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In vivo evaluation of mineral bioavailability in groundnut haulm based complete diets supplemented with organic and inorganic mineral sources in goats

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ABSTRACT

A study was carried out to evaluate *in vivo* mineral bio-availability in groundnut haulm based complete diets supplemented with organic and inorganic mineral sources in goats. A basal complete diet was prepared with GNH and concentrate mixture (8% maize, 10% soybean meal, 21.5% de-oiled rice bran and 0.5% salt) in 60: 40 ratio. The basal diet was treated as control (T_1) and 3 more diets were prepared by supplementing basal diet with commercial mineral mixture at 1.5% (T_2), inorganic mineral supplements at 26.4g (8.3 g $ZnSO_4$, 4.0 g $CuSO_4$ and 14.0 g $MnSO_4$) (T_3) and organic mineral supplements @ 72g (12g Zn-P,10 g Cu-P and 50g Mn-P) (T_4). The CP, CF, EE, TA, AIA and NFE contents of the basal diet were 15.8, 20.0, 1.4, 17.8, 9.7 and 45.0% respectively. *In vivo* metabolic studies were carried out on 4 complete diets T_1, T_2, T_3 and T_4. The DMI was 2.7 kg/% body weight which is in accordance with ICAR (1998) recommendation. The DCP intake was 115.7, 121.2, 117 and 117 g/animal/day in T_1, T_2, T_3 and T_4 respectively. There was no significant difference between treatments with regard to DMI or DCP intake. Significant differences were also not observed between treatments with regard to total nitrogen excretion (g/day), N retention (g/day) and N retention expressed as % of intake. The N-retention expressed as % of intake in T_1, T_2, T_3 and T_4 were 57.1, 58.1, 52.0 and 54.1% respectively. The mineral supplementation did not influence the nitrogen retention in all the treatments. Positive nitrogen balances were observed in all the treatments showing that there was no negative effect of mineral supplementation on N- balance. The copper retention expressed as % of Cu intake in T_1, T_2, T_3 and T_4 were 65.1, 64.8, 70.8 and 75.0% respectively, suggesting that significant differences were observed between the treatments with regard to Cu intake (g/d) and copper retention (g/day). The zinc retention (g/day) and zinc retention expressed as per cent of intake showed significant differences between the treatments. Mn retention expressed as per cent of intake was 18.0, 38.2, 32.3 and 33.7% respectively in T_1, T_2, T_3 and T_4 treatments. Significant differences were observed between the treatments with regard to Mn intake (g/day), Mn retention and Mn retention expressed as % of intake. The plasma Cu, Mn and Zn concentrations in all the animals increased at the end of the metabolic study, as compared to the values at the start of the experiment. It can be concluded that the organic mineral supplements were better bio-available than the inorganic mineral supplements.

Key words: Cu, Goats, In- organic mineral, Mineral bio availability, Mn, Organic mineral, Zn

India possesses 123.5 million goats and 58.2 million sheep producing 0.47 million tonnes of chevon and 0.23 million tonnes of mutton annually (FAO 2002). Sheep and goats are the most important small ruminant species of economic value to the small, marginal farmers and landless labourers in India. In India 4.4% of country's cultivated area is under fodder crops and forest grazing resources are also dwindling @ 1.5×10^6 ha/year (Reddy 1989). Even though in India goats are managed mainly on grazing, there is a need to popularize intensive system of management due to continuous depletion of the grazing land.

It is necessary to economize feeding under intensive system of management utilizing various types of agro-industrial by products and agricultural crop-residues (Pradhan 1997). The digestibility of crop residues and mineral availability is adversely influenced by the abnormally high lignin and silica contents. Inclusion of these crop residues in complete diets will help in improving their utilization. Supplementation of minerals is a costly affair. A thorough knowledge on the bioavailability of the minerals from different sources of mineral supplements will help the farmers to feed their animals most economically and earn more profits. Knowledge about the bioavailability of the minerals will help in providing the animals with the required minerals in the optimum quantity and right proportion.

Ruminant diets are usually high in fiber, and considerable digestion of fiber occurs via microbial fermentation in the

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rumen. However, association of minerals with fiber fractions in feedstuffs and/ or binding of minerals to undigested ûber constituents in the gastrointestinal tract may alter bioavailability of some trace minerals in ruminants. The pH in the rumen environment is only slightly acidic (6.0–6.8), and in the rumen, many trace minerals exist largely in an insoluble form. At least some of the metal complexes that are formed in the rumen remain insoluble even under the acidic conditions found in the abomasum (Spears, 2003). Lambs supplemented with Zn proteinate had higher Zn retention than lambs given a similar concentration of Zn in the form of zinc oxide, an inorganic source (Lardy *et al.* 1992). The *in vivo* studies are used to find out the bioavailability of the minerals (Ceresnakova *et al.*2005). The present study is taken up to study the bio-availability of minerals in the organic and inorganic supplements.

MATERIALS AND METHODS

The feed ingredients were analyzed for proximate principles as per AOAC (2007) methods. Cell wall constituents of groundnut haulms were analyzed as per the procedures described by Goering and Van Soest (1970). The feed and fodder samples (0.5g) were digested in microwave oven digester using 15 ml of concentrate nitric acid for estimating the minerals by AAS. The Cu, Zn and Mn were estimated using atomic absorption spectrophotometer.

The groundnut haulms were ground in a hammer mill and a basal complete diet was prepared with a ratio of 60: 40 groundnut haulms and concentrate mixture (maize-8, soybean-10, DORB –21.5 and salt 0.5%). The basal diet was treated as control (T_1) and 3 more diets were prepared by supplementing basal diet with commercial mineral mixture at 1.5% (T_2), inorganic mineral supplements at 26.4g (8.3g $ZnSO_4$, 4.0g $CuSO_4$ and 14.0 g $MnSO_4$) (T_3) and organic mineral supplements @ 72g (12g Zn-P,10 g Cu-P and 50g Mn-P) (T_4). A metabolism trial was conducted using 4 bucks in a latin square design (LSD) following a 20 days preliminary period and 7 days collection period. During preliminary period bucks were housed in separate pens (2 m × 1 m) with individual feeder and water troughs. During the collection period they were harnessed with faecal bags, individually placed in metabolism cages equipped with mesh screen and drain pans which allow collection of faeces and urine, separately.

In vivo metabolic studies were carried out on bucks in a 4×4 Latin square design fed on four complete diets T_1, T_2, T_3 and T_4. The live weights of the bucks were recorded before (33.5±0.5 kg) the start and at the end (36.3±0.4 kg) of trial period for 3 consecutive days. The bucks were offered experimental diets daily at 9.00 AM and 3.00 PM daily in divided quantities. The feed refusals of the previous day were recorded to assess the actual intake of the diets by the animals. The faecal and urine samples were collected daily at 8.30 AM. Apparent digestibility of the nutrients was calculated.The rations were analyzed for proximate analysis (AOAC) and forage fiber analysis (Vansoest 1970).

Aliquots of the total mixed rations (TMR) offered and feed refusals during collection period were composited in polythene bags and stored until analyzed. All feed samples were analyzed for copper, manganese and zinc content by using atomic absorption spectrophotometer after digesting by wet digestion method in accelerated microwave digester (CEM). The rations were analyzed for proximate analysis (AOAC) and forage fiber analysis (Van Soest 1970).

The total quantity of faeces voided by the animals in 24h was collected in faecal bags harnessed to the animals. Total weight of faeces voided was recorded and was mixed thoroughly and an aliquot of 10% of the total faeces voided were taken separately to determine DM content and proximate principles and fresh sample was considered for CP estimation (AOAC, 2007). Faecal samples were analyzed for copper, manganese and zinc content using Perkin Elmer Atomic absorption Spectrophotometer (AAS Analyst-300) after digesting by wet digestion method in accelerated microwave digestor (CEM).

Total quantity of urine voided in 24h by each animal was collected and recorded. A 5% aliquot was preserved with the addition of a few ml of conc. hydrochloric acid and kept in a refrigerator. The N content of urine samples was estimated as per AOAC (2007). Mineral content (Cu, Zn and Mn) was estimated by using Perkin Elmer Atomic Absorption Spectrophotometer (AAS Analyst-300) after wet digestion method in CEM accelerated microwave digester (5 ml of urine sample and 15 ml of conc. nitric acid was taken for wet digestion). The data were analyzed as per standard statistical methods (Snedecor and Cochran 1994).

RESULTS AND DISCUSSION

In vivo metabolic trials were conducted in 4 × 4 Latin square design, where bucks were offered four complete diets T_1, T_2, T_3 and T_4.

Ingredient composition of complete rations: Four complete rations were formulated with same basal diet consisting of roughage (GNH) to concentrate in the ratio of 60: 40 supplemented with commercial mineral mixture (T_2), inorganic mineral supplements (T_3), and organic mineral supplements (T_4) and without mineral supplements (T_1). The DORB content varied slightly to adjust the mineral

Table 1. Ingredient composition (%) of complete rations

Parameter	T_1	T_2	T_3	T_4
Groundnut haulms	60	60	60	60
Maize	8	8	8	8
Soybean meal	10	10	10	10
Deoiled ricebran	21.5	20.0	21.5	21.5
Commercial mineral mixture	-	1.5	-	-
$ZnSO_4$ (8.3 g) + $CuSO_4$ (4.0 g) + $MnSO_4$ (14.0 g)	-	-	0.0264	-
Zn-P (12 g) + Cu-P (10 g) + Mn-P (50 g)	-	-	-	0.072
Salt	0.5	0.5	0.5	0.5
Total	100	100	100	100

supplementation (Table 1). All the diets were isonitrogenous and isocaloric. The commercial mineral mixture was supplemented as per the company's specification. The organic and inorganic supplements were included in the rations as per the NRC (2007) taking into consideration the available mineral present in the supplements.

Chemical composition of complete rations: The chemical composition of complete rations (Table 2) revealed that all the rations contain same chemical composition as all the 4 rations contain same basal diet. The addition of mineral supplements to the basal diet did not alter the chemical composition of the rations as they are added in very small amounts.

The basal or control ration (T_1) contained 31, 49 and 149 mg/kg of Cu, Zn and Mn respectively. The mineral content of the basal diet was taken into consideration while calculating the quantity of organic and inorganic mineral supplementation.

Cell wall constituents of complete rations: Since all the 4 treatments contain the same basal diet the cell wall constituent composition was similar in all the 4 treatments. The NDF, ADF, cellulose, HC, ADL and silica content of the T_1 was 40.3, 33.3, 23.3, 7.0, 12.1, and 3% respectively (Table 3).

Plane of nutrition: The DM intake was 939, 957, 949 and 888 g/day/animal in T_1, T_2, T_3 and T_4, respectively (Table 4). Significant differences were not observed with regard to dry matter intake (g/day) and DCP intake (g/day) between the treatments. The mineral supplementation did not show any effect on the dry matter intake and DCP intake of the animals. The supplements were present in minute quantities and they do not have any pretreatment effect on the rations. As all the four treatments have the same basal diet, significant differences were not observed with regard to the plane of nutrition in goats.

Nitrogen utilization: The N intake was 23.6, 24.0, 24.0 and 22.4 g/day/animal in T_1, T_2, T_3 and T_4, respectively, without any significant difference (Table 5). Similarly significant differences were not observed with regard to nitrogen excretion and retention (g/d) between the treatments, since the treatments were isonitrogenous and isocaloric diets. The mineral supplementation did not show any significant effect on nitrogen utilization in goats. All the treatments indicated positive nitrogen balance. Similar findings were reported by Ward *et al.* (1992) who found that there was no difference between $CuSO_4$, CuO or Cu-lysine for dry matter intake. Ward *et al.* (1993) also reported that no difference in Cu source was found when looking at gain, feed conversion, feed intake, plasma copper, ceruloplasmin or immune response.

The average body weight of the goats was around 35 kg. The animals have consumed around 2.7 kg DM per% body weight in all the treatments which is in accordance with the recommendation of ICAR (1998) for 35 kg body weight group of goats. The animals were weighed at the start of the metabolic trial and at the end of the metabolic trial period which showed an increase in body weight in all the animals.

Digestibility coefficient of nutrients: The digestibility coefficient (%) of DM were 63.9, 67.2, 68.3, 65.2 for T_1,

Table 2. Chemical composition (%) of complete rations

Parameter	T_1	T_2	T_3	T_4
Dry matter	93.4	93.4	93.4	93.5
Organic matter	92.2	92.4	92.2	92.2
Crude protein	15.8	15.6	15.8	15.7
Crude fiber	20.0	21.0	20.0	20.0
Ether extract	1.4	1.4	1.4	1.3
Total ash	17.8	17.6	17.8	17.8
AIA	9.7	9.7	9.7	9.7
NFE	45.0	44.4	45.0	45.2
Trace mineral (mg/kg)				
Copper	31	46	41	56
Zinc	49	214	79	82
Manganese	149	170	186	204

Table 3. Cell wall constituents (%) of complete rations (dry matter basis)

Parameter	T_1	T_2	T_3	T_4
NDF	40.3	40.3	40.3	40.2
ADF	33.3	33.3	33.3	33.2
cellulose	23.3	23.1	23.3	23.3
Hemi cellulose	7.0	7.0	7.0	7.0
ADL	12.1	12.2	12.1	12.1
Silica	30	3.1	3.0	3.1

Table 4. Effect of mineral supplementation on plane of nutrition in goats

Parameter	T_1	T_2	T_3	T_4
Body wt (kg)	35.5±1.2	35.5±1.1	34.7±1.5	35.3±1.6
Metabolic body wt (kg)	14.5±0.4	14.6±0.4	14.3±0.5	14.5±0.5
DMI (g/d)	939±100	957±93	949±130	888±134
DMI (% body wt)	2.7±0.3	2.7±0.3	2.7±0.3	2.6±0.4
DMI (g/d/ $w^{0.75)}$	64.1±5.7	65.5±5.2	66.4±9.2	60.8±8.3
DCP intake (g/day)	115.7±12.3	121.2±11.1	117±16.8	117±16.0
DCP intake (g/d/$w^{0.75}$)	7.9±0.7	8.3±0.6	8.2±1.2	7.3±1.0

Table 5. Effect of mineral supplementation on nitrogen utilization in goats fed on complete diets

Parameter	T_1	T_2	T_3	T_4
N intake (g/d)	23.6±2.6	24.0±2.3	24.0±3.3	22.43.4
N excretion (g/day)				
Faecal	5.1±0.7	4.5±0.7	5.3±1.0	5.31.0
Urinary	4.9±0.5	5.6±1.0	6.0±0.8	4.80.6
Total	11.0±1.0	10.0±1.6	11.3±1.8	10.01.4
N retention (g/d)	13.6±1.7	13.9±1.6	12.7±2.7	12.32.2
N retention (%) of intake	57.1±1.3	58.1±4.5	52.0±6.1	54.1±3.4

T_2, T_3 and T_4, respectively (Table 6). Significant differences were not observed with regard to DM, CP, CF, EE and NFE digestibility coefficients (%) in goats. The mineral supplementation did not alter the nutrient digestibility of the complete rations. Similar findings were reported by Berhanu *et al.,* (2003) who also found that the digestibility of DM, OM, CP, EE and CF did not differ among the groups supplemented with zinc and iodine. The low crude fibre digestibility in the present study can be attributed to the high crude fiber content of groundnut haulms (21.1%) and DORB (20%) which were included to the basal diet in larger proportion.

Copper balance: The average daily copper intake was 29.0, 44.0, 39.0 and 49.7% respectively in T1, T2, T3 and T4 groups. The copper intake was significantly ($P<0.05$) higher in goats fed with organic mineral supplementation (49.7 g/d) when compared to other treatments (Table 7). The urinary excretion of copper was not at traceable ppm level. All the treatment groups were in positive copper balance. The copper retention was significantly ($P<0.05$) higher in organic mineral supplemented group than other groups. This shows that the Cu was more bioavailable in the organic form than the inorganic form. Similar findings were also reported by Kincaid *et al.,* (1986) who noticed significant ($P<0.05$) increase in both plasma and liver Cu content in ruminating calves fed copper propionate compared to copper sulphate. Manspeaker (1987) also reported that chelated trace minerals were absorbed more rapidly than their inorganic counterparts. Mondal *et al.* (2007) studied the effect of supplementation of 2 sources of Cu on plasma lipid profile and mineral balance in Black Bengal goats. The results indicated copper propionate supplementation was equally effective like copper sulphate in alteration of plasma lipid profile, but is more effective for mineral absorption and retention than equimolar concentration of copper sulphate.

Table 6. Effect of mineral supplementation on digestibility coefficients (%) in goats

Parameter	T_1	T_2	T_3	T_4
DM	63.9±2.2	67.2±0.6	68.3 3.2	65.2±1.5
CP	78.4±1.4	82.1±1.9	78.2±2.9	76.6±1.9
CF	31.0±2.2	35.01±1.6	32.1±5.9	31.9±2.5
EE	53.8±2.5	53.8±5.2	60.0±3.2	57.1±2.8
NFE	80.8±1.2	77.1±2.1	77.4±2.4	77.0±1.7

Table 7. Effect of mineral supplementation on copper balance with complete diets in goats

Parameter	T_1	T_2	T_3	T_4
Cu intake (g/d)	29.0±3.0^c	44.0±4.3^{ab}	39.0±5.3^b	49.7±7.5^a
Cu excretion				
Faecal (g/d)	9.92±0.5	15.8±3.2	11.0±1.1	12.6±2.2
Urinary (g/d)	-	-	-	-
Total (g/d)	9.92±0.5	15.8±3.2	11.0±1.1	12.6±2.2
Cu retention (g/d)	19.1±2.7^c	28.1±2.6^b	27.8±4.5^b	37.1±5.5^a
Cu retention per cent of intake	65.1±2.7	64.8±4.8	70.8±2.5	75.0±1.3

Mean values bearing different superscripts (abc) letters in a row differ significantly ($P<0.05$).

Zinc balance: The average daily intake of zinc values for T_1, T_2, T_3 and T_4 were 46.0, 153.3, 75.1 and 73.0 respectively (Table 8). Significant differences were not observed with regard to Zn intake, Zn excretion through faeces and urine. The Zn urinary excretion was less in the organic supplemented group than others indicating better bioavailability of Zn from zinc propionate than other forms of zinc supplementation. Significant differences ($P<0.05$) were observed with regard to Zn retention. The T_2 group supplemented with commercial mineral mixture showed better retention than other treatments. The faecal output in the T_2 group was less even though the Zn intake was high, which indicated that the Zn in the T_2 group had better absorption. The retention was significantly ($P<0.05$) higher in T_2 than other treatments. The commercial mixture had other minerals along with Cu, Zn and Mn. The presence of other minerals might have increased the absorption and retention of Zn in T_2 group. The increase in intake of Zn also increased Zn retention. Similar findings were reported by Stake *et al.,* (1975) who reported that increase in dietary concentrations of Zn to 600 ppm nearly doubled the concentration of Zn in plasma of calves.

Zn retention was significantly ($P<0.05$) higher in Zn supplemented organic and inorganic groups when compared to control group without any significant difference between the organic and inorganic sources of Zn supplementation showing that there was not much difference in retention with regard to organic or inorganic Zn supplementation. The Zn excretion in faeces was numerically higher in organic Zn supplemented group than the inorganic Zn supplemented group without significant difference indicating that the organic zinc was less available. Contrary to this Kegley and Ledoux (1992) reported that similar absorption of zinc was found from zinc propionate and zinc oxide, but increased retention of zinc from zinc propionate as a result of reduced urinary Zn excretion of lambs. Spears (1989) and Lardy *et al.,* (1992) corroborated with each other that absorption was essentially identical for inorganic and chelated Zn, being about 40% but that the chelated form of zinc was retained better ($P<0.05$) than the inorganic form of zinc. Cao *et al.,*(2000) reported that bio-availability estimates relative to 100% for zinc sulfate were 130, 110 and 113 for zinc propionate, zinc amino acid chelate and zinc methionine complex, respectively. The lower urinary excretion of Zn and higher faecal excretion of zinc from organic zinc supplemented group when compared to other zinc sources supplementation indicated that the organic zinc source has better bioavailability with lower digestibility.

Manganese balance: The average daily manganese intake was 140, 162.5, 176.3 and 181.1 g/d respectively in

T_1, T_2, T_3 and T_4 groups (Table 9). Significant ($P<0.05$) differences were observed between the treatments with regard to Mn intake and retentions. The Mn intake was significantly ($P<0.05$) higher in organic Mn supplemented group than other groups. Even though significant differences were not observed between the treatments with regard to Mn excretion through faeces and urine the numbers with regard to faecal Mn excretion suggest that Mn from commercial mineral mixture supplementation is better than the other forms of supplementation. The urinary Mn excretion suggest that organic Mn supplement has better bio-availability than other forms of supplementation. Significant ($P<0.05$) differences were observed with regard to Mn retention between control and other treatments but not between the supplemented groups. The Mn retention as per cent of intake did not show significant difference between organic and inorganic sources of supplementation but slight numerical increase in Mn retention as per cent intake in organic Mn supplementation when compared to inorganic source was observed indicating better bio-availability.

Similar reports were made by Henry *et al.* (1992) who studied the relative bio-availability of Mn from feed grade Mn-methionine complex, two feed grade MnO sources using reagent grade $MnSO_4$, H_2O as the standard in crossbreed wether lambs. The results indicated that Mn as Mn-methionine complex or reagent grade $MnSO_4$ was more available for lambs than that of two feed grade MnO sources. The estimated relative bio-availabilities based on multiple linear regression coefficients of bone, kidney and liver Mn concentration on total dietary Mn concentrations were 100, 121, 70 and 53% for $MnSO_4$, H_2O, Mn-methionine complex, manganese oxide A and manganese oxide B respectively.

Efficiency of absorption of many trace minerals and dietary factors that affect bioavailability of minerals differ greatly between ruminants and non-ruminants. In ruminants, microbial digestion in the rumen and reticulum precedes mammalian digestion in the abomasum and small intestine. Ruminant diets are usually high in fiber, and considerable digestion of fiber occurs via microbial fermentation in the rumen. However, association of minerals with fiber fractions in feedstuffs and/ or binding of minerals to undigested fiber constituents in the gastrointestinal tract may alter bioavailability of some trace minerals in ruminants. The pH in the rumen environment is only slightly acidic (6.0–6.8), and in the rumen, many trace minerals exist largely in an insoluble form. At least some of the metal complexes that are formed in the rumen remain insoluble even under the acidic conditions found in the abomasum (Spears 2003). In the present study also it was observed that the mineral bioavailability was correlated to the digestibility of fiber. When there was improvement in the fiber digestibility the mineral bioavailability was high.

Plasma mineral concentration: The Cu, Mn and Zn concentration at the beginning of the metabolic trial (0 day) were 0.55, 0.57, 0.51, 0.55; 0.09, 0.08, 0.05, 0.08; 0.96, 0.93, 0.64 and 0.82 ppm respectively in four animals (Table 10). The animals were fed on experimental diets (T_1, T_2, T_3 and T_4) in a 4×4 latin square experiment. Metabolic trials were conducted in bucks. After the end of the experimental period the blood was again collected and plasma analysed for Cu, Mn and Zn contents. The Cu, Mn and Zn contents increased to 0.71, 0.72, 0.70, 0.72; 0.14,

Table 8. Effect of mineral supplementation on zinc balance with complete diets in goats

Parameter	T_1	T_2	T_3	T_4
Zn intake (g/d)	46.0±4.9	153.3±47.1	75.5±9.9	73.0±11.1
Zn excretion (g/day)				
Faecal	26.0±2.0	22.2±2.1	26.0±3.1	30.5±5.0
Urinary	0.06±0.03	0.05±0.03	0.06±0.03	0.02±0.01
Total	26.04±2.0	22.32±2.1	26.0±3.0	30.5±4.9
Zn retention (g/d)	19.9±3.1^c	136.1±41.7^a	49.4±8.2^b	42.3±7.0^b
Zn retention per cent of intake	42.5±3.0^c	89.0±0.4^a	64.6±3.4^b	58.0±2.8^b

Mean values bearing different superscripts (abc) letters in a row differ significantly ($P<0.05$).

Table 9. Effect of mineral supplementation on Manganese balance with complete diets in goats

Parameter	T_1	T_2	T_3	T_4
Mn intake (g/d)	140.0±14.9^c	162.5±15.8^b	176.3±24.1^{ab}	181.1±27.4^a
Mn excretion (g/day)				
Faecal	118.8±10.5	97.7±7.7	114.5±14.9	120.320.9
Urinary	2.0±0.4	1.9±0.3	1.9±0.3	1.60.3
Total	115.8±14.8	99.7±7.7	116.6±14.9	121.820.6
Mn retention (g/d)	24.3±0.5^b	62.9±8.2^a	59.7±17.7^a	59.3±8.0^a
Mn retention per cent of intake	18.0±2.1^b	38.2±1.6^a	32.3±6.4^a	33.7±2.7^a

Mean values bearing different superscripts (abc) letters in a row differ significantly ($P<0.05$).

Table 10. Plasma mineral concentration (ppm) under different dietary treatments

Parameter	Animal-1	Animal-2	Animal-3	Animal-4
Copper				
0 day	0.55	0.57	0.51	0.55
90 days	0.71	0.72	0.70	0.72
Manganese				
0 day	0.09	0.08	0.05	0.08
90 days	0.14	0.11	0.12	0.12
Zinc				
0 day	0.96	0.93	0.64	0.82
90 days	1.20	1.23	0.96	1.40

0.11, 0.12, 0.12; 1.2, 1.23, 0.96 and 1.4 ppm respectively in these 4 animals. As all the animals received T_1, T_2, T_3 and T_4 diets during 4×4 latin square switch over design all the animals showed an increase in plasma Cu, Mn and Zn concentration after the experimental period. Similarly Suliman *et al.,* (1988) found that sheep deficit in Zn had serum Zn values of 0.44 µg/ml which increased to 0.78 µg/ml when they were given a ZnO supplementation. In another experiment carried out by Spears (1989) it was observed that the lambs where the plasma Zn concentrations were well below normal (80 to 100 µg/ml) when supplemented with 5 mg/kg of diet had higher ($P<0.05$) plasma zinc concentrations.

Neathery *et al.*(1973) has found plasma Zn was reduced (0.79 vs 0.96 ppm Zn) after 6 weeks in cows fed 17 vs 40 ppm. Cows fed diets with 8 ppm Mn had 130 ng of Mn/ml of whole blood in cows supplemented with 600 ppm Mn. Eckert *et al.* (1999) reported that the ewes fed on diets supplemented with dietary Cu at the rate of 30 mg/kg showed 1. 2 µg/ml of blood plasma. Kegley and Spears (1994) found an increase in both ceruloplasmin and plasma copper concentrations in growing cattle when the level of copper supplementation in calves was increased to 30 mg of daily copper intake from both $CuSO_4$ and copper lysine.

The following conclusions were drawn from the study of the release of trace minerals in GNH based complete diets in goats supplemented with organic and inorganic mineral sources. The *in vivo* studies showed that the mineral supplementation to groundnut haulm based complete diets had no effect on the dry matter intake and DCP intake in goats. The mineral supplementation to GNH based complete diets had no effect on nitrogen balance and nutrient digestibility. The mineral supplementation to GNH based complete diets showed significant ($P<0.05$) difference with regard to copper, zinc and manganese retention. The organic copper and manganese supplementation showed better Cu and Mn retention as % of intake than inorganic supplements. It can be concluded that the organic mineral supplements were better bioavailable than the inorganic mineral supplements in goats.

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