MINERAL AND VITAMIN
REQUIREMENTS AND DEFICIENCIES

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ABSTRACT

Quantitative requirements for calcium, phosphorus, vitamin A and D have been established for goats. Requirements for magnesium, sodium, potassium, chlorine, sulfur, selenium, iodine, iron, copper, molybdenum, zinc, manganese, cobalt, nickel, vanadium, vitamin E, B, have been suggested for goats and symptoms when rations are deficient in these and other minerals and vitamins have been described from specific research with goats. Twelve categories of interferences with mineral and vitamin absorption have been discussed.

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I. INTERACTIONS

Recent English, French, and German reviews of requirements of minerals and vitamins by goats and signs of their deficiencies have been published by Honeker (1950), Haenlein (1980), Voelker and Steinberg (1983), National Research Council (1985), Morand-Fehr et al. (1981), Hennig et al. (1983). In general, the world literature on these topics is not extensive, especially concerning vitamins for goats, when compared to the number of studies conducted with cattle or sheep. For example, half biologically assumed similarity and asserted lack of economic significance, goat requirements have been and are widely extrapolated, right or wrong, from cattle and sheep requirements (Hoekstra et al. 1974; Underwood 1977; Georgievskii et al. 1982; Kearl 1982). Evidence, however, is accumulating on unique metabolic differences of goats from other domestic ruminants (Haenlein 1980; Owen and Wahed 1985; Morand-Fehr et al. 1985; Narjiase and Kansali 1985).

Ruminants have generally been exempted from external requirements of especially the B-vitamins, because microbial activity in the rumen provides presumably sufficient quantities of these essential vitamins at all times (Kearl 1982). Symptoms of deficiencies of vitamins B, C and K have not been reported for goats, except for vitamin B$_1$ (Miyazaki et al. 1981, 1984). However, deficiencies of vitamin B$_1$ (thiamine) in cattle and sheep have been discussed (Bogin et al. 1985), as well as the general need to modify requirements according to production levels, disease status, internal parasite infestation and nutritional imbalances (Haenlein 1963).

Type and quantity of forages or roughages fed as a basic ration is widely held as a determinant for the supplementary levels of mineral and vitamin needs. Legume-type forages (e.g., alfalfa, red clover) provide easily the most important mineral calcium, for milk production needs. However, supplying sufficient minerals and vitamins for top growth, reproduction and milk production under indoor stable and corral feeding conditions is complicated by the absence of browse which is an important free choice supplement on the open range for goats. Furthermore, many studies have shown significant imbalances, deficiencies or even toxic substances and inhibitors of minerals and vitamins in prevailing forages fed to livestock around the world and in the USA (Stout et al. 1977; Hall 1976; Perdomo et al. 1976; Unanian and Feliciano-Silva 1984; Haerdt et al. 1976).

Understanding daily mineral and vitamin requirements of goats to compensate for daily losses in milk, feces, urine and needs for growth and maintenance are complicated by the difficulty of translating metabolic needs into quantities in the feed that should be present to satisfy these needs. At least 12 categories of interferences are responsible for this difficulty (Haenlein 1980; Ashmore and Christy 1985; Olentine 1984; Brent 1981; Ammerman and Goodrich 1983): (1) Mineral cations compete for anionic ligands to form insoluble precipitates. As phosphates, oxalates, lipids and phytates from plant leaves and seeds increase in processed diets, the absorption of calcium, zinc, manganese, magnesium and iron decrease. (2) Mineral
cations compete for transport proteins across the intestinal cell wall. Excess copper will inhibit iron absorption due to preferential binding of copper to transferrin. (3) Competing mineral cations may block enzyme reactions because of their displacement of a required co-factor as co-factor. Lead intake displaces zinc which is a required co-factor in hemoglobin formation. When cobalt displaces zinc in carboxypeptidase there is less activity of peptidases. (4) Vitamins affect mineral absorption. Vitamin D and lactose enhance calcium absorption, vitamin C that of iron in the gut. Vitamin D can be depressed by the presence of niacin. Close relationships exist between selenium and vitamin E and cobalt and vitamin B. (5) Non-digestible fiber in the diet in high amounts will depress absorption of most minerals and increase fecal losses. (6) The pH of the rumen and gut influence mineral solubility and absorption. The more alkaline the lumen, the lower the mineral absorption but the less interference with some vitamin absorption, e.g. B1. (7) Minerals chelated between two amino acids are absorbed at a much higher rate as dipeptides and escape many of the above interferences. (8) Some feeds contain vitamin antagonists. Antimetabolites to block or destroy some vitamins are produced in the rumen under certain conditions, e.g. against thiamin (B1). (9) Biological availability is sometimes normally low in certain sources, such as that of niacin in cereal grains. (10) Under "wiederkäuergerichte" (ruminant appropriate) feeding conditions there is abundant rumen synthesis of B-complex, C and K vitamins; however, high performance animals like milking goats often require rations which because of their high grain supplementation are no more "wiederkäuergerichte". Generally, the difficulties of mineral interrelationships are recognized in a diagram shown in Figure 1., those of vitamins in Figure 2. (11) Mineral contents of drinking water and other feed constituents such as nitrates, feed preservatives, animal treatments, e.g. antibiotics, coccidiostats, monensin, amprolium, steroids, estrogens interfere with mineral and vitamin absorption. (12) Chemical and physical forms of mineral supplements affect their biological availability, such as iron oxide vs. iron sulfate, finely ground vs. coarse. Despite these difficulties and because of them it is very important for high productivity with healthy animals and under economic conditions of the goat enterprise especially for the high milking doe and the one that bore quadruplets, to take the daily supplementation and the daily needs of goats for minerals and vitamins very seriously. It has been stated that to predict absorption and to balance daily mineral intake is nearly impossible because of the many mentioned interferences (Ashmead and Christy 1985). This also explains additionally to the paucity of literature why few precisely formulated mineral and vitamin requirements of goats exist and why among authors not much quantitative agreement is found. Furthermore, it is beginning to be recognized that differences in requirements between goats are not only due to different productivity levels, but that breeds of goats due their adaptation to different environments in evolution, in the Swiss Alps vs. the Negev and African desert vs. the West African jungle vs. the Indian.
Figure 1  Mineral Interrelationships

Figure 2  Vitamin Interrelationships
highlands, have different needs (Shkolnik et al. 1980; Ayers and Foote 1992).

II. MINERAL REQUIREMENTS AND DEFICIENCIES

Calcium requirements have been stated by the NRC subcommit-
tees on goat nutrition to be 5 g per 100 kg bodyweight for main-
tenance (NRC 1981). Additional recommendations for such a large
dairy goat in heavy milk production, 8 kg per day with 3.5% milk
fat, are 16 g Ca for a total of 21 g assuming any additional
needs for activity of grazing and drinking, growth and late
pregnancy, which all would be unlikely for a goat with such a
level of milk production. The recommended total of 21 g Ca per
day would represent a mineral concentration of 0.7% in the total
ration on a dry matter basis assuming an intake level of 3% of
bodyweight. This compares exactly with the same recommendation
by Harris (1979) if 3% dry matter intake is correct, however,
high milking goats (such as 8 kg/day) often eat as much as 5% of
bodyweight which would lower the calcium concentration need
in the daily ration to 0.4%. The content of goat milk in Ca
would be about 130 mg/100 ml in average (Haeulein 1980; Jenness
1980), which at the 8 kg per day production level would trans-
late into a loss of 12 g Ca to be replaced by the 16 g recom-
manded for milk production within the 21 g total. This repre-
sents a 25% safety margin which may or may not be enough under
conditions of the above stated 12 categories of interferences
with absorption especially for calcium. New studies by Randy et
al. (1984) with yearling Alpine does weighing 34 kg and eating
2.2% of bodyweight daily resulted in 31% absorption for calcium
when the ration contained 1.2% calcium.

Nevertheless, reports of calcium deficiencies in goats
appear to be much less frequent than for cows at comparable
production levels. Hypocalcemia and parturient paresis or milk
fever occur in goats in relation to different dietary regimes
especially under certain calcium to phosphorus ratios (Anderson
Overby and Odegard 1980). No quantitative limits have been
published.

Phosphorus requirements are at 14.7 g total per day for the
same size goat and production (NRC 1981), which is 0.49% of
daily dry matter intake at 3% of bodyweight and compares to
0.4%, recommended by Harris (1979). At an average P content in
goose milk of 100 mg/100 ml, it would translate to 8 g P per 8 kg
daily production loss vs. the recommended NRC daily need of
11.2 g within the 14.7 g total or a 25% safety margin (NRC 1981).
Studies by Adeoye and Akinsoyina (1985) with 7 months old West
African dwarf goats weighing 19 kg showed requirements of
0.56 g P per day for maintenance and 1.99 g when gaining 100 g
daily, while dry matter intake was 4.3% of bodyweight and di-
gestibility of P was 49%.

Deficiencies of phosphorus result in delayed growth, appe-
tite loss, unthriftness and reduced reproductive efficiency
(NRC 1981). Phosphorus deficient forages are encountered but

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deficiency reports are few under range conditions and are more expected under barn feeding and high milking conditions. It is important that calcium to phosphorus ratios do not vary too much from the ideal 1.2:1, especially since an excess of phosphorus in relation to calcium and potassium has been held responsible for the occurrence of urolithiasis or urinary calculi in goats (Sato and Omori 1977; Bellenger et al. 1981; James and Chandran 1975).

No other mineral requirements have been formulated by the NRC (1981) for goats.

Magnesium is required for many metabolic enzyme systems and is closely associated with the metabolism of calcium and phosphorus. In French studies with goats grazing heavily fertilized young grass, low in sodium but high in potassium and nitrogen, the absorption of Mg was depressed (Rayssiguier 1984). The resulting Mg deficiency was considered responsible for poor growth, low milk production and disorders of Ca, P and lipid metabolism. Studies by House and Bird (1975) had shown that supplementary K is Mg sparing by increasing cellular uptake and retention of Mg while decreasing Mg loss in urine. Magnesium requirements are 0.2% in the ration of dairy goats according to Morand-Fehr (1981) and Harris (1979). While the NRC has none for goats, their sheep requirements are less (0.12, 0.15 and 0.18%) (NRC 1985) for growth, late pregnancy and early lactation ewes; but those for dairy cattle are 0.07% for calves, 0.2% for lactating cows, and at least 0.23% for high milking cows (NRC 1978). Magnesium deficiency can occur in goats resulting in tetany or hyperirritability.

Salt (sodium chloride) is recommended in the total daily ration at the level of 0.5% (NRC 1981; Morand-Fehr 1981). Free choice salt is usually provided on range and in stables. Excess consumption occurs in goats with apparently no ill effects. Deficiency of salt (sodium) leads to a craving to lick and chew fences, dirt, wooden troughs, doors, soil (geophagia) and reduced feed intake, milk and meat production losses (Scheliner 1972; Cunha 1982; Andersson and Olsson 1981; Baldwin 1976).

Potassium requirements of goats have not received much research attention. In analogy to sheep and dairy cattle needs the recommendations by NRC (1981) are 0.5% in the daily dry matter intake for growing and 0.8% for milking goats. Studies by Naga et al. (1978) showed that concentration and rate of growth of rumen microorganisms, especially bacteria, were depressed when K intake by goats was decreased from 1.2 to 0.8% in diets that contained up to 2.2% urea. Some forages especially on winter range, can be very low in K contents and require feed supplementation (Karn and Clanton 1977). When forages are being fed to their K contents decrease. K loss from damaged hay is also low in K content. Summer heat and lack of shade increased K losses by perspiration in Holstein cows more than in Jersey cows (Mallonee et al. 1985) and increasing K supplementation to 1.1% (even 1.64%) had benefits up to 25% in feed intake and milk yield. Deficiencies of K can result in emaciation in goats and poor muscle tone, retarded growth and depressed production.
X, Na and Cl ions play a major role in the water metabolism, osmotic balance and kidney regulation of goats especially under desert conditions when even milking goats usually only drink and rehydrate every 2 to 4 days and imbibe amounts of water often exceeding 40% of their dehydrated bodyweight (Choshniak et al. 1984; Malloy and Clevens 1980). Addition of ammonium chloride to cow diets increased retention of X, Na, Ca, S and Cl but decreased P and Mg (Abgaryan 1983). Chloride deficiency symptoms like polydipsia, polyuria, anorexia, dehydration, decreased respiration, bloody feces and renal lesions in the tubular epithelium of the outer medulla have been described for dairy calves and cows with reversal to normal after 9 days on diets of 0.48% Cl, but with lethal consequences after 24 to 46 days on diets with only 0.063% Cl (Nethery et al. 1981; Pettman et al. 1984).

Sulfur is needed by rumen microorganisms for protein synthesis. High urea rations require sulfur supplementation. Sulfur is also needed for mohair production. Most mature forages and especially those containing tannin are low in available sulfur, as is corn silage (Cunha 1982). Goats on the range, especially Angoras, browse freely on tannin – containing plants. NRC (1981) recommends available sulfur to nitrogen ratios of 1:10 and ratio contents between 0.16 to 0.32% when protein contents range from 10 to 20%. Sulfur containing amino acids given postruminally to Angora goats have stimulated mohair production (Reis and Schinkel 1964). Deficiencies of sulfur produce poor goat performance, excessive salivation, lacrimation and alopecia.

Among the minor or trace minerals, selenium has received some research interest in recent years because of documented soil and forage deficiencies in Se in vast areas of the USA and elsewhere, and because of its relationships with reproductive efficiency, copper, cadmium, mercury, sulfur, vitamin E metabolism and involvement in enzyme and leukocyte functions (Aziz et al. 1984; Robbins et al. 1985; Hussein et al. 1985; Gupta et al. 1982; Froslie et al. 1980). Se requirements of sheep are 0.1 to 0.2 mg/kg dry matter intake (DMI) for non-lactating ruminants (NRC 1985), the higher level when legume forages are fed. Deficiencies of Se result in degeneration of cardiac and skeletal musculature, unthriftiness, early embryonic death, placental retention, periodontal disease and reduced growth. Some forages may produce Se toxicity indicated by soreness and sloughing of hooves, marked reproductive inefficiency, shedding of hair and woolhair, diarrhea, dullness, lameness, loss of appetite, alkali disease, emaciation, liver cirrhosis.

Iodine requirements for dairy cattle are 0.25 mg/kg dry matter intake daily if growing or non-lactating but 0.5 mg/kg for late pregnancy and high milking cows (NRC 1978). Some areas have iodine deficient soils and the forage rations need supplementation, usually in the form of iodized salt (containing about 0.01% iodine). A 1% iodized salt addition to the concentrate mix is usually providing sufficient iodine. Sheep recommendations (NRC 1985) are 0.1 to 0.8 mg/kg diet, depending on increased need for pregnancy, lactation or when goitrogens are in the diet from brassicas or licoensa. Goats seem to differ from...
sheep and dairy cattle by a higher excretion rate of iodine in milk (Lengemann 1979). Deficiency of iodine in goats appears typically as goiter, weak kids, stillbirth, nakedness, reduced wool growth, decreased conception rate, foot rot (Raikes and Pachauri 1984; Megarry and Jones 1983; Groppel et al. 1981; Kategile et al. 1978). Iron requirements of newborn goat kids may be more critical than in cattle or sheep (Lintzel and Radeff 1931). Also internal parasite infestations are usually more serious in goats than in cattle and may require higher supplementations to prevent anemia, more often observed in goats than in cattle. An Fe requirement of 100 mg/kg dry matter intake has been stated for dairy calves up to 3 months and 50 mg for other dairy cattle (NRC 1978). Sheep of all classes are supposedly adequately provided with 30 mg/kg diet (NRC 1985). The typical deficiency symptom for Fe is anemia (Wanner and Boss 1979).

Copper requirements need to consider present molybdenum levels and other interfering substances such as sulfur, zinc, iron and calcium. For dairy cattle 10 mg Cu/kg dry matter intake are recommended under normal conditions, but more when Mo is high in forages (NRC 1978). The addition of 0.5% CuSO₄ to salt is usually adequate in copper-deficient areas. Sheep appear to be more resistant to Mo toxicity but more sensitive to Cu excess than cattle. Goats have not been studied sufficiently. Sheep recommendations vary with age and production level and Mo levels from 1.0 to 8.6 mg and 14 to 23 mg/kg diet (NRC 1985). Deficiencies of Cu produce "swayback" in sheep, weak lambs, partial paralysis of hindquarters, lack of strength and crisp of wool, lack of pigmentation of wool of black sheep, anemia, osteoporosis and infertility (Beust et al. 1983; Sharma and Prasad 1985; Bremer 1984; Virgins et al. 1981).

Molybdenum requirements are not known for goats; for sheep they appear to be very low (NRC 1985). Molybdenum excess (5 to 20 mg/kg diet) produces diarrhea and weight loss but can be controlled by increasing copper intakes by 5 mg/kg diet.

Zinc requirements for goats have not been established (NRC 1981) but a minimum is at 10 mg/kg diet dry matter. Sheep recommendations are at 20 mg for growth and 33 mg for normal reproduction of males, pregnancy and lactation in females (NRC 1985). Diets high in calcium interfere with zinc absorption. Dairy cattle requirements are at 40 mg/kg diet (NRC 1978). Deficiencies of zinc result in poor wound healing, parakeratosis, stiff joints, small testicles, low libido, reduced feed intake, weight loss, swollen feet (Chhabra et al. 1980; Nelson et al. 1984).

Manganese is another essential trace element especially for reproductive efficiency. Requirements for goats may be around 20 mg/kg diet (Anke et al. 1973; NRC 1981; Ward et al. 1979). Dairy cattle are supposed to have 40 mg (NRC 1978). High dietary calcium and phosphorus levels increase manganese requirements. Deficiency symptoms are retarded growth, disturbed reproduction, abnormalities of the newborn, including deformities, delayed estrus of females, silent heat and lower conception rate.
Cobalt is needed to promote synthesis of vitamin B₁₂ in the rumen. Sheep have requirements of 0.1 mg/kg diet dry matter (NRC 1985) which equal recommendations for dairy cattle (NRC 1978). A number of Co deficient areas in the USA need Co supplementation of the forages. Addition to salt at 2.5 g Co/100 kg salt is sufficient. Deficiency symptoms include lack of appetite, emaciation, anemia, decreased estrus and decreased production. Supplementary Co also protects against "Phalaris staggers" from ingestion of the grass phalaris tuberosa that contains alkaloids that interfere with Co metabolism.

Other trace elements, fluorine, tin, arsenic, cadmium, lithium, vanadium, lead, chromium, aluminum, nickel, silica and toxic minerals have been studied very little in goats so that requirements and deficiency symptoms are not yet very conclusive (NRC 1981, 1978, 1965; Amsden and Goodrich 1983). Some highly interesting work is presently done at the University of Jena - East Germany, establishing essentialities in goats, quantifying their requirements and mineral interrelationships (Anke et al. 1985; Anke et al. 1986A, 1986B).

The requirement for nickel by goats is between 300 and 350 microgram/kg diet dry matter (Anke et al. 1983). Deficiency rations resulted in decreased growth, reduced birth weight of kids, anemia, disturbed metabolism of Fe, Ca, Zn, carbohydrates, triglycerides, increased magnesium deposit in bones, parakeratoles, disturbed microbiological urea conversion into amino acids in the rumen. Nickel appears to be essential for certain metabolic processes of microorganisms and their enzymes (urease), such as are found in the gastro-intestinal flora. Thus the importance of Ni in rumen and cecal digestion can be understood. Different Ni contents were identified in forages and feeds from different soils; magnesium rich dolomitic soils produced forages with relatively higher Ni contents, while clay and granite soils had Ni-poor flora. Grain seeds were lower in Ni than those from legumes. Evergreen oak branches, heather and leafy vegetables were good sources of Ni.

Vanadium has been established to be required by goats for normal reproduction, prevention of abortion, normal feed intake, milk production and Fe metabolism (Anke et al. 1984). Requirements are about 10 to 25 microgram Vanadium/kg diet dry matter. Lithium deficiencies have also been produced in goats and different contents in feedstuffs were related to differences in soils. Supplies of 1 to 2 microgram Li/kg diet were insufficient for normal development, growth and birth weights.

Nevertheless, it has been stated that no immediate dangers of clinical deficiency diseases due to these minor trace elements exist presently because of apparent sufficient supplies in normal rations of goats.

### III. VITAMIN REQUIREMENTS AND DEFICIENCIES

Fat soluble vitamins A, D and E can not be synthesized in the rumen of goats and must therefore be supplied in the diet directly or by way of precursors (Voelker and Steinberg 1981). Vitamin
A supplies are obtained by goats from plant carotenes or commercial vitamin A esters. Requirements for goats have been extrapolated from those for sheep and dairy cattle in the absence of sufficient studies with goats (NRC 1981). A 100 kg dairy goat needs 2,400 international units (IU) vitamin A for maintenance daily plus 30,400 IU for the production of 8 kg milk per day (as in the example above). Assuming this goat looses 16,000 IU vitamin A in those 8 kg of milk, the requirements should suffice for replacement balance if a 50% rate of absorption and conversion can be assumed. Deficiency symptoms due to vitamin A are loss of appetite, impaired vision, night blindness, unthriftness, nasal discharge, keratinization of mucal membranes, lowered resistance to infections, malformed kids, and abnormal spermatozoa in buck semen. High nitrate intake in the diet interferes with the conversion of carotene to vitamin A, thus increases vitamin A requirements.

Vitamin D is needed by goats to prevent osteoporosis, parturient paresis, calcium and phosphorus deficiency, and amounts of 480 IU for maintenance of the 100 kg goat plus 6,080 IU for the 8 kg milk per day are necessary (NRC 1981). Vitamin D is also called the antirachitic factor because of its preventive function. Sunshine providing ultraviolet radiation is needed for the conversion of sterols to vitamin D. Absence of sunshine may increase requirements of vitamin D by feed supplementation.

Vitamin E is related to selenium metabolism and both are required for normal reproductive efficiency in goats, although no quantitative data are available (NRC 1981). Sheep should receive 20 IU vitamin E/kg diet dry matter if small lambs, and 15 IU if above 20 kg bodyweight (NRC 1985), when dietary selenium levels are above 0.05 mg/kg. Deficiency symptoms are forms of a muscular dystrophy called "white muscle disease". Kids may be born with this affliction in the absence of stored reserves of vitamin A, D and E. Colostrum is an important source for newborn kids to overcome their natural deficiency at birth, assuming that their dams have not been deficient during their pregnancy (Voelker and Steinberg 1981). High producing dairy goats may suffer retained placenta and poor involution of the uterus when vitamin E and/or selenium are deficient.

Water soluble vitamins of the B complex, vitamins C and K are normally synthesized in the rumen of goats in sufficient amounts to provide all possible needs to does and bucks, but not necessarily to newborn, still monogastric kids (up to 2 months), sick goats and those under drastic dietary changes, under oral medications and digestive upsets including diarrhea and internal parasitc stress (NRC 1981). However, no quantitative data have been published. Cobalt is necessary for the synthesis of vitamin B12. Sulfate feed supplementation interferes with vitamin B12 synthesis in the rumen. Under high-grain feeding conditions, vitamin B12 may be inactivated by thiaminase causing a deficiency in vitamin B, despite a functional rumen (NRC 1978). The condition may be accompanied by lactic acidosis and the appearance of pellagra and pellagra-like malacia, which can be corrected by intravenous administration of
vitamin $B_1$ (Voelker and Steinberg 1981). Goats on high grain rations have been recommended to be supplemented daily with 50 to 60 mg vitamin $B_1$ per day. Therapeutic doses are 6.6 to 11 mg/kg bodyweight 4 times per day. Deficiency in vitamin $B_1$ results in polyneuritis, poor leg coordination, inability to stand in kids and diarrhea.

Vitamin $B_2$ or riboflavin problems have not been described in goats but are discussed for dairy cattle (NRC 1978). This is also the case for vitamin $B_6$ (pyridoxine), pantothenic acid, biotin, niacin, folic acid, choline and vitamin $B_{12}$, since their importance has been demonstrated especially in calves under certain conditions, e.g. with milk replacer diets.

It is hoped that this review not only elucidates the areas where improved nutritional management of goats may result in improved performance, but also where new research may yield very useful information to help the goat industry for the production of better mohair, cabrito-chevon meat, goat milk and goat cheeses.
Literature Cited


