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Evaluation of Potassium Status of Grazing Goats in South, Punjab, Pakistan

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Abstract: A study was conducted to determine the potassium status of lactating, non-lactating and male goats on farm located in Southern Punjab. A mineral supplement were available to all animals throughout the year. Soil, forage, water, feed and animal samples (blood plasma, milk, faeces, and urine) were taken 8 times fortnightly during winter and summer seasons. On the basis of results of analyses soil K^+ was deficient for the requirements of plants during summer while forage K^+ concentrations were below the critical values during both seasons. The contribution of feed K^+ in maintaining the K^+ level of animals was also not prominent. From plasma analyses it was found that K^+ was below the normal levels in lactating and male goats during both seasons and in non-lactating goats only during summer. The loss of K^+ through milk, faeces and urine was high during both seasons. Overall K^+ status of these goats based on plasma concentrations may be considered inadequate mainly due to low forage K^+ concentration which were found low to deficient.

Key words: Potassium, status, goats, soil, forage, water, milk and plasma

Introduction

Under nutrition is commonly accepted to be the most important limitation to livestock production in different countries (Ogebe and McDowell, 1998 and McDowell and Valle, 2000). Lack of sufficient energy and protein is often responsible for sub-optimum production. Numerous investigators, however have observed that ruminants sometimes deteriorate in spite of an abundant feed supply. Mineral deficiencies or imbalances in soils and forages have long been held responsible for low production and reproduction problems among tropical livestock (McDowell, 1985; McDowell *et al.*, 1993; Vargas and McDowell, 1997; Tiffany *et al.*, 2001).

Specific mineral requirement are difficult to pinpoint since exact needs depend on chemical form and numerous mineral interrelationships. The chemical form of mineral elements varies greatly in amount of dietary minerals supplied and in biological availability (Judson and McFarlane, 1998 and McDowell, 2002).

Mineral nutrition disorders range from acute mineral deficiency or toxicity diseases, characterized by well-marked clinical signs and pathological changes, to mild and transient conditions too difficult to diagnose and expressed as a vague unthriftness or unsatisfactory growth and production (Vargas and McDowell, 1997). K^+ is chemically very much like Na^+ and is associated with Na^+ in many biological systems. In contrast with Na^+, which is the main electrolyte in the plasma and extracellular fluids, K^+ is present primarily inside the cells (Thompson, 1978). Potassium is essential for life, being required for a variety of body functions including osmotic balance, acid-base equilibrium, several enzyme systems, and water balance (McDowell, 1985). K^+ deficiency for ruminants results in nonspecific signs such as slow growth reduced feed and water intake, lowered feed efficiency, muscular weakness, nervous disorders, stiffness, decreased pliability of hide, emaciation, intracellular acidosis, and degeneration of vital organs (Thompson and Troch, 1978). Beede *et al.* (1983) reported that K^+ deficiency for lactating dairy animals resulted in dramatic reductions in feed and water intake, milk yield, and blood plasma K^+ concentrations within 3-5 days after administration of a K^+ deficient diet. Potassium therapy of deficient animals reversed the condition within 12-24 hours (McDowell, 1985).

K^+ content of many concentrates, which would be basic ingredients for feedlot animals and high milk producing dairy animals, is below the requirement. The estimated requirement of 0.6-0.8% K^+ for beef and dairy animals receiving high grain diets would not be provided, since grains often contain less than 0.5% K^+ (McDowell, 1997)

The maximum tolerable level of K^+ is suggested to be 3% (NRC, 1980 and McDowell, 1985). Because ingested K^+ beyond the requirement is quickly excreted, K^+ toxicosis is not a practical problem under normal conditions. High K^+ content in forages during critical times of the year can be antagonistic to Mg^+

absorption and utilization and thus can influence the incidence of grass tetany.

The main reason for lack of widespread K^+ deficiency, even when forages contain less than the requirement, is likely due to other nutrient deficiencies of forages. Mature forages are often deficient in energy, protein, P^{++}, Na^+, Ca^+, and a number of trace element. It is likely that a K^+ deficiency will not be expressed as long as there are other nutrients that are even more deficient (McDowell and Valle, 2000). Research is needed to evaluate any benefits derived from K^+ supplementation to grazing livestock, since there is almost no information on this subject.

It was therefore the objective of this investigation of examine the interrelationships of K^+ within the soil-plant-animal systems in one locality at goat ranch, Pakistan and to know the deficient levels during particular season of the year for this mineral supplementation to the grazing goats.

Materials and Methods

This study was conducted, during 2000-2002, at the Livestock Experimental unit, located in the southern part of the province of Punjab, Pakistan.

The farm was established about 40 years ago and consisted of 14,000 hectares land and close to 7000 animals. The climate is sub-tropical, semi-arid continental characterized by two distinct seasons, winter and summer. Samples from those animals were collected which had been in the pastures for not less than 1-2 years prior to sample collection. All the animals at the farm had access to feed containing mixture of different minerals, in addition to grazing the improved varieties of forages throughout the year.

For sampling purpose, 30 animals were grouped into 3 classes, according to age, physiological status and gender, with 10 animals per class as follows: Class 1 contained 10 lactating goats, class 2 comprised 10 non-lactating goats, and class 3 consisted of 10 male goats. These animals were ear tagged at each ranch.

Samples of soil, forage, feeds, water, and animal blood plasma, milk, faeces, and urine (urine only from female animals) were collected at goat ranch of the farm fortnightly in each season. Sampling periods were January, February and June, July, corresponding to the winter and summer seasons. The mean temperature of the year ranged from 25-28°C and the average relative humidity was 25-45%.

Samples of forage were collected from those species that were most frequently grazed by goats at that ranch. The forage species collected were: *Medicago sativa, Avena sativa, Trifolium alexandrium, Hordeum vulgare, Cichorium intybus, Lathyrus odoratus, Chenopodium morale* during winter, and *Cyperus rotandus, Tribulus terrestris, Pennisetum glaucum, Cynodon dactylon, Digitaria decumbens, Cynodon plectostachyum, Panicum milliacum, Sorghum bicolor, Setaria italica* during summer. As mineral status of soil differed from place to place, therefore soil and corresponding forage samples were collected at three different places with 5 replications from each place. All the samples were analyzed for potassium concentration. Soil, forage, and plasma minerals concentrations were compared to established critical values to determine the various categories of deficient levels.

The critical level for soils indicates the element concentration below which normal growth and mineral composition of forage may be adversely affected. For forage samples, it indicates the lowest requirement of the element or organic constituent to avoid deficiency symptoms in animals. Plasma critical levels indicate the concentration below which specific signs of deficiency may occur. Interpretation of these critical values was done with caution taking into consideration the management, nutritional, environmental and individual factors that affect the availability, supply and utilization of each nutrient.

Sample collection: Soil samples were taken from different surfaces up to 15-20cm depth at three different points from each pasture using a stainless steel sampling auger. The samples were air-dried, ground using a Wiley mill with a 2 mm sieve and mixed. These samples were stored in plastic bags.

Using the hand plucked method, forage samples were collected from three different points in each pasture ranch on the same spots from where soil samples were collected, twice a day, in the morning and the late afternoon, after following the grazing animals closely and hand plucked materials comparable to those grass species and plant parts eaten. The plucking of forage samples was done at 15 cm from the ground to simulate the grazing behavior of animals. The samples were washed with 1% HCl followed by 3-4 washings with distilled water to remove foreign material. Then they were air-dried. The air-dried samples were oven dried at 65°C. These were ground to powder and stored in clean and dry plastic bags for chemical analysis.

Water samples were collected from the particular channel or site from where it is being supplied to the animals at farm. These samples were stored in plastic bottles till further analysis. One drop of 0.1% of sodium hexametaphosphate $(Na\ PO_3)_6$ per 25 ml was added in each bottle to check the precipitation of salt

during storage.

Feed samples were picked up from the feed that is being offered to animals. Feed samples were dried at 60°C for six hours, while mixing the samples regularly. The samples were preserved in polyethylene bags for the analyses of macro and micro-nutrients.

Blood samples were taken from male and female goats that were offered feed using the same ingredients being raised at the farm. Blood disposable needles for goats were used to collect the blood from the jugular vein. Twenty ml of the blood were drawn into a clean sterile test tube having anticoagulant (EDTA). The blood samples were centrifuged at 3000 rpm for 20 minutes to separate the plasma. The plasma samples were stored at −20°C till further analysis.

The milk samples were collected from lactating goats by hand milking. Then 20 ml of milk samples were collected in test tube containing 100 mg of sodium azide as preservative. Samples were frozen at −20°C until analysed.

After cleaning and thorough washing the external genitalia of the animals, catheters were fixed in urethra of female animal only and the urine was collected into clean glass beakers. The urine samples thus collected, were kept at −20°C for further investigation.

Fecal samples from each animal were collected manually from the rectum of the animals and put in small plastic bags, oven-dried at 55°C for 96 h and were stored in polyethylene bags for further analysis.

Sample preparation: All the samples except soil were prepared for analysis according to techniques outlined by Fick *et al.* (1979). Whereas, soil K^+ analyses were conducted following the methods described by Rhue and Kidder, (1983), using the Mehlic 1-extracting solution method (0.05N HCl + 0.025N H_2SO_4). These prepared samples were diluted as required, and analyzed on flamephotometer (Jenway PFP-7).

To ensure the quality of the analysis, a certified standard was analyzed after every six samples. When the standard was not within the acceptable limit, the flamephotometer was recalibrated. The final quantities were computed by comparison of sample reading with standard curves.

Results

Pasture samples

Soil: Both seasons and fortnights had a significant effect on soil K^+ concentration (Table 1). A consistent decrease in soil K^+ with time of sampling was generally observed during both seasons at different fortnights (Fig. 1a). However, the soil K^+ level in winter was higher than that found in summer.

Forage plants: Seasons and fortnights affected the forage K^+ level significantly and a markedly higher K^+ concentration in forage was observed during winter than that in summer (Table 1). A trend of consistent decrease in forage K^+ was found during both seasons with time of sampling (Fig. 1b).

Water: There was no seasonal or sampling period effect on water K^+ level (Table 1), however the water K^+ level was significantly higher in winter than that in summer during the first three fortnights. There was a consistent increase in water K^+ level during winter from fortnight 2 to onwards. In contras, in summer, the water K^+ level did not vary at all time intervals (Fig. 1c).

Feed: There was a marked sampling period effect on feed K^+ level, but seasons did not have any significant effect on it (Table 1). However, a consistent increase in feed K^+ was found up to last fortnight of sampling in winter, whereas in summer, the change in feed K^+ concentration with time was almost non-consistent (Fig. 1d).

Animal Samples

Lactating Goats

Plasma: No significant effects of seasons or fortnights were observed on plasma K^+ concentration (Table 2a). During winter, a pattern of consistent decrease in K^+ was found with time. Whereas during summer, plasma K^+ level remained uniform at all fortnights except the first one where it was very low (Fig. 2a).

Faeces: Non-significant seasonal effect and significant of that of fortnights was observed on fecal K^+ level (Table 2a). The excretion of K^+ through faeces increased consistently with time of sampling during both seasons (Fig. 2b).

Urine: Both seasons or fortnights had no-significant effects on urine K^+ concentration (Table 2a). There was a consistent increase in K^+ through urine with time during winter, whereas during summer, the urine K^+ level decreased consistently up to the 3rd fortnight (Fig. 2c).

Milk: Significant seasonal effect and non-significant that of fortnights was found on milk K^+ concentration (Table 2a). Considerable fluctuations were found at different fortnights in milk K^+ level during both seasons (Fig. 2d).

Non-Lactating Goats

Table 1: Analysis of variance of data for K^+ concentration in soil, forage plants, water and feed at different fortnights during winter and summer seasons at goat ranch

Source of variation	Degree of freedom	Mean squares			
S. O. V.	df	Soil	Forage plants	Water	Feed
Season (s)	1	7049.03***	698896.00***	0.361^{ns}	18576.10^{ns}
Error	8	69.46	9341.25	0.409	7122.48
Fortnight (FN)	3	1746.96	380473.33***	0.307^{ns}	25482.07**
Sx En	3	237.69**	2073.33^{ns}	0.608^{ns}	39898.57***
Error	24	47.18	18229.58	0.275	4703.03

, * = Significant at 0.01 and 0.001 levels, respectively
ns = non significant

Table 2a: Analysis of variance of data for K^+ concentration in blood plasma, faeces, urine and milk of lactating goats at different fortnights during winter and summer seasons

Source of variation	Degree of freedom	Mean squares			
S. O. V.	df	Plasma	Faeces	Urine	Milk
Season (S)	1	234.24^{ns}	19189.01^{ns}	728665.31^{ns}	312500.00
Error	18	1902.91	318190.07	1189019.17	5430.00
Fortnight (FN)	3	159.52^{ns}	173227.71***	20855.58^{ns}	1333.33^{ns}
S x FN	3	357.27**	26459.038^{ns}	75603.45**	83166.67**
Error	54	60.68	11399.29	16457.74	19564.82

Table 2b: Analysis of variance of data for K^+ concentration in blood plama, faeces and urine of non-lactating goats and that of plasma and faeces of male goats at different fortnights during winter and summer seasons

Source of variation	Degree of freedom	Mean squares				
S.O.V.	df	Non-lactating goats			Male goats	
		Plasma	Faeces	Urine	Plasma	Faeces
Season (S)	1	661.83^{ns}	12801.80^{ns}	1114156.01^{ns}	3052.06^{ns}	459348.05^{ns}
Error	18	2532.62	438218.53	2837957.11	2768.09	591798.33
Fortnight (FN)	3	4.18^{ns}	18962.43***	43666.41^{ns}	4294.01***	6186.35^{ns}
S x FN	3	249.65**	1582.63**	11213.05^{ns}	1074.16***	2537.68^{ns}
Error	54	59.16	338.34	31059.73	89.79	4670.74

*, **, *** = Significant at 0.05, 0.01 and 0.001 levels, respectively.
ns = non-significant

Plasma: There was non-significant effects of both seasons and fortnights on plasma K^+ concentration (Table 2b). During winter, plasma K^+ level decreased consistently with time (Fig. 2e). Conversely, during summer plasma K^+ level remained almost unaffected at the last three fortnights.

Faeces: Significant fortnight effect and non-significant that of seasons was observed on fecal K^+ level (Table 2b). A progressive increase in fecal K^+ was found with sampling time during both the winter and summer seasons (Fig. 2f).

Urine: No seasonal or sampling period effects were observed on urine K^+ level (Table 2b). During both seasons, no significant change in K^+ excreted through urine was observed with time (Fig. 2g).

Male Goats

Plasma: There was a marked sampling period effect on plasma K^+ concentration, but seasons had no significant effect on it (Table 2b). In both seasons, there was a consistent decrease in plasma K^+ with time (Fig. 2h).

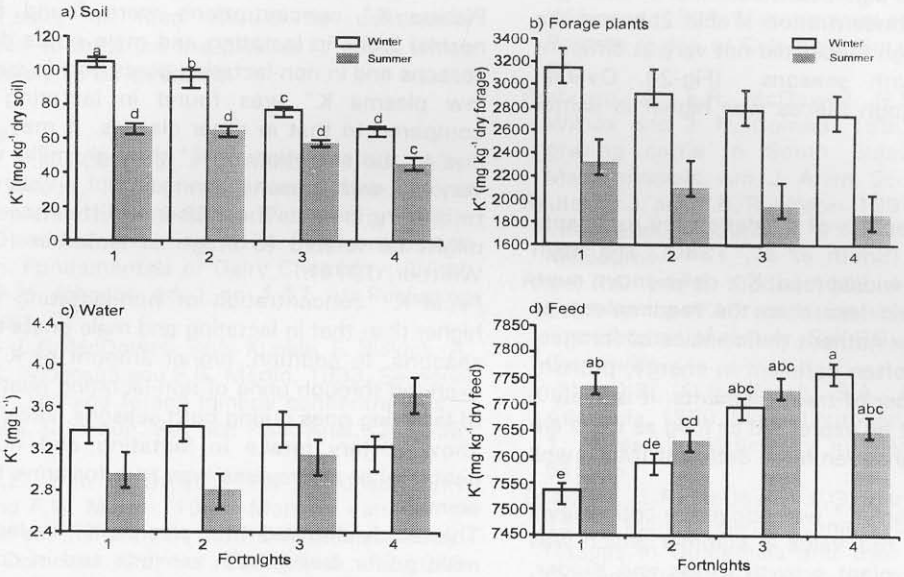

Fig .1: K^+ concentration in (a) soil, (b) forage plants © water and (d) feed at (Means with the same letters do not differ significantly at $P<0.05$)

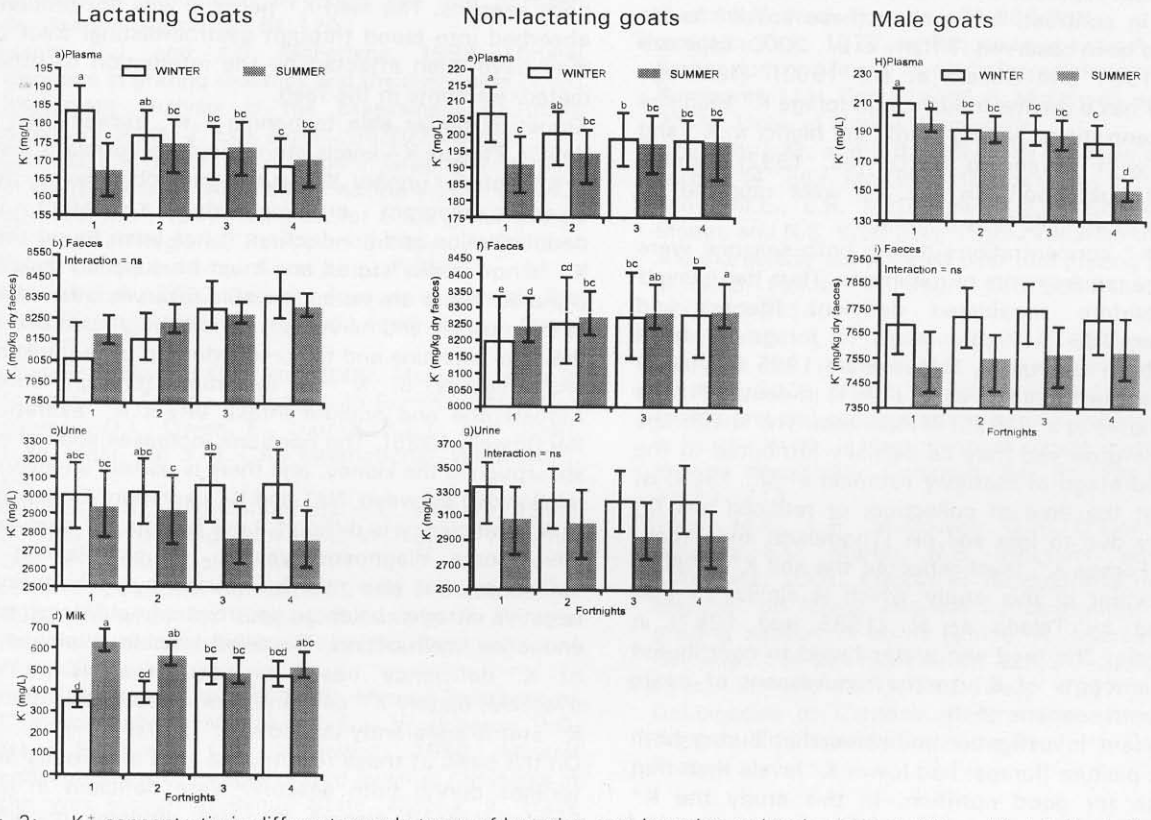

Fig. 2: K^+ concentratio in different sample types of lactating, non-lactating and male goats at different fortnights during winter and summer seasons
(Means with the same letters do not differ significantly at $P<0.05$)

Faeces: There was no significant seasonal or fortnight effect on fecal K^+ concentration (Table 2b), and the excretion of K^+ through faeces did not vary at different fortnights during both seasons (Fig-2i). Overall, excretion of K^+ through faeces was higher in winter than that in summer.

Discussion

There are very few reports of K^+ deficiency ruminants exclusively forages (Smith *et al.*, 1980). The main reason for lack of widespread K^+ deficiency, even when forages contain less than the requirement, is probably due to other nutrient deficiencies of forages. Mature forages are often deficient in energy, protein, P^+, Na^+, and a number of trace elements. It is likely a K^+ deficiency will not be expressed as long as there are other nutrients that are even more deficient (McDowell and Valle, 2000).

In the present study soil K^+ was above the critical level in winter and below this value in summer which was deficient for normal plant growth (Rhue and Kidder, 1983). Low soil K^+ value in summer may be due to K^+ leaching with rainwater. Similar levels of soil K^+ have earlier been reported by Tiffany *et al.* (1999) in north Florida. In contrast, lower than these soil K^+ levels have also been observed (Tiffany *et al.*, 2000; Espinoza *et al.*, 1991 and Cuesta *et al.*, 1993). Plant age generally has a greater influence on forage K^+ than soil K^+ concentrations; young plants are higher in K^+ and decline with advancing (McDowell, 1992). Similar seasonal fluctuations in soil K^+ were reported by Pastrana *et al.* (1991) in Colombia.

Forage K^+ concentrations during both seasons were below the requirements of ruminants. Thus these levels are therefore considered deficient (Reuter and Robinson, 1997). Higher levels of forage K^+ have already been reported by Tejada *et al.* (1985 and 1987) in Guatemala, Espinoza *et al.* (1991) in central Florida and Prabowo *et al.* (1990) in Indonesia. The low forage K^+ levels observed may be partially attributed to the advanced stage of maturity (Gomide *et al.*, 1969) of plants at the time of collection, or reduced soil K^+ solubility due to low soil pH (Thompson and Troeh, 1978). Forage K^+ level reflected the soil K^+ level to some extent in this study which is similar to that observed by Tejada *et al.* (1985 and 1987) in Guatemala. The feed and water found to contributed similar amounts of K^+ to the requirement of goats during both seasons of the year.

The present investigation indicates that during both seasons pasture (forage) had lower K^+ levels than that adequate for good nutrition. In this study the K^+ deficiency may have been due to decreasing content of this mineral by leaching into deep soil, or with increasing forage maturity particularly during the extended summer.

Plasma K^+ concentrations were found below the normal limits in lactating and male goats during both seasons and in non-lactating goats only in summer. The low plasma K^+ was found in lactating goats as compared to that in other classes. It may have been due to the secretion of K^+ through milk, which was very low with seasonal changes, but it was not related to dietary intake. The seasonal difference in milk K^+ might be related to stage of lactation (Corbin and Whittier, 1974).

Fecal K^+ concentration of non-lactating goats was higher than that in lactating and male goats during both seasons. In addition, higher amount of K^+ was also excreted through urine of non-lactating goats than that of lactating ones during both seasons. Fecal K^+ did not show dietary intake in lactating and non-lactating goats, while the reverse was true for urine K^+ in these animals.

This study showed that plasma K^+ in lactating and male goats during both seasons and in non-lactating goats during summer was only lower than the normal limits. This may have been due to the low forage K^+ level, although feed contained higher level of K^+ during both seasons. The feed K^+ perhaps was not properly absorbed into blood through gastrointestinal tract or may have been affected by the interaction of other dietary elements in the feed.

Kidney is better able to handle a K^+ excess than a deficit. Plasma K^+ levels are difficult to correlate with a K^+ deficit, urinary K^+ levels, and changes in the electro-cardiogram produced by a defect in depolarization and conduction. It has been found that K^+ is not readily stored and must be supplied daily in the diet. There are no appreciable reserves other than in the muscles and nerve cells. It is mainly absorbed in the small intestine and to some extent in large intestine and majority of K^+ is excretion through urine. Aldosterone and sodium intake affect K^+ excretion (McDowell, 1985). The hormone increases sodium re-absorption in the kidney, and there is usually an inverse relationship between Na^+ and K^+ excretion. Evaluation of K^+ deficiency is difficult. Low plasma K^+ analyses have some diagnostic values for establishing a deficiency, but also may be caused by malnutrition, negative nitrogen balance, gastrointestinal losses, and endocrine malfunction. Because reliable evaluations of K^+ deficiency based on tissue analysis are not available, dietary K^+ concentration is best indicator of K^+ status apparently (McDowell, 1997).

On the basis of these results, the soils in summer and forages during both seasons were deficient in K^+. Similarly blood plasma K^+ also showed marginal deficiency in all classes of goats during both seasons. Although supplementation was seemed to have

contributed to the well being of the animals the plus K^+ containing salts or feed should be continually supplemented to enhance the plasma K^+ level which was found likely to be deficient.

References

Beede, D.K., P.L. Schneider, P.G. Mallonee, R.J. Collier and C.J. Wilcox, 1983. In: 6th Annual International Mineral Conference, pp. 5-26. St. Petersburg, Florida.

Corbin, E.A. and E.O. Whittier, 1974. The composition of milk. In: Fundamentals of Dairy Chemistry. (Webb B.H. and A.H. Johnson, eds.), pp: 1-57. Avi Publishing Co. Wesport, CT.

Cuesta, P.A., L.R. McDowell, W.E. Kunkle, F. Bullock, A. Drew, N.S. Wilkinson and F.G. Martin, 1993. Seasonal variation of soil and forage mineral concentrations in north Florida. Commun. Soil Sci. Plant Anal., 24: 335-347.

Espinoza, J.E., L.R. McDowell, N.S. Wilkinson, J.H. Conrad and F.G. Martin, 1991. Monthly variation of forage and soil minerals in Central Florida. I. Macrominerals. Commun. Soil Sci. Plant Anal., 22:2023-2056.

Gomide, J.A., C.H. Noller, G.O. Mott, J.H. Conrad and D.L. Hill, 1969. Mineral composition of six tropical grasses as influenced by plant age and nitrogen fertilization. Agron. J., 61:120.

Judson, G.J. and J.D. McFarlane, 1998. Mineral disorders in grazing livestock and the usefulness of soil and plant analysis in the assessment of these disorders. Aust. J. Exp. Agric., 38:707-723.

McDowell, L.R. 1985. In: Nutrition of Grazing Ruminants in Warm Climates. Academic Press New York, pp-443.

McDowell, L.R., 1997. Minerals for Grazing Ruminants in Tropical Regions. Extension Bulletin, Anim. Sci. Dept. Centre for Trop. Agric.,Univ. Florida, pp: 81.

McDowell, L.R., 2002. Recent advances in minerals and vitamins on nutrition of lactating cows. Pak. J. Nutr., 1:8-19.

McDowell, L.R. and G. Valle, 2000. Major minerals in forages. In: Forage Evaluation in Ruminant Nutrition (Givens, D.I., Owen, E., Oxford, R.F.E. and Omed, H.M., eds). pp: 373. CAB International, Wallingford, UK.

McDowell, L.R., J.H. Conrad and F.G. Hembry, 1993. Mineral for Grazing Ruminants in Tropical Regions. Univ. of Florida, Gainesville.

McDowell, L.R., J.H. Conrad, G.L. Ellis and L.K. Loosli, 1983. Minerals for Grazing Ruminants in Tropical Regions. Extension Bulletin Anim. Sci. Dept., Univ. of Florida.

National Research Council, 1980. Mineral Tolerance of Domestic Animals. Natl. Acad.. Sci., Washington, D.C.

Ogebe, P.O. and L.R. McDowell, 1998. Mineral concentrations of forages grazed by small ruminants in the wet season in Benue State, Nigeria. II. Trace minerals and forage crude protein. Commun. Soil Sci. Plant Anal., 29:1211-1220.

Pastrana, R., L.R. McDowell, J.H. Conrad and N.S. Wilkinson, 1991. Macromineral status of sheep in the Paramo region of Colombia. Small Rumin. Res., 5: 9-21.

Prabowo, A., L.R. McDowell, N.S. Wilkinson, C. J. Wilcox and J. H. Cornad, 1990. Mineral status of grazing cattle in South Sulawesi, Indonesia; I. Macrominerals. Am. J. Anim. Sci., 4:111-120.

Reuter, D.J. and J.B. Robinson, 1997. Plant Analysis. An Interpretation Manual. 2nd ed. CSIRO Publishing: Melbourne.

Rhue, R.D. and G. Kidder, 1983. Analytical procedures used by the IFAS extension soil laboratory and the interpretation of results. Soil Sci. Dept., Univ. Florida, Gainesville.

Smith, O.B., O.B. Kasali, S.A. Adeyanju and A.A. Adegbola, 1980. Mineral nutrition in tropical livestock, 1. Potassium deficiency in bovine. J. Anim. Sci., 51:396.

Tejada, R., L.R. McDowell, F.G. Martin and J.H. Conrad, 1985. Mineral element analyses of various tropical forages in Guatemala and their relationship to soil concentrations. Nutr. Rep. Int., 32:313-323.

Tejada, R., L.R. McDowell, F.G. Martin and L.H. Conrad, 1987. Evaluation of the macro-mineral and crude protein status of cattle in specific regions in Guatemala. Nutr. Rep. Int., 35:989-998.

Thompson, D.J., 1978. In: Proceedings Latin American Symposium on Mineral Nutrition Research with Grazing Ruminants. (J.H. Conrad and L.R. McDowell, eds.), pp: 73-79, Univ. of Florida, Gainesville.

Thompson, L.M. and F.R. Troeh, 1978. Soils and Soil Fertility (4th Ed.). Mc Graw-Hill Book Co., Inc., NY.

Tiffany, M.E., L.R. McDowell, G.A. O'Connor, F.G. Martin, and N.S. Wilkinson, 1999. Variation of forage and extractable soil minerals over two grazing seasons in North Florida. Commun. Soil Sci. Plant Anal., 30:2743-2754.

Tiffany, M.E., L.R. McDowell, G.A. O'Connor, H. Nguyen, F.G. Martin, N.S. Wilkinson, and E. C. Cardoso, 2000. Effects of pasture-applied biosolids on forage and soil concentrations over a grazing season in North Florida. I. Macrominerals, crude protein, and *in vitro* digestibility. Commun. Soil Sci. Plant Anal., 31:201-213.

Tiffany, M.E., L.R. McDowell, G.A. O'Connor, H. Nguyen, F.G. Martin, N.S. Wilkinson and N.A. Katzowitz, 2001. Effects of residual and reapplied biosolids on forage and soil concentrations over a grazing season in north Florida. II. Microminerals. Commun. Soil Sci. Plant Anal., 32:2211-2226.

Vargas, E. and L.R. McDowell, 1997. Mineral Deficiencies of Cattle in Central America and the Carbean, Emphasizing Cost Rica. Proc. Int. Conf. Liv. Trop.