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MINERAL STATUS AND PROFILES (BLOOD, BONE AND MILK) OF THE GRAZING RUMINANT WITH SPECIAL REFERENCE TO CALCIUM, PHOSPHORUS AND MAGNESIUM

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"It is natural that the scientific study of ruminant nutrition should have been directed in the first instance to the animals provided with food directly by man. Therefore much literature is available relating to cattle hand-fed in feedlots for beef production or in byres for milk production, and to cattle and sheep fed in barns or yards during the winter when pastures are covered with snow. Much less research has been done on the grazing animal" (McDonald, 1968).

This paper is intended to focus on some aspects of mineral nutrition pertaining to sheep and cattle under range conditions in South Africa. Due to the well established phosphorus deficiency in native grassland pastures and the consequent economic importance in beef cattle production, I decided to confine myself to phosphorus. Instead of merely reviewing existing literature on phosphorus deficiencies I have included some of our own results. Calcium and to a minor extent magnesium, are both important in phosphorus metabolism and will therefore be included in the discussion.

The livestock industry in the Republic of South Africa is almost entirely dependent on the native pasture for satisfying their nutritional needs. Unfortunately however, several nutritional deficiencies put a limitation on animal production in most pastoral areas covered mainly by grass. In this regard the well known phosphorus deficiency was discovered in some classic research during the early part of this century (Theiler, 1912; Theiler, 1920, Theiler, Green & Du Toit, 1924; Theiler, 1927). Severe phosphorus deficiencies in pasture are by no means typical of South African native pastures. Underwood (1966) stated "there is no doubt that phosphorus deficiency is the most wide-spread and economically important of all the mineral disabilities affecting grazing livestock". Most of the soils supporting these kind of pastures are low in phosphorus. According to Cohen (1975) these pastures are also largely devoid of legumes and have a low crude protein content, a factor which is almost invariably associated with low organic matter digestibility. Phosphorus insufficiency in the ruminant is reflected in retarded growth, poor reproductive performance, reduced milk yield and wool growth, and impaired skeletal and dental health (Hemingway, 1967).

Calcium and phosphorus

It is usual to consider calcium and phosphorus together in their effect on nutrition. According to Hemingway (1967) this tends to obscure the paramount role of phosphorus in a wide range of biological systems.

"Phosphorus deficiency is predominantly, but not exclusively, a condition of grazing ruminants, especially cattle, whereas calcium deficiency is more a problem of hand-fed animals, especially pigs and poultry" (Underwood, 1966). National Research Council (1964) states that there are areas in several states of the U.S.A. where the forage from pasture or range requires calcium supplementation. However, a calcium deficiency seems likely to occur only on soils in humid regions under conditions in which rainfall exceeds evapotranspiration for most of the year and where bases have been depleted, soil acidity has developed and where the pasture consists mainly of quick growing grasses without any leguminous species (Underwood, 1966; Kamprath & Foy, 1971). Williamson & Payne (1959) report that in several tropical regions pastures are so deficient in calcium that pathological bone conditions are induced. However, McDonald (1968) states that a survey of the literature has confirmed the surprising conclusion by Russell & Duncan (1956) that there is no authentic record of a primary calcium deficiency in grazing cattle or sheep. Underwood (1966) notes that the lower incidence of calcium than of phosphorus disorders is attributable to 3 major factors: (i) a higher concentration of calcium than of phosphorus in the leaves and stems of most plant species (phosphorus is concentrated in the seeds); (ii) a wider distribution of phosphorus deficient than of calcium deficient soils; (iii) a lesser decline in the concentration of calcium than of phosphorus with advancing maturation of the plant.

Table 1

The reproduction performance of cows and ewes as well as the birth and weaning mass of their progeny as a result of phosphorus supplementation

		+ P	– P
Beef cows:			
Conception rate (%) in:			
	1978	79,2	83,3
	1979	79,2	45,8
	1980	90,5	72,7
Calves:			
Birth mass (kg) in:			
	1978	31,8	31,5
	1979	37,7	32,0
Weaning mass (kg) at 210 days in:			
	1979	178,1	151,1
	1980	224,3	189,3
Dorper ewes:			
Conception rate (%) in:			
	1979	76,0	80,0
	1980	100,0	100,0
Lambs:			
Birth mass (kg) in:			
	1979	4,7	4,4
	1980	4,9	4,9
Weaning mass (kg) at 100 days in:			
	1979	21,8	20,5
	1980	24,5	22,3

The special interest in phosphorus under grazing conditions lies in the difference between cattle and sheep in their response to a deficiency. The results in Table 1 represent some of our own experimental observations where reproducing sheep and cattle are kept on native pasture of the Armoedsvlakte Research Station near Vryburg identified by Theiler and his co-workers to be severely phosphorus deficient.

The results in Table 1 clearly demonstrate contrasting responses by breeding cows and ewes and the growth rate of their offspring to phosphorus supplementation. This lack of response by sheep is in agreement with the results of Underwood, Shier & Beck (1940) where they gave phosphorus supplements to sheep that were grazing on pastures supported by severely phosphorus-deficient soils. Similarly, Du Toit, Malan & Rossouw (1930) noted that sheep could remain apparently normal and healthy in areas where cattle would suffer from extreme phosphorus deficiency.

This difference between sheep and cattle is so profound that many writers have difficulty in accepting the evidence. McDonald (1968) stressed the need for research in a genuine pastoral situation in order to help explain this difference between the 2 ruminant species. Although an effort to offer an explanation in this regard was made by this author, it will have to be investigated.

In a research programme presently conducted at Armoedsvlakte on severely phosphorus-deficient pastures a strict comparison between sheep and cattle is made. The phosphorus content of pasture samples collected by oesophageally fistualted cattle and sheep is given in Table 2.

Although the plant material collected by the oesophageally fistulated animals is contaminated with phosphorus, it does give an indication of the quantity of phosphorus ingested by the animals. It must be mentioned that the oesophageally fistulated cattle were not kept continuously with the experimental cows. They grazed the same kind of pasture next to the experimental camps without supplementary phosphorus. About a week prior to sampling they were joined with the experimental cows in the respective treatments. The oesophageally fistulated sheep were kept continuously with the ewes in the 2 different treatments. This is the only possible explanation for the substantially lower phosphorus content of samples collected by the oesophageally fistulated sheep in the – P treatment. Clark (1953) found that the phosphorus concentration of saliva in deficient sheep and cattle was approximately half that in normal animals. The overall high phosphorus content of the samples collected by oesophageally fistulated animals is somewhat surprising.

Magnesium

"No generalisations can be made concerning soil properties and the occurrence of hypomagnesemia or grass tetany in cattle of sheep" (Beeson, 1959). The characteristic tetany associated with hypomagnesemia is essentially a disease of grazing animals and has attracted much attention in research. In sheep the disease is chiefly seen in lactating ewes, while in cattle, pregnant and lactating cows are most frequently affected. According to McDonald (1968) there is much evidence that calcium and magnesium are intimately related in the aetiology of the condition. It is evident from reviews by Wilson (1964)

Table 2

The phosphorus content of forage samples collected by oesophageally fistulated cattle and sheep as well as by hand from native pasture at Armoedsvlakte in April 1979

	Samples collected by oesophageally fistulated animals		Samples collected manually	
	+ P	– P	+ P	– P
P concentration in samples collected from the pasture grazed by cattle (%)	0,193	0,197	0,057	0,056
P concentration in samples collected from the pasture grazed by sheep (%)	0,251	0,155	0,086	0,083

Table 3

Factors affecting magnesium utilisation by ruminants (Reid & Horvath, 1980)

Factor	Effect
Nitrogen fertilization of forage; application of poultry manure	Interaction of high protein content of forage with high K to reduce Mg availability (Wilkonson, Stuedemann, Jones, Jackson & Dobson, 1972).
Underfeeding and/or low available carbohydrate	May be factors in winter and spring forms of tetany. Protein – energy imbalances may depress Mg absorption (Metson, Saunder, Collie & Graham, 1966).
Level of Mg intake from diet	Variable effect on apparent availability. Improved retention at increased intakes (Joyce & Rattray, 1970).
Other interfering ions	Reports of increased tetany on low Na pastures. Possible relationship with Ca, P, Mn. (Grunes, 1973).

Table 3 (continue)

Factor	Effect
Complexing of Mg by dietary components in alimentary tract	Formation of soaps with higher fatty acids. Reaction with organic acids and plant or bacterial cell wall fractions (Kemp, Deijs & Kluvers, 1966; Molloy, 1971; Fitt, Hutton, Thompson & Armstrong, 1972).
Plant species	Different availability of Mg in grasses vs legumes, and between species of grass. (Reid, Jung & Gross, 1976; Reid, Jung, Roemig & Kocher, 1978; Powell, Reid & Balasko, 1978).
Method of conservation	Reduced availability with grass drying; possible improvement with ensiling (Powley & Johnson, 1977).
Soil ingestion	Decreased loss of Mg in faeces and increased absorption and retention (Grace & Healy, 1974).

and, Bould (1964) that in hypomagnesemia, environmental conditions dominate the aetiology, while in hypocalcaemia the metabolic factors are dominant.

Contrary to the situation with hand-fed animals, grass tetany can be induced very quickly and magnesium must be given frequently (every day or 2) to protect highly susceptible animals. Management and plant factors which may alter the availability of magnesium to the grazing ruminant are presented in Table 3.

Reid & Horvath (1980) are of the opinion that given the complexity of environmental, management and metabolic factors intervening between soil and animals, it is not surprising that any relationship of soil characteristics to the incidence of hypomagnesemic tetany is difficult to define. According to these authors, tetany is a serious problem to livestock producers in most temperate countries and the severity of the problems appear to be increasing.

In South Africa tetany appears to be a problem in lactating ewes and their lambs grazing small grain pastures.

The phosphorus, calcium and magnesium status of animals

Some 20% of the total body phosphorus is found in non-skeletal material in contrast to only 1% of body calcium. Phosphorus occurs to the extent of 0,15 - 0,20% of soft body tissues. Magnesium follows very much the same distribution in the animal body as phosphorus in the sense that 70% occurs in the skeleton while 30% is found in the soft tissues.

The problem of measuring the status of the animal regarding these 3 minerals, stems from the fact that they are mainly stored in the bones. The animal can and does draw on this reserve in times of inadequate consumption. As a result, the amounts in the blood are at best weakly related to intake, retention or total storage.

Phosphorus

Despite the fact that blood phosphorus concentration is an unsatisfactory indication of the long term phosphorus status of the animal, it is still being used. As a result of this complication the large body of results relating blood phosphorus levels to phosphorus status contains some anomalies (Cohen, 1973 b; Theiler, du Toit & Malan, 1937). According to Cohen (1974) and Wise, Ordoveza & Barrick (1963) blood levels tend not only to rise and fall with the phosphorus content of the diet, but also as a result of excitement (Gartner, Ryley & Beattie, 1965). Mobilization of skeletal phosphorus could raise blood levels which in actual fact means a depletion of reserves (Cohen, 1974).

The normal concentration of blood inorganic phosphorus is 4 - 8 mg per 100 ml, and sometimes rather higher values are recorded. Under conditions of an insufficient phosphorus intake, concentrations may fall as low as 1 - 2 mg/100 ml. "A normal blood phosphorus concentration must not, however, be regarded as an index of adequate bone nutrition. Nor is severe bone depletion necessarily associated with subnormal blood phosphorus values" (Hemingway, 1967).

Calcium and Magnesium

A normal blood calcium concentration is between 8 and 12 mg per 100 ml plasma. Duncan (1958) concluded that bone phosphorus is less readily mobilized than bone calcium, so that low serum inorganic phosphorus concentrations are normally the first sign of inadequate dietary phosphorus.

The magnesium concentration of blood is fairly constant within the range of 2 to 5 mg per 100 ml serum.

Phosphorus, calcium and magnesium profiles in blood, bone and milk

Blood

Measurement of the inorganic phosphorus content of blood or plasma has long been used as an indication of phosphorus status. Because of the ease of obtaining samples it will probably continue to be one of the most useful diagnostic procedures despite some limitations. Similarly, calcium and magnesium concentrations in blood serve as an indication of the animal's status regarding these two minerals.

What kind of blood profiles could be expected with sheep and cattle grazing native pastures deficient in phosphorus?

The concentration of phosphorus, calcium and magnesium in plasma of breeding cows at Armoedsvlakte is given in Table 4.

The results in Table 4 show that once the phosphorus concentration in plasma of breeding cows has dropped to such low levels, there appears to be no possibility of recovering to normal levels. As indicated in Table 4 supplementing the cows with a phosphorus/salt lick, normal phosphorus levels in plasma could be maintained. In a similar experiment at Glen, the phosphorus concentration in blood plasma of beef cows returns to a normal level after a sharp drop during lactation. Results in this regard are presented in Table 5.

Table 4

The average phosphorus, calcium and magnesium concentration in plasma of beef cows grazing native pasture at Armoedsvlakte with or without phosphorus supplementation

DATE	TREATMENT					
	+ P			- P		
	P	Ca	Mg	P	Ca	Mg
	mg %	mg %	mg %	mg %	mg %	mg %
July 1978: Pregnant heifers	6,53	7,65	2,27	4,51	8,47	2,15
January 1979: Lactating cows	3,92	9,04	2,41	1,79	10,51	2,35
April 1979: Lactating cows	5,64	7,97	2,59	1,56	8,43	2,35
June 1979: Lactating cows	6,09	8,84	2,02	1,80	9,53	2,16
August 1979: Pregnant cows	5,91	7,29	1,99	2,35	8,23	2,55
February 1980: Lactating cows	4,05	7,72	2,41	1,62	8,28	2,31
June 1980: Lactating cows	5,64	8,45	2,21	1,83	9,58	2.20

Table 5

The average phosphorus, calcium and magnesium concentration in plasma of beef cows grazing native pasture at Glen with or without phosphorus supplementation

DATE	TREATMENT					
	+ P			– P		
	P	Ca	Mg	P	Ca	Mg
	mg %	mg %	mg %	mg %	mg %	mg %
August 1978: Pregnant heifers	7,24	8,55	2,37	7,91	8,10	2,66
February 1979: Lactating cows	4,32	9,22	2,55	4,93	9,48	2,54
June 1979: Lactating cows	2,78	8,85	2,57	1,92	8,93	2,47
October 1979: Pregnant cows	5,50	9,92	2,94	5,36	10,57	3,11

Table 6

The average phosphorus, calcium and magnesium concentration in plasma of Dorper ewes grazing native pasture at Armoedsvlakte with or without phosphorus supplementation

DATE	TREATMENT					
	+ P			– P		
	P	Ca	Mg	P	Ca	Mg
	mg %	mg %	mg %	mg %	mg %	mg %
April 1979: Pregnant ewes	4,27	7,52	1,96	1,55	8,39	2,09
June 1979: Lactating ewes	4,40	9,33	2,23	2,30	9,50	2,12
August 1979: Lactating ewes	3,27	8,11	1,99	1,76	8,97	2,14
February 1980: Pregnant ewes	4,28	8,36	2,67	3,85	8,89	2,28
June 1980: Lactating ewes	3,31	8,91	2,15	2,15	9,46	2,19

In the experiment at Armoedsvlakte the influence of phosphorus supplementation on the concentration of phosphorus in plasma of breeding Dorper ewes, is also investigated. Results are presented in Table 6.

From the results in Table 6 it is evident that a sharp drop in blood phosphorus concentration of Dorper ewes does take place when grazing the phosphorus deficient native pastures at Armoedsvlakte. Contrary to the beef cows, however, reproduction performance has not been affected thus far (see Table 1).

Bone

Cohen (1973a) reviewed some of the evidence to suggest that blood analysis may lead to unreliable conclusions. It was shown by Cohen (1973a; 1973b) that when using the technique developed by Little (1972a) for collecting rib-bone samples by biopsy, that the phosphorus content of bone was a more reliable estimate of phosphorus status than blood.

This technique of Little (1972a) was used for collecting rib-bone samples from beef cows and Dorper ewes. This would allow a direct comparison of blood and bone analyses as an indication of phosphorus status.

The phosphorus, calcium and magnesium content (mg/cc fresh bone) of rib-bone samples of beef cows and Dorper ewes is given in Tables 7 and 8, respectively.

Corresponding figures for beef cows at Glen are given in Table 9.

Table 7

The average phosphorus, calcium and magnesium content of rib-bone samples of beef cows grazing native pasture at Armoedsvlakte with or without phosphorus supplementation

DATE	TREATMENT					
	+ P			– P		
	P	Ca	Mg	P	Ca	Mg
	mg/cc	mg/cc	mg/cc	mg/cc	mg/cc	mg/cc
July 1978: Pregnant heifers	178,0	382,1	7,38	166,9	365,3	5,15
January 1979: Lactating cows	176,5	362,4	3,78	159,8	348,8	3,13
June 1979: Lactating cows	129,5	272,1	4,90	94,3	204,4	3,25
August 1979: Pregnant cows	154,2	257,8	5,87	122,0	209,5	4,83
February 1980: Lactating cows	124,0	266,7	4,31	107,6	232,2	3,33

Table 8

The average phosphorus, calcium and magnesium content of rib-bone samples of Dorper ewes grazing native pasture at Armoedsvlakte with or without phosphorus supplementation

DATE	TREATMENT					
	+ P			- P		
	P	Ca	Mg	P	Ca	Mg
	mg/cc	mg/cc	mg/cc	mg/cc	mg/cc	mg/cc
April 1978: Pregnant ewes	129,6	295,5	5,26	118,0	262,0	4,50
June 1979: Lactating ewes	145,2	298,5	5,28	107,3	229,6	3,38
August 1979: Lactating ewes	125,7	215,6	5,37	85,9	157,1	4,57
February 1980: Pregnant ewes	143,1	299,6	4,98	124,3	267,7	4,10

Table 9

The average phosphorus, calcium and magnesium content of rib-bone samples of beef cows grazing native pasture at Glen with or without phosphorus supplementation

DATE	TREATMENT					
	+ P			- P		
	P	Ca	Mg	P	Ca	Mg
	mg/cc	mg/cc	mg/cc	mg/cc	mg/cc	mg/cc
August 1978: Pregnant heifers	187,1	371,7	6,7	184,6	385,2	7,4
February 1979: Lactating cows	178,0	373,9	5,7	166,6	353,3	5,6
June 1979: Lactating cows	133,4	255,4	4,1	111,4	209,6	3,3
October 1979: Pregnant cows	153,7	304,0	5,5	133,3	256,6	4,0

Benzie, Boyne, Dalgarno, Duckworth & Hill (1959) found that the radiological density of bone in lactating ewes decreased. This finding suggested that the expression of bone composition per unit of volume may provide a better index of the magnitude of mineral changes than that per unit of weight. Therefore the phosphorus, calcium and magnesium content per unit of volume was preferred in this study.

Milk

Sheehy, O'Donovan, Day & Curran (1948) as quoted by Hemingway (1967), provided a phosphatic supplement to cows at grass with severe aphosphorosis. Milk production 3 months after calving fell to less than 4,5 ℓ per day. Yields from the treated cows rose to 6,7 ℓ per day within two weeks and that of the untreated cows continued to fall to 2 ℓ per day over a period of 8 weeks. Cohen (1975) states: "there is no evidence that the provision of supplemental phosphorus for beef cattle in Australia will improve milk yield".

Bisschop (1964) reported a response in milk yield as a result of phosphorus supplementation at Armoedsvlakte in older cows only. However, he supplied phosphorus in the form of bone meal at a rate of 140g per day. This contained 27% crude protein. Therefore it is not clear whether the response in milk yield was the result of the phosphorus or the protein being supplemented.

Bisschop (1964) also found that neither the phosphorus nor the calcium content of milk was influenced by a bone meal supplementation to cows grazing the phosphorus deficient pasture at Armoedsvlakte.

In the present study at Armoedsvlakte until now milk yield has not been measured. However, the results in Table 1 show that the calves of the cows supplemented with phosphorus weaned considerably heavier than those of the cows receiving no phosphorus. Although this difference could be the result of the calves consuming phosphorus from the licks provided to their mothers, it also points to the possibility of a lower milk yield in the unsupplemented group of cows. The possibility of a lower milk yield is supported by a sharp drop in live mass of the cows not supplemented with phosphorus directly after calving until the calves were weaned. In a similar trial at Glen with beef cows, it also appears as if differences in growth rate of calves, was the result of both differences in milk yield as a result of phosphorus supplementation and a response of the calves themselves to the phosphorus consumed from the lick provided to their mothers. In this specific trial, one group of cows was offered no phosphorus, the second received a salt/dicalciumphosphate (50 : 50) lick, while the third one received its phosphorus directly in the rumen via a rumen canula according to NRC (1970) standards. The ranking of the calves in the 3 treatments in terms of weaning mass, was Group 2, Group 3, Group 1 in the 2 calving seasons until now. The calves in Groups 1 and 3 have no access to a phosphorus lick because it is not available to their dams. The calves in Group 2 do have access to the phosphorus lick provided to their dams. The higher growth rate of the calves in Group 3 in comparison with that of Group 1, points to the possibility of a higher milk yield of the cows as a result of supplementary phosphorus provided via the rumen canula.

In Table 10 the phosphorus and calcium concentration of milk of cows in the Armoedsvlakte and the Glen trial, is presented.

The results have not been analyzed statistically, but there appears to be a lower concentration of both phosphorus and calcium in the milk of cows not supplemented with phosphorus.

Practical implications

The understanding of phosphorus nutrition in the grazing situation is hampered by the absence of reliable methods for measuring phosphorus intake and status. The lack of information on the phosphorus intake of the grazing ruminant makes it almost impossible to measure the response to a specific quantity of supplemental phosphorus. Due to the variation in phosphorus content of the available pasture, a specific level of additional phosphorus may produce a different response from time to time.

The contamination of samples collected by oesophageally fistulated animals with phosphorus via the saliva (Lombard & Van Schalkwyk, 1963; Langlands, 1966; Little, 1972b) renders this method unsuitable for measuring phosphorus intake. Cohen (1974) suggested a technique for the estimation of phosphorus intake from the total excretion of phosphorus in faeces. This approach has also been suggested by Belonje (1975) and its use and application is described by Belonje & Van den Berg (1980a; 1980b). However, it has not been tested in the real grazing situation since accurate measurement of phosphorus intake under such conditions, is virtually impossible. Therefore a study of the phosphorus status of the animal as an indication of phosphorus intake appears to be the best available approach at present.

In spite of the limitations of blood analyses for assessing phosphorus status, it has been and is still widely used. Unfortunately, however, the large amount of literature relating blood phosphorus levels to status, point to some anomalies. For example Theiler *et al.* (1937) found that the blood phosphorus concentration could drop to very low levels in heifers and still allow normal growth.

Table 10

The average phosphorus and calcium concentration of the milk of cows grazing native pasture at Armoedsvlakte and Glen with or without phosphorus supplementation

	EXPERIMENTAL SITE				
	ARMOEDSVLAKTE		GLEN		
	+ P	− P	+ P	− P	PR
	n = 10	n = 10	n = 8	n = 7	n = 8
P concentration of milk (%)	0,116	0,096	0,109	0,093	0,113
Ca concentration of milk (%)	0,136	0,114	0,138	0,119	0,139

+ P = Cows supplemented with phosphorus in the form of a lick (50% salt : 50% dicalciumphosphate).
− P = Cows not supplemented with phosphorus but access to a salt lick.
PR = Phosphorus provided via rumen canula as dicalciumphosphate.

Blood profiles also tend to be a reflection of the short term phosphorus status since changes in phosphorus intake are almost immediately detected in blood analyses.

Bone analyses as proposed by Little (1972a) show much promise as an indication of phosphorus status. In the research programme presently being carried out at Glen and Armoedsvlakte, the phosphorus content per unit volume of bone, clearly shows to what extent bone phosphorus is mobilized in times of inadequate intake. The results in Tables 6 & 8 indicate that according to blood analyses a phosphorus deficiency was already eminent in pregnant Dorper ewes, while bone phosphorus content reached a lowest value during late lactation. However, the real problem in using bone analyses at the moment is the complete absence of "normal levels" of bone phosphorus content. It was suggested by Little & Shaw (1979) that a bone phosphorus content of 120 mg per cc taken from the 12th rib indicates a deficiency of phosphorus in beef cattle. They consider 150 mg P per cc bone as adequate. This merely shows that much work needs to be done in an effort to standardize this technique for measuring phosphorus status.

In the investigation at Armoedsvlakte sheep and cattle are compared in terms of their response to phosphorus supplementation when grazing phosphorus deficient pasture. Although both bone and blood analyses indicate a severe phosphorus deficiency in sheep, it has not been reflected in reproduction efficiency and growth of the lambs so far. One could possibly expect that to occur as soon as the lambing rate per ewe per unit of time is increased. However, it must be stressed that throughout the world the response by grazing sheep to phosphorus supplementation has been rather insignificant.

As far as calcium and magnesium are concerned, blood, bone and milk profiles indicate an adequate intake by both sheep and cattle when grazing native pasture in South Africa.

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