Mineral deficiencies in sheep often present as part of a multifactorial disease problem. In diagnosing these deficiencies, it is essential to consider them as part of an overall differential disease diagnosis, along with the potential for infectious, genetic, metabolic and non-mineral dietary contributions to a disease condition. Clinical signs presenting in the animal should be considered foremost. These clinical signs should be compared to the well-documented clinical effects associated with the various mineral deficiencies (Underwood 1977). This examination should consider whether the signs appear to be acute or chronic in form, what tissues are predominantly affected and the age or class of animal affected. For example, an apparent ataxic condition confined to lactating mature ewes may suggest possible calcium or magnesium deficiency. In contrast, an ataxic condition confined to young lambs may indicate copper or selenium deficiency.

Where clinical signs are relatively specific, the possibilities in the differential diagnosis may be greatly simplified. Examples include white muscle disease associated with selenium and/or vitamin E deficiencies, and goitre associated with iodine deficiency. Where signs are non-specific (e.g. ill thrift) a number of mineral and non-mineral factors may need to be considered in the differential diagnosis. This includes the presence of subclinical deficiencies, where reduced animal production may be transient and associated with few, if any, specific signs.

In determining mineral nutrition of animals, response to treatment is often proposed as the definitive diagnosis. However, carefully controlled response trials cannot always be conducted on-farm, due to the seasonal nature of mineral deficiencies and the time frames required to reach a diagnosis. Therefore, an approach based on measurement of specific indicators of mineral nutrition and the likely response to supplementation may be more beneficial (Grace 1983; SCA 1990). Using this approach, an indicator of mineral nutrition should be recognised for what it represents—a reflection of overall nutrition for that mineral. It may not accurately reflect the actual biochemical impairment which leads to a specific disease lesion.

This is well demonstrated in the case of copper, which is required for activity of a number of enzymes in most tissues. Each copper enzyme in each tissue has a different rate of depletion or repletion with changes in copper intake. Rates of depletion also vary with the mechanism by which a deficiency is induced, i.e. simple or thiomolybdate, with some copper enzymes in some tissues being affected by thiomolybdates far more than others (Paynter 1984). Decreases in plasma copper concentration reflect decreases in plasma caeruloplasmin activity, which in turn reflect decreases in liver copper reserves and the capacity of the liver to synthesise this enzyme (Paynter 1986). Plasma copper is therefore highly correlated with depletion of liver copper reserves, but is only indicative of the changes that may be occurring with other copper enzymes in other tissues.

In assessing mineral status, the terms marginal and deficient are often used to differentiate sub-optimal mineral intakes.
These terms are defined as follows:

- **deficient**—indicates depleted reserves associated with impairment of biochemical or physiological processes, and responses to treatment are expected;
- **marginal**—indicates reduced reserves, and production responses to treatment may be observed.

In using these definitions, it should be noted that a deficient level of an indicator should not be taken to indicate that clinical disease is present. Onset of clinical disease is often triggered by other dietary or non-dietary factors; the mineral deficiency is a predisposing requirement to the clinical disease condition. In a diagnostic sense, an example is white muscle disease and selenium nutrition. White muscle disease should not be diagnosed solely on the basis of low concentrations of blood selenium or glutathione peroxidase; elevated plasma creatine kinase activities should be used to determine the presence of significant muscle damage.

In the remainder of the review, the relative merits and uses of various indicators in soils, diets and tissues for determining mineral status in sheep are discussed.

**Soil Indicators of Mineral Status**

Soil indicators have limited direct applicability in determining mineral nutrition of grazing animals, their principal use relating to defining requirements for plant growth (Grace 1983; Hosking et al. 1986). Specific soil tests are of most use where there is a high correlation of the soil indicator with the mineral supply to the plant, over a range of soil types and plant species. Few indicators, apart from phosphorus, potassium, and possibly sulfur, fit this category, and even these are restricted to periods when plants are actively growing.

Soil classifications based on type and pH may provide limited general information on mineral availability. Similarly, associations of local soil types with a specific mineral problem may be useful in estimating the extent of a problem at a local level. Granite derived soils and leached sands may be low in minerals such as copper and selenium. Highly acid soils may have low availability of the major cations and molybdenum but be high in manganese. In contrast, alkaline soils may have low availability of manganese, zinc and cobalt (Grace 1983; Hosking et al. 1986) and high availability of molybdenum (Leech and Thornton 1987), and are unlikely to produce selenium deficiency (Reuter 1975).

**Sampling**

For assessment of the major nutrients in relation to pasture requirements, soil cores of the top 10 cm soil profile are commonly used. The final sample for each area usually comprises 15–30 cores, representing each soil type. These samples may be then air dried (max. 40°C) prior to subsampling for further analysis (Rayment and Higginson 1992).

**Analysis**

As many of the analytical procedures used for soils are based on extractable (rather than total) mineral concentrations, results are highly method-specific. Rayment
and Higginson (1992) have documented individual standard methods of analysis commonly used for Australian soils.

**Interpretation**

Interpretation of soil results is highly dependent on the analytical method used. In general, soil analytical measurements for macrominerals are calibrated against plant responses, rather than any specific animal responses, and any extrapolations to animal nutrition are based on animal dietary requirements. Soil measurements of trace minerals have a generally poor correlation to animal requirements (Hosking et al. 1986).

**Dietary Indicators of Mineral Status**

For many minerals, determination of total dietary mineral concentrations provides a useful overall indicator of the adequacy of mineral nutrition to the animal (Table 1). Dietary analysis also forms the basis for understanding the seasonal nature of mineral deficiencies in grazing sheep, and may be the preferred measure of mineral nutrition to the animal where direct animal indicators are of limited value or where dietary interferences in availability to the animal are minimal. Examples include calcium, sodium, potassium, manganese and zinc (SCA 1990).

It should be emphasised that while dietary measurements of these and other minerals may not accurately correlate with their clinical deficiencies, they do form a strong basis for screening for adequacy of these minerals and eliminating them from a differential diagnosis in the animal. Where other dietary factors may interact and affect availability of a mineral to the animal, dietary analysis is important in defining the extent of these interactions and, in some cases, the most appropriate form of treatment. However, for all minerals where dietary interactions may occur, a diagnosis of deficiency should be based, where possible, on animal rather than on dietary measurements.

**Sampling**

All dietary sources, including pastures, supplements and water, should be accounted for when dietary mineral intakes are measured. This may not be achievable with sheep on free choice diets where selective intakes of dietary components may occur, particularly where these dietary components are highly variable in composition and palatability. In these situations, pasture samples should be representative of those being selected by the animal and the area being grazed, and also reflect stocking rate. Separation of pasture samples into the main species, e.g. clovers and grasses, allows the assessment of seasonal variations in mineral concentrations within and between species composing pastures, and enables predictions of mineral nutrition to be made between seasons on the basis of pasture sward composition. This is particularly important where large seasonal species variations occur in pasture composition at marginally deficient sites.
Analysis

Analytical methods used for determining dietary minerals are principally based on the determination of total mineral concentrations. A number of methods and instruments is available for single or multi-element assays. All assays should be verified by the use of appropriate standard reference materials, which are readily available commercially.

Interpretation

Minimum dietary mineral requirements for sheep are shown in Table 1. Note that these values are approximate only, even for those minerals where availability may not be affected by other dietary factors. Their principal use should be to determine the level of adequacy of minerals. When dietary indicators are used to assess mineral nutrition of animals, the reserves available in the animal should be considered. Where animal reserves are minimal, deficiency may be induced within a few days. Magnesium is an example. In contrast, where there are considerable reserves or conservation of nutrients by the animal, deficiency may not be reached for several months. Examples include calcium, sodium, cobalt and selenium (SCA 1990).

For minerals essential for rumen function, particularly sulfur, dietary estimates of requirements may be improved by the inclusion of dietary nitrogen (SCA 1990). This inclusion is particularly relevant when the nitrogen content of the diet is outside that seen with green pasture-based diets, as occurs with senescent pastures and diets supplemented with nitrogen. More complex dietary interactions may occur with magnesium and copper availabilities in diets. For example, dietary sodium, potassium, nitrogen and phosphorus have all been implicated in affecting magnesium nutrition (SCA 1990). Critical values for magnesium availabilities from diets and soils have been proposed that empirically account for at least some of these interactions (Kemp and 't Hart 1957; Lewis and Sparrow 1991). For copper, where the main interferences in uptake are associated with increased dietary molybdenum and sulfur concentrations, critical values for copper availability can be calculated (Suttle and McLauchlan 1978) which appear to closely correlate to copper nutrition in the sheep (Givens and Hopkins 1978; Paynter, unpubl.).

Considerable differences may occur in mineral concentrations of different pasture species. Direct extrapolation of results from one pasture species to others is not possible. Examples of pasture species mineral variations include: the large differences in sodium concentrations measured in natrophiles (sodium-tolerant plants that include many perennial grasses) and natrophobes (sodium-intolerant plants that include fescue, lucerne, and sorghums) (Smith et al. 1983); the lower magnesium, molybdenum and sulfur concentrations in many subterranean clover cultivars compared to other clover species (Evans et al. 1990); and the decreased copper availability in cruciferous species (Merry et al. 1983) and in annual grasses versus clovers (Paynter 1989).

Superimposed over all these dietary measurements are the variable effects of soil intake with sheep grazing at pasture (Grace 1983). In particular, soil ingestion...
may be a major source of cobalt and iodine (SCA 1990). Direct assessment of these elements in the animal is therefore recommended.

**Table 1.** Minimum dietary mineral requirements for sheep (dry matter basis).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Unit</th>
<th>Dietary requirement&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium&lt;sup&gt;b&lt;/sup&gt;</td>
<td>g/kg</td>
<td>1.5–2.6</td>
</tr>
<tr>
<td>Phosphorus&lt;sup&gt;b&lt;/sup&gt;</td>
<td>g/kg</td>
<td>1.3–2.5</td>
</tr>
<tr>
<td>Magnesium&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>g/kg</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>K/(Ca + Mg)</td>
<td>&lt;2.2</td>
</tr>
<tr>
<td>Potassium&lt;sup&gt;b&lt;/sup&gt;</td>
<td>g/kg</td>
<td>5.0</td>
</tr>
<tr>
<td>Sodium&lt;sup&gt;b&lt;/sup&gt;</td>
<td>g/kg</td>
<td>0.7–0.9</td>
</tr>
<tr>
<td>Sulfur&lt;sup&gt;b&lt;/sup&gt;</td>
<td>g/kg</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>g/g N&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.08</td>
</tr>
<tr>
<td>Cobalt&lt;sup&gt;b&lt;/sup&gt;</td>
<td>mg/kg</td>
<td>0.07</td>
</tr>
<tr>
<td>Copper&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg available Cu/kg</td>
<td>0.24</td>
</tr>
<tr>
<td>Iodine&lt;sup&gt;b&lt;/sup&gt;</td>
<td>mg/kg</td>
<td>0.5</td>
</tr>
<tr>
<td>Iron&lt;sup&gt;b&lt;/sup&gt;</td>
<td>mg/kg</td>
<td>40</td>
</tr>
<tr>
<td>Manganese&lt;sup&gt;b&lt;/sup&gt;</td>
<td>mg/kg</td>
<td>15–25</td>
</tr>
<tr>
<td>Selenium&lt;sup&gt;b&lt;/sup&gt;</td>
<td>mg/kg</td>
<td>0.05</td>
</tr>
<tr>
<td>Zinc&lt;sup&gt;b&lt;/sup&gt;</td>
<td>mg/kg</td>
<td>20–30</td>
</tr>
</tbody>
</table>

<sup>a</sup> Lower values for maintenance. Upper values or single values are for rapidly growing/lactating sheep.

<sup>b</sup> Values derived from SCA (1990).

<sup>c</sup> Critical ratio derived from Kemp and ‘t Hart (1957).

<sup>d</sup> Estimated from copper, molybdenum, sulfur concentrations (Suttle and McLauchlan 1978).

**Animal Indicators of Mineral Status**

Direct animal measurements potentially offer the best indicator of mineral nutrition in the sheep, as they account for dietary selection and the variable uptake and availability of minerals. Indicators of mineral nutrition based on tissue or body fluid analyses are now available for the majority of minerals shown to be essential and commonly affecting nutrition of the sheep. Most of these indicators have been well calibrated against production or clinical responses to treatment, over a range of environmental conditions. For many minerals, several different indicators are available for assessment of nutrition; each has advantages and disadvantages, depending on the situation (Tables 2 and 3).

This review does not cover all these indicators extensively. For this, the reader is referred to reviews by Grace (1983), Hosking et al. (1986), Caple and Halpin (1985) and SCA (1990). Instead, the indicators listed below are those found by this reviewer to be currently in use for practical diagnostic purposes for those minerals principally affecting production. For these reasons, animal indicators of manganese status are not covered. Blood manganese concentrations are very low and other tissues show relatively small changes with deficiency (Paynter 1987).

Similarly, while determination of mineral concentrations in faeces potentially provides an indication of mineral intake from all dietary sources including soil, and overcomes dietary sampling problems associated with selective intakes, final faecal concentrations are dependent on feed digestibility and may not account for true availability of minerals from complex sources such as soils. These two major variables alone limit the defining of critical faecal concentrations as direct measures of mineral nutrition in the animal.

Several mineral indicators used for sheep show a relatively wide range of values in
their correlation with dietary uptake. Others have a limited range of application, principally relating to nutrition below adequacy. Examples of the former include blood selenium concentrations or glutathione peroxidase activities with selenium nutrition, plasma vitamin B12 with cobalt nutrition, plasma sulfate with sulfur nutrition, liver copper with copper nutrition and urine sodium and magnesium as possible indicators for sodium and magnesium. Examples of the latter include plasma copper, zinc, magnesium and phosphate, all of which plateau with adequacy due to homeostatic mechanisms such as urinary thresholds or controls on enzyme synthesis. Applicability of each of the major indicators is shown in Tables 2 and 3.

### Table 2. Summary of significant macro-mineral indicators in the sheep.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Units (^a)</th>
<th>Range</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Deficient</td>
<td>Marginal</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plasma Ca(^b)</td>
<td>mmol/L (mg/L)</td>
<td>&lt;1.25 (&lt;50)</td>
<td>1.25–2.12 (50–85)</td>
</tr>
<tr>
<td>eye fluid Ca(^b)</td>
<td>mmol/L (mg/L)</td>
<td>&lt;1.0 (&lt;40)</td>
<td>–</td>
</tr>
<tr>
<td>urine Ca(^c)</td>
<td>(\mu)mol/mosmol</td>
<td>–</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plasma Mg(^b)</td>
<td>mmol/L (mg/L)</td>
<td>&lt;0.33 (&lt;8)</td>
<td>0.33–0.74 (8–18)</td>
</tr>
<tr>
<td>eye fluid Mg(^d)</td>
<td>mmol/L (mg/L)</td>
<td>&lt;0.5 (&lt;12)</td>
<td>–</td>
</tr>
<tr>
<td>urine Mg(^c)</td>
<td>(\mu)mol/mosmol</td>
<td>&lt;1</td>
<td>1–2</td>
</tr>
<tr>
<td>Phosphorus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plasma inorganic P(^b)</td>
<td>mmol/L (mg/L)</td>
<td>–</td>
<td>&lt;1.3 (&lt;40)</td>
</tr>
<tr>
<td>faecal P</td>
<td>mmol/kg DM (g/kg DM)</td>
<td>&lt;64.5 (&lt;2)</td>
<td>–</td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>urine Na(^c)</td>
<td>(\mu)mol/mosmol</td>
<td>&lt;1</td>
<td>1–10</td>
</tr>
<tr>
<td>parotid saliva</td>
<td>mmol/L:mmol/L</td>
<td>&lt;5</td>
<td>5–14</td>
</tr>
<tr>
<td>Na/K(^c,e)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plasma inorganic S(^b)</td>
<td>mmol/L (mg/L)</td>
<td>&lt;0.3 (&lt;10)</td>
<td>0.3–0.8 (10–25)</td>
</tr>
</tbody>
</table>

\(^a\) Alternative units with corresponding values are shown in parentheses. 
\(^b\) Paynter (unpublished data). 
\(^c\) Caple and Halpin (1985). 
\(^d\) Lincoln and Lane (1985). 
\(^e\) SCA (1990).
Sampling

Samples taken for analysis must be representative of the presenting disease or the flock. In a disease investigation, samples should be taken from both affected and normal animals. If the sampling is for monitoring purposes, the number of sheep to be sampled depends on the expected normal variance for the indicator being measured.

Table 3. Summary of significant trace mineral indicators in the sheep.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Units</th>
<th>Range</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Deficient</td>
<td>Marginal</td>
</tr>
<tr>
<td>Cobalt</td>
<td>nmol/L (µg/L)</td>
<td>0.18 (&lt;0.25)</td>
<td>0.18–0.52 (0.25–0.7)</td>
</tr>
<tr>
<td>plasma B_{12}^{b}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>µmol/L (mg/L)</td>
<td>&lt;4.7 (&lt;0.3)</td>
<td>4.7–9.4 (0.3–0.6)</td>
</tr>
<tr>
<td>plasma Caeruloplasmin^{c}</td>
<td>U/L</td>
<td>&lt;5</td>
<td>5–40</td>
</tr>
<tr>
<td>red cell SOD^{c,g}</td>
<td>U/g Hb</td>
<td>&lt;200</td>
<td>200–400</td>
</tr>
<tr>
<td>liver Cu^{c}</td>
<td>µmol/kg wet (mg/kg wet)</td>
<td>&lt;80 (&lt;5)</td>
<td>80–240 (5–15)</td>
</tr>
<tr>
<td>Iodine</td>
<td>µmol/L (µg/L)</td>
<td>&lt;1</td>
<td>1–2</td>
</tr>
<tr>
<td>plasma T_{4}^{e} lamb/ewe^{b,d}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>milk^{b,d}</td>
<td>µmol/L (µg/L)</td>
<td>&lt;0.6 (&lt;80)</td>
<td>–</td>
</tr>
<tr>
<td>thyroid/body weight^{b,d}</td>
<td>g/kg</td>
<td>&gt;0.4</td>
<td>–</td>
</tr>
<tr>
<td>Selenium</td>
<td>µmol/L (µg/L)</td>
<td>&lt;0.25 (&lt;20)</td>
<td>0.25–0.76 (20–60)</td>
</tr>
<tr>
<td>whole blood Se^{b}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>whole blood GSHpx^{d,g}</td>
<td>U/g Hb</td>
<td>&lt;30</td>
<td>30–50</td>
</tr>
<tr>
<td>plasma Se^{b,e}</td>
<td>µmol/L (µg/L)</td>
<td>&lt;0.15 (&lt;12)</td>
<td>0.15–0.51 (12–40)</td>
</tr>
<tr>
<td>Zinc</td>
<td>µmol/L (mg/L)</td>
<td>&lt;6.1 (&lt;0.4)</td>
<td>6.1–9.2 (0.4–0.6)</td>
</tr>
</tbody>
</table>

^{a} Alternative units with corresponding values are shown in parentheses.  
^{b} SCA (1990).  
^{c} Paynter (1986).  
^{d} Hosking et al. (1986).  
^{e} Paynter et al. (1993).  
^{f} Whelan et al. (1994).  
^{g} SOD = superoxide dismutase, T_{4} = thyroxine, GSHpx = glutathione peroxase.
For blood selenium or glutathione peroxidase, the minimum is 5–7 animals (Paynter et al. 1993). A minimum of 10 animals is suggested for blood copper, vitamin B₁₂ (Grace 1983) and for urine sodium and magnesium (Caple and Halpin 1985). For monitoring purposes, samples should preferably be taken at the time of year when lowest nutrition of a mineral is expected.

Prior to sampling, sheep should not be subjected to extended periods of starvation. This has been shown to affect the concentrations of several mineral indicators including plasma vitamin B₁₂ (Miliar et al. 1984) and plasma phosphate (SCA 1990). Age of the sheep being sampled also may have an effect. Plasma vitamin B₁₂ concentrations are normally low in preweaned lambs; weaned or adult sheep should be sampled to assess flock cobalt nutrition (Hosking et al. 1986). Similarly, plasma copper and caeruloplasmin are normally lower in neonatal lambs than in older lambs or ewes, but not red cell copper superoxide dismutase (Paynter 1986). In the sheep there are also significant differences between serum and plasma copper concentrations and caeruloplasmin activities, as caeruloplasmin is sequestered into the clot during clot formation (Paynter 1982).

Contamination associated with sampling can be a major problem where minerals are assayed directly, particularly at trace concentrations. Sample collection tubes and associated processes should be checked to ensure that contamination is negligible. Faecal contamination of urines may present major errors in urinary magnesium and sodium determinations (Caple and Halpin 1985). Post collection treatment and storage of samples should also be considered. Haemolysis may interfere with colorimetric endpoint assays; the subsequent hydrolysis of red cell phosphate esters may increase free phosphate concentrations in plasma.

**Analysis**

Many of the major mineral assays suitable for assessment of mineral nutrition in sheep are now well defined analytically, with commercial kit methods available for most. In addition, commercial quality control materials, suitable for use in both internal and external quality assurance programs, are now available for most blood, urine and tissue mineral assays. Analytical methods and results should be verified by using these materials.

Where there is a high correlation between two indicators in assessing nutrition of a mineral, the indicator used is often determined on the basis of suitability of equipment and expertise available. The assay of glutathione peroxidase activity or total selenium in whole blood, and caeruloplasmin activity or total copper in plasma are examples. In each case, there is a high correlation between indicators (Caple et al. 1980; Paynter 1986). Each has advantages or disadvantages in relation to stability, contamination, equipment requirements etc., and indicators should be chosen which most suit these particular requirements.

Haemolysis in samples can be a major source of interference in some colorimetric endpoint assays. This potential interference should be removed by appropriate sample pretreatment or appropriate sample blank-
ing in the assay. Potential interference in vitamin B₁₂ assays by inactive analogues of vitamin B₁₂ is not a significant factor in sheep plasma. Only minor amounts of analogues appear to be absorbed and present in the plasma of sheep relative to that measured with cattle (Halpin et al. 1984).

In the determination of mineral concentrations in single urine samples, variations in mineral concentrations associated with changes in water intake may be greatly reduced by the inclusion of a measure of total urine solute concentration, using either osmolarity or specific gravity in the determination (Caple and Halpin 1985).

Interpretation

Summaries of mineral indicators in the sheep and the ranges associated with deficient and marginal nutrition of these minerals are shown in Tables 2 and 3. It is emphasised that the values in these tables are approximate. Correlations and calibrations of mineral indicators with field treatment response trials are often compromised by the large seasonal variations apparent with mineral nutrition (Hosking et al. 1986). Few indicators, particularly in trace minerals, have been extensively calibrated against production responses under true steady-state equilibrium conditions.

Thus, Whelan et al. (1994), on the basis of their field responses in wool growth in sheep, suggest that critical values for whole blood and plasma selenium concentrations may be 0.76 and 0.50 μmol/L, respectively, somewhat higher than the values derived in previous reviews (e.g. Hosking et al. 1986; SCA 1990). However, using the correlation established between glutathione peroxidase activity and selenium concentrations in whole blood of sheep (Caple et al. 1980), 0.76 μmol/L is similar to that established independently using glutathione peroxidase as an indicator of selenium nutrition (Paynter et al. 1993). In the practical sense, the between- and within-seasonal variations in these indicators with sheep grazing at pasture overshadow these apparent differences in defining deficient or marginal nutrition.

For several minerals, the phase of deficiency, i.e. depletion or repletion, can be determined at a single sampling time point. This determination is possible where indicators for the same mineral have different turnover rates. For copper, red cell copper or red cell superoxide dismutase provide a longer term reflection of copper intake than plasma copper. Simultaneous measurement of both these indicators can be used to determine if an animal is in a depletion, repletion or steady-state phase of copper nutrition (Paynter 1986).

A similar approach is possible for determining selenium nutrition. Whole blood selenium concentrations and glutathione peroxidase activities reflect selenium intake from several months previously. In contrast, plasma selenium concentrations respond more rapidly to selenium intake (SCA 1990; Paynter et al. 1993).

Interpretation of results should always reflect the seasonal nature of mineral deficiencies. For mineral indicators well correlated with dietary mineral intake over a wide range, the expected mineral nutrition through successive seasons can often be
broadly predicted. This is not possible for indicators with a range of applications largely confined to nutrition below adequacy, and interpretation of these indicators should be confined to the period of sampling only.

References


Trace Element Supplements for Sheep at Pasture

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Glenside, South Australia 5065
Australia

Outline

Oral supplements
  Drenches
  Copper oxide particles
  Intraruminal pellets
  Large intraruminal boluses
  Intraruminal devices of variable geometry

Injectable supplements

Indirect methods of supplementation
  Fertilizers and foliar sprays
  Mineral licks and blocks
  Water medication

Detrimental effects and interactions

Concluding comments

Acknowledgments

References
Various methods are available for supplying trace elements to grazing sheep. A survey of stock owners in South Australia showed that injections were regarded as the most convenient means of administering trace elements to grazing animals (Judson and Taylor 1993). Soil or plant treatments, mineral licks or blocks, drenches and intraruminal pellets are also convenient means of providing trace elements.

Once the need for a trace element supplement has been established (Paynter, this publication), the choice of treatment will be influenced by a number of factors including the likely duration of the deficiency, additional management procedures required, the cost of the supplement and whether the pasture may also respond to the trace element. Table 1 gives a summary of the common supplements used to correct or prevent trace element deficiencies in sheep. Figure 1 shows some of the delivery systems available.

**Oral Supplements**

**Drenches**

Drenches are generally cheaper than other supplements but they are usually short-acting, particularly for elements such as zinc and manganese (Egan 1972) which the animal does not have the capacity to store in physiologically significant quantities. In practice, the inconvenience of frequent treatments can be reduced if the trace element can be given with other supplements such as an anthelmintic. However, the reliance on infrequent anthelmintic drenches as the sole vehicle may result in variable and transient responses to supplementation and such responses also may be impaired by the anthelmintic (Suttle et al. 1988).

Cobalt drenches are short-acting although the animal can store vitamin B$_{12}$, the physiologically active form of cobalt, in the liver. The major limitation is the poor retention of the cobalt in the rumen to permit its incorporation into the vitamin by the rumen microorganisms. For young rapidly growing sheep, weekly drenches of cobalt were needed to maintain optimum growth rate but larger and less frequent doses of cobalt were not as effective (Stewart et al. 1955; Lee and Marston 1969).

Although the liver of sheep can readily store selenium and copper, the maximum single oral dose is limited by consideration of toxicity. Sodium selenate and sodium selenite are widely used as selenium supplements and both are equally effective in raising blood selenium concentrations when given orally or subcutaneously, although the latter method is more effective (Meads et al. 1980). Most of the selenium in a salt given by mouth is reduced in the rumen to elemental selenium which is unavailable. The suggested dose of selenium for sheep, based on blood analysis rather than growth rate, is 0.1 mg/kg liveweight and the duration of effect has varied from 0.5–3.0 months (Hosking et al. 1986; Tasker 1992). The variation in estimates of the effective life of the supplement is due in part to the severity of the deficiency and to the method of assessment, whether responses to the supplement are measured in plasma or whole blood and the concentration of selenium accepted as indicative of adequate status (Langlands et al. 1990b).
**Figure 1.** Delivery systems for trace elements. The scale shown is centimetres.

**Intraruminal pellets**

(a) Selenium pellets (10 g) containing 5% by weight elemental selenium in an iron matrix.

(b) Cobalt pellets (10 g) containing 30% by weight cobaltic oxide in an iron matrix.

(c) Salt encrusted cobalt pellets recovered from the rumen of sheep.

(d) Demonstration of the use of an applicator in administering pellets to sheep.

(e) Steel grub screws (10 g) are given orally with selenium or cobalt pellets to reduce salt deposition on the pellet.

(f) An applicator used to administer cobalt and selenium pellets, steel grub screws and copper oxide capsules to sheep.

**Copper oxide particles**

(g) Copper oxide particles (2.5 g) in a soluble capsule. The particles are composed of a mixture of cupric and cuprous oxide coating a copper core.