Soils, pastures and trace elements in deer

N.D. Grace

Trace element deficiencies have a marked influence on health, animal performance and profitability of deer enterprises in New Zealand. As deer farming began in the late 1960s the investigations of Co, Cu and Se deficiencies in the 1930s, late 1940s and mid 1950s, respectively, involved only sheep and cattle. Therefore there is a dearth of information on the trace element nutrition of deer. This is not a satisfactory situation and must be addressed if veterinarians are to establish effective animal health programmes for deer farmers. This paper reviews trace element nutrition of deer and the effect that soil : pasture interactions have on the supply of trace elements to grazing deer.

Soil factors

The uptake of trace elements by plants is influenced by soil factors such as the origin of parent material, soil formation, soil chemistry and soil moisture (Flemming 1965).

(a) Parent material and soil formation

New Zealand soils are derived from three main types of parent rock namely, metamorphic, sedimentary and igneous (volcanic). Central North Island ash showers have been deposited from violent eruptions over the last 200,000 years and the mineral content of these soils is dependent both on the material that has erupted from the volcano in the area and the subsequent weathering. Basalt and andesitic rocks which originate from a more explosive eruption are rich in ferromagnesium minerals and they weather rapidly to release trace elements such as Cu, Se and Co into the soils where they become available for plant uptake. Granite and rhyolitic rocks are formed by a great heat deep in the earth's crust and are low in trace elements particularly Co and Se. The pumice soils of the central plateau of the North Island are examples of such soils (Clark and Towers 1983).

(b) Soil moisture

The effect of soil moisture on the availability of trace elements to plants is appreciable as chemical and physiochemical factors influence the solubility and form of trace element in the soil. A high soil moisture status has been observed to increase Co, Mn, Fe and Mo concentrations in plants while the effect on Cu was not consistent. The increase in availability of Co, Fe and Mn to plants was associated with a chemical reduction to the more soluble lower valent form of the cation. The magnitude of the effect is influenced by the soil type (Flemming 1965).

(c) Soil pH

A change in soil reaction, or pH, has a marked influence on the plant uptake of some trace elements. For example increasing the soil pH, through liming, will increase the plant uptake of Se and especially Mo and reduce that of Mn. A decrease in pH increases the plant uptake of Co, Cu and Zn but the effects are small (Truog 1948).

Soil : plant relationship

The relationships between soil and plant trace element concentrations are complex with strong associations only being observed in the case of Co and Se.

(a) Cobalt

The EDTA extractable soil Co concentrations in the yellow brown pumice and the yellow brown loam soils have been observed to be correlated to plant Co concentrations. To ensure that the pasture Co concentration will exceed 0.08 mg Co/kg DM, that is the dietary Co requirement for sheep, with a probability greater than 74% the soil EDTA extractable Co concentration must be at least 1.4 mg/kg DM (Hawke *et al.* 1994).

(b) Selenium

Pastures containing < 0.03 mg Se/kg DM, where Se responsive ill-thrift in lambs is observed, are associated with soils containing less than 0.5 mg Se/kg air dry soil. Se is present as selenite ($SeO^{2-}{}_3$) and selenate ($SeO^{2-}{}_4$) in the soil solution (Millar 1983).

(c) Copper

The Cu concentrations of pasture (2.1 to 7.7 mg/kg DM) have a very poor relationship to soil Cu (2 to 150 mg/kg DM) concentrations and therefore soil Cu concentrations cannot be used to predict pasture Cu concentrations (Wells 1957).

(d) Iodine

Iodide is thought to be the major form of I in the soil and concentrations can range from 1.7 to 8.5 mg/kg dry soil while pasture I concentrations range from 0.1 to 1.4 mg I/kg DM. There is a large variation in the ability of plants to take up I from the soil with I being generally more available from acid soils. Plants growing on soil low in I will have a low I concentrations (Aller *et al.* 1990).

Factors influencing pasture trace element concentrations

Many factors can influence the trace element concentrations in pasture such as season, botanical composition and topdressing with trace elements.

(a) Season

Season reflects the stage of maturity as the plant moves from a vegetative to a flowering stage as well as climatic changes in temperature and rainfall. In New Zealand decreases in Co, Se, Zn and Mn concentrations and increases in I concentrations were observed in the spring while season had little effect on Cu concentrations. The magnitude of the changes are difficult to predict but 2-fold changes in trace element concentrations due to season have been observed (Reay and Waugh 1983).

It should be noted that pasture samples which are collected during winter and early spring usually have varying amounts of soil adhering to the stems and leaves which can result in erroneously high values for Fe, Mn and Co in unwashed plant samples because soils are much higher in these trace elements when compared to herbage.

(b) Botancial composition

Pasture species show a wide variation in their ability to accumulate trace elements. Comparison between white clover, red clover and ryegrass in terms of their trace element concentrations are given in Table 1. For a particular trace element comparison, plants were grown on the same soil and harvested under the same conditions. Generally legumes have a higher mineral element content when compared to grasses (Flemming 1965; Grace 1983).

Table 1. Trace element content (mg/kg DM) of grasses and clovers.

	Cu	Se	I	Co	Mn	Fe	Zn
White clover	10 6	0 008	0 91	-	44	124	25
Red clover	19 1	-	0 47	0 19	59	80	46
Ryegrass	4 0	0 01	1 46	0 07	85	102	19

(c) Distribution of minerals in pasture plants

The distribution of the trace elements in pasture plants could be important when the selective grazing behaviour of deer is considered. The distribution of trace elements between the seed head, leaves and stem of perennial ryegrass and red clover are shown in Table 2.

Table 2. The distribution of some trace elements (mg/kg DM) between the seedhead, leaves and stems of perennial ryegrass and red clover.

	Cu	Co	Mn	Fe	Zn
Perennial ryegrass					
Head	4 5	0 04	18	39	37
Leaves	5 0	0 04	41	101	20
Stem	4 0	0 03	56	22	13
Red clover					
Head	11	0 10	60	64	40
Leaves	17	0 11	136	134	42
Petioles	14	0 07	19	24	12

The mineral contents of the leaves were found to be higher than for the stems

(d) Topdressing with trace element amend fertilisers

Using fertilisers as a carrier topdressing with Co, Se and Cu can be an effective approach to increase plant trace element concentrations in sheep and cattle. On sheep and cattle farms Se and Cu are applied in the autumn and Co in early spring. The very high initial intakes of Co, Se and Cu over several weeks allow the trace element stores in the liver and other tissues of the grazing animal to become repleted. During periods of low Co, Se and Cu intakes of these stores then become depleted.

On sheep and cattle farms Se and Cu are generally applied in the autumn and Co in early spring. The timing of the applications fits in with (a) the reproductive demands for Se of sheep at mating and for cattle during mid and late pregnancy (b) the need to increase liver Cu stores, especially in cattle, before winter when liver Cu stores can become depleted and (c) to meet the increase in the Co demands of lambs and perhaps calves.

Cobalt

Applying 60 g Co/ha as 350 g $CoSO_4.5H_2O$ annually will increase the pasture Co concentrations (Sherrell 1984). The initial uptake over first 4 to 6 weeks is rapid and the Co concentrations peak at 4 to 8 times the untreated pasture Co concentrations (i.e. from 0.05 to 0.3 mg Co/kg DM). During the next 4 to 6 weeks the Co concentration decrease markedly and then more slowly over the next 8 to 12 months to the concentrations of untreated pastures. Cobalt has to be applied annually and the magnitude of the response in pasture uptake is depended on soil and plant factors and amounts of Co applied (Sherrell 1984). In Southland the high Mn soils impair the uptake of Co by plants while this approach is very effective on the North Island pumice soils (Adams et al. 1969).

Selenium.

The application of 10 g Se/ha as 48 g $NaSeO_4.10H_2O$ (applied as 1 kg of prills/ha) is very effective in increasing pasture Se concentrations increasing from 0.01 to 0.15 mg/kg DM (Watkinson 1983). The pattern of Se uptake by pasture and changes in pasture Se concentrations is similar to that already described for Co. The Se therefore has to be applied annually. The uptake of Se by the pasture is dependent on soil and plant factors and the amounts of Se applied.

Copper.

The recommended rate of Cu application per hectare is 1 to 1.25 kg Cu as 5 to 6 kg $CuSO_4.5H_2O$ which after about 6 weeks increases pasture Cu from 5 to about 20 mg/kg DM (Cunningham and Perrin 1947). However, the response is again variable being influenced by soil and plant factors. In one study where a high application rate of 4 kg Cu/ha was applied to 6 small paddocks. On 4 paddocks the pasture Cu concentration increased to 45 mg Cu/kg DM while on 2 other areas the Cu concentrations exceeded 120 mg Cu/kg DM (Grace *et al.* 1998)

Molydbenum.

Pastures, particularly clovers, require Mo to ensure effective nitrogen fixation. Clover Mo concentrations need to be about 0.5 mg Mo/kg DM. Topdressing with 20 g Mo/ha as 50 g of $Na_2Mo0_4.H_2O$ every 4 to 5 years will increase and maintain pasture Mo concentrations (During 1972). The over use of Mo on pastures can result in high Mo intakes, which in the presence of S, will reduce Cu absorption and storage in cattle, sheep and deer. The deer appear to be less sensitive in terms of changes in their Cu metabolism to increases in pasture Mo concentrations (Osman and Sykes 1989).

Trace element metabolism and dietary requirements of deer

To ensure optimum animal performance in terms of growth rates and reproductive performance the intakes of all nutrients, including trace elements, must be adequate to meet the needs of deer. These intakes are expressed as a dietary trace element requirements. The paucity of data from trace element supplementation studies, indoor feeding experiments, slaughter and isotope investigations means that the dietary trace elements requirements for deer are not well defined. At present the guidelines for dietary trace element requirements and biochemical criteria to assess trace element status are based largely on information obtained from cattle and sheep studies.

An effective approach to determine the dietary Co, Se and Cu requirements of deer is to compare the growth rates of young deer when untreated control and treated animals are grazing pastures with low Co, Se and Cu concentrations. The trace element status is assessed from changes in blood and or liver Vitamin B_{12}, Se and Cu concentrations. If the deer are deficient then the treated animals will grow significantly faster than the untreated controls. Clinical signs of any disease which respond to trace element supplementation also provide value information on dietary requirements as well as the biochemical and physiological function of the trace element.

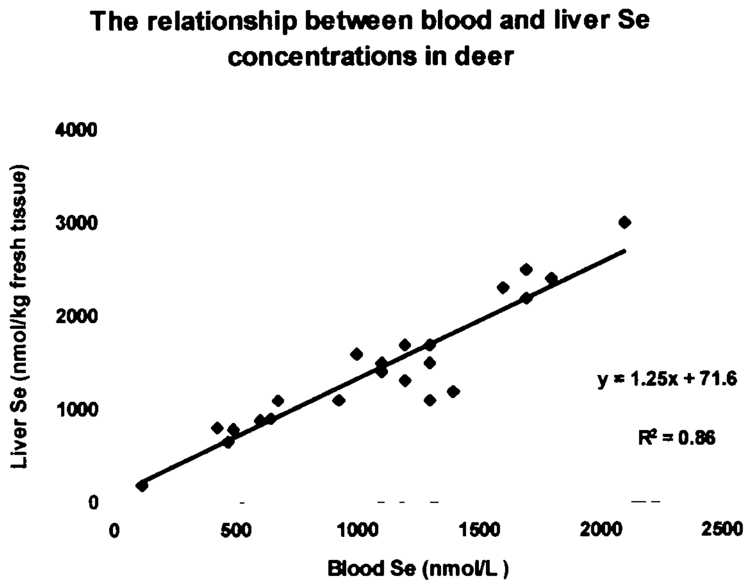
(a) Cobalt

Animal Performance. In two studies (Clark *et al.* 1986) the growth rates of Vitamin B_{12} injected and untreated 8-9 month old red deer hinds (trial 1) and 40 10-14 month red deer hinds (trial 2) grazing pasture containing 0.05 to 0.1 mg Co/kg DM for at least 4 months were monitored along with changes in serum Vitamin B_{12} and pasture Co concentrations. No significant growth responses (184 v 187 g/day for trial 1; 135 v 146 g/day for trial 2) to Vitamin B_{12} supplementation were observed while the lowest serum Vitamin B_{12} concentrations were 83 and 119 pmole/L for trials 1 and 2 respectively. The treated deer had significantly elevated serum Vitamin B_{12} concentrations which were twice those of the controls at the end of study (Clark *et al.* 1986). No data on liver Vitamin B_{12} concentrations were presented. The red deer appear to have a lower dietary Co requirement than sheep because lambs grazing pasture containing < 0.08 mg Co/kg DM with serum Vitamin B_{12} < 336 pmol/L would have responded to Vitamin B_{12} supplementation.

(b) Selenium

Animal performance· A Se supplementation study with 38 red deer, 3 to 4 months of age, grazing pastures containing 30 to 57 μg Se/kg DM showed that the animals receiving 6 oral doses of Na_2SeO_4 (1 mg Se/10 kg liveweight) or 1 ml Deposel injection (50 mg Se as Ba SeO_4) had similar growth rates to untreated control over the 12 month study. The mean calculated blood Se concentrations were 400, 800 and 1200 nmol/L for control, Na_2SeO_4 and $BaSeO_4$ treated deer, respectively, (Mackintosh *et al.* 1989). The mean respective growth rates were 101, 93 and 103 g/day for the above animals. In a second study (Grace and Wilson unpublished 1999) with 36 stags, aged 4-5 months, grazing a pasture containing 10 to 30 μg Se/kg DM also showed no growth response to Se supplementation when groups of animals treated with 0.5 1 and 2 ml Deposel injections of $BaSeO_4$ (25, 50 and 100 mg Se) were compared to untreated control animals over a 9 month period. The mean blood Se concentrations of the untreated and treated deer were 120 and 1400 nmol/L, respectively, while the respective daily growth rates were 176 and 182 g/day. In sheep growth responses to Se supplementation would occur in animals with blood Se < 130 nmol/L grazing pastures containing < 30 μg Se/kg DM.

Relationship between blood and liver Se concentrations Increasing Se intakes or status of deer will increase both blood and liver Se concentrations. A linear relationship between blood and liver Se concentrations is illustrated in Figure 1 showing that blood or liver Se concentrations can be used to assess the Se status of deer (Grace and Wilson unpublished data, 1999).



Copper

The influence of dietary factor.. The metabolism of Cu is complex because it has been found in sheep and cattle that dietary factors can reduce the absorption and storage of Cu. Limited data suggests that an induced or secondary Cu deficiency occurs in deer. In sheep and cattle it has been observed that increasing the pasture Mo concentrations (0.5 to 4 mg Mo/kg DM), in the presence of S, impaired Cu absorption and the storage of Cu in the liver, especially in cattle, through the formation of thiomolybdates in the gut and their presence in blood (Grace 1994). Increasing dietary Mo intakes (1.7 to 6.5 mg Mo/kg DM) in silage fed deer and sheep resulted in a depletion of liver Cu stores in deer at a rate much less than for sheep (Freudenberger *et al.* 1987). Likewise feeding deer and sheep very high Mo diets (3 to 24 mg/kg DM) for 16 days caused a marked increase in the blood TCA insoluble fraction, which contains the thiomolybdates, in sheep but little change in deer (Osman and Sykes 1989). The effect of Mo on the Cu metabolism of deer appears to be less than that for sheep and cattle.

High intakes of Fe and Zn by sheep and cattle can decrease Cu absorption but the magnitude of the effect depending on the form of Fe and Zn ingested (Grace 1994). There does not appear to be any data for deer. Increased soil ingestion taken has been observed to decrease Cu absorption in grazing ruminants. However a recent study with sheep given 100 g of yellow-brown/yellow-grey earth for 126 days no changes in their plasma or liver Cu concentrations were observed (Grace *et al.* 1996).

Age The liver Cu concentrations in the liver of the foetus/neonate are much greater than those of the hind (5650 v 166 µmol/kg fresh tissue) (Reid *et al.* 1980). The effect of Cu supplementation of hinds during gestation on foetal liver Cu concentration is not known.

Season Season has a marked effect on the Cu status of deer as high liver and plasma Cu concentrations of 2360 µmol/kg fresh tissue and > 11.3 µmol/L respectively in February are at least halved by September to 1157 µmol/kg fresh tissue and 4.4 µmol/L respectively (Mackintosh et al. 1986b). The cause of this decline in Cu status, which is also observed in cattle and sheep is not known. Increased soil and Mo intakes have been suggested as possible factors but have yet not been proven.

Animal performance A Cu supplementation growth response study with 74 weaner red deer stags with initial liver Cu concentrations of 67 and 80 µmol/kg fresh tissue and mean serum Cu of 9.3 µmol/L (range 2.0 to 19.1) showed no significant increase in liveweight when animals given 4 g CuO needles in April and 8 g CuO needles in June were compared untreated control over 9 months (Wilson 1989).

The mean serum Cu concentrations during the period from June to October were 3.8 and 8.5 µmol/L for untreated and Cu treated deer respectively (Wilson 1989).

Relationship between serum and liver Cu concentrations.

The relationship between serum Cu concentrations and liver Cu concentrations is illustrated in Fig. 2. (Mackintosh et al. 1986b).

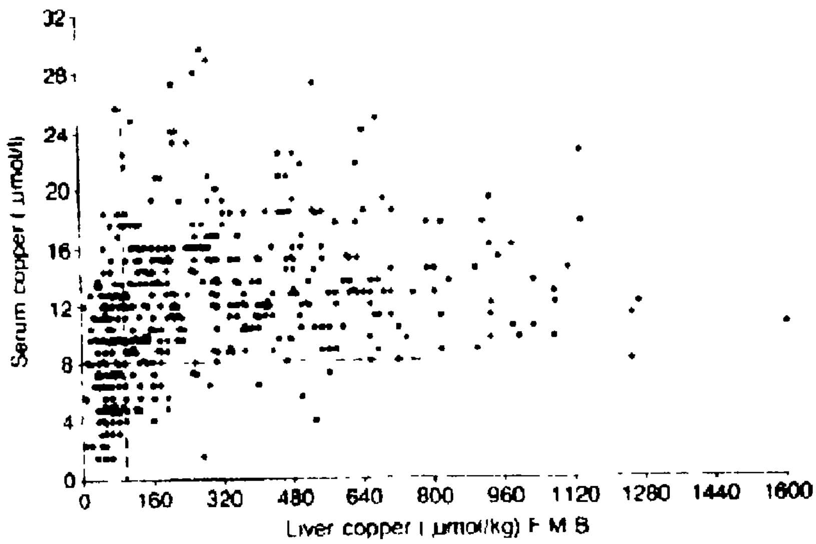


Figure 2

When liver Cu concentrations are < 100 µmol/kg fresh tissue about 50% of the deer will have a serum Cu concentration of < 8 µmol/L. The liver acts as a Cu store and when Cu intakes are inadequate blood Cu concentrations are maintained at the expense of the liver Cu stores. As these become more and more depleted an increasing number of deer have low Cu concentrations.

Clinical signs that are responsive to Cu supplementation:

In farmed deer the two clinical conditions which are responsive to Cu supplementation have been reported. They are enzootic ataxia and osteochondrosis.

Enzootic ataxia is characterised by ataxia and progressive hind leg inco-ordination in association with bilateral symmetrical demyelination of the spinal cord (Wilson et al. 1979; Mackintosh et al. 1986; Clark and Hepburn 1986). The condition of the animal deteriorates as its ability to move and forage becomes progressively worse. The liver Cu concentrations of these animals are less than 60 µmol/kg fresh tissue while the serum Cu concentrations of the unaffected animals in the herds were low (< 6.8 µmol/L). Enzootic ataxia has also been well documented in sheep but an important difference is that in sheep it occurs in the new born and young lamb whereas in deer the clinical signs are not observed until the animals are 9 months of age or older. On properties where enzootic ataxia has been diagnosed Cu supplementation has prevented further cases occurring.

Osteochondrosis is a disturbance in the endochondral ossification affecting rapidly growing young animal of several species including deer, cattle and horses (Thompson *et al.* 1994; Audige *et al.* 1995). The pathogenesis of osteochondrosis is not well understood but appears to involve the trauma of weight-bearing superimposed on rapidly cartilage. The lesions observed in the cartilage vary from foci of thickened, wrinkled cartilage to loose flaps of cartilage which have become separated from the subchondral bone. Irregular thickenings may be observed in the physes of the long bones. The aetiology of osteochrondrosis is likely to be multifactorial with Cu being a likely factor as low serum (< 5.1 μmol/L) and liver Cu concentrations (< 53 μmol/kg fresh tissue) have been found to be associated with the disease. Copper is important in maintaining the integrity of the collagen fibres as it is a cofactor for the enzyme lysyl oxidase which is required for the formation of cross-linkages between collagen molecules (Siegel *et al.* 1970). Since collagen is a key component of the cartilage matrix, any cartilage formed during a period of Cu deficiency would be more frail and therefore would be more likely to suffer damage under the stress of weight-bearing Increasing the Cu stores and status of deer should reduce the incidence of the disease.

Trace element supplementation of deer

Copper deficiency appears to be the most important trace element problem in deer but there is little information on the efficacy of the various strategies for Cu supplementation.

(a) Cu topdressing.

When pastures are topdressed with 1 to 1.5 kg Cu/ha as $CuSO_4.5H_2O$ the uptake of Cu or the Cu concentrations the plants are influenced by soil and plant factors. Generally speaking pasture Cu concentrations of 5 mg Cu/kg DM can be increased to 15 to 20 mg Cu/kg DM for 6 to 10 months. A relationship between pasture Cu concentrations and liver Cu concentrations in grazing young sheep has been determined (Grace *et al.* 1998). As there are no data available for deer it is difficult to assess the effectiveness of this approach to increase the Cu status of deer.

(b) Copper oxide needles

Treating weaned red deer stags grazing a low Cu property with 10 g CuO needles orally increased and maintain liver Cu concentrations for at least 5 months (mean values were 75.7 v 189.8 μmol kg fresh tissue for untreated and treated group respectively) Booth *et al.* 1989.

(c) Copper injection.

Injecting 3 to 5-year-old red deer stags, mean liveweight of 144 kg, with a Cu-Ca-EDTA injection (Coprin) at the rate of 1 mg Cu/kg liveweight as 2 subcutaneous injections 5 weeks apart increased and maintained liver Cu concentrations for at least 28 weeks (mean values were 160 v 412 μmol Cu/kg fresh tissue for untreated and treated groups respectively) (Harrison *et al.* 1989).

None of the Cu supplementation studies have determined the effect of increasing the Cu status of the hind has on the foetal liver Cu concentrations, the Cu stores in the new born calf and the possible effect of an increase in the Cu status on the incidence of osteochondrosis in young animals. Increasing dietary Cu intakes appears to have little or no effect on milk Cu concentrations in ruminants and horses (Flynn 1992). There are no data for deer.

Given the very limited information on the efficacy of Cu supplements in deer it is therefore difficult to recommend an effective Cu supplementation strategy to prevent Cu deficiency in deer.

Conclusions

1. The soil/plant/animal interactions are complex and can influence the intakes of Co, Se and Cu to grazing deer.
2. Suitable criteria to determine the Co (Vitamin B_{12}), Se and Cu status of deer, have not been well established because of a dearth of information from well designed nutrition studies.
3. No significant growth responses to Vitamin B_{12} and Se supplementation in young deer have been found in animals grazing pastures containing 0.04 to 0.08 mg Co/kg DM and 0.02 to 0.03 mg Se/kg DM respectively. The mean serum Vitamin B_{12} and blood Se concentrations of the untreated control deer were as low as 83 pmole Vitamin B_{12}/L and 120 nmole Se/L, respectively. Sheep are more sensitive to Co deficiency than deer while sheep and cattle are more sensitive to Se deficiency than deer.
4. No growth responses to Cu supplementation have been observed in deer with serum and liver Cu concentrations of < 6.3 μmole/L < 70 μmol/kg fresh tissue, respectively. However, animals with enzootic ataxia and osteochondrosis have liver Cu concentrations of < 60 μmol/kg fresh tissue and affected herds appear to respond to Cu supplementation.
5. The efficacy of various Cu supplements has not been well documented.

References

Adams, S. N., Honeysett, J. L., Tiller, K G , Norrish, K 1969 Factors controlling the increase of cobalt in plants following the addition of a cobalt fertiliser *Australian Journal of Soil Research* 7 29-42

Aller, A. J ; Bernal, J. L , Nozal M. J. Deban, L 1990 Effects of selected trace elements on plant growth *Journal of Science, Food and Agriculture* 51 447-479

Audigé, L , Wilson, P R., Morris, R. S ; Davidson, G W 1995 Osteochondrosis, skin abnormalities and enzootic ataxia associated with copper deficiency in a farmed red deer (*Cervus elaphus*) herd *New Zealand Veterinary Journal* 43 70-76

Booth, D. H , Wilson, P R , Alexander, A M 1989 The effect of oral oxidised copper wire on liver copper in farmed red deer *New Zealand Veterinary Journal* 37. 98-101

Clark, R. G., Barbage, J., Marshall, P McD , Valler, T ; Wallace, D 1986 Absence of a vitamin B12 weight gain response in two trials with growing red deer (*cervus elaphus*). *New Zealand Veterinary Journal* 34: 199-201

Clark, R G ; Hepburn, J D 1986: Deer liver and serum copper levels *Surveillance* 13 1 11-14

Clark, R G, Towers N R. 1984: Introduction *In* Mineral requirements of grazing ruminants *Ed* N D Grace New Zealand Society of Animal Production 9-12

Cunningham, I J., Perrin, D D 1947 Copper compounds as fertilisers for pastures deficient in copper. Department of Agriculture Publication 36, Wellington, New Zealand Department of Agriculture

During, C 1972. Fertilisers and soils in New Zealand farming. New Zealand Department of Agriculture bulletin No. 409

Flemming, G. A 1965. Trace elements in plants with particular reference to pasture species *Outlook on Agriculture* 4: 6 270-285.

Flemming, G A 1973 Mineral Composition of Herbage. *In* Chemistry and Biochemistry of Herbage *Ed* G W Butler and R. W Bailey Academic Press, London and New York Vol. 1· 529-566

Flynn, A 1992: Minerals and Trace Elements in Milk *Advances in Food and Nutrition Research* 36: 209-252.

Freudenberger, D. O ; Familton A. S , Sykes A. R. 1987· Comparative aspects of copper metabolism in silage-fed sheep and deer (*Cervus elaphus*) *Journal of agricultural Science, Cambridge* 108 1-7.

Grace, N. D 1983 The Lamb's Requirements for Minerals and the Supply from Herbage and Milk *Lamb Growth Technical Handbook.* Animal Industries Workshop Lincoln College 175-191

Grace, N D 1994. Managing trace element deficiencies New Zealand Pastoral Agriculture Research Institute Ltd, Palmerston North.

Grace, N. D , Rounce J R , Lee J L 1996 Effect of soil ingestion on the storage of Se, vitamin B_{12}, Cu, Cd, Fe, Mn, and Zn in the liver of sheep fed lucerne pellets *New Zealand Journal of Agricultural Research* 39. 325-331.

Grace N D.; Knowles S O., Rounce J R., West D M , Lee J. 1998 Effect of increasing pasture copper concentrations on the copper status of grazing Romney sheep. *New Zealand Journal of Agricultural Research* 41 377-386

Harrison, T. J , Sykes; A R.; Familton, A S 1989· Efficacy of Coprin in deer and sheep An evaluation and comparative study. *Proceedings of the New Zealand Society of Animal Production* 49. 11-14

Hawke, M F ; O'Conner, M. B., Johnston, T J M., Waller, J E., Addison, B 1994 Monitoring cobalt status – experiences in the central North Island *Proceedings of the New Zealand Grassland Association* 56: 249-254

Mackintosh, C G , Gill, J , Turner, K 1989 Selenium supplementation of young red deer (*Cervus elaphus*) *New Zealand Veterinary Journal* 37 143-145

Mackintosh, C G ; Orr, M B , Turner K 1986. Enzootic ataxia in Wapiti *Deer Branch course Proceedings of a Deer course for Veterinarians (New Zealand Veterinary Association)* 3 165-169

Mackintosh, C G , Wilson, P R ; Beatson, N S , Turner, K , Johnstone, P 1986: Preliminary report of the liver serum copper relationship in red deer *Deer Branch course Proceedings of a Deer course for Veterinarians (New Zealand Veterinary Association* 3 156-164

Millar, K J 1983 Selenium *In* Mineral requirements of grazing ruminants *Ed* N. D Grace New Zealand Society of Animal Production 38-47.

Osman, N. H. I , Sykes, A R. 1989 Comparative effects of dietary molybdenum concentration on distribution of copper in plasma in sheep and red deer (*Cervus elaphus*) *Proceedings of the New Zealand Society of Animal Production* 49 15-19

Reay, P F , Waugh, C. 1983· Element composition of ryegrass and white clover leafblades – seasonal variation in a continuously stocked pasture *New Zealand Journal of Agricultural Research* 26: 341-348

Reid, T C , McAllum, H J F , Johnstone, P. D 1980 Liver copper concentrations in red deer (*Cervus elaphus*) and wapiti (*C canadensis*) in New Zealand 28 261-262

Sherrell, G C 1984 Cobalt deficiency topdressing recommendations. AgLink FPD 814 Ministry of Agricultural and Fisheries, Wellington

Siegel, R. C., Pinnel, S R., Martin, G. R. 1970: Cross-linking of collagen and elastin Properties of lysyl oxidase. *Biochemistry* 9 4486-4492

Thompson, K G ; Audigè, D G ; Julian, A F , Orr, A. B , McSporran, K. D., Wilson, P. R. 1994. Osteochondrosis associated with copper deficiency in young farmed red and wapiti x red deer hybrids *New Zealand Veterinary Journal* 42 137-143

Watkinson, J. H. 1983 Prevention of selenium deficiency in grazing animals by annual topdressing of pasture with sodium selenate. *New Zealand Veterinary Journal* 31 78-85

Wilson, P R 1989 Bodyweight and serum concentrations of farmed red deer stags following oral copper oxide wire administration *New Zealand Veterinary Journal* 37: 94-97

Wilson, P R., Orr, M. B., Key, E L. 1979 Enzootic ataxia in red deer *New Zealand Veterinary Journal* 27: