Recent advances in trace mineral deficiencies and their control

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The study of trace element metabolism has intensified in the last 20 years due mainly to the availability of highly purified diets and to the development of sophisticated instrumentation capable of detecting minute amounts of elements in tissues and feeds. Since 1957, Se, Cr, Sn, V, F, Si and Ni have been isolated as essential nutrients for animal metabolism (Schwartz 1974). The recommended requirements for established trace elements have also changed. It is now recognised that the Zn requirements of Zn for chicks is greater than that originally proposed by ARC (1963). Preston and Willis (1974) have also suggested that the Zn requirements of cattle may be lower than initially proposed. It is also clear that precise requirement for many trace elements has not yet been determined, as shown by the absence of recommendations for Mn, I, Cu, Zn, Mo and Se in laying poultry. (See ARC, 1963 and NRC).

In the following paper, I wish to discuss some selected aspects of advances in trace element metabolism, with emphasis on findings which may be of local practical importance. Three areas are considered, the distribution of trace element deficiency in the livestock industries of Australia, the significance of diet-trace element interactions and some recent studies of Co deficiency in Queensland.

Trace Element Deficiencies in Australia

Fig. 1 shows an approximate distribution of Cu, Co, Se and I deficiency in grazing animals in Australia. It is interesting to note from this distribution that deficiencies have been recorded mainly where intensive animal production is practised, and it is not clear whether the more extensive areas would show similar deficiencies given an intensive research input. Trace element deficiencies in the pig and poultry industries are rare due mainly to addition of requirements during ration formulation.

Copper and Molybdenum

Ataxia in young pigs in Queensland has been associated with low liver copper levels (McGavin *et al.* 1962). Cu deficiency of sheep and cattle has been reported in all states of Australia presenting a variety of symptoms from 'depigmentation' and 'steely wool' in sheep to anaemia, temporary sterility and profuse diarrhoea in cattle (Bennetts et *al.* 1941). In all Australian studies, Cu supplementation alone prevented deficiency .

In the studies of Dick (1956), high levels of Mo and sulphate induced Cu deficiency providing an explanation for the symptoms of Go toxicity. More recently, Suttle (1974) has reported that Mo interacts with organic as well as inorganic S in limiting Cu utilization by sheep and these findings may have practical importance. Suttle calculated that for a feed containing 0.5 mg Mo/kg, increasing the concentration of S in

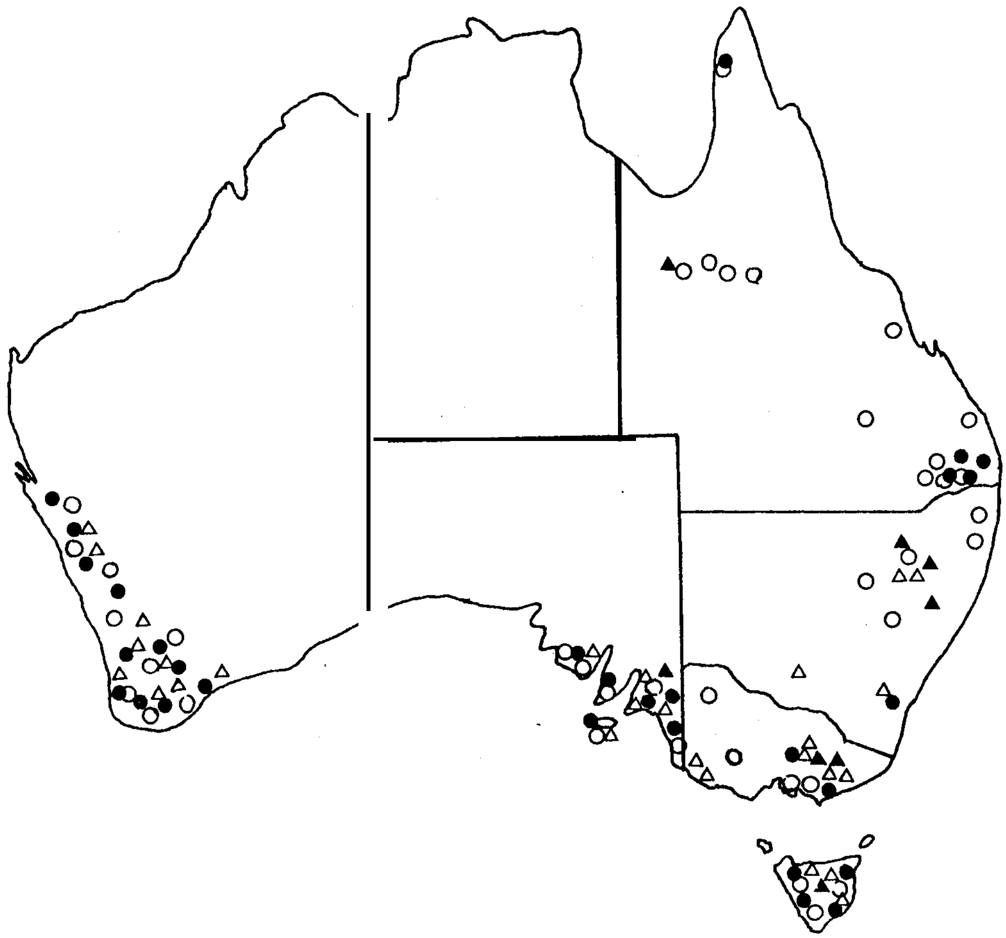

Fig. 1. The distribution of Trace Element Deficiency symptoms in grazing stock in Australia. (● cobalt, ○ copper, △ selenium, ▲ iodine).

the feed from 2 to 3 g/kg (≃ 13 → 19% crude protein) decreased the availability of dietary Cu by 50%. Where Cu levels in pasture are marginal it is possible that fertilizer application (N and P) may result in induced Cu deficiency. In the U.K. survey studies indicate that Cu deficiency may be more prevalent than previously suspected (Davies and Baker 1974). It is also likely that from the low levels of Mo and S in cereals, Cu toxicity could also be a problem, and on all concentrate rations small supplements of Mo may be indicated. The significance of these interactions in Australian feeds is not known.

The interaction between Cu, Mo and S differs in ruminants and non-ruminants. In ruminants, dietary S is rapidly reduced to $S^{=}$ and favourable conditions exist for the formation of an unavailable form of Cupric thiomolybdate when diets are rich in Mo (Suttle 1974). High Mo intakes have been shown to decrease ruminal $S^{=}$ concentrations (Bryden and Bray 1972) and to decrease the soluble copper flowing from the rumen (Bird 1970), thereby inducing Cu deficiency. In non-ruminants, dietary sulphate competes with Mo for a common absorptive pathway (Huisingh, Gomez and Matrone 1973), and exerts a protective effect against Mo toxicity.

Payne (1976) has reported a misfeathering syndrome in day old chicks which is responsive to Mo supplementation, and has demonstrated that Mo deficiency may be induced by copper sulphate. Apart from this study Mo deficiency has not been recorded under practical feeding conditions, although Ellis *et al.* (1958) found that increasing dietary Mo in sheep from 0.36 to 2.36 ppm increased cellulose digestibility in the rumen and lamb growth rate. Since ruminants in Australia graze pastures with Mo contents in this range, further studies in this area may be warranted.

Manganese and Zinc

There is little information in Australian literature to suggest that either Zn or Mn deficiency is a problem of practical importance in pigs and poultry. Occasional minor outbreaks of parakeratosis have been reported in Queensland piggeries (Anon 1972/73). The Mn requirements of pigs and poultry vary with species, criteria of adequacy and the nature of the rest of the diet. Australian wheat appears adequate in Mn (Underwood *et al.* 1947; Murphy and Law 1974), although diets based on sorghum or maize may require additional Mn (Underwood 1971). The Zn content of Australian wheat is also low, and supplementation is indicated.

The requirements of non-ruminants for Zn are influenced by the protein source used; plant proteins with their high phytic acid content render Zn less available for absorption. It has also been reported that high Ca levels in pig diets may increase the dietary requirement for Zn, (Hoekstra *et al.* 1967).

It is only recently that a response of grazing sheep to Mn/Zn supplementation has been reported in Australia. Egan (1972) found that fertility in ewes was markedly increased by dietary supplements of Mn, Zn or Mn and Zn. Pasture levels of these elements were not particularly low and provided little indication of a likely deficiency. As was shown with Cu and Co, trace element levels in pasture may be useful to detect severe deficiency, but provide little information on conditions where marginal deficiency is a problem. Foetal death occurs in rats where the dam suffers a brief exposure to low intakes of Cu or Mn (Hurley and Schrader 1972) and it is well known that the Zn requirements of rams for testicular development and spermatogenesis are greater than those growth, (Underwood and Somers 1969) suggesting that transient deficiencies of Mn or Zn may be of significance where poor reproductive performance of stock is observed.

Iodine

Endemic goitre, due to iodine deficiency, has been recorded mostly in Eastern Australia. Underwood (1971) has comprehensively reviewed the field of iodine metabolism in animals. However, recent studies cf goitre incidence in Tasmania by Stratham and Bray (1975) and King (1976) deserve comment. Both studies suggest that the incidence of congenital goitre in sheep may be under-estimated -if thyroid enlargement detected by palpation is the sole criterion. King found that 27% of lambs without palpable thyroids apparently died of iodine deficiency, suggesting that the incidence of iodine deficiency based on thyroid enlargement may be under-estimated.

In Northern Queensland, Hopkins and Pratt (1976) found that supplementation with iodine (and the provision of shade) significantly improved the fertility of Merino ewes. From this experiment, it was not barley diet. The efficacy of Se or vitamin E supplementation was not tested, but the generally low Se content of plant products should be recognised when plant proteins are used to replace animal proteins in rations. Selenite uptake by plants is inhibited by both sulphate and phosphate (Asher 1977), and with continued cropping of low Se soils, the Se content of feed grains will decline. Since the addition of Se to feed-stuffs is illegal in most states, future trends in the content and availability of Se in grains should be monitored.

All states of Australia (excepting Queensland) have recorded responses of grazing animals to Se supplementation. In sheep, Se therapy has prevented nutritional muscular dystrophy (NMD) in lambs, increased both body weight gain and wool growth (McDonald 1975), and has enhanced reproductive capacity (Wilkins 1977). In cattle NMD (cardiac form) has been diagnosed in calves, but body weight response to Se was absent (Gabbedy et *al.* 1977). The recent development of Se pellets for intraruminal administration (Handreck and Godwin 1970) are a practical solution to the provision of Se to deficient animals on a continuous basis. Se deficiency is most often found in high rainfall areas where pasture improvement has been undertaken and is therefore in areas of high animal production potential. There is a need for further study on a national basis to define the factors responsible for both high risk and marginal areas of Se deficiency.

Cobalt

The detection cf Co deficiency in sheep and cattle has had a major effect on animal production in Australia, particularly in Western Australia, South Australia and Tasmania (Underwood 1971; Albiston 1975). Co deficiency is of little significance in non-ruminants. The symptoms of Co deficiency are generally those associated with malnutrition and often complicated by Cu deficiency and a high incidence of intestinal parasites. 'Unthriftiness' is a term applied to the symptom of sporadic or marginal deficiency.

It is only recently that Co deficiency has been described in sheep (Norton and Hales 1976) and cattle (Winter *et al.* 1977) grazing improved tropical pastures in Queensland. With the introduction of new tropical grass species into Australia, there has been a rapid expansion of improved pasture planting in soils generally deficient in most trace elements essential for plant growth. Both Co and Cu deficiency in these areas have been suspected for some time (Donaldson *et al.* 1964). Tropical pastures are low in nutritive value compared with temperate pastures, but little attention has been given to the significance of trace element content of these pastures on animal production. The results in Table 1 are from a supplementation trial with breeding ewes grazing N- fertilized (200 kg N/ha) Pangola grass (*Digitaria decumbens*, Stent .) in south-eastern Queensland.

Co supplementation, either applied to the pasture or by direct administration as a pellet increased lamb birth weight, weight gain to weaning and survival compared with unsupplemented ewes. In this latter group, 24% of lambs born were either born dead or survived less than a day. Milk production in unsupplemented ewes was only 30% of that in the supplemented groups and was the major contributor to poor lamb growth. Ewes on all treatments lost weight post-weaning suggesting that further supplementation was required. Despite supplementation cf lambs, post-weaning growth was also poor. Continuing studies are examining the

Table 1. Effect of cobalt supplementation of ewes grazing N-fertilized Pangola grass pastures in south-eastern Queensland.

Treatment	Reproduction: Lambs Born / Ewes Joined	Reproduction: Lambs Weaned / Ewes Lambing	Ewe Wt Change (Joining to Weaning) kg/9 months	Milk Production (0-4 wks) 1/wk	Lamb Growth: Birth wt (kg)	Lamb Growth: 0-4 wks (g/d)	Lamb Growth: 4-12 wks (g/d)
No supplement	$^{17}/_{16}$	$^{8}/_{14}$	- 12.6	2.66	3.6(8)*	128	110
Pasture sprayed (360 g $CoSO_4.2H_2O$/ha)	$^{9}/_{8}$	$^{9}/_{8}$	- 2.6	9.07	4.5(8)	239	150

need for more frequent and/or high levels of Co supplements and the possibility of further trace element deficiencies being present.

These studies may have wider application than a simple description of a regional deficiency (250,000 ha) particularly where animals are grazed on tropical pastures. The pastures in this study contained apparently adequate levels of Co (0.11±0.02 ppm), but total intake was clearly inadequate. The low feed intake usually associated with the low digestibility of tropical pastures may be responsible, which indicates that current requirement recommendations in terms of pasture concentrations are of little value in assessing adequacy for animals grazing pastures of low nutritive value.

Pregnancy and lactation hastened the onset of severe cobalt deficiency and it is likely that the Co requirements of lactating ewes may be higher than dry ewes. High calf mortality and lactational failure has been reported in young breeding cattle near Rockhampton (Anon 1963/64). This condition was not responsive to Cu, and it would seem from results with sheep, that Co supplements may be required. Tropical pastures have many characteristics which increase the likelihood of trace mineral deficiencies occurring in grazing animals. They are usually grown on infertile soils in high rainfall areas, and after a rapid growth phase produce a bulk of low quality feed underlain by a deep litter of dead plant material. Grazing animals are not only presented with a feed of low quality, but are denied access to the soil as a source of trace element. Little is known about the Co status of tropical soils or the capacity of new pasture species to accumulate trace elements under field conditions.

The 'newer' trace elements

Schwartz (1.974) has reviewed recent developments on the essentiality of Cr, Sn, V, F, Si and Ni. With the exception of Cr, deficiency symptoms are found at dietary concentrations well below those found in conventional rations. Cr deficiency has been detected in malnourished children, where its absence interferes with normal carbohydrate metabolism (Mertz 1974). The significance of these trace elements in practical rations is unknown, although induced deficiency through interaction with other trace elements and dietary factors must be considered as a future possibility.

Interactions between trace e lements

The significance of interactions between some essential trace elements has been discussed in previous sections. Increasing levels of heavy metal contamination in the environment demand an understanding of their effects on animal and human health. Fig. 2 shows some interactions which may occur between trace elements in biological systems.

Davies (1974) has classified interactions between trace elements into two types. Competitive interactions are an isomorphous replacement of one element by another and are characterized by mutually negative effects between elements. For example, high dietary Zn inhibits Cu utilization in pigs (Campbell and Mills 1974) and high dietary Cu inhibits Zn utilization (Richie et *al.* 1963). The action of the toxic metals Hg, As and Cd act as competitive inhibitors of essential trace elements. Non-competitive inhibition occurs where the absence or presence of one element determines the subsequent metabolic fate of another

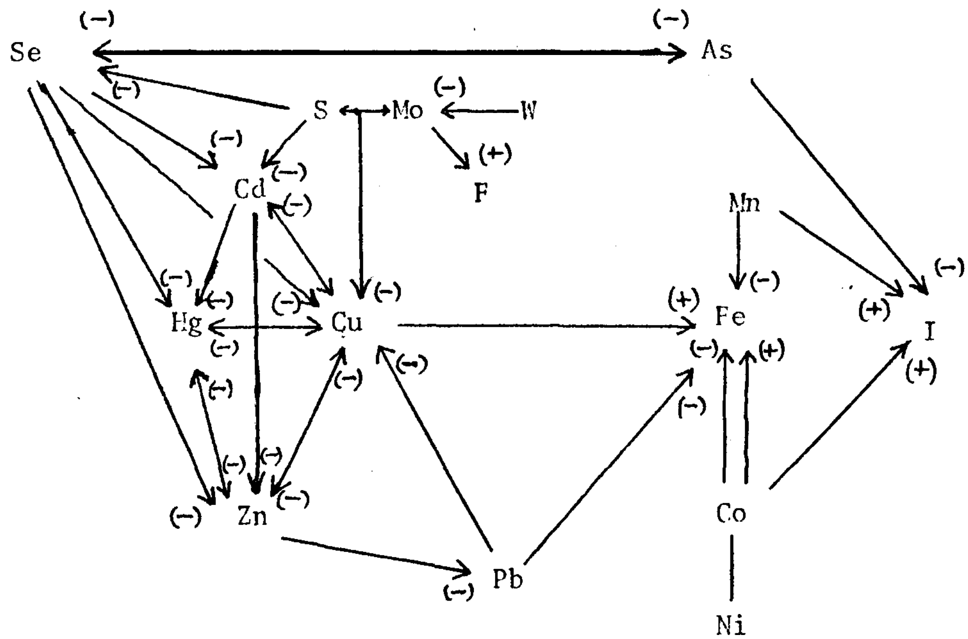

Fig. 2. *Biological interactions between trace elements. The direction of an arrow between two elements indicates direction of interaction from antagonist to agonist (-) represents a negative interaction (inhibition) and (+) represents a positive interaction (stimulation). After Cavies (1974).*

element. Dietary Cu stimulates haematopoesis through its role in mobilizing Fe from Fe stores for haemoglobin synthesis, thereby increasing Fe availability. Whilst there is considerable information available now on interactions between trace elements, less is known about the availability and form of trace elements in feeds, particularly in pastures.

CONCLUSIONS

Trace element deficiencies in non-ruminant stock in Australia are rare, but may not always remain so. Requirements vary with species, type of production and feed components used, and because of trace element interactions, high rates of addition to diets will not necessarily ensure that all dietary requirements are met. In ruminant stock, frank deficiencies of Cu, Co and Se are still being discovered under grazing conditions. The significance of marginal and/or transient deficiencies of trace elements is unknown, but with the development of more sensitive criteria for detection of deficiency, this aspect should receive more attention, particularly in the tropical areas of Australia.

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