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THE CHANGING SOIL ENVIRONMENT:

MINERAL INTERACTIONS BETWEEN PLANTS AND ANIMALS

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Abstract. Complex interactions between minerals and other components of the feed can affect the availability of minerals, and lead to health problems in grazing livestock. The mineral nutrition of grazing animals varies during the year, being dependent on pasture growth, the uptake of minerals by different pasture species, cation-anion content of herbage, soil ingestion, and the mineral content of the water supply. Applications of fertilizers and changes to animal management, such as time of lambing or calving, can predispose mineral disorders in grazing livestock. Grass tetany in lactating cows may be associated with low magnesium absorption due to either low Mg, or high potassium and low sodium intakes, or high ammonium in the rumen. Calcium metabolism in animals may be affected by their acid-base balance which can be modified by the cation-anion balance of the diet and its digestibility. This can be an important consideration for the prevention of milk fever in cows and hypocalcaemia in ewes during late pregnancy and lactation. Fertiliser treatments aimed at increasing pasture production may have adverse effects on mineral interactions. High superphosphate applications may reduce selenium concentrations in pasture and animals, potash fertilizers may predispose grass tetany, and liming pastures to increase soil pH may induce copper deficiency in susceptible lambs and calves. While some of these mineral interactions can be predicted, the only practical way of ensuring that they are not detrimental to livestock is to monitor the mineral nutrition of animals and pastures.

Mineral interactions between plants and animals are usually only of concern when various metabolic and deficiency disorders become apparent in grazing livestock. Minerals for plants and animals are classed as macrominerals or trace elements on the basis of the quantities required (Table 1). Pregnant and lactating animals are the most susceptible to inadequate macromineral nutrition (Ca, P, Mg, Na). Young growing animals (lambs up to 18 months, cattle up to 2 years) are more susceptible to trace element deficiencies (Cu, Co, Se, I). In this paper the more important mineral interactions which cause problems in grazing livestock in south-eastern Australia will be reviewed.

Mineral concentrations in pasture

The mineral requirements of livestock are well-established, but this information is of limited value for assessing the mineral nutrition of grazing animals. Neither the actual amounts ingested, nor the availability of the minerals in the diet, can be predicted with sufficient accuracy. Seasonal changes in pasture growth, composition and mineral concentrations, selective grazing, and pasture shortages due to drought or high stocking rates, make it difficult to predict mineral intake in extensive grazing situations. However, the values in Table 1 are useful to refer to when unravelling mineral problems in livestock on farms.

Seasonal occurrence of mineral disorders in animals

Disorders in grazing animals associated with mineral deficiencies are often seasonal (Table 2), and result from increased demand or rapid growth coinciding with reduced herbage mineral content or mineral availability. Young animals are often more susceptible than mature animals which may have sufficient reserves of minerals to meet their requirements during temporary seasonal deficiencies.

Calcium metabolism in cows and ewes

The cation-anion content of the diet can influence the acid-base balance of cows (Block, 1984), and ewes (Grant *et al.*, 1992). Acid-base balance of cows and ewes can have important effects on their ability to maintain their plasma Ca concentrations during periods of sudden increase in Ca demands. Such periods include parturition, and acute feed deprivation in either lactating or pregnant animals. In cows, maintenance of plasma Ca concentration is important for prevention of milk fever around calving, and also for prevention of grass tetany in lactating cows with low plasma Mg concentrations.

Several equations have been developed to describe the balance of inorganic ions in the diet (Oetzel, 1991).

Table 1. Recommended minimum mineral concentrations in pasture dry matter for grazing livestock[1].

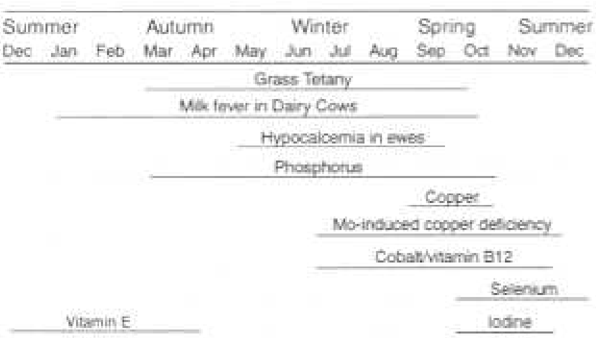
Mineral	Livestock type		
	Cattle	Sheep	Horses
Major mineral elements (g/kg DM)			
Calcium	1.9 to 4.0	1.5 to 3.0	3.0 to 6.0
Phosphorus	1.8 to 3.0	1.3 to 2.5	2.0 to 4.0
Magnesium	2.0	1.2	1.0
Sodium	0.8-1.5	0.7 to 0.9	1.0
Potassium	5.0	4.5	3.0
Sulphur	1.5	2.0	1.5
Trace elements (mg/kg DM)			
Copper[2]	10.0	5.0	10.0
Cobalt	0.11	0.11	0.1
Selenium	0.05	0.05	0.1
Iodine	0.1	0.5 (2.0)[3]	0.1
Zinc	25	20 to 30	40
Manganese	25	15 to 25	40
Iron	40	40	50

[1] Based on data presented by Anon(1990), Grace (1983), NRC (1989). These amounts represent the average requirements for growth, pregnancy and lactation. When a range is given, the higher values are for rapidly growing or lactating animals, and the lower values are for those at maintenance or with a low level of production.

[2] Copper nutrition can be affected adversely by concentrations, per kg DM, of molybdenum >2 mg, sulphur >3 g, iron >500 mg, zinc >100 mg or cadmium >5 mg.

[3] 2 mg/kg in presence of goitrogens

Table 2. Seasonal occurrence of deficiencies of minerals and vitamins in grazing ruminants in South-eastern Australia, and related disorders.



The equations [Na + K - Cl] and [(Na + K) - (Cl + S)] are most commonly used, and the values are expressed as meq/kg diet. Diets having a cation-anion content greater than 400 meq/kg DM induce a metabolic alkalosis in cows and ewes which can be detected by their urine pH being greater than 8.

The acid-base balance of cows may be manipulated by reducing the digestibility of feed, such as by feeding hay. With increased roughage intake, and a lower digestibility of roughage, there is increased salivation and HCO_3 outflow to the rumen. The regeneration of plasma HCO_3 by the kidney results in a more acid urine being excreted. In southern Australia, cows usually excrete a more alkaline urine (pH up to 9.0) while grazing green autumn and winter pastures than when grazing summer pastures (Table 3). Urine Ca and Mg concentrations in grazing cows increase during spring, peak in summer, then decline in autumn. This seasonal pattern of urine Ca excretion appears unrelated to the ages of the cows, stage of lactation, milk production, pasture Ca concentration or estimated intake, but is related to the seasonal change in their acid-base balance.

Table 3. Mean (± SEM) plasma and urine Ca concentration and urine pH in 20 dairy cows sampled in August and December.

Month	Plasma Ca concentration (mmol/l)	Urine Ca concentration (µmol/mosmol)	Urine pH
August	1.96 ± 0.06	0.3 ± 0.17	8.9 ± 0.3
December	2.60 ± 0.03	12.9 ± 0.9	7.2 ± 0.2

Prevention of milk fever in dairy cows

Feeding hay to dairy cows and restricting their intake of green pasture for two weeks before calving has been the most common method used for preventing milk fever in Victoria. In seasonally calving herds, this feeding system has the advantage that it allows farmers to keep pregnant cows heavily stocked in a small paddock or hay feedlot. Winter and early spring pastures which have often been treated with nitrogen and K fertilizers can be spelled in preparation for the lactating herd. Potash fertilizers may increase the cation-anion balance of pasture and induce a metabolic alkalosis in cows, making them more susceptible to hypocalcaemia. Monitoring urine pH of cows is a simple method for determining if they are at risk.

Prevention of hypocalcaemia in ewes

In sheep, we have observed that pregnant and lactating ewes are unable to maintain plasma Ca as high on green winter and spring pastures as they do when grazing poorer quality summer and autumn pastures (Grant *et al.*, 1988). Irrespective of their Ca intake, ewes do not absorb sufficient dietary Ca to meet their requirements during pregnancy, and for milk secretion in early lactation. Ewes may mobilize up to 20% of their skeletal Ca reserves during this period. The efficiency of Ca absorption from green pastures with high water contents may be less than that from dry roughage and concentrate diets. In addition, the high alkalinity (Na + K - Cl >400 meq/kg DM) of green pasture diets may alter the acid-base balance of ewes to make them more alkalotic and depress osteoclastic bone resorption, rendering them more susceptible to hypocalcaemia (Grant *et al.*, 1992).

Complex mineral interactions between plants and amimals

Grass Tetany, or hypomagnesemic tetany, in lactating beef and dairy cows is often the outcome of interactions between several minerals which result in a decrease in Mg in the cow's cerebrospinal fluid surrounding the brain. Lactating cows are most at risk because of the loss of Mg in milk.

Magnesium absorption is affected directly by ruminal K, ammonia and phosphorus concentrations (Grace *et al.*, 1988). Whether a lactating animal with low plasma Mg develops grass tetany depends on its ability to maintain plasma Ca concentration. A reduction in plasma Ca (<2.0 mmol Ca/l) in cows with hypomagnesemia (plasma Mg <0.65 mmol/l) leads to a decrease in Mg concentration in the cerebrospinal fluid and rapid development of signs of excitability and grass tetany. The development of hypocalcaemia may not necessarily be due to inadequate intake of Ca. The ingestion of pasture with a cation-anion content (Na + K - Cl) exceeding 400 mEq/kg DM, is likely to induce a metabolic alkalosis leading to reduced mobilisation of Ca from bone stores and development of hypocalcaemia.

Potassium is the most important factor reducing Mg absorption from the rumen of cattle in Australia, and the application of potash fertilizers is often associated with losses of cattle from grass tetany. Soils either naturally high in K, or those fertilised with potash, and low in Na are high risk areas for grass tetany (Jolly and Leaver, 1974). Potassium concentration increases in herbage from May, reaches a peak (2.5-5%) between August and October, and by December has decreased to levels similar to those found in May. The peak is usually at least 2% higher than the minimum for the year. There are differences between species in their ability to extract K from soil when grown alone. Cocksfoot (*Dactylis glomerata*) usually has a higher K% than perennial ryegrass (*Lolium perenne*) when grown on the same soil (Hosking, 1986).

The recommended minimal concentration of Mg in pasture for ruminants is 0.2% (2 g/kg DM) for lactating and pregnant cattle (Table 1). However, if N and K are high, the Mg concentration should be at least 0.25%. Concentrations above 4% N (40 g N/kg DM) and 3% K (30 g K/kg DM) are considered detrimental (Grunes and Welch, 1989). Milliequivalent ratios of K/(Ca + Mg) in pasture of 2.2 or higher are also considered hazardous. These ratios are calculated using values for K, Ca and Mg on a milliequivalent basis. One option for farmers to reduce grass tetany in their herds is to select paddocks where the K/(Ca + Mg) ratios in pasture are below the critical level for grazing during late autumn and winter.

There are several reasons why grass tetany continues to be a problem for the beef cattle industry in southern Australia. Most herds are grazed on improved pastures, which contain mainly grass species during autumn and winter. Grass pastures usually have lower Mg and Ca concentrations than legume pastures. Cows are calved in the autumn with the object of producing vealer calves which are finished on spring pastures. With this beef production system, cows invariably become fat over spring and summer and, after calving in the autumn, lose bodyweight during lactation between May and September. It is not uncommon for older (over 6 years), and fatter (condition score over 4 on a 1 to 5 scale) cows in herds to lose up to 1 kg liveweight/day in this main risk period for grass tetany. The main loss of Mg in cows is via milk, and essentially no Mg is obtained from the tissues mobilised during loss of liveweight to support lactation. The selection of beef bulls based on growth rate of calves means that cows are being bred for high milk yields. Cows which maintain milk yield by losing liveweight in early lactation are predisposed to hypomagnesemia and grass tetany if they do not receive additional Mg in the diet, or hay to prevent the weight loss. The problem is compounded if susceptible cows are grazed on pastures fertilized with potash.

Grass tetany in cows less than six years-old in beef herds is often associated with low Mg and high K concentrations in pasture, occasionally with low sodium concentrations and, rarely, with low phosphorus concentrations. As a general conclusion, the more complex mineral interactions are likely to be involved in herds where grass tetany occurs in first and second calving cows as well as older cows.

Interactions affecting trace element nutrition

Disorders in animals associated with deficiencies of copper, selenium, and cobalt have occurred on farms following increased applications of superphosphate, lime and trace elements to pastures to increase livestock production. These include:

- myopathy in sheep associated with Se deficiency;
- illthrift, fatty liver and photosensitization in lambs, associated with vitamin B^{12} deficiency;
- bone fragility in lambs associated with copper deficiency; and,
- coat colour changes and poor growth in young cattle due to copper deficiency associated with high iron and molybdenum levels in pasture.

Selenium nutrition

Allaway (1973) proposed that any soil-animal-plant chain that is operating on acid soil will ultimately become depleted of "biologically-effective" forms of selenium. This is because the forms of Se excreted in the faeces and urine of animals may be bound in acid soils and only slowly converted to the available forms.

We have examined the interactions involving Se nutrition of sheep in a trial designed to assess the optimum ratio of stocking density and superphosphate application to pasture for wool production in the Western District of Victoria. Twenty-five plots were prepared in 1975 on a pasture which had received a total of 2.75 tonnes superphosphate/ha over the preceding 28 years. Each plot received a basal treatment of muriate of potash ranging from 60 kg/ha in 1975 to 200 kg/ha in 1980. In 1977, each plot received 105 kg/ha of potash containing copper (2%) and molybdenum (0.05%). The design of the trial incorporated 5 stocking densities (12,15,18,21 and 24 Polwarth wethers/ha) and 5 superphosphate application rates (0,5,10,15 and 25 kg P/ha/year). Sheep were replaced after 3 years.

The effects of superphosphate application on the Se nutrition of the sheep were evident within 3 years (Caple *et al.*, 1980). The Se nutrition was lowest in sheep on plots which received the highest applications of superphosphate, and erythrocyte glutathione peroxidase (GSHPx) activity in the sheep was negatively related to the rate of application of superphosphate (Table 4). However, there was no effect of stocking density. Comparison of erythrocyte GSHPx activities in sheep in 1977 with those in 1980 indicated that no further reductions in Se nutrition of the sheep grazing the plots had occurred after 6 years (Halpin *et al.*, 1981).

Pasture phosphorus concentrations and available soil phosphorus increased with increasing fertiliser application rate (Table 5). This caused a decrease in pasture Se concentration, which was reflected in decreased Se nutrition of sheep. There was no significant difference between the Se content of grasses and clovers in each pasture (Grass on plots receiving 0 and 25 kg P/ha/yr contained 59 and 23 µg/kg respectively when data for all stocking densities were grouped, and clover Se concentrations were 48 and 18 µg/kg respectively). Pasture sulphur concentrations were variable between plots, and were not related to any treatment.

Table 4. Mean (±SE) blood glutathione peroxidase (GSHPx) activities in wethers grazing plots receiving different amounts of superphosphate and stocked at 12 or 21 sheep/ha.

Plot treatment		Sheep Se nutrition
Stocking rate (sheep/ha)	P applied (kg/ha)	Blood GSHPx (units[1])
12	0	77±5
12	10	56±4
12	25	55±5
21	0	52±4
21	10	45±3
21	25	29±2

[1] µmol NAPDH oxidised/min/gHb

On the acid soils of these plots, decreased Se content of pastures was associated with increased phosphate application. Decreased pasture Se may be due to dilution effects associated with the increased plant growth following superphosphate treatment. Pasture Se has also been reported to be affected by botanical composition (Davies and Watkinson, 1966). In this study the grass content of the pasture was increased by fertilizer treatment. Sulphate has been shown to reduce (Prattley and McFarlane, 1974), and phosphate to increase uptake of Se by legumes. Increased sulphur in the diet may also reduce Se retention in sheep when sulphur and Se intakes are low. In this trial the sulphur content of the pastures was not affected by fertilizer treatment and the sheep were receiving adequate dietary sulphur.

Cobalt and vitamin B^{12} nutrition

In the above trial, plasma vitamin B^{12} concentrations in sheep were negatively related to the application rate of superphosphate, but there was no

Table 5. Mean soil pH and available phosphorus, and pasture yield, composition and concentrations of sulphur, phosphorus and selenium on plots receiving different amounts of superphosphate for 6 years.

Fertiliser applied	Soil parameters		Pasture parameters				
(kg P/ha/yr)	pH	Avail.P[2] (mg/kg)	Yield (t DM/ha)	Grass (%)	S (g/kg)	P (g/kg)	Se (µg/kg)
0	5.3	5.7	4.0	52	2.0	2.0	57
5	5.3	7.2	5.3	57	1.6	2.3	41
10	5.2	7.8	5.8	57	2.0	2.7	40
15	5.2	10.3	6.4	62	1.9	2.7	27
25	5.2	15.8	6.7	71	1.8	3.2	22

[1] Within each fertilizer treatment, plots had been grazed continuously by 10 sheep at stocking densities ranging from 12 to 24 sheep/ha; [2] Estimated as Olsen-P; [3] Tonnes of dry matter per hectare

significant interaction with stocking density. Plasma vitamin B^{12} levels in the sheep on each plot were significantly higher in December than in July. Mean concentrations in sheep grazing plots receiving 0 and 25 kg P/ha/yr were 4.2 and 2.4 µg/l, respectively, in July and 6.2 and 5.0 µg/l, respectively, in December. Fertiliser treatment may have affected cobalt nutrition by reducing either pasture availability or vitamin B^{12} synthesis in the rumen.

Copper nutrition

Copper nutrition of grazing animals is affected by their intakes of molybdenum, sulphur and iron which may interfere with the absorption of copper. When pastures are limed to increase the soil pH by 1 or 2 units, there is a tendency for copper concentration in plants to stay much the same, whereas the Mo concentrations may rise several fold (Rooney *et al.*, 1977). On pastures where the Cu:Mo ratio has decreased to less than 3, copper deficiency disorders in livestock can be expected. A recent demonstration of high input grazing systems on farms in Victoria has confirmed that high fertilizer and lime treatments can reduce copper and selenium nutrition of sheep and, in extreme cases, result in copper deficiency disorders such as bone fragility in lambs (Caple, 1994).

Conclusions

The interactions involving minerals in the soil-plant-animal chain are complex and often contradictory, and the effects of intensive agricultural practices are difficult to predict. The most effective way to examine the significance of these interactions is to monitor the mineral nutrition of the animals, then analyse pasture to determine which interactions are likely to be detrimental for animal health and performance. The decision to supplement animals either directly or indirectly through mineral applications to pasture can be based on the cost-effectiveness of either method, and the probability of obtaining increased production and profitability.

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