1. Introduction

Trace element supplementation of grazing animals and pastures has produced spectacular improvements in the productivity of sheep, beef and dairy enterprises in Victoria. This fact is widely known to farmers, and interest in the use of trace elements is further stimulated by suppliers of a wide range of trace element remedies, licks, mineral additions and fertilisers.

Indeed there is a tendency among farmers and others to assume that if pastures or livestock are not thriving, then the cause must be trace mineral deficiency. Such an assumption can be quite misleading. Compared with other soil fertility problems, drought, underfeeding and parasitism, trace element deficiencies are not the major cause of unsatisfactory productivity of pastures and grazing animals in southern Australia.

It is essential that pasture or animal problems be investigated by professional advisers skilled in the mineral requirements of pastures and livestock and supported by competent field and analytical laboratory backing.

1.1 *Mineral requirements of livestock*

Minerals required by livestock are classified as either macrominerals or trace elements, on the basis of the quantities required.

The **macrominerals** (average daily requirement in gram amounts per head) are needed for structural purposes (calcium, phosphorus, sulphur), in the maintenance of osmotic and acid-base balance (sodium, potassium, chlorine) and as contributors to energy transfer, nerve impulse transmission, and normal enzyme activity (potassium, calcium, magnesium, phosphorus).

The **trace elements** (average daily requirement in microgram amounts per head) act primarily as catalysts in enzyme systems. They function either as co-factors (manganese) or by contributing structurally and functionally to the activities of enzymes (zinc, copper, molybdenum, selenium), hormones (iodine) or vitamins (cobalt).

It is important to note that while the information published in textbooks and requirement statements (ARC 1980, Grace 1983, NRC 1978, Underwood 1981), summarised in table 1.1, is useful for preparing feed mixtures, it is really of limited use in 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 and mineral composition, selective grazing, and pasture shortages due to drought or high stocking rates, make it difficult to predict mineral intake in extensive grazing situations.

Table 1.1: Recommended minimum element concentrations in pasture dry matter for grazing cattle and sheep[1]

	Cattle	**Sheep**
Macrominerals	**g/kg**	**g/kg**
Calcium	3.5	3.0
Phosphorus	3.0	2.0
Sodium	1.5	1.0
Chlorine	2.0	1.0
Potassium	5.0	4.5
Sulfur	1.5	2.0
Magnesium	1.5	1.0
Trace elements	**mg/kg**	**mg/kg**
Iron	40	40
Zinc	25	20
Manganese	25	25
Copper[2]	5 to 12	5
Cobalt	0.10	0.10
Iodine	0.50	0.50
Molybdenum	0.10	0.10
Selenium	0.05	0.05

[1] Based on data presented by the ARC (1980), Grace (1983), NRC (1978), Underwood (1981) these amounts represent the average requirements for growth, pregnancy or lactation, in grazing livestock.
[2] Copper requirements are strongly affected by the concentrations of molybdenum, sulphur and iron.

1.2 *Tests to assess trace element nutrition in livestock*

A range of laboratory tests has been developed to provide a practical means for assessing the trace element nutrition of pastures and grazing animals.

Biochemical tests on diets (pasture and supplements), body fluids (blood, urine, saliva) and tissues (liver, bone) have been devised for the assessment of nutritional status of livestock.

It is important to emphasise that these biochemical tests assist in the determination of trace element nutrition, but are not substitutes for the traditional approach of investigating broader health and production problems which may be more important.

A definitive diagnosis can be made only from measured improvements in health and production of animals following supplementation. However, carefully controlled response trials cannot always be conducted on farms and predictions of likely benefits from supplementation may have to be based on information relating production responses to the results of biochemical tests of nutritional status.

A range of biochemical indicators (table 1.2) provides a practical means for assessment of trace element status of animals in a flock or herd. These indicators and their values are tabulated in the chapter on each trace element.

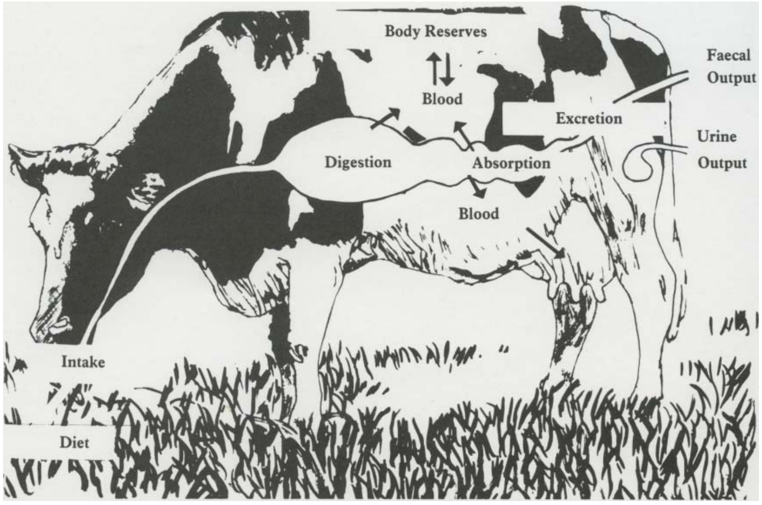

Table 1.2: Recommended biochemical indicators for detection of trace element deficiencies in livestock

Mineral	Component
Copper	Liver copper Plasma copper and ceruloplasmin Erythrocyte copper and superoxide dismutase Dietary copper, molybdenum, sulphur
Cobalt	Liver vitamin B12 Plasma vitamin B12 Dietary cobalt
Selenium	Blood glutathione peroxidase Liver selenium Dietary selenium
Iodine	Milk iodine Thyroid iodine content
Manganese	Dietary manganese
Zinc	Plasma zinc Dietary zinc

1.3 Mineral requirements for pasture production

At least 15 mineral elements are considered to be essential for plant growth.

The **macrominerals** (present in g/kg concentrations) are nitrogen, phosphorus, potassium, calcium, magnesium, sodium, chlorine and sulfur.

The **trace elements** (present in mg/kg concentrations) include manganese, iron, copper, zinc, molybdenum, boron and cobalt (Grace 1983). Stimulation of growth has been reported for aluminium, arsenic, chromium, fluorine, iodine, lithium, selenium and titanium, but the evidence is generally inconclusive and most of these elements are more commonly known for their toxicity to plants (Sauchelli 1969).

While the roles of the macrominerals in the physiology of plants is generally well understood, those of the trace elements is much less so. Plants require minerals for protein synthesis (nitrogen, sulfur), structural purposes (calcium, magnesium, boron), photosynthesis (magnesium, iron, manganese, molybdenum, chlorine), energy transfer (phosphorus), enzyme activity (potassium, calcium, magnesium, copper, zinc, molybdenum), cell turgor and cation-anion balance (potassium, calcium, magnesium, sodium, manganese) and nitrogen fixation in legumes (molybdenum, cobalt, iron).

The minimum concentrations of minerals in plants required for maximum growth have been determined for many elements using nutrient solution culture (Chapman 1966, Loneragan and Snowball 1969, Asher and Ozanne 1967). However, these concentrations may be considerably lower than those required for optimum yield in the field (table 1.3). Plants in solution culture do not have to overcome the effects of various environmental stresses such as high manganese, salt and low oxygen in the root zone, high transpiration rates and grazing pressure as occurs in the field.

Different plant species and cultivars have different requirements for a mineral. Soil deficiencies can therefore influence the botanical composition of pastures as well as their productivity.

Table 1.3: Minimum element concentrations in whole tops of subterranean clover for its optimum growth

Trace element	mg/kgDM
Zinc	14
Manganese	25
Copper	6
Cobalt	0.04
Molybdenum	0.5

1.4 Tests to assess trace element levels in pastures

Soil and plant tests can be useful aids in the formulation of fertiliser recommendations to improve pasture growth.

Soil testing attempts to represent the quantity of element that is readily available to the plant. Laboratories around the world use different soil test methods.

To be useful the soil tests must have been calibrated with growth responses in local field trials because of likely soil and other environmental differences. For elements such as potassium and phosphorus, departmental soil testing methods have been found to be quite useful; but soil testing has not been useful for most other elements, particularly the trace elements.

The small concentrations and the variety of chemical forms of trace elements in the soil, plus the multiplicity of factors that may affect their availability to plants, make soil tests for trace elements very difficult to interpret. For example, soil copper analysis is no longer available from this Department because research over many years indicated that the correlation between soil copper (EDTA Cu) and copper deficiency in both pastures and livestock was poor (Conley 1983). Many private laboratories continue to offer these analyses.

Plant tissue analysis is more useful than soil testing in the assessment of the trace element status of both plants and animals. Minerals are normally measured as total elements, thus making the testing itself relatively easy. For some elements however, such as selenium, cobalt and molybdenum, whose concentrations are normally very low, inadequate sensitivity in detection and soil contamination have been problems.

Appropriate and representative sampling of both soils and plants is essential. High fertility patches or other abnormal areas should be avoided when sampling soil and pasture. An adequate number of soil cores and standardisation of depth of soil sampling are important factors affecting the interpretation of results. Specific sampling of areas of poor pasture growth or of particular plant species or plant parts, perhaps at a critical time of the year, may be required. Recent studies on the critical concentrations of trace elements in plants have highlighted the mobility of minerals within plant tissues; it has been recommended that only the youngest fully open leaf (YFOL) of a particular species should be sampled for some trace element analyses.

Analysis of mixed herbage, representing what the animals are eating, will be more useful than testing a selected plant species when assessing the nutrition of grazing animals.

1.5 Definitions, units and abbreviations

The concentrations of trace elements in the diet, blood, liver or milk are quoted on a weight basis (mg/l; mg/kg) or a molar basis (mmol/l; mmol/kg).

kg	= kilogram	(1000 gram)
mg	= milligram	(1/1000 g)
ug	= microgram	(1/1000 mg)
ng	= nanogram	(1/1000 ug)
	= litre	
ml	= millilitre	(1/10001)
ppm	= parts per million = mg/kg	
mol	= mole = atomic mass in grams	
mmol	= millimole	(1/1000 mol)
U	= units of enzyme activity	

Conversion of values from a weight basis to a molar basis is done by dividing the weight values by the atomic mass of the trace element, as in the following equation:

$$\frac{\text{mg/kg}}{\text{atomic mass}} = \text{mmol/kg}$$

Analysis of plant and animal tissues is usually given on a dry matter basis (mg/kg DM). With animal tissue the analysis is sometimes given on a wet basis (mg/kg wet weight).

Atomic masses and chemical symbols which may be useful in this review are shown in table 1.4.

Table 1.4: Chemical symbols and atomic mass for each of the elements discussed in this review

Aluminium (Al)	26.9	Iron (Fe)	55.8
Boron (B)	10.8	Manganese (Mn)	54.9
Cobalt (Co)	58.9	Molybdenum (Mo)	95.9
Copper (Cu)	63.5	Selenium (Se)	78.9
Iodine (I)	126.9	Zinc (Zn)	65.4

Range of normal values

Most government and private laboratories will provide a reference range of values representing deficient, marginal or adequate concentrations for the assays they use. For this review, deficient and marginal are described as follows:

Deficient indicates depleted reserves associated with impairment of biochemical or physiological processes; response to treatment may be expected.

Marginal indicates reduced reserves only; economic responses to treatment are likely only if there is a further period of deficiency.

Soil pH

There are several methods of assessing soil pH. All measurements of soil pH referred to in this review have been on 20 g soil in 100 ml water (1:5).

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Appendix 1

Index of trace elements and vitamins for each numbered reference

A limited number of single papers or manuals refer to "all" trace elements and vitamins as noted below. These numbers are not therefore listed under each individual trace element and vitamin.

"All" Trace Elements: 3, 77, 125, 233, 288, 327, 344, 345, 349

"All" Vitamins: 3

INDIVIDUAL ELEMENTS

INDIVIDUAL VITAMINS