The multifactorial nature of trace nutrient nutrition and the supplementation of trace elements to livestock in South Africa

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Requirements

The requirement of an animal for a trace mineral is based on the assumption that all other minerals and interfering components are present at specific required levels. Any deviation would change the requirement for the specific mineral. Underwood & Suttle (1999) stated that: "Ideally diagnostic limits (like dietary requirements) should be set on the assumption that the supply of other nutrients is non-limiting." White (1996) pointed out that the critical value for a mineral requirement is determined experimentally with all other nutrients and conditions non-limiting and within the normal physiological range.

Trace element requirements are a function of some predetermined measure of response (White, 1996). However, the criteria and critical values accepted as requirements are continuously changing because of the following reasons (Corah, 1996):

- The dramatic improvement in productivity of livestock because of the genetic improvement of farm animals and refinements in management, health control and nutrition;
- Major advances in technology which led to new insight in the role and function of micronutrients, e.g. their role in the immune system of the animal.
- Major advances in dissipating technology and transmitting information and in tracing of new information.

According to Mertz (1995) the use of new analytical methods to induce trace element deficiencies and the development of reliable "trace" analyses enabled nutritionists and toxicologists to apply much stricter criteria than in the past to develop criteria for trace element requirements. As a consequence, estimates of nutrition requirements rose and those of toxicological limits declined.

Determination of a requirement will be affected also by the prevailing conditions or antagonists at the test site. In New Zealand compared to other countries, relatively low levels of selenium supplementation overcome a deficiency of the mineral (Grace & Clark, 1991). Requirements and blood selenium concentration as a criterion of deficiency are lower than in countries such as the United States. This lower need for selenium could be due to high levels of vitamin E in the pasture or a low challenge to selenium dependent functions in the animal.

Multifactorial nature of trace minerals metabolism

Factors affecting bio-availability

One of the main factors affecting bio-availability of trace elements is interactions, both antagonistic and synergistic, between minerals. This is highlighted by the well-known wheel of interactions between minerals. However, such interactions are often not simple, direct or easily predictable. Judson & McFarlane (1998) pointed out the difficulty in applying Suttle & McLauchlan's formula (ARC, 1980) for predicting availability of dietary copper based on its interaction with molybdenum plus sulphur, because iron at concentrations of between 500 and 6000 mg / kg feed inhibits the availability of copper as well. To this could be added the other minerals interacting with copper, such as zinc, sulphur independent of molybdenum and cadmium. Such multiple interactions probably exist in the metabolism of most, if not all trace minerals.

The different chemical form and valence state of elements differ in bio-availability. Minerals in the organic form do not react to vitamins and other ions in the same way as inorganic minerals. Consequently, a completely different scenario in terms of requirements and conditions for optimum supply exists where minerals present in organic compounds are fed (McDowell, 1996).

Differences in absorption of an element will exist when it is ingested as part of a diet or on an empty stomach, e.g. elements in drinking water (Mertz, 1995). This would be relevant especially in monogastric animals and hind-gut fermenters.

Many non-nutritional factors can affect mineral metabolism, e.g. gastrointestinal parasites (Judson & McFarlane, 1998), genetic differences among breeds and individuals (Suttle, 1994), age, etc.

Synergistic reactions

A synergistic or complementary role between vitamin E and selenium in glutathione peroxidase is well documented. This interaction does not displace the requirements for each nutrient, but high vitamin E levels in pastures may lower the dietary requirements for selenium (Judson & McFarlane, 1998). It is hypothesised that vitamin E and selenium form part of an involved and integrated system of antioxidants which protect the body against harmful end-products of metabolism, inflammatory reactions and foreign pollutants, in general called “free radicals" (Aruoma, 1997). The antioxidant system comprises of several components:

a) Preventative antioxidants, e.g. caeruloplasmin (Cu), metallothionine (Cu), albumin (Cu), transferrin (Fe), ferritin (Fe) and myoglobin (Fe), preventing the formation of new “Reactive Oxygen Species” (ROS), such as $O_2^{X!}$, OH^X and other non-radical oxygen derivatives such as hydrogen peroxide (H_2O_2) and hypochlorous acid (HOCl).

b) Scavenging antioxidants which remove ROS, once formed, thus preventing radical chain reactions: They consist of enzymes such as superoxide dismutase (Cu, Mn, Zn) glutathione peroxidase (Se), glutathione reductase, catalase, metalloenzymes and small molecules such as glutathione, ascorbate (vitamin C), tocopherol, (vitamin E), bilirubin, uric acid, carotenoids and bioflavonoids (Randox Laboratories brochure).

Although individual antioxidants do not necessarily act against each kind of free radical, their protection of the body is a combined action of all, where one may alleviate the need for another.

Supplementation of trace minerals

White (1996) pointed out that large differences exist between authorities with respect to recommended requirements, mainly because of the differences in absorption coefficient used and whether or not a safety factor has been included to meet the requirements of practically all animals. Recommended requirements are thus well above minimum requirements, usually two standard deviations above the mean. It is obvious that it is impossible to state rigid requirements for livestock. Underwood & Suttle (1999) proposed the use of “marginal bands” to cover the range between adequate and inadequate. This permits the user to allow for the inevitable uncertainties surrounding precise mineral needs in a particular context. As the number of individual falling within the marginal band increases, so does the likelihood of a significant proportion of the population benefiting from mineral supplementation.

An important decision of the animal nutritionist is to decide which minerals and how much of each should be supplemented. Except for a knowledge on the mineral requirements of the animal, as much as possible information on the quantity of each mineral, including antagonists, supplied through the animal's feed and water should be obtained and be used. In many of his publications on the topic, Lee McDowell promotes the supplementation of trace minerals based on the requirements of the grazing animal. Using the NRC recommendations, he suggests the following levels of supplementation (Table 1).

McDowell (1996) stressed that it is advisable to formulate free-choice mixtures on the basis of analyses or other available data, supplementing a proportion of the requirement, e.g. 25 or 50% according to the specific situation. “However, when no information on mineral status is known for a given region, a free-choice complete mineral supplement is definitely warranted”. However, Underwood & Suttle (1999) warned against such a "free-choice complete mineral supplement" approach and stated it as follows: “The provision of extra minerals beyond the animal’s needs is economically wasteful, confers no additional benefit on the animal and can be harmful. Commercial mineral mixtures often contain minerals which, although basically essential to the animal, are already present in adequate amounts in the pastures and feeds the animals will consume. There can be no automatic justification for the purchase and use of such “shotgun” mixtures of minerals, which are designed to cover a very wide range of environments and feeding regiments and which often contain an unnecessarily wide margin of safety as an insurance against deficiency. The shotgun approach can be dangerous because of a possible disturbance of the overall dietary mineral balance and the consequent adverse effects on the absorption and utilisation of certain minerals by the animal.”

Mertz (1994) referring to human nutrition, raised the same warning: “There is an optimal intake for every nutrient, beyond which deleterious interactions can lead to marginal toxicities.” He also warned against the reducing of only one risk factor of a multifactorial condition by nutrition intervention. Any substantial change of one nutrient for extended periods will affect the requirement for other nutrients with which the first interacts.

Table 1: Quantities of trace mineral supplements to meet 25%, 50% and 100% of requirements (McDowell, 1996)

Element	NRC Requirements mg/kg DM	Percentage of mineral in mixture (50 g)* for the following % requirements		
		25%	50%	100%
Cobalt	0.1	0.0005	0.001	0.002
Copper	10	0.05	0.10	0.2
Iodine	0.8	0.004	0.008	0.016
Manganese	25	0.125	0.25	0.5
Zinc	50	0.25	0.5	1.0
Iron	50	0.25	0.5	1.0
Selenium	0.2	0.001	0.002	0.004

* This assumes an average consumption of 50 g per day of mineral mixture for cattle and 10 kg of total dry feed per animal daily.

Legislation in South Africa

At present Act 36 of 1947 prescribes that the level of trace mineral supplementation should be determined by the level of phosphorus supplemented. One scientific argument against this approach is that the metabolism of none of the trace elements is related directly to the metabolism of phosphorus. In Table 2 the proportion of trace mineral requirements supplied if supplemented according to the Act, is calculated.

Table 2 Trace mineral supplementation, according to Act 36 of 1947, assuming P supplementation of 6 g or 12 g P /day for beef animal consuming 10 kg dry matter per day

Element	Act 36 of 1947 / 6 g P / day mg/day	Required by cow (NRC) 10 kg DMI		Supplemented % of requirement	
		mg/kg	mg/day	P6 lick	P12 lick
Fe	75-150	50	500	15-30	30-60
Co	0.15-0.3	0.1	1.0	15-30	30-60
Cu	15-30	10	100	15-30	30-60
Mn	60-120	25	250	24-48	48-96
Zn	60-120	50	500	12-24	24-48
I	0.75-1.5	0.8	8.0	9-19	19-39
Se	0.15-0.3	0.2	2.0	7.5-15	15-30
Mo	0.75-1.5	-	-	-	-

At the P6 level of supplementation approximately 25% of the requirements of the cow is supplied and at the P12 level 50% up to almost 100% of requirements are supplemented. This calculations are based on the NRC standards, as used by McDowell (1996), and are, in general, higher than those published by other organisations (White, 1996).

Mineral supplementation and status of livestock in different regions

Although one can accept McDowell's suggestion that a "shotgun" approach can be used when no information at all is available on the trace mineral supply situation in a specific area, attempts should be made to obtain such information. It seems advisable that the decision on the supplementation of trace minerals to grazing animals should be based on a knowledge of the mineral status of the animals in the specific region. General deductions can be made if the soil type, soil pH and type of vegetation are known (Judson & McFarlane, 1998). McDowell (1996) suggested that for most regions it would be appropriate to include selenium, unless toxicity problems have been observed; that iron could be supplemented in temperate region, but that both iron and manganese could be excluded in regions with acid soils. He recommended that, where internal parasitism is a problem, iron supplementation might be beneficial. It can be accepted that it is likely that animals in region with calcium rich soils may suffer from a deficiency of zinc and manganese. However, exceptions exist, e.g. in the Ghaap plateau area of the Northern Cape, where manganese is mined, the soil, even the limestone, can contain high concentrations of manganese (Van Ryssen, 1992).

As the knowledge of the mineral nutritional situation in specific regions is expanding, regions can be mapped according to probable mineral status of the grazing animals there. The information for such maps can be arrived from soil mineral content, plant mineral concentrations or mineral status of the animals themselves, e.g. Oldfield (1999) put together all available information on selenium status worldwide. In South Africa research has been conducted to identify areas of deficiency and excess, e.g. Van der Merwe & Perold (1967) investigated the problems of cobalt ("duinetering") and copper deficiencies in the old Cape Province; Bath (1979) published a map of the copper status of sheep in the Karoo and Van Tonder (1986) summarised the problem of copper toxicity in the Karoo; Boyazoglu (1976) attempted to identify mineral deficient areas based on the mineral concentrations in the livers of grazing animals; etc. Unfortunately plenty of South African information have never been published, or appeared in theses and publications with a limited distribution.

Furthermore, it should be realised that some information may not be not relevant or even reliable anymore, e.g. some of the selenium analyses done in the 1960's (Bath, 1979). Laboratory and experimental techniques to measure mineral concentrations and enzyme activities improved, or the situation in an area might have changed. This could be due to the wider distribution of feeds between regions would cancel out regional problems, farming practices changed or mining activities and other forms of pollution could have changed the situation in an affected area. Examples of these are: acid rain and other forms of pollution could increase the occurrence of selenium and copper deficiencies near factories and power generating plant; copper pollution in the vicinity of the Phalaborwa copper mine; the recent occurrence of copper and selenium deficiencies in beef cattle in Natal was suggested to be the result of the exclusion of chicken litter as a winter supplement to the animals; etc. Furthermore, the contribution of water to the mineral intake has largely been ignored and underestimated (Meyer, unpublished results). Different animal species are becoming important, e.g. in game farming where parameters for mineral status are largely unknown, e.g. the Tsessebe seems to be prone to selenium deficiency (Grant, 1999, personal comm.).

Indicators of mineral status

It is important to ensure that the criteria used to try to establish the mineral status of animals would supply reliable results. Care must be taken not to waste money and time on collecting and measuring tissues and material which are worthless as indicators of mineral status (Van Ryssen, 1997). In Table 3 the tissues and material which are worth analysing, are presented. It is interesting to note that liver analyses, which have been used widely for all possible minerals, are considered worth analysing only to determine the copper, selenium and vitamin B_{12} status of animals. Even with the measurements suggested, it is important to interpret the results correctly, because some measurements are reliable only within certain limits of mineral intake or mineral status of the animal (Paynter, 1996).

New analytical techniques are continuously developed, especially in human health studies, to measure the trace nutrient status of the body. Arthur (1999) published a number of functional measures to predict the iodine and selenium status of the body. Analytical kids have been developed to monitor both individual antioxidant components and the overall status of the antioxidant system in the body (Randox Laboratories brochure). Techniques have been developed and are used also in human health studies where total oxidative damage, oxidative damage to lipids and proteins are measured (Aruoma, 1997). These developments are sure to be taken over in investigations on the trace nutrient status of farm animals and should contribute to the development of a better basis to predict the nutrient status of animals and to supply supplements accordingly.

Table 3 Useful analyses in assessing mineral disorders of livestock (Judson & McFarlane, 1998) *(Values in brackets and italics, added by author)*

Element	Liver	Blood / Plasma	Milk	Feed *(Water)*
Co	B_{12}	MMA, B_{12}	B_{12}	
Cu	Cu	Cu, *(Cp, SOD)*		Cu, Mo, S, Fe, (Z*n)*
I		T_4, T_3	I	
Mn				Mn *(Ca,Fe)*
Se	*(Se)*	Se, GSH.Px	Se	*(Se, S, As,Ag,Mo)*
Zn		Zn		Zn *(Ca,Fe Cu)*

MMA = Methylmalonic acid, T_4, T_3 = Tetra- & Tri-iodothyronine;
GSH-Px = Glutathione peroxidase; Cp = Caeruloplasmin; SOD = red blood superoxide dismutase.

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