorb certain minerals made the interpretation rather difficult. An increase in element concentration concomitant with continuing digestion of DM indicates that the element is not associated with the fraction being digested or that there is an influx of mineral elements from the solvent (tap water and rumen fluid). The effect could be accentuated by the presence of bacteria strongly attached to the residues and not removed during washing. There is need to elucidate these factors in order to get a better understanding of the release of minerals present in ruminant feeds.

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MATERIALS AND METHODS

Feeds

A total of eight feeds were used, six from Sri Lanka (*Panicum maximum* ecotype Guinea 'A' (Guinea grass), *Glyricidia maculata* (glyricidia), *Artocarpus heterophyllus* (jak leaves), untreated and urea-treated rice straw and rice bran) and two from the Netherlands (maize silage and wheat straw). Guinea grass (cut after 1 month), glyricidia and jak leaves are some of the most common green roughages fed to ruminants in Sri Lanka. These feeds were dried in a forced-draught oven at 60℃ for 36 h. Urea treatment of straw was performed by mixing chopped (2-3 cm) straw with urea solution (4 kg urea dissolved in 100 liters water/100 kg straw dry matter) and stored in air-tight bags for 10 days. After this the bags were opened, mixed and dried at 50℃. The roughages were ground to pass through a 5 mm sieve.

Treatment and procedure

The original feeds and the residues left after washing with tap water or after incubation in the rumen were used in this study. With the tap water and rumen incubation treatments, 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 to be incubated in the rumen were tied and attached by a 25 cm nylon cord to a 750 g polypropylene block suspended by a 70 cm nylon cord to the inside of the cannula cap. The bags were incubated for 24 and 48 h in the rumen of cows 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%). After removal from the rumen the bags were immediately plunged into an ice bath, rinsed in tap water and subsequently washed for 20 min in a washing machine (wool wash programme, V360 - Bosch). The tap water treatment bags plus contents 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.

After determining the organic matter (ashing at 550℃) remaining in the 24 and 48 h rumen incubated residues, residues were mixed in a 1:1 ratio (dry matter basis) and the composite sample (hereafter referred to as rumen residue) was used for further treatment.

The original feeds and their tap water and rumen residues were subjected to the following treatments, namely;

(a) dilute hydrochloric acid (Acid, pH 5.0)
(b) Neutral detergent solution without EDTA (NDS, pH 6.9-7.1)
(c) NDS followed by Acid

For treatment with acid, 1 gram of the sample was weighed into a 25 ml beaker and moistened with acid. After 30 minutes it was filtered through a nylon filter (Nybolt PA40/30; pore size 41 micron) in a Buchner funnel and washed 5 times with acid, followed by 5 times with cold (20℃) demineralized water.

For treatment with NDS the procedure described by Goering and van Soest (1970) was followed, but after boiling the residue was filtered through the nylon filter and washed 5 times with hot demineralized water.

For a third set of samples, the procedure described above with NDS treatment was followed by acid treatment.

All above treatments were done in duplicate, and the residues with the filters were transferred into porcelain crucibles and dried at 103℃ for 12 h to estimate dry matter loss.

Laboratory analyses

The 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, water-washed and rumen incubated-residues, and residues left after treatment with acid or NDS, were analyzed for Ca, Mg, P, Na, K, Cu and Zn (International Organization for Standardization TC/34/10 N 333, 1987).

Statistical analysis

The data on the proportion of dry matter and minerals remaining in the residue were subjected to an analysis of variance procedure (Statistical Analysis Systems, 1982).

RESULTS AND DISCUSSION

Feeds

The chemical composition and organic matter digestibility *in vitro* (IVOMD) of the test feeds, and the proportion of dry matter remaining after incubating in the rumen for 24 and 48 h are given in table 1. The mineral composition of each of the test feeds is given in table 3.

The NDF content ranged from 331 g/kg (glyricidia) to 777 g/kg (wheat straw). In spite of the wide difference in NDF content between wheat straw and rice bran (455 g/kg), the proportion of DM released after incubation in the rumen for 24 and 48 h was similar (16 and 30 %, respectively). It is of interest to note that jak leaves contained a high proportion of cell solubles (100 - NDF) compared with maize silage (609 and 473 g/kg, respectively), and conversely that maize silage contained 147 g/kg more hemicellulose (NDF-ADF) than jak leaves (259 and 112 g/kg,

Table 1. Chemical composition, *in vitro* organic matter digestibility (IVOMD) and dry matter recovery (DMR) after incubating in the rumen for 24 or 48 h

	Composition (g/kg DM)						IVOMD (%)	DMR (%) after incubation	
	DM %)	Crude protein	Ash	Neutral detergent fiber	Acid detergent fiber	Neutral detergent lignin		24 h	48 h
Rice straw									
Untreated	93.8	44	105	746	445	47	44.8	82	59
Treated	94.2	66	105	742	446	48	57.5	74	46
Wheat straw	94.1	41	124	777	494	55	40.5	84	70
Guinea grass	94.5	127	119	686	368	38	56.9	68	48
Glyricidia	93.9	302	102	331	197	43	70.0	25	18
Jak leaves	92.7	126	84	391	279	72	52.1	56	32
Maize silage	96.2	87	49	527	268	-	66.1	59	43
Rice bran	90.3	107	209	455	303	97	45.2	84	70

Table 2. The effect of washing with acid, neutral detergent solution (NDS) and NDS+acid on the dry matter content of testfeeds, and their water washed or rumen incubated residues (% of the amount initially present)

	Original feed			Washed with water				Rumen incubated			
	Acid	NDS	NDS+Acid	Control	Acid	NDS	NDS+Acid	Control	Acid	NDS	NDS+Acid
Rice straw											
Untreated	87	78	75	82	80	70	70	58	56	45	48
Treated	86	79	76	82	80	72	71	49	47	38	41
Wheat straw	83	75	72	79	76	69	68	46	44	35	37
Guinea grass		62	39	36	54	50	27	36	22	21	17
Glyricidia	71	46	44	64	62	37	45	29	28	17	21
Jak leaves	91	63	57	80	76	52	57	54	54	44	47
Maize silage	76	51	46	52	50	37	40	35	34	26	28
Rice bran	93	84	81	85	83	72	76	65	63	53	56
Mean	81	64	61	72	70	54	58	45	43	34	37

respectively). In theory, minerals associated with the cell solubles would be removed by NDS treatment, and the hemicellulose fraction would be quickly digested by rumen microbes releasing the minerals associated with it.

The difference in solubility of DM in the rumen between 24 and 48 h ranged from as low as 7% (glyricidia) to 28% (treated rice straw) of the original dry weight. With rice straws, guinea grass and jak leaves a considerable proportion of DM was solubilized between 24 and 48 h in the rumen.

The concentrations of minerals varied widely among the test feeds. For instance, Ca concentration ranged from 1.4 g/kg DM for rice bran and wheat straw to 16.3 g/kg DM for jak leaves (table 3). Wheat straw had low concentrations for most of the minerals studied. Rice bran contained appreciable quantities of P (9.5 g/kg DM) and Zn (77.3 mg/kg DM). The concentration of Na in all feeds, except rice straw, was low, particularly in glyricidia (0.1 g/kg DM). The Zn concentration in maize silage was unusually high (362 mg/kg), nearly ten times as high as the average value reported in the literature (32 mg/kg), possibly due to storage of the silage in zinc trays for 2 days before drying.

The eight feeds were of contrasting fibre content and mineral composition and this made it possible to examine the effects of these factors on the release of mineral elements in water and in the rumen.

Dry-matter loss

The dry matter (DM) residues from the various treatments, expressed as a percentage of DM initially present in the feeds are presented in table 2. Treatment with acid removed 38% of the DM of guinea grass, while it removed only 7% from rice

Table 3. The effect of washing with acid, neutral detergent solution (NDS) and NDS+acid on the mineral content of testfeeds, and their water washed or rumen incubated residues (% of the amount initially present)

	Content in feed DM	Original feed			Washed with water				Rumen incubated			
		Acid	NDS	NDS +Acid	Control	Acid	NDS	NDS +Acid	Control	Acid	NDS	NDS +Acid
Calcium	**(g/kg)**											
Rice straw												
Untreated	5.1	93	74	67	147	133	136	136	84	78	79	83
Treated	4.9	93	71	72	150	146	146	148	79	69	72	78
Wheat straw	1.5	102	30	38	155	127	155	134	146	122	129	143
Guinea grass	16.0	93	62	67	125	117	119	127	55	47	50	54
Glyricidia	115.6	70	54	54	82	78	35	80	10	9	9	10
Jak leaves	16.3	83	87	88	80	78	76	63	27	25	23	25
Maize silage	2.3	31	18	23	68	56	71	47	62	50	56	61
Rice bran	1.4	84	76	23	275	247	209	232	191	165	149	139
Mean		81	59	54	134	123	118	121	82	71	71	74
SE (DF =8)	3.1	3.8	2.4	9.4	7.2	10.2	12.1	6.3	8.9	8.3	9.2	
Mangesium	**(g/kg)**											
Rice straw												
Untreated	1.9	72	35	36	23	18	13	15	83	7	9	10
Treated	1.8	64	29	33	17	14	10	13	79	6	8	6
Wheat straw	0.6	107	11	13	27	20	29	34	125	20	23	27
Guinea grass	5.8	26	20	24	6	5	4	5	23	2	2	3
Glyricidia	5.3	32	18	22	10	8	2	9	19	1	1	1
Jak leaves	2.1	65	69	75	22	20	21	15	111	5	5	5
Maize silage	1.1	10	8	10	11	5	8	9	47	4	6	11
Rice bran	5.0	87	52	34	49	43	36	31	6	5	4	7
Mean		59	30	31	21	17	15	16	62	6	7	9
SE (DF =8)	2.3	4.3	3.8	1.1	1.3	1.2	0.9	9.3	1.7	1.8	1.0	
Phosphorus	**(g/kg)**											
Rice straw												
Untreated	2.7	38	67	58	26	22	142	142	25	23	68	78
Treated	2.5	24	50	52	14	14	146	150	25	22	62	72
Wheat straw	0.4	50	66	63	33	28	225	215	193	164	250	267
Guinea grass	3.7	21	44	53	17	13	75	110	16	13	40	45
Glyricidia	3.7	45	69	70	35	23	77	170	5	4	18	19
Jak leaves	1.5	44	550	543	38	35	409	322	18	16	106	120
Maize silage	2.0	7	15	9	4	4	37	21	17	14	29	35
Rice bran	9.5	78	50	32	48	44	42	42	5	5	12	10
Mean		38	113	110	26	22	148	146	38	33	73	81
SE (DF =8)	4.3	18.1	17.9	2.9	2.6	22.1	26.1	4.6	3.9	12.9	13.2	
Sodium	**(g/kg)**											
Rice straw												
Untreated	5.4	12	27	24	4	1	42	32	3	1	30	21
Treated	5.4	10	33	23	4	1	44	37	3	1	25	19
Wheat straw	0.2	50	708	603	32	29	878	515	62	24	798	399
Guinea grass	0.5	20	366	311	32	11	681	519	19	7	255	149
Glyricidia	0.1	118	3031	934	200	57	3736	1061	46	13	556	283
Jak leaves	1.3	11	246	164	12	5	236	230	6	2	53	76
Maize silage	0.1	45	1039	460	61	24	841	566	52	19	494	320
Rice bran	0.2	71	1697	1186	82	56	1417	960	45	30	936	614
Mean		42	891	463	55	23	984	490	29	12	393	235
SE (DF =8)	5.2	18.7	123.1	9.6	5.6	99.7	112.3	4.1	3.6	76.2	21.2	

Table 3. Continue

	Content in feed DM	Original feed			Washed with water				Rumen incubated			
		Acid	NDS	NDS +Acid	Control	Acid	NDS	NDS +Acid	Control	Acid	NDS	NDS +Acid
Pottassium	**(g/kg)**											
Rice straw												
Untreated	12.5	8	0	0	1	0	0	0	1	0	0	0
Treated	13.0	9	0	0	1	0	0	0	1	0	0	0
Wheat straw	7.4	15	1	0	1	0	0	0	1	0	0	0
Guinea grass	15.0	2	1	0	1	0	0	0	0	0	0	0
Glyricidia	25.6	1	1	0	1	0	0	0	0	0	0	0
Jak leaves	11.4	4	1	0	1	0	0	0	0	0	0	0
Maize silage	12.6	1	1	0	0	0	0	0	0	0	0	0
Rice bran	6.9	43	3	2	16	9	2	2	2	1	1	1
Copper	**(mg/kg)**											
Rice straw												
Untreated	2.1	99	142	122	587	558	801	313	518	521	181	324
Treated	1.6	98	274	166	864	840	1474	540	644	618	296	440
Wheat straw	1.6	64	158	110	687	554	436	432	564	491	232	411
Guinea grass	2.1	202	412	299	561	528	1109	491	504	454	198	273
Glyricidia	5.3	48	88	63	325	298	125	199	130	135	62	109
Jak leaves	3.8	57	96	83	364	340	136	212	178	166	47	91
Maize silage	4.5	62	86	72	270	261	127	155	191	169	109	131
Rice bran	9.0	89	122	60	173	195	124	115	96	87	51	63
Mean		90	172	122	479	447	541	307	353	330	147	230
SE (DF =8)	9.2	8.8	8.7	12.8	10.9	86.3	12.1	14.1	11.9	8.7	9.4	
Zinc	**(mg/kg)**											
Rice straw												
Untreated	38.1	83	205	129	120	86	216	118	67	60	98	71
Treated	27.5	103	259	158	130	143	308	182	101	78	125	90
Wheat straw	12.8	127	119	126	225	137	370	186	178	141	224	227
Guinea grass	35.5	86	193	131	114	96	222	155	55	53	78	65
Glyricidia	25.8	84	118	91	124	108	67	106	23	21	31	35
Jak leaves	15.6	150	329	233	196	152	258	226	52	46	100	81
Maize silage	361.8	19	41	46	8	7	12	6	21	20	22	21
Rice bran	77.3	93	96	61	89	79	74	76	22	20	24	25
Mean		93	170	122	126	101	191	132	65	55	88	77
SE (DF =8)	12.1	33.2	23.6	21.1	14.3	22.1	20.1	8.5	7.3	16.3	9.9	

bran. Acid treatment after NDS treatment removed 2-6% of DM. The ranking order remained unchanged. Washing with tap water removed 15% (wheat straw) to 48% (maize silage) of DM, and on an average 28% was removed. Acid treatment of water washed residues removed 2-5% of the DM. In wheat straw 65% of the DM remained in the nylon bag after incubation and 81% of this was NDF fraction.

Mineral solubility

The data on the recovery of minerals after treating with acid, NDS and NDS + acid are given in table 3. Statistical analysis of variance showed significant effects ($p<0.01$) due to feed, treatment and feed× treatment interaction for all minerals except K.

Ca

In five of the eight feeds studied (rice straws, wheat straw, guinea grass and rice bran), washing with tap water resulted in Ca recoveries of over 100%. With rumen- incubated residues only two (wheat straw and rice bran) of the above five feeds showed recoveries over 100%. When there was a influx of Ca from the tap water or rumen fluid, both acid and NDS treatment failed to remove the adsorbed Ca completely. With glyricidia and jak leaves, 80% of the Ca remained in the water washed residues, and subsequent washing with acid did not remove any further Ca. In glyricidia the recovery after NDS treatment was reduced to 35%, whereas with jak leaves the figure remained unchanged. The behaviour of these two feeds with a difference in NDF content of 60 g may be due to a difference in fibre type.

The problem of high Ca content in the residues as compared with the amounts initially present in the original feeds was more acute in feeds which contained little Ca, such as wheat straw and rice bran (<1.5 g/kg DM). With these feeds, the Ca recovery even in the rumen-incubated residues increased 1½ to 2 fold. This suggests that low quality feeds with low Ca contents, such as wheat straw and rice bran (IVOMD<45%), would not only make no contribution to the Ca pool in the rumen, but would act as a sink in sorbing Ca from the rumen environment. There is evidence to indicate that the Ca concentration in the rumen fluid of cows fed a basal ration of wheat straw was not influenced by the presence of a mineral mixture (Ibrahim et al., 1990).

Figure 1 shows the relationship between the NDF content of the feed (rice bran excluded) and the recovery of Ca in the rumen residues before and after treatment with NDS. In general, the higher the NDF fraction, the higher was the recovery of Ca. Also, the solubility of Ca remaining in the rumen residues was not affected by NDS treatment confirming its association with the NDF fraction. The amount associated (as % of initial concentration) with the cell wall fraction varied from 9% (glyricidia) to 79% (rice straw). The values found in our study for guinea grass and glyricidia are within the range (11 to 52%) reported for grasses and legumes in literature (Kincaid and Cronrath, 1983; Whitehead et al., 1985). In our study a much wider range of feeds was used, and the CEC of different plant fibres as indicated by van Soest (1982) would further explain the differences found in this study as regards the release of Ca present in feeds.

Mg

With Mg, there was hardly any difference between the untreated water-washed feed residues and the same residues after treatment with acid or NDS, indicating that there was little or no absorption from tap water. On the other hand, all feeds except rice bran sorbed Mg when incubated in the rumen (notably wheat straw and jak leaves where the recovery was more than 100%), but, treatment with acid or NDS was capable of removing the absorbed Mg from the rumen residues (see figure 1). As with Ca, the amount and type of NDF seems to affect the release or sorption of Mg. Notably, the type of fibre and its effect on Mg release is well demonstrated with the behavior of jak leaves (figure 1). The increased recovery of Mg in the rumen-incubated residues could be due also to microbial contamination of the plant fibres, as there is evidence that microbial cell walls have an affinity for Ca and Mg ions (Fitt et al., 1974). It is possible that the NDS treatment not only removed the sorbed Mg ions, but also the adhered microbes.

Comparison of NDS treatment of the original feeds with that of water washed residues (mean Mg recovery of 30 cf. 15%) indicates that about 50% of the Mg present in the NDF could be easily removed with water. The proportion of the total Mg associated with the cell walls of guinea grass and glyricidia was 2 to 4%, and this is within the range of 3-7% reported by Whitehead et al. (1985) for grasses and legumes. In our study, with the other feeds the proportion of the Mg associated with cell wall ranged between 8% (maize silage) to 36% (rice bran). Rice bran, which had a third of its Mg within the cell wall matrix, released 83% of this in the rumen. The higher degradability of the potentially degradable NDF fraction of rice bran in the rumen during the early hours of rumen incubation (Ibrahim et al. unpublished) would be a possible cause for the high release of Mg.

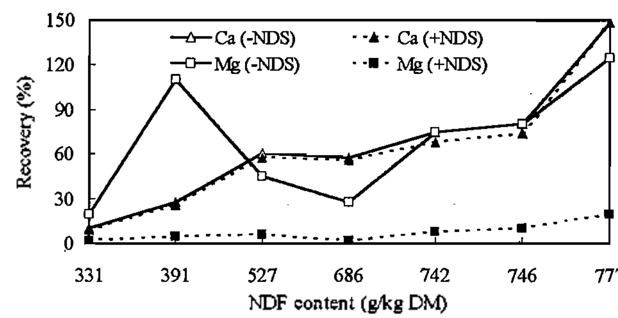

Figure 1. Relation between neutral degergent fibre (NDF) content and the recovery of Ca and Mg from rumen incubated residues before (-NDS) and after (+NDS) treatment with neutral detergent solution (NDS)

P

Although NDS itself contained P, the type of fibre and the pre-treatment (original feed, water or rumen residue) affected the recovery of P. For example, the fibre content of jak leaves was half that of wheat straw (392 cf. 777 g/kg DM) and the concentration of P was 4 times greater than in wheat straw (1.5 cf. 0.4 g/kg DM), but with NDS treatment the latter released 36% of the P whereas, with jak leaves P increased by 550%. The presence of latex/resins in jak leaves and their ability of sorb P from solvents would be a possible reason for the increased recoveries.

The mean recovery of P after acid treatment was higher than that after water treatment (38 cf. 26%), and acid treatment of the water residues did not affect the recovery of P (mean of 22%). Although the P content in guinea grass and glyricidia was similar (3.7

g/kg DM), guinea grass released significantly more P when washed with acid or water (79 and 83%, respectively). However, glyricidia released 95% of P in the rumen as compared to 84% with guinea grass. This indicates that, in glyricidia, part of P is associated with the fibre fraction and is released with cell wall degradation. On the other hand, in guinea grass more than 80% of the P is present in a readily soluble form.

Among the feeds studied, only wheat straw incubated in the rumen produced a P recovery above 100%. Although some of this was removed by acid treatment, the concentration was still higher than in the original sample. The initially low P content in wheat straw would be a possible explanation for higher recoveries when treated with NDS or during rumen incubation. All rumen-residues except rice bran and glyricidia, when washed with NDS sorbed substantial amounts of P. In another study using the same eight feeds (Ibrahim et al., 1990), it was demonstrated that the release of P in rumen fluid was highly dependent on the P status of the fluid. They reported mean recoveries of 68 and 276% for rumen fluids containing P levels of 53 and 62 mg/l, respectively and, in the present investigation, the P recovery in jak leaves was 550% (table 3). The variation in sorption capacity of the feeds in the study with rumen fluids, and in the present study with NDS, could be attributed to differences in initial P concentration, the amount of plant fibre degraded, the type of plant fibre and other organic compounds associated with cell walls (latex/resins).

The proportion of herbage P associated with the cell walls of grasses and legumes could range from 6 to 34% (Kincaid and Cronrath, 1983; Whitehead et al., 1985). In the present study with the data obtained from the water and rumen residues, one could say that in tropical feeds about 4 to 28% of the P is associated with the cell walls. In a similar study (Ibrahim, unpublished data) using some tropical feeds (guinea grass, glyricidia, jak leaves and rice bran), it was found that 6 to 9% of the P remained in the residue after incubating in the rumen for 10 days.

Na and K

The ND solution contained Na and except rice straws all feeds, and their water or rumen residues, sorbed Na to varying extent. With both tap water and rumen residues, washing with acid removed a considerable proportion of the sorbed Na. The Na content in glyricidia was low (0.1 g/kg DM) and it increased two-fold when washed with tap water, but subsequent washing of the residues with acid removed part of the sorbed Na. It is of interest to note that glyricidia and maize silage contained similar Na contents, and in spite of the low NDF content in glyricidia (331 cf. 527 g/kg DM) it sorbed almost 3 times more Na than did maize silage. A possible explanation is that the low pH in maize silage may have hindered the fibres from sorbing more Na. This explanation is further strengthened by the fact that the rumen-incubated residues of these two feeds showed a similar pattern of Na release or absorption. Wheat straw and rice bran had similar concentrations of Na (0.2 g/kg DM), but rice bran with 40% less NDF (455 cf. 777 g/kg DM) sorbed more Na from the solvent (table 3).

The Na content in rice straw was high (5.4 g/kg DM) and about 96% was released in tap water or in the rumen. Nevertheless, both the water-washed and rumen residue samples of rice straw showed a tendency to sorb Na from NDS. The Na content in other feeds was comparatively very low and, although the proportions released in water and in the rumen were substantial, in absolute terms the quantity released was marginal. In general, based on the data obtained for feeds with high Na content (rice straws and jak leaves) and that remaining after water and/or acid treatment, it was clear that the amount of Na associated with the fibre was negligible.

With K, neither the concentration in the feed nor the type of feed affected the solubility of K. Wheat straw and rice bran which contained comparatively low amounts of K (c. 7 g/kg) released 85-99 % in water and in the rumen.

Cu

With all feeds, the recovery of Cu after washing with tap water or rumen incubation (except rumen residues of rice bran) was more than 100%, and neither acid nor NDS treatment was able to remove the sorbed Cu. The high recoveries could have been caused by the presence of Cu in water (from the pipes which were made of Cu) and/or from rumen fluid. In general, the recoveries were 500 to 800% in feeds with low Cu contents (straws and guinea grass) and 200 to 300% in feeds with high Cu contents. The mean recovery in water-washed controls was 479% compared to 353% for rumen-incubated controls. Also, the NDS treatment of water residues had no positive effect on Cu recovery (479 cf. 541%) but, with the rumen residues, the recovery was reduced to less than half (353 cf. 147%). The lower fibre content in the rumen-incubated residues would partly explain the lower recoveries indicated above. Nevertheless, feeds with high NDF (straws and guinea grass) tend to sorb more Cu than those with low NDF content.

With the type of feeds used in this study, the amount of Cu associated with the cell wall complex could range from 5 to 34% (Edwards et al., 1977; Whitehead et al., 1985; Ibrahim et al., 1990) but, with the data obtained in the present study, no firm conclusions could be made.

Zn

Maize silage and rice bran which had high initial Zn contents, released 92 and 11%, respectively in water and 78% in the rumen. The higher solubility of the maize silage DM in water (50% cf. 15% with rice bran) reflects the difference in solubility of Zn in water between these two feeds. Moreover, the higher fibre content in rice bran, coupled with the higher release after rumen-incubation, indicates that the Zn in rice bran is closely associated with the fibre fraction. All feeds sorbed Zn from water and the extent of sorption was related to the initial concentration of Zn and also to the NDF content. For example, guinea grass with high Zn and NDF contents (35.5 mg and 686 g/kg, respectively) sorbed more or released less Zn compared to glyricidia with low Zn and NDF contents (25.8 mg and 331 g/kg, respectively).

With the majority of the feeds and their water and rumen residues, the Zn recovery increased after NDS treatment indicating the presence of Zn as an impurity in the reagents used to prepare NDS. From the data obtained after NDS treatment of the water residues of glyricidia, maize silage and rice bran, it could be said that 67, 12 and 74%, respectively of Zn present in these feeds is associated with the plant fibre. Whitehead et al. (1985) working with two grasses and two legumes reported that 24-78% of the Zn is associated with the cell wall fraction.

CONCLUSIONS

Except for K, the extent to which the minerals were released or sorbed varied with the amounts initially present, the NDF content and the type of feed or plant fibre. The acid or NDS treatment of the tap water-washed residues gives an indication of the proportion of mineral elements associated with the fibre component or with the cell solubles. Rumen residues provides information on the proportions remaining or sorbed to the undigested fibre component.

REFERENCES

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

Blaney, B. J., R. J. W. Gartner 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.

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

Fitt, T. J., K. Hutton and W. R. Otto. 1974. Relative affinities of isolated cell walls of rumen bacteria for calcium and magnesium ions. Proc. Nutr. Soc. 33:106A -107A.

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

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

Ibrahim, M. N. M., S. Tamminga and G. Zemmelink. 1995. Degradation of tropical roughages and concentrate feeds in the rumen. Anim. Feed Sci. Technol. 54:81-92

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. and D. M. Veira. 1981. Effect of dietary protein on the solubilities of manganese, copper, zinc and 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.

Playne, M. J., M. G. Echevarria and R. G. Megarrity. 1978. Release of nitrogen, sulphur, phosphorus, calcium, magnesium, potassium and sodium from four tropical hays during their digestion in nylon bags in the rumen. J. Sci. Food 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.

Rooke, 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. Grass Forage Sci. 38:311-316.

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

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.

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.

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

Ward, G. M. and L. H. Harbers. 1982. Technical note: Effect of pH on extractability of calcium and oxalate from alfalfa leaflets. J. Dairy Sci. 65:154-158.

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. Food Agric. 36:311-318.