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Minerals release kinetics in the rumen from five commonly available dry fodders

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ABSTRACT

The extent to which the macro and micro minerals present in various fodders released in the rumen were studied in 5 commonly fed dry fodders (paddy straw, ragi straw, wheat straw, maize kadbi and oat hay) in 3 adult cattle fitted with rumen cannula by in sacco nylon bag technique. The dry fodders were incubated in the rumen for different periods i.e. 10 h, 24 h, 48 h and 72 h and minerals release kinetics in the rumen were studied. There were significant differences in element release in the rumen between experimental fodders and the particular minerals. The rate of release of Ca and P was higher from oat hay and maize kadbi than from paddy, ragi and wheat straws. As compared to Ca, the release of P, Mg and K at different periods of incubation in the rumen was higher from various dry fodders. The pattern of Mg release was different from Ca and P. The release of individual elements over all incubation times is very well expressed by cubic polynomials ($R2 > 0.9$). Overall, across dry fodders, the release of mineral elements ranked as follows: K > Mg > P > Cu > Mn > Zn > Ca. Among all minerals, K showed the highest (98 to 100%) and Ca and Zn showed the lowest release in the rumen at different periods of incubation from fodders. It could, therefore, be concluded that the pattern of macro and trace minerals release in the rumen varied from feeds to feeds and the time of incubation influenced the release of minerals from fodders. Calcium and zinc need a longer time for their maximum release in the rumen for making it available for absorption.

Key words: Dry fodders, Macro minerals, Micro minerals, Release of minerals, Rumen incubation

Several factors affect the potential availability of minerals from feedstuff. So, it is important to know not only the concentration of mineral elements in feeds, but also the extent to which they are solubilised and released in rumen and thus absorbed from the gut. Differences in solubility of individual mineral elements can be ascribed to the ability of cell walls to bind certain elements to their surface (cation exchange capacity) that can also be influenced by NDF concentration in feed (Emanuele *et al.* 1991) or to the content of organic acids in plant structures underlying the ability to bind and retain ions of metals (Ward *et al.* 1979, Van Soest 1982). The development of alternative methods to predict mineral absorption would considerably benefit to the livestock production. In this regard, a method for measuring mineral solubility and release in rumen may be useful in predicting their absorption. Very few studies deal with ruminal solubility of minerals. The utilization of mineral from mineral supplements has been reviewed extensively but scanty information is available on the utilization of minerals from feeds and fodders. The study of ruminal release of minerals could give a better indication to the minerals availability from feeds. So, the study was carried out to assess the extent to which macro and trace minerals present in various feeds and fodders were released in the rumen.

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MATERIALS AND METHODS

Experimental feed: Commonly fed dry fodders, viz. paddy straw, wheat straw, ragi straw, maize kadbi and oats hay were examined the release of macro and micro minerals in the rumen based on their importance for ruminant feeding. The fodder samples were air dried and later oven dried at 60 °C for 48 h and ground to pass in a 2 mm screen Wiley mill. They were stored in plastic containers for later analysis. For nylon bag incubation studies the roughages were ground to pass thorough a 5 mm sieve.

Rumen incubation of feedstuffs in nylon bags

Animal and diet: The animal experimentation was approved by the Institutional Ethics Committee for feeding and management of animals during trial period. The release of mineral elements from dry fodders were determined using *in sacco* method The trial was carried out on 3 adult male cattle, fitted with a large rumen canula and housed in individual pens. The average body weight of animals was 450 kg. The animals were fed a diet (1 kg concentrate with *ad lib*. non- legumes fodder) and vitamin-mineral mixture premix at 2 weeks before and during the trial. The intake of water was *ad lib*.

The feedstuffs (5 g) were placed into the nylon bags (pore size, 50 mm; internal dimensions, 5 cm × 10 cm) and after a 14 days adaptation period to the diet, nylon bags containing test feed samples (5 g) were placed into the rumen of each animal. Three bags were used for each fodder, animal and incubation time and were introduced in the rumen just before the morning feeding, and bags were removed at each incubation time, determined per feedstuff according to a preliminary dry matter degradation study. The time of incubation was 10, 24, 48, 72 h. Two paper weights (approximately 600 g) put in a nylon bag and tied with nylon cord, were used as inert weight to keep the test bags deep onto the rumen. Immediately after removal, the bags were kept in the ice and then washed with continuous flow of water for 3 min in low speed of washing machine. To remove the adsorbed mineral, bags were dipped in acidic water (5 ml HCl/ litre of distilled water) followed by final dipping in distilled water. The bags were then dried in hot air oven as 70 °C for 48 h and the residues were ground to pass through a 1 mm sieve in a laboratory mill. The quantity of a mineral remaining in each bag at each incubation time was expressed as a percentage of the mineral originally present in the bag prior to rumen incubation.

Minerals analysis: The test feeds were analysed for macro minerals estimation by Inductively Coupled Plasma (ICP) spectrophotometer. The samples were processed by wet oxidation method using nitric and perchloric acids (AOAC 1990). The prepared extractions were analysed for calcium (Ca), magnesium (Mg), potassium (K), copper (Cu), manganese (Mn) and zinc (Zn) using spectrometer. The phosphorous (P) content in feeds and fodders was analysed in spectrophotometer by metavandate method of Fiske and Subbarow (1925). Mineral standards (National Institute of Standards and Technology, NIST certified) were run in each analysis to ensure the accuracy of estimation.

Statistical analysis: The data on the observed losses of mineral elements from fodders were evaluated as follows:

- by calculation of basic variation statistical characteristics.
- the influence of fodder and time of observations was evaluated by two-way analysis of variance.
- dependences of the analysed traits on time were evaluated by estimation of parameters of linear functions and polynomials, the most suitable polynomial was the polynomial of the second and third (cubic) degree.

Mathematical and statistical processing was done on the basis of statistical methods of Grofik and Fl' ak (1990) and by help of statistical program package (SPSS,ver.15).

RESULTS AND DISCUSSION

The mineral composition of dry fodders is presented in Table 1. Because of the importance of mineral elements, either macro or micro, it is necessary to know their content in forages and their solubility in the digestive tract as well. Solubility and release from the structure of feed are important preconditions of utilization of mineral elements in animals. There are large differences between feeds in the content of cell walls, and in the representation of individual fractions (cellulose, hemicelluloses and lignin) that influence the degradability of cell walls (Ceresnakova *et al.* 2000) and release of mineral elements (Ledoux and Martz 1991, Flachowsky *et al.* 1994). Our results suggested possible differences amongst the dry fodders in the content of mineral elements. Paddy and ragi straw contained highest Mn level in comparison to other test feeds. Highest Ca content was estimated in ragi. Gowda *et al.* (2004) also reported a higher Ca content in ragi straw than paddy straw. The Cu and Zn content was found highest in oat hay as compared to other dry fodders.

There are different concentrations of macro and microelements in fodders (Table 1), and their release during incubation in the rumen is also different. It is demonstrated in Table 2 by minimum (6 h incubation), maximum (72 h incubation) and mean values from all incubations. The rate and amount of their release is not connected with their original concentration. There were significant differences ($P < 0.01$) in incubation time between dry fodders

Table 1. Macro and micro minerals composition of dry fodders (DM basis)

Fodders	Ca	P	Mg	K	Cu	Mn	Zn
	...%				...µg/g...		
Paddy straw	0.29	0.11	0.16	2.59	6.80	111.20	6.20
Ragi straw	0.45	0.14	0.23	3.01	9.60	107.20	18.90
Wheat straw	0.23	0.10	0.15	1.68	5.20	48.70	15.20
Maize kadbi	0.37	0.11	0.21	2.10	3.90	35.30	7.10
Oat hay	0.37	0.27	0.36	1.79	15.20	58.10	22.80

Table 2. Basic statistical characteristics of the release of macro and micro minerals from dry fodder' over all times in the ruminal incubation

Feedstuffs	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
	Ca				P			
Paddy straw	16.35	3.68	11.20	19.20	58.45	14.36	37.70	69.50
Ragi straw	19.33	4.95	12.60	23.60	61.87	8.99	49.90	70.20
Wheat straw	16.80	3.76	12.00	20.40	60.55	11.57	44.70	69.90
Maize kadbi	25.05	7.59	14.30	31.00	57.22	16.30	34.60	71.10
Oat hay	23.67	4.03	18.30	27.60	61.32	14.65	40.20	72.40
	Mg				K			
Paddy straw	81.65	3.97	75.80	84.60	99.00	0.40	98.40	99.30
Ragi straw	81.28	3.02	76.80	83.30	99.55	0.37	99.00	99.80
Wheat straw	83.80	5.30	75.90	87.00	99.50	0.41	99.00	100.00
Maize kadbi	81.82	2.46	78.30	83.90	99.75	0.24	99.50	100.00
Oat hay	69.57	12.70	50.70	78.10	99.63	0.36	99.10	99.90
	Cu				Mn			
Paddy straw	40.27	12.90	23.50	51.10	31.28	6.79	22.90	38.40
Ragi straw	45.33	11.57	30.10	55.60	38.72	5.55	31.80	44.10
Wheat straw	46.55	9.96	32.40	54.90	39.90	13.97	21.40	51.90
Maize kadbi	51.22	12.46	34.80	62.50	35.97	7.88	24.60	41.80
Oat hay	48.45	8.21	36.60	55.40				
	Zn							
Paddy straw	26.98	1.68	24.80	28.80				
Ragi straw	29.20	3.92	25.20	34.60				
Wheat straw	38.75	4.65	32.30	42.50				
Maize kadbi	37.55	3.27	32.80	40.20				
Oat hay	46.65	5.34	39.50	51.60				

Table 3. Parameters estimates of the linear function $y = b_0 + b_1t$ of macro and micro minerals release from dry fodders in the time of ruminal incubation

Feedstuffs	b_0	b_1	R^2	b_0	b_1	R^2
			Ca		P	
Paddy straw	11.74±1.98	0.1198±0.0438	0.788	41.02 ±8.573	0.4527±0.1898	0.740
Ragi straw	12.90±2.24	0.1670±0.0497	0.849	49.94±3.565	0.3099±0.0789	0.885
Wheat straw	11.71±1.26	0.1321±0.0280	0.917*	45.75±5.728	0.3844±0.1268	0.821
Maize kadbi	15.62±4.18	0.2451±0.0926	0.777	36.34±7.964	0.5425±0.1763	0.825
Oat hay	18.30±1.52	0.1397±0.0337	0.895*	43.53±8.733	0.4623±0.1933	0.741
			Mg		K	
Paddy straw	77.04±2.646	0.1199±0.0585	0.677	98.52±0.2696	0.0124±0.0059	0.682
Ragi straw	78.01±2.284	0.0847±0.0505	0.584	99.15±0.2762	0.0104±0.0061	0.592
Wheat straw	78.17±4.087	0.1461±0.0904	0.566	98.92±0.0976	0.0149±0.0021	0.959*
Maize kadbi	78.77±1.376	0.0793±0.0304	0.772	99.71±0.2767	0.0010±0.0061	0.014
Oat hay	55.44±9.144	0.3671±0.2024	0.622	99.20±0.2276	0.0110±0.0050	0.707
			Cu		Mn	
Paddy straw	23.38±5.621	0.4388±0.1244	0.861	21.91± 1.679	0.2433±0.0371	0.955*
Ragi straw	30.03±4.716	0.3974±0.1044	0.878*	31.17±1.743	0.1961±0.0385	0.928*
Wheat straw	34.06±5.350	0.3243±0.1184	0.789	21.59±6.041	0.4756±0.1337	0.864
Maize kadbi	34.69±4.960	0.4296±0.1098	0.885*	26.46±4.772	0.2471±0.1056	0.732
Oat hay	38.46±4.867	0.2595±0.1077	0.744	33.68±7.568	0.3453±0.1675	0.680
		Zn				
Paddy straw	25.06±1.165	0.0498±0.0257	0.652			
Ragi straw	24.02±1.610	0.1346±0.0356	0.877*			
Wheat straw	32.83±2.370	0.1537±0.0524	0.811			
Maize kadbi	33.61±1.999	0.1022±0.0442	0.728			
Oat hay	39.57±2.148	0.1838±0.0475	0.882*			

*P < 0.05.

Table 4. Parameter estimation of polynomials $y = b_0 + b_1t + b_2t^2$ of macro and micro minerals release from dry fodders in the time of ruminal incubation

Feedstuffs	b_0	b_1	b_2	R^{2**}	b_0	b_1	b_2	R^{2**}
		Ca				P		
Paddy straw	7.822	0.4045	–0.0034	0.980	25.59	1.574	–0.0136	0.935
Ragi straw	8.458	0.4897	–0.0039	0.986	42.95	0.8184	–0.0061	0.988
Wheat straw	9.117	0.3209	0.0022	0.998	34.21	1.223	–0.0101	0.989
Maize kadbi	7.643	0.8246	–0.0070	0.965	21.17	1.645	–0.0133	0.972
Oat hay	15.51	0.3424	–0.0024	0.976	27.41	1.634	–0.0142	0.946
		Mg				K		
Paddy straw	72.67	0.4372	–0.0038	0.881	98.07	0.0454	–0.0004	0.893
Ragi straw	73.70	0.3983	–0.0038	0.929	98.72	0.0417	–0.0003	0.823
Wheat straw	70.76	0.3854	–0.0065	0.898	98.86	0.0200	–6.123e–005	0.964
Maize kadbi	76.45	0.2481	–0.0020	0.923	99.14	0.0425	–0.0005	0.991
Oat hay	40.17	1.477	–0.0134	0.867	98.81	0.0390	–0.0003	0.901
		Cu				Mn		
Paddy straw	11.73	1.286	–0.0102	0.999	18.53	0.4885	–0.0029	0.997
Ragi straw	20.38	1.099	–0.0085	0.997	27.56	0.4588	–0.0032	0.999
Wheat straw	24.53	1.017	–0.0084	0.945	9.19	1.3770	–0.0109	0.997
Maize kadbi	24.62	1.161	–0.0088	0.995	17.58	0.8926	–0.0078	0.948
Oat hay	30.88	0.8102	–0.0066	0.888	21.82	1.2070	–0.0105	0.862
		Zn						
Paddy straw	24.67	0.0779	–0.0003	0.660				
Ragi straw	25.64	0.0164	–0.0014	0.906				
Wheat straw	28.14	0.4950	–0.0041	0.984				
Maize kadbi	30.38	0.3375	–0.0028	0.894				
Oat hay	35.40	0.4870	–0.0036	0.985				

** $P < 0.01$.

(Tables 3, 4). Polynomial (second order) functions of the release of individual elements from feeds in dependence on incubation time have high values of R^2, however, not all of them are statistically significant (Table 4).

The pattern of minerals released from different dry fodders at different period of incubation in the rumen is shown in Figs 1 and 2 by cubic polynomials that have high statistical significance ($P < 0.01$) in all fodders. Minerals released from the feeds increased on advanced period of incubation and highest release was observed at 72 h of incubation in the rumen. Among the dry fodders, maize kadbi and oat hay showed highest release of Ca (28–31.0%), P (71–72%), K (99–100%), Cu (55–63%), Mn (41–56%) and Zn (40–52%) at 72 h of incubation. There was no significant differences in the release of Ca from paddy, ragi and wheat straws whereas it was significantly ($P < 0.05$) higher in maize kadbi and oat hay than other dry fodders (Fig. 1). Lower values of Ca release from straws can be explained by its function in the plant in which it is important for the stability of cell walls and membranes (Flachowsky *et al.* 1994). Mc Manus *et al.* (1979) confirmed that Ca accounted for 34% and 64% of all minerals found in the cell walls of grasses and legumes, respectively. Therefore, the amount of released Ca does not increase before the increase of cell wall degradation. Forages with the highest neutral detergent fibre (NDF) concentration sequestrated Ca in the intestines (Emnuele *et al.* 1991).

Mineral requirements of rumen microbes are not negligible (Durand *et al.* 1987). Rumen phosphorous availability could play an important role in dietary P quality (Bravo *et al.* 2000). There was no significant difference in the release of P in the rumen from dry fodders studied. However, as compared to Ca, the release of P at different periods of incubation in the rumen was higher from different fodders. The pattern of P released from different fodders is shown in Fig 1. The maximum (72%) release of P was found in oat hay at 72 h of rumen incubation. Emanuele *et al.* (1991) reported that grasses released more P in the intestine than legumes.

The paddy straw, ragi straw, maize kadbi and wheat straw showed similar pattern of Mg release and there was any hardly difference in Mg release between 48 and 72 h of incubation. Whereas, it was significantly ($P < 0.05$) lowered in oat hay as compared to other fodders. The fastest and highest Mg release (84.6%) was estimated in paddy straw followed by wheat straw maize kadbi and ragi straw.

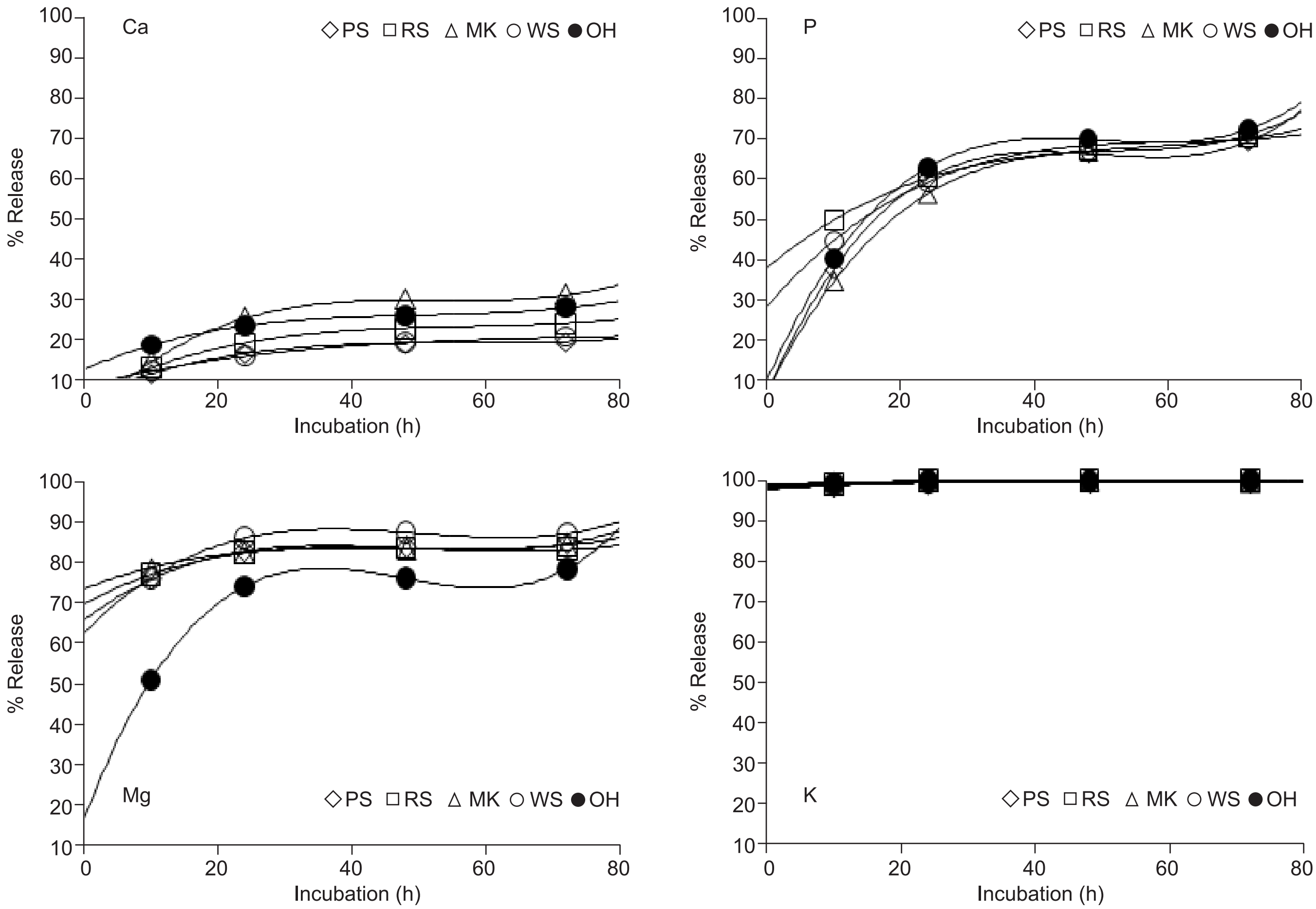

Fig 1. Macro minerals release kinetics in the rumen from dry fodders (Cubic polynomials of mineral release in relation to incubation time)

Emanuele *et al.* (1991) reported that 88 to 98% of total Mg was released in the rumen. The release of Mg from legumes was higher than grasses and dry forages (Ceresnakova *et al.* 2005).

Among all the minerals, K showed the highest release in the rumen at different period of incubation from different fodders (Fig.1). Almost all the K in feeds was release between 10 to 72 h of incubation. The K released from fodders ranged from 98 to 100%. There was no significant difference within the feedstuffs in the pattern of K release in rumen. At 72 h of incubation, almost all (>99%) the K was released from all the feed classes studied. Emanuele *et al.* (1991) reported that potassium release from forages studied was complete in the rumen.

Ceresnakova *et al.* (2005) reported that the rumen is a major site of Ca and Mg release from the forages because there are highly significant regressions on NDF degradation. More than 60% of P, Mg and K were solubilised as early as the feeds were washed (in nylon bags) by *in sacco* method (Ledoux and Martz 1991). Other authors (Flachowsky *et al.* 1994, Gralak *et al.* 1997 and Trinacty *et al.* 2000) found a similar tendency and described differences between the feeds. The *in sacco* nylon bag technique is useful for determining of differences amongst the feedstuffs in the release of mineral elements in the rumen.

There was a significant difference in the release of Cu, Zn and Mn from various fodders at different periods of incubation in the rumen (Fig 2; Tables 2, 4). The highest release of Cu was observed in maize kadbi (62.5%) and of Mn in oat hay (55.8%) at 72 h of incubation. The release of Zn was statistically similar between paddy and ragi straw whereas it was significantly ($P < 0.05$) higher in wheat straw than paddy or ragi straw at different periods of incubation in the rumen. Significantly ($P < 0.01$) highest release of Zn (51.6%) was estimated in oat hay at 72 h of rumen incubation. Among all minerals, Ca and Zn showed the slow release in the rumen. Emanuele and Staples (1990) ascribed the less and slow Zn release from forages to its linkage to cell walls and concluded that Zn could be a part of plant proteins. Kabaiji and Smith (1988) explained low water solubility and release of Zn from plants by its bond to various complexes from which it was released in the rumen

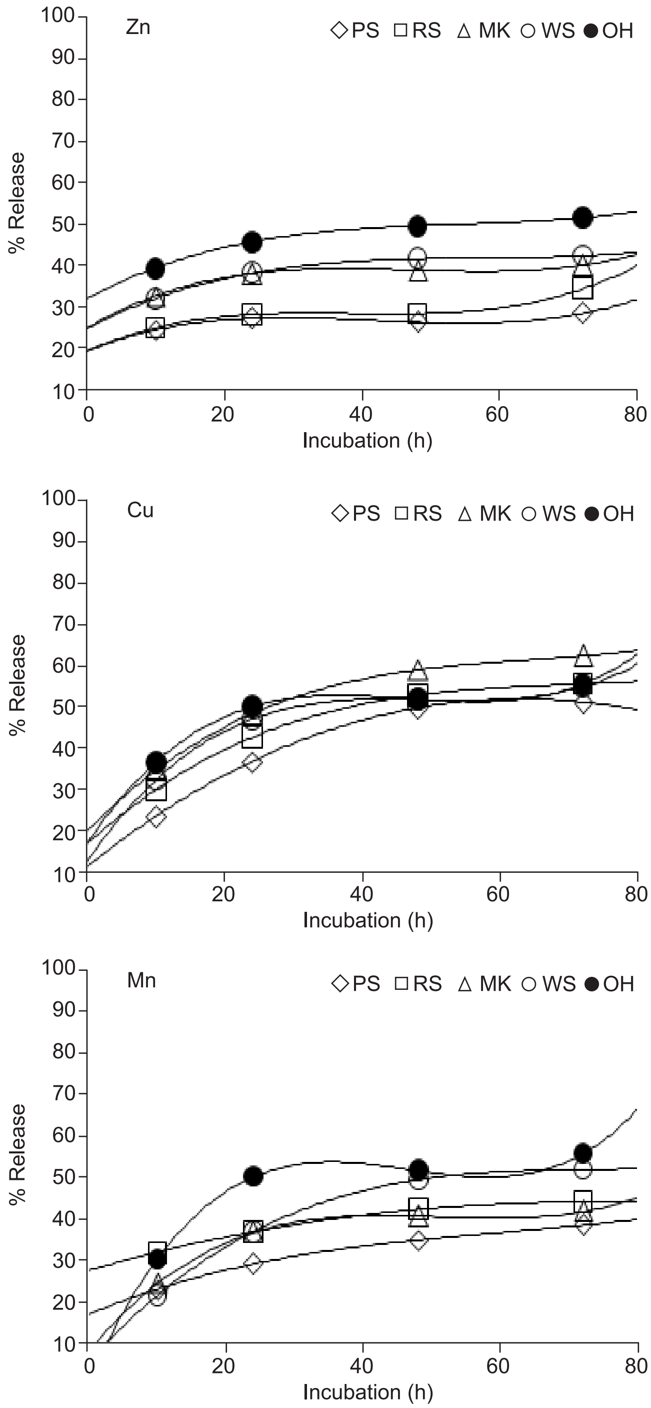

Fig 2. Micro minerals release kinetics in the rumen from dry fodders (Cubic polynomials of mineral release in relation to incubation time).

gradually. Ceresnakova *et al.* (2005) suggested that the low release of Zn in the rumen from forages and Cu from grasses must be taken into account with Zn and Cu requirements of animals.

Ranking of minerals based on maximal extent of release in the rumen was K > Mg > P > Cu > Mn > Zn > Ca. The pattern of release of macro and micro minerals in the rumen from different fodders are summarized below:-

Minerals	Pattern of release
Ca	Oat hay > maize kadbi > ragi straw > wheat straw > paddy straw
P	Oat hay > maize kadbi > ragi straw > wheat straw > paddy straw
Mg	Wheat straw > paddy straw > maize kadbi > ragi straw > oat hay
K	All fodders released > 99% k at 72 h of incubation
Cu	Maize kadbi > ragi straw > oat hay > wheat straw > paddy straw
Mn	Oat hay > wheat straw > ragi straw > maize kadbi > paddy straw
Zn	Oat hay > wheat straw > maize kadbi > ragi straw > paddy straw

Based on findings of the study it may, therefore, be concluded that both the type of fodder and the incubation time influence the proportion of minerals released in the rumen. The *in sacco* nylon bag technique was adequate for detecting difference among feeds classes in the pattern of mineral release. Ranking of minerals from greatest to smallest degree of release was K > Mg > P > Cu > Mn > Zn > Ca. So, those minerals with low degree of release may be associated to the fibre or structural fraction of the fodders. The study could give a better indication to the mineral availability from various feedstuffs. The information generated would provide a useful guideline for selecting fodders to supply various minerals for practical supplementation and could be of help in formulating diet for the ruminants in areas where mineral deficiencies are common and mineral supplementations are either rare or none at all.

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