Copper requirement of animals and pastures in New Zealand pastoral agriculture – a review

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Abstract

More copper (Cu) is required for the growth of cattle and deer than sheep and pasture. National and regional farm surveys showed that mean pasture Cu concentrations were generally within or above the required range for pasture growth and lambs but below that for cattle and deer. There was a significant pasture yield response measured on Recent and Brown soils and Podzols that had pasture Cu concentrations in the deficient range. Pasture concentrations of molybdenum (Mo) of up to 7 mg/kg for lambs and 10 mg/kg for deer had no effect on liveweight gain if pasture Cu concentrations were 7 to 8 mg/kg or greater. From twenty-one sites, there were only significant responses to Cu in animal liveweight gain and wool weight from lambs injected monthly with Cu and deer grazing pasture top dressed with copper sulphate, both on pasture with high Mo concentrations. In three trials, daily drenching of animals with copper sulphate or chelated Cu or the use of Cu capsules or copper oxide (CuO) wire particles was more effective at increasing liver Cu concentration than Cu injections or topdressing in the short term with copper sulphate. There is a need for more research on the response in liveweight gain of cattle and deer from different fertiliser and animal Cu treatments at varying pasture Mo concentrations.

Keywords: Cu deficiency, liver Cu, molybdenum, pasture Cu, serum Cu

Introduction

New Zealand soils are mainly formed from mafic and intermediate igneous and argillaceous sediments and shales that contain higher Cu concentrations than felsic rocks (McLaren and Cameron 1984). As such, Cu deficiency for pasture growth is mainly confined to strongly-weathered Podzols, Organic soils that lack mineral Cu and some Pumice soils derived from rhyolite (Wells 1957). Surveys of farm levels of Cu in soil and pasture have been carried out, both nationally (e.g. Cunningham et al. 1956) and regionally (e.g. Forbes 1978a). In addition, three farm surveys were carried out to measure pasture and liver and serum Cu concentrations from the same animals from seven months to two years (e.g. Morton 1986). The effect of different methods of Cu supplementation on pasture and liver Cu concentrations were also reported at three sites (e.g. Grace 1992).

At twenty-one sites, the response in animal liveweight gain and/or pasture, serum and liver Cu concentrations was measured from Cu, Mo and sulphur (S) treatments (e.g. Hogan et al. 1971).

Although animals that are farmed on Cu-deficient soils have pastures that cannot take up sufficient Cu for their requirements, Cu availability can also be limited by high pasture Mo concentrations. Molybdenum can interact with Cu and sulphur (S) in the rumen and reduce the amount of Cu that is absorbed into the blood (Grace et al. 2010). The earliest research on cattle and sheep requirements for Cu and interactions with Mo was at the Wallaceville Research Centre near Upper Hutt from the 1950's to the 1970's (e.g. Cunningham and Hogan 1959). The later research of Litherland et al. (1999) with cattle and Grace et al. (2005) with deer provided more information on this interaction. The effect of pasture S concentration on the liver Cu concentrations of lambs and cattle was also reported by Grace et al. (1997) and Litherland et al. (1999).

There have been small plot trials at eight sites (eg. Harris et al. 1966) and pot trials with five soils (Sherrell and Rawnsley 1982) carried out to measure pasture yield responses to Cu. A combination of six mowing (e.g. Sherrell 1989) and one five-soil pot trial (Sherrell and Rawnsley 1982) measured pasture Cu uptake from a range of rates of copper sulphate application.

The purpose of this paper is to assemble all the New Zealand research on Cu requirement of animals and pastures into one source so that the results can be easily accessed, and any knowledge gaps identified.

Reference ranges

The reference ranges for Cu concentrations in pasture, (Morton and Roberts 2024), together with serum and liver requirements for sheep, cattle and deer (Grace et al. (2010) are shown in Table 1. The reference ranges for the diagnosis of Cu deficiency for sheep, cattle and deer are based on the effects of Cu supplementation on the presence or absence of clinical signs together with the impact on animal performance in overseas studies carried out for sheep by Suttle et al. (1972) and MacPherson and Gray (1985), cattle by Suttle and Angus (1978) and a New Zealand study for deer by

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2024.86.3674

Table 1 Reference ranges for pasture, serum and liver Cu for pasture growth and animal requirements on New Zealand farms.

		Pasture (mg/kg)	Serum (μmol/L)	Liver (μmol/kg)	Reference
Ryegrass/white clover	Deficient	<5			Morton and Roberts (2024)
	Low	5			
	Optimum	6-7			
	High	>7			
Lucerne	Deficient	<7			Sherrell (1989)
	Optimal	7-8			
Sheep	Deficient		<4.5	<45	Grace et al. (2010)
	Marginal		4.5-8	45-95	
	Adequate	5-6	>8	>95	
Cattle	Deficient		<4.5	<45	Grace et al. (2010)
	Marginal		4.5-8	45-95	
	Adequate	9-11	>8	>95	
Deer	Deficient		<5	<60	Grace et al. (2010)
	Marginal		5-8	60-100	
	Adequate	>11	>8	>100	

Wilson and Grace (2001). Validation of these reference ranges for grazing animals by means of field trials in New Zealand has been limited by the lack of measured responses in animal performance to Cu treatment.

The use of soil Cu concentration to assess the availability of Cu for pasture growth has been limited by the small number of trials where soil Cu concentrations have been compared with pasture yield responses. There have only been a small number of trials in New Zealand that measured pasture yield responses to Cu application at different pasture Cu concentrations (Table 2) so the reference ranges in Table 1 are mainly based on those from overseas research. Reference ranges for dietary Cu requirements in Table 1 were determined from a combination of feeding studies (Mills et al. 1976) and a quantitative factorial model using data from various Cu metabolism studies (Agricultural Research Council 1980; Grace 1983). Validation of these ranges by calibrating pasture Cu concentration with animal liveweight gain (LWG) has only occurred in two New Zealand trials with lambs (Cunningham and Hogan 1959; Hogan et al. 1971) and one with deer (Grace et al. 2005).

Farm surveys of soil and pasture Cu

National surveys

Wells (1957) used sweet vernal as an indicator plant for Cu adequacy and found that the mean value was below the adequate range of pasture Cu concentration (Table 1). There was a weak, significant association between the Cu concentration in the topsoil and that of sweet vernal. The large national survey of pasture Cu concentrations reported by Cunningham et al. (1956) showed that about twice the number of farms that had pasture Cu concentrations of less than 5 mg/kg and greater than 3 mg/kg Mo were in the South compared with the North Island. Longhurst et al. (2004) reported that the mean grass and legume Cu concentrations were in the high range for pasture growth and within or above the adequate range for sheep but marginal for cattle and deer requirements.

Regional surveys

In the Wairarapa region, Wells (1969) reported a mean pasture Cu concentration of 11.5 mg/kg which was in the high range for pasture growth and above or within the adequate range for animals (Table 1). The mean concentration of Cu in white clover was also within the optimum range for growth. McLaren et al. (1984)

Table 2 Effect of copper sulphate application on plant yield measured at different soil and pasture concentrations. NS denotes a lack of significance at the 5% level of probability.

Site	Soil order/ sub group	Soil Cu concentration (mg/kg) or pasture Cu concentration of control (mg/kg)	Duration (years)	Rate (kg/ha) and application interval of copper sulphate	Pasture or legume DM yield response	Reference
Winchmore Research Station (Mid Canterbury)	Stony Brown		9	25 initially, 10 every 4 years thereafter	NS	Harris et al. (1966)
Westport	Podzol	Pasture 2.0	2	5	144% in first cut (P<0.05)	McNaught and During (1970)
Te Anau	Allophanic		2	5	NS in two trials	Cullen and Arnold (1971)
Central Canterbury (2 sites)	Recent	Lucerne 1.0 – 2.0	2	5	Significant responses on Eyre recent soil (P<0.01)	Carran et al. (1974)
Central Plateau	Pumice	Pasture 3.5 – 4.3	2	0, 0.5, 1, 1.5, 2, 4	NS	Forbes (1978b)
Northland (pot trial)	Acid Brown (3 sites)	Soil 0.5	0.5	0, 5, 10, 20	White clover - Significant up to 10 kg/ha (P<0.05)	Sherrell and Rawnsley (1982)
	Podzol (1 site)	Soil 1.3			White clover - NS	
	Granular (1 site)	Soil 2.0			White clover - NS Ryegrass -NS for all three soils	
Central Plateau (pot trial)	Pumice (1 site)	Soil 1.0	0.5	0, 5, 10, 20	White clover - NS Ryegrass - NS	Sherrell and Rawnsley (1982)
Central Plateau	Pumice	Soil 1.3 Lucerne 3.6	4	0, 1.25, 2.5, 3.75, 5, 10	NS	Sherrell (1989)

found that the mean lucerne Cu concentration was in the deficient range for growth and below the adequate range for cattle on Canterbury farms. A farm survey with lucerne on Pumice soils in the Taupo district showed that the mean Cu concentration was in the optimal range for lucerne growth but below the adequate range for cattle or deer (Forbes 1978a). There was a strong curvilinear relationship between soil and plant Cu concentration ($r^2 = 0.84$). On Canterbury Recent and Pallic soils, Adams and Elphick (1956) reported mean Cu concentrations in ryegrass and white clover to be within the optimal range for pasture growth and the adequate range for sheep but below the adequate range for cattle or deer. Sherrell and McIntosh (1987) reported that the mean Cu concentrations were in the high range for pasture growth and adequate range for sheep but not for cattle or deer on sedimentary soils in the Kaiwera Valley in Eastern Southland. In all the surveys where it was measured, soil Cu concentration decreased at greater soil sampling depths.

Overall, mean Cu concentrations were generally optimal for mixed pasture, ryegrass, white clover and lucerne growth and adequate for sheep but not for cattle or deer. The mainly narrow range of soil Cu concentrations at 0 – 75 mm depth (0.56 – 2.09 mg/kg) and pasture Cu concentrations mainly measured by different concentrations of EDTA extractant (6.4 to 11.5 mg/kg) restricted the ability to derive a meaningful relationship between these two parameters, but the overall results indicated that soil Cu concentrations needed to be greater than 1 mg/kg for pasture Cu concentrations to be in the optimal range for pasture growth.

Effect of Cu application on pasture yield

Although the emphasis of most of the Cu research has justifiably been on the requirements for animals which are higher for cattle and deer (Grace et al. 2010) than for pasture (Morton and Roberts 2024) and sheep (Grace et al. 2010), there has been some work carried out on the effect of Cu application on pasture yield with the results shown in Table 2.

The only soil types that showed a pasture or legume yield response to Cu were a Podzol (McNaught and During 1970), an Acid Brown (Sherrell and Rawnsley 1982) and a Recent soil (Carran et al. 1974). At all three sites, pasture Cu concentration for the control was in the deficient range for pasture growth. However, pasture at two other sites on Pumice soils (Forbes 1978b; Sherrell 1989) showed no significant response ($P>0.05$) in yield despite pasture Cu concentrations also being in the deficient range. On the seven soils where soil Cu measured was measured, one soil that was Cu-responsive had a concentration of below 1 mg/kg whereas the six non-responsive soils all had soil Cu concentrations of 1 mg/kg and greater (Sherrell and Rawnsley 1982).

The inconsistent relationship between pasture Cu concentration and pasture or legume yield resulted in a lack of validation for the reference ranges shown in Table 1. However, results from the soils in which both soil Cu concentration and yield were measured supported the evidence from the larger farm surveys of a tentative critical concentration of below 1 mg/kg for a significant pasture yield response to Cu to occur.

Effect of Cu application on pasture Cu concentration

Although as expected there was an increase in pasture Cu concentration with applied copper sulphate, most of the eleven trials (Forbes et al. 1978b; Sherrell and Rawnsley 1982; Knowles et al. 1998; Morton and Smith 2000; Smith 2004) were too short in duration to confirm the recommended frequency of copper sulphate application of every 4 – 5 years (Morton 2019). However, in the two trials of four years duration (Hogan et al. 1964; Sherrell 1989), pasture Cu concentrations remained adequate over that time span. Over all the trials, copper sulphate applied to pasture resulted in significantly increased pasture Cu concentrations ($P<0.05$) up to an application rate of 10 kg/ha.

Farm surveys of pasture, serum and liver Cu

West Coast of the South Island

The adequacy of Cu in recently developed Brown and Podzol soils was investigated in a survey of Cu status on twelve Grey Valley sheep farms on the West Coast of the South Island for twelve months with the results shown in Table 3.

For both soil orders, the marginal mean pasture Cu concentrations were more indicative of the short-term supply of Cu as measured by the marginal serum Cu concentrations than the long-term supply as measured by the adequate liver Cu concentrations.

Wairoa district

Pastures in the Wairoa district were reported to have a reduced Cu supply for animal requirements where pasture Mo concentrations were greater than 0.5 mg/kg (Korte et al. 1999). This was partly attributed to high pasture S interacting with Cu and Mo in the rumen (Grace et al. 2010). This issue was investigated in a survey of Cu status in the Wairoa district, only one farm having received Cu supplementation, with the results shown in Table 4.

This survey showed that only 14% of the farms had pasture Cu concentrations within the adequate range for cattle. But despite most of the farms having pasture Mo concentrations well above those required

Table 3 Percentage of pasture and lamb serum and liver Cu concentrations in each reference range on sheep farms in the Grey Valley (adapted from Morton 1986).

Reference ranges		Pasture Cu (mg/kg)	Serum Cu (µmol/L)	Liver Cu (µmol/kg FW (fresh weight))
Brown soils[1]				
Responsive	<6 mg/kg for pasture[2], <6.4 µmol/L for serum[2], <95 µmol/kg for liver[3]	0	0	0
Marginal	6-10 mg/kg for pasture[2], 6.4 -12.6 µmol/L for serum[2]	80	75	0
Adequate	>10 mg/kg for pasture[2], >12.6 µmol/L for serum[2], >95 µmol/kg for liver[3]	20	25	100
Podzol soils[4]				
Responsive	As above	4	0	0
Marginal	As above	84	75	0
Adequate	As above	12	25	100

[1]Pastures on one farm on Brown soils had received 5 kg/ha of copper sulphate
[2]Ellison (1972)
[3]Grace et al. (2010)
[4]Pastures had received 9-31 kg/ha of copper sulphate

Table 4 Mean pasture Cu, Mo, iron (Fe) and S concentration and liver Cu concentration in weaner cattle and breeding cows on eleven farms in the Wairoa district over two years (adapted from Litherland et al. 1999).

Measure		Pasture				Liver
		Cu (mg/kg)	Mo (mg/kg)	S (%)	Fe (mg/kg)	Cu (µmol/kg FW)
Farm mean		8.4	1.8	0.27	436	136
Cattle requirements	Adequate level/range	9-11[1]	<0.5[2]	0.18[1]	>40[2]	>95[1]
Pasture requirements	Optimum range	6 - 7[3]	0.10 - 0.20[3]	0.28 - 0.35[3]	50 - 65[2]	
Percentage of farms within* or above* adequate range	Cattle requirements	14*	44*	100*	100*	86*
	Pasture requirements	100*	100*	44**	100*	

[1] Grace et al. (2010)
[2] Korte et al. (1999)
[3]Morton and Roberts (2024)

for legume growth (0.1 mg/kg – Morton and Roberts 2024) at between 2 – 3 mg/kg, nearly all of the farms had adequate liver Cu concentrations for cattle (Table 4). Pasture S concentrations were in the optimal range of 0.27 – 0.32% for pasture growth (Morton and Roberts 2024) on about half of the farms so S would be less expected to interact with Mo to reduce liver Cu concentrations. Very high concentrations of Fe as occurred from this survey can also reduce liver Cu concentrations when ingested from soil on the pasture foliage (Grace et al. 2010) but this was not observed in this survey. The results indicated that, on these soils, pasture Cu concentrations of 7 mg/kg and greater will result in adequate liver Cu concentrations for cattle if pasture Mo concentrations do not exceed 3 mg/kg.

Eastern Southland

Following reports of widespread trace element deficiencies in the Wendon Valley in Eastern Southland, a survey of twelve sheep, beef and deer farms was carried out. None of the farms had received Cu supplementation and the results are shown in Table 5.

In this survey, the high proportion of pastures with Cu concentration below the adequate range for cattle and deer but above that for sheep requirements was consistent with the animals having liver Cu concentrations that were inadequate for the long-term supply of Cu for cattle and deer (Table 5). Pasture Mo

Table 5 Results from a survey on twelve farms of pasture Cu and sheep, cattle and deer serum and liver concentrations in the Wendon Valley for seven months (adapted from Grace et al. 2000).

Measure		Pasture Cu	Animal Cu	
		(mg/kg)	Serum (µmol/L)	Liver (µmol/kg FW)
Farm mean	Sheep	8.5	13.9	1759
	Cattle	8.5	7.9	54.7[1]
	Deer		8.6	82
Adequate range for animal requirements	Sheep	>5 - 6[2]	>8[2]	>95[2]
	Cattle	>9 - 11[2]	>8[2]	>95[2]
	Deer	>10[3]	>8[2]	>100[2]
Optimum range for pasture growth		6 - 7[4]		
Percentage of farms below adequate concentration/range	Sheep requirements	0	0	0
	Cattle/deer requirements	86	16	100

[1]Seven farms surveyed
[2]Grace et al. (2010)
[3]Morton (2019)
[4]Morton and Roberts (2024)

concentrations were below 1 mg/kg on most of the farms. Serum Cu concentrations were adequate on most of the farms which indicated a sufficient short-term supply of Cu. The liver Cu concentrations were adequate for sheep but not for cattle or deer. The mean liver Cu concentrations of sheep was very high which may have been associated with soil Cu ingestion. The results from this survey highlight the greater risk of deficiency for cattle and deer for Cu compared with sheep and indicate the ability of pasture Cu concentrations to predict liver Cu concentrations.

Response in pasture and liver Cu concentrations to more than one method of Cu supplementation at the same site

Cu supplementation methods can vary in their effectiveness depending on the source of Cu used. The results of Grace (1992) showed that drenching lambs and cows with Cu daily or injecting cows with Cu calcium (Ca) - edetate were effective at elevating liver Cu concentrations compared with no Cu. West and Sargison (1998) showed that a Cu capsule was much more effective initially at increasing liver Cu concentration than Cu topdressing and Cu injections in bulls. But at Day 314, liver Cu concentrations were significantly greater from topdressing than control ($P<0.10$). Pasture Cu concentrations in pasture from the control group were within the optimum range and pasture Mo concentration was low (0.4 – 0.7 mg/kg). Balemi et al (2010) reported that daily oral copper sulphate and chelated Cu and administration of a Cu bolus increased liver Cu concentrations of dairy cows over the control. The increase from the Cu bolus was significantly greater ($P < 0.05$) than that from Cu-Ca edetate injection.

The conclusions from this small number of trials were that the insertion of a Cu capsule, Cu bolus or CuO wire particles and daily drenching with copper sulphate or chelated Cu was generally a more effective means of increasing liver Cu concentrations than Cu – Ca edetate injection or Cu in the shorter term, topdressing. However, it should be noted that the trials reported by West and Sargison (1998) and Balemi et al. (2010), liver Cu concentrations were already very high, pasture Mo concentrations were low in the case of West and Sargison (1998) and that there was only one study where Cu topdressing was trialled.

Effect of copper, molybdenum and sulphur on pasture, serum and liver concentrations and performance of animals

The effect of Cu, Mo and S supplementation of animals and topdressing on pasture, serum and liver Cu concentrations and liveweight gain and wool weight from different sites is shown in Table 6.

Lambs grazing pastures with a high mean Mo concentration of 10 mg/kg showed a decrease in liver Cu concentrations but not blood Cu concentration or liveweight gain where mean pasture Cu concentration was 7 mg/kg (Cunningham and Hogan 1959). Hogan et al. (1971) reported a significant response ($P<0.05$) in the LWG and wool weights of lambs grazing pastures on an Allophanic soil (Table 6). The lambs in this trial were injected with Cu directly into the bloodstream so there was a smaller possibility that Cu availability was reduced by high pasture Mo intake. The site had a

Table 6 Response in pasture, serum and liver Cu concentrations and LWG and wool weight of animals to Cu, Mo and S supplementation and fertiliser application. NS denotes a lack of significance at the 5% level of probability.

Site	Soil order	Animal type	Rate of Cu or Cu compound (kg/ha) and method of supplementation	Pasture Cu and Mo conc. (mg/kg) and S conc. for some studies (%)	Serum or blood Cu response	Liver Cu response	LWG/ Wool weight (kg) response	Reference
Wallaceville Research Station, UpperHutt		Lambs	One group on pasture without Mo applied, Other group on pasture that had 2 applications of 210 g/ha of ammonium molybdate	No Mo - 0.7 + Mo - 10 Cu conc. No Mo - 8 + Mo - 7	Lambs in both groups had normal blood concentrations	Lambs on pasture with Mo applied. decreased from 380 to 106 mg/kg dry matter (DM)	Small reduction in both measures from lambs grazing high Mo pastures	Cunningham and Hogan (1959)
Wallaceville	Allophanic	Lambs	6-12 g Cu/head (hd)/month injected vs no Cu For previous 14 years 180-220 g/ha/yr of sodium molybdate applied	Cu ranged from 4 to 15 Mo ranged from 5 to 20	+Cu increased from 0.07 to 0.14 mg/100 ml ($P<0.01$)	+Cu increased from 43 to 92 mg/kg DM ($P<0.01$)	+Cu - LWG increased from 17.1 to 22.7 ($P<0.05$) Wool weight increased from 2.4 to 2.8 ($P<0.05$)	Hogan et al. (1971)
West Coast, South Island (7 farms)	6 Recent 1 Sand	Dairy calves	Cu injection at start				LWG - NS	Morton (1981)
West Coast (1 farm)	Recent	Lambs	Cu injection at start				LWG - NS	Morton (1981)
Waikato	Organic	Weaner stags	0 vs 12 g/hd of CuO wire particles		No Cu - 0.1 to 6.7 μmol/L + Cu - 5.2 to 14.7 ($P<0.01$)		+Cu - gained extra 3.1 kg (NS)	Wilson (1989)
		Stags	No Cu vs log oxidised Cu wire particles			No Cu - constant at 103 μmol/kg fresh weight (FW) FW for 2 months + Cu - increased from 103 to 850 ($P<0.05$)		Booth et al. (1989)
Palmerston North	Recent	Lambs	0 and 4 g elemental S/hd/day drenched	6 Mo<0.5	Plasma Cu increased from 0.85 to 0.90 mg/L (NS)	Increased from 173 to 274 mg/kg DM (NS)		Grace et al. (1997)

Woodville	Brown	Lambs	0 vs 4 copper sulphate topdressed	No Cu - 8 +Cu - 21 Mo 1.2		Increased from 280 to 2047 nmol/kg ($P<0.001$)		Grace et al. (1998)
Wairoa district	Pumice	Lambs	0, 0.4 and 4 copper sulphate topdressed	8, 13 and 41 with increasing rate of Cu application Mo 1.1		Increased from 270 to 900 to 3270 μmol/kg FW with increasing rate of Cu application ($P<0.05$)		Knowles et al. 1998
Palmerston North	Recent	Ewes and lambs	5 g CuO wire particles/ewe in early pregnancy	5.7 Mo 0.48 S 0.27	NS	Increased for 185 days for ewes, 36 days for lambs ($P<0.05$)		Grace et al. (2004)
Palmerston North	Recent	Deer	0 vs 3 copper sulphate topdressed on pastures containing 2.0, 4.6 and 11.3 Mo	Control = 9 +Cu increased from 9 – 95	NS overall response to Cu Medium and high Mo reduced from 9.2 to 3.8 and 3.9 μmol/L after 176 days ($P=0.003$)	NS overall Medium and high Mo reduced Cu from 131 to 20 μmol/kg FW after 176 days ($P<0.001$)	Reduced from 130 g/day to 100 g/day when pasture Mo concentration exceeded 10 ($P=0.002$)	Grace et al. (2005)
Winton, Southland	Pallic	Deer	0 and 6.7 copper sulphate as liquid with pasture Mo 1 – 2	Initially 1-2 Increased to >1000 one day after liquid Cu applied. At Day 30 decreased to <100	Increased from <8 to 13 -16 μmol/L ($P<0.05$)	Increased from <100 to 300 - 400 μmol/ kg FW ($P<0.01$)		Smith et al. (2006)
Rotorua	Pumice	Deer	Same Cu treatments as above with pasture Mo 6 – 8	Initially 2-8 Increased to >1000 one day after liquid Cu applied. At Day 60 decreased to >100	Increased from <8 to 17 μmol/L ($P<0.05$)	Increased from 100 to 500-900 μmol/kg FW ($P<0.01$)		Smith et al. (2006)
Mid and North Canterbury (12 farms)	Pallic and Brown	Young deer (5 – 7 months)	0 vs 5 g CuO wire particles/hd in autumn and 10g/hd three months later		First three months No Cu declined from 12.5 to 8.6 +Cu declined from 12.5 to 10.3 ($P<0.001$) Second three months both groups averaged 9.4 (NS)		NS	Nicol et al. (2003)

long history of high annual Mo applications causing a significant loss in liveweight ($P<0.05$) when pasture Mo concentration ranged from 5 to 20 mg/kg. The results reported by Morton (1981) showed a lack of significant response in LWG to Cu injection for dairy calves and lambs on West Coast Recent and Sand soils. Wilson (1989) reported that CuO wire particles administered to young deer increased serum Cu concentration from within the mainly deficient to within the mainly adequate range (Table 1) but there was no significant increase in LWG. With stags, Booth et al. (1989) found that Cu wire particles significantly increased liver concentrations from just within the adequate range compared with the control group where there was no change.

In a trial with lambs (Grace et al. 1997), the lack of effect on serum and liver Cu concentrations from dosing slow-release elemental S suggested that the optimal pasture Cu together with low pasture Mo concentrations was sufficient to minimise the effect of any interaction with S. Grace et al (1998) found a large increase in liver Cu concentrations from the application of copper sulphate at a relatively low pasture Mo concentration of 1.2 mg/kg. On Pumice soils, Knowles et al. (1998) significantly increased pasture and liver concentrations of lambs by application of up to 4 kg/ha of copper sulphate at a low pasture Mo concentration of 1.1 mg/kg with pasture Cu concentration being a reliable indicator of liver Cu concentration. Treating ewes with CuO wire particles in early pregnancy significantly increased their liver Cu concentrations for much longer than lambs but did not increase serum Cu concentrations of either stock class (Grace et al. 2004). Grace et al. (2005) reported no significant response ($P>0.05$) in deer serum and liver concentrations from topdressing copper sulphate on to pastures with Cu concentrations just within the deficient range and pasture Mo concentrations of 4.6 and 11.3 mg/kg. Only when pasture Mo concentration was above 10 mg/kg was the liveweight of the deer significantly reduced.

Smith et al. (2006) showed on a Pumice soil that even at deficient pasture Cu concentrations for deer requirements, applying liquid copper sulphate on to a pasture mass of greater than 3000 kg DM/ha to increase pasture Cu concentration to very high levels and grazing soon after in the autumn could be an effective method of supplementation as measured by adequate liver and serum Cu concentrations (Table 1) and despite high pasture Mo concentrations of 6 – 8 mg/kg. In a study on Canterbury deer farms, Nicol et al. (2011) reported a significant decrease in the plasma Cu concentrations of young deer in the control group but the administration of CuO wire particles had no significant effect on LWG.

Over all the trials there was an insufficient number where LWG was measured to verify the reference ranges for pasture, serum and liver Cu concentrations. In four out of five trials where both were measured, pasture Cu concentration was a reasonably accurate indicator of the adequacy of liver Cu concentration expressed as µg/kg FW. Administering Cu capsules and CuO wire particles and topdressing with copper sulphate or spraying liquid copper sulphate generally increased serum and liver Cu concentrations. Liveweight gain from lambs (Cunningham and Hogan 1959) and deer (Grace et al. 2005) were not affected at pasture Mo concentrations of up to 10 mg/kg if pasture Cu concentrations were 7 - 8 mg/kg or greater. But where pasture Mo concentrations increased up to 20 mg/kg, lamb LWG and wool weight were significantly increased from monthly injections of Cu (Hogan et al. 1971). In most of the trials where LWG was measured, liver Cu concentration was measured in uncalibrated units or not at all.

Application of copper sulphate to pasture increased serum and liver Cu concentration where pasture Mo concentrations were less than 2 mg/kg (Grace et al. 1998, Knowles et al. 1998 for lambs) but not at pasture Mo concentrations of greater than 2 mg/kg (Grace et al. 2005).

Conclusions

1. The calibration between pasture, serum and liver Cu concentrations and animal performance has been limited in New Zealand because of a lack of animal LWG responses and hence most of the reference ranges are based on overseas research results.
2. National and regional farm surveys showed that the mean pasture Cu concentrations were generally adequate for growth and sheep requirements but not for cattle and deer requirements.
3. Pasture and legume yield response trials showed that Cu was limiting growth on Recent and Brown soils and Podzols which had deficient pasture Cu concentrations but not at two non-responsive sites on Pumice soils that were also deficient in pasture Cu.
4. Application of copper sulphate up to 10 kg/ha increased pasture Cu concentrations but while most of the trials were of insufficient duration to confirm the recommended frequency of application of 4 – 5 years, optimal pasture Cu concentrations were measured four years after Cu application in two trials.
5. Although there were several concentrations of EFTA extractants used to measure soil and plant Cu concentrations, comparing those parameters plus pasture Cu concentrations and responses in pasture yield, indicated that responses only occurred when soil Cu concentration was below 1 mg/kg.
6. Research at three sites on several methods of Cu supplementation of animals and fertiliser application to pasture showed that Cu capsules or boluses, CuO wire particles and daily drenching with copper sulphate

or chelated Cu were more effective at increasing liver Cu concentrations than Cu injections or, in the shorter term, topdressing.
7. Two out of three smaller farms surveys and five out of six trials demonstrated that pasture Cu concentration predicted liver and/or serum Cu concentrations reasonably accurately.
8. In three trials and a survey, provided that pasture Cu concentrations were 7 - 8 mg/kg or greater, the LWG of lambs and deer were not affected at pasture Mo concentrations of up to 10 mg/kg.
9. To be effective at increasing serum and liver Cu concentrations from the topdressing of copper sulphate, the results from three trials with lambs and deer showed that pasture Mo concentrations needed to be less than 2 mg/kg and pasture Cu concentrations greater than 8 mg/kg.
10. The last two conclusions, although based on limited LWG and liver Cu data, supported the concept that because injection of Cu into the bloodstream of the animal avoided the gut and hence interaction with Mo, the critical pasture Mo concentration was much higher than that where topdressed Cu was ingested into the gut with pasture and subject to interaction with Mo.

Research requirements

There is a need for more work to measure the liveweight gain and liver Cu concentration of cattle and deer from the application of copper sulphate to pastures with high Mo concentrations compared with animal treatment at the same sites.

ACKNOWLEDGEMENTS

I thank FANZ for funding the writing of this paper and wish to express my appreciation to all the researchers who carried out and published research on Cu requirements of pasture and animals.

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