MICRO-NUTRIENTS UPTAKE EFFICIENCY AS A FUNCTION OF FORM AND PLACEMENT – A REVIEW

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Abstract:

A review of micro-nutrients in arable and pastoral farming systems has found low uptake efficiencies for copper and zinc of between 0.01 to 8.5% of the applied micro-nutrients. The uptake efficiency of copper and zinc was strongly affected by application method compared to solubility, with the best results from the incorporation of fine powders and solutions into soils. This was followed by seed row application of copper or zinc coated granules or fluids. Some advantages have also been seen with the application of metal chelates, however at a significantly higher cost. In contrast to the cationic micro-nutrients, the uptake of anionic micro-nutrients borate and molybdate have shown lower susceptibility to soil fixation with uptake efficiencies of between 1 to 20%, however this may lead to localised phyto-toxic effects if applied as high concentration granules.

The objective of this review is to determine the state of knowledge in regards to the following areas:

- Application of micronutrients as a granule blended with fertiliser, as a coating on fertiliser or liquid solution
- The effect of placement method on the uptake of micronutrients.

Introduction:

In addition to the macronutrients (N, P, K, Mg, Ca, S and Si), micronutrients (B, Cl, Mn, Fe, Zn, Cu, Mo, Ni, Se and Na) are required for optimal plant growth. In New Zealand deficiencies occur related to specific crop requirements and soils and are not wide spread. Molybdenum deficiency in legume crops (clover and lucerne) have been reported in Northland, the lower North Island and the South and East Coasts of the South Island (Sherrell and Metherell 1986) while boron, zinc and copper are restricted to groups of sandy and peat soils. In contrast to New Zealand, large areas of the south-western Australian wheat growing area suffer from deficiencies of zinc and copper (Brennan 2006; Brennan and Bolland 2008) which require initially high level applications of copper and/or zinc to overcome the acute deficiency followed by low level annual maintenance applications to obtain optimum yields. The residual effects of these initial applications of zinc and copper may last for 20-30 year as it is slowly released from the soil absorption sites. The residual effects of Fe and Mn fall to below 50% of the initial yield response within 1year for Fe and 6 years for Mn (Brennan et al. 2001; Brennan and Highman 2001).

The residual effect of copper, zinc are strongly affected by cultivation, which breaks up and mixes the residual copper and zinc throughout the soil increasing its uptake by the subsequent crops. The trend to no-till systems prevents this process and deficiencies of copper and zinc in wheat have been observed after 7 years of no-till in south-western Australia (Bolland and Brennan 2006). Thus the move to no-till as a means of soil carbon accumulation and soil conservation requires improved delivery of copper and zinc to plants.

In addition to the plant requirements of micronutrients grazing livestock require additional selenium, cobalt, copper and iodine to prevent disorders such as “white muscle disease”, “bush sickness” in cattle and sheep and ‘goitre’ in lambs. To increase the levels of these required micronutrients in grazed forage, it is common practice to apply micronutrients with fertiliser as blended granules to prevent segregation of the products during transport and during spreading. This approach relies on the average micronutrient content of the grazed sward not the individual plant as illustrated by Loganathan and Hedley (2006) with a study of spatial and time dependence of Se release and uptake by pasture swards from commercial granular Se fertilisers. This work showed a high proportion of plants in a sward may be low in Se but the whole sward provided sufficient Se due to the high levels in plants close to the Se fertiliser granule (Loganathan and Hedley 2006). These results were taken to field trials by McLaren and Clucas (2006) who showed Se recoveries of 15 to 17% of applied Se in the pasture in the first year (McLaren and Clucas 2006). Adams et al. (1969) showed little residual effects of cobalt application on herbage Co content after 1 year and low recoveries of 0.02-2.8% of applied Co (Adams et al. 1969).

In both cropping and pastoral systems there is a potential to increase the uptake efficiency of Fe, Mn, Zn, Cu and Co which have the potential to be adsorbed and immobilised in soils reducing their ultimate uptake. This review of the current literature in respects to solid fertiliser products and their application hopes to find a way forward to increased efficiency and reduced application rates of micronutrients, which may pose a risk to the environment in the future.

Form and placement factors effecting uptake of micronutrients

Fine powders or granular micronutrients

The application of blended micronutrients as either (fine) crystalline or granulated products have a number of issues, particularly with regards to physical separation following handling and during application in the field (Douglas et al., 1985). For example, broadcasting of dry mixed Molybdenum and superphosphate resulted in high variability in spreading pattern (CV 40% at 12 m bout width) while wet mixed produced lower variability (CV 23%) (Douglas et al., 1985).

Granulation of micronutrients to increase their particle size is a method commonly used when bulk blending fertilisers to reduce segregation of materials. In the case of zinc granules, size and water solubility are important factors in plant uptake (Mortvedt, 1992). Mortvedt (1992) showed that in maize pot trials the dry matter response from Zn granules was optimum at

100% water soluble Zn (w.s. Zn) for 1.7 to 2.4 mm granules. However, finely ground (<0.15mm) Zn products produced higher dry matter yield regardless of Zn solubility (7 to 100% w.s. Zn). In Australian trials, (Mortvedt and Gilkes, 1993) reported that Ghosh (1990) had found similar effects to particle size. Ghosh (1990) compared the relative effectiveness of zinc granules or coated ammonium phosphates, compared to $ZnSO_4$ solution and found powdered zinc materials ($ZnSO_4$ granules and Zn fortified single superphosphate, MAP and DAP) were between 78 to 95% effective compared to $ZnSO_4$ solutions, while the same granular zinc materials were only 3 to 12% effective. Similar effects for copper have also been noted by Grundon (1991), who compared slow release copper sulphate, formed by impregnation of copper sulphate into polymer to crystalline copper sulphate in wheat pot trials. Grundon (1991) found the slow release copper failed to produce grain while the crystalline copper sulphate treatment produced grain.

In contrast to the metal (cationic) micronutrients which are susceptible to absorption by soil organic matter, non-metal (anionic) micronutrients such as boron (B) and molybdenum (Mo) show lower tendencies to be adsorbed in soils and show higher mobility and plant uptake (Table 3).

Placement of Micronutrients

In terms of placement of Cu and Zn granular or powdered micronutrients, Karamanos (2005) found that broadcast and incorporation of fine $CuSO_4$ was more effective than seed row placement. This was mostly due to the immobilisation of the metals in the application zone, which was rapidly out grown by the feeder roots limiting root interception. These results are not surprising, due to the reported low mobility of zinc and copper in many soils (Flaten, 2004; Gilkes, 1979; Gilkes, 1975; Hettiarachchi, 2010; Moraghan, 1996).

However, with low or no-till systems, seed row placement or surface broadcast applications are the only available options.

Fluid application

Holloway et al. (2006) reported the application of granular micronutrients at low rates was less effective than fine powders or fluids due to the low mobility of the Zn, manganese (Mn) and Cu in calcareous soils. Holloway et al. (2006) has shown in South Australia that Zn and Mn added to suspension or applied as a separate fluid were 40 to 80 % more effective than coated granules or blended fertilizers when banded. This result appears to contrast the findings of Mortvedt (1967) who found banding fluid NP+Zn gave poor results compared to the full incorporation of dilute fluid NP+Zn. The addition of Zn EDTA in fluid fertilizers may increase effectiveness of Zn by increasing the diffusion of Zn away from the addition point (Prasad, 1981).

Uptake efficiency of micronutrients – Placement and Form

The effect of application method on the recovery of Zn and Cu is clearly shown in tables 1 and 2, with broadcast and incorporation of fine powder or liquid micronutrients resulting in uptake efficiencies of 0.8 to 8.5% of applied Zn and 0.14 to 0.35% for applied Cu.

Table 1. Uptake efficiencies of applied Zn of different methods, materials and crops

Application Method	Percentage of applied Zn recovered in plant tops						
Broadcast/incorporated granule	0.05%		1.1%		1.8%		
Broadcast/incorporated powder			2.8%				
Banded powder							
Banded granule					1.0%		
Solution mixed		2%		8.5%		3.7-7.0%	0.8-0.9%
Seedrow/banned liquid				1.8%			
Seedrow Granule							
Reference	(Slaton, 2005)	(Prasad, 1981)	(Mortvedt, 1992)	(Mortvedt, 1967)		(Brennan, 2001)	(Holloway, 2010)
Plant	Rice	Corn	Corn	Corn	Corn	Lentils and Chickpea	Wheat
Form	ZnSO4	ZnSO4	ZnSO4	ZnO/UAN	ZnO/MAP	ZnSO4	ZnSO4

In the case of copperized single superphosphate (Cu SSP) the highest uptake (0.44%) occurred when the granule separation from the plant was small (1 cm) and reduced with distance to 0.01% at >3 cm (Gilkes, 1979).

Table 2. Uptake efficiencies of applied Cu by different methods, materials and crops

Application Method	Percentage of applied Cu recovered in plant tops					
Broadcast/incorporated granule	0-0.35%	0.05%		0.06%		
Broadcast/incorporated powder						
Banded powder						
Banded granule						
Solution mixed			0.14%			
Seedrow/banned liquid						
Seedrow Granule		0.01%			0.01%	0.44-0.01%
Reference	(Muller, ca.1980)	(Malhi, 2005)	(Malhi, 2009)			(Gilkes, 1979)
		grain Cu only				
Plant	Clover	Wheat	Wheat	Wheat	Wheat	Wheat
Form	Cu SSP	CuSO4	CuEDTA	CuSO4	CuO coated MAP or DAP	Cu SSP

In contrast to the divalent cations Zn and Cu, the anionic micronutrients boron (B) and molybdenum (Mo) (Table 3) show high plant uptake, due to increased mobility in soil (Mortvedt, 1994). The higher mobility of the anions allows more rapid movement away from the point of application resulting in higher root interception.

Table 3. Uptake efficiencies of applied Boron and Molybdenum by different methods, materials and crops

Application Method	Boron					Molybdenum	
Broadcast/incorporated granule				20%	2.4-4.0%		
Broadcast/incorporated powder							
Banded powder							
Banded granule							
Solution mixed	1%	17-23%	11%			0.5-4.6%	0.5-14.5%
Seedrow/banned liquid							
Seedrow Granule					4.0-6.9%		
Reference	(Lou, 2003)	(Stangoulis, 2001)	(Davis et al. 2003)	(Muller, ca.1980)	(Malhi, 2003)	(Gupta, 1980)	(Widdowson, 1971)
Plant	Oil Rape	Oil Rape	Tomato	Turnips	Canola(oil rape)	Alfalfa	White clover
Form	Boric acid	Boric acid	Boric acid	Boric acid	U.S Borax granules	Sodium Molybdate	Sodium Molybdate

Conclusion:

From the review of current literature, the application method used for micronutrient metals such as Cu and Zn plays an important role in growth response and uptake. This is mainly due to the rapid absorption of these metals by soil organic matter. The most effective strategies to increase plant uptake are:

- Chelates of the metal ions increase dispersion of micronutrients
- High solubility compounds to increase dissolution and diffusion
- Incorporation of the trace metal evenly throughout the soil improve root interception

Incorporation however requires a high degree of soil disturbance which results in the loss of soil organic matter and structure. This has led to a significant move to direct drilling, strip tillage, low till practices to conserve soil. In these systems, seed row placement of metal ($CuSO_4$, Zn SO_4 etc.) coated fertiliser granules within 2 cm of the seed is also an acceptable method of application.

There are some indications that application of Zn and Cu trace elements in a fluid fertilizer may increase micronutrient uptake. This effect is however likely to be due to increased plant root vigour in the fluid fertilizer zone and the increase in available P.

In terms of the non-metal micronutrients uptake efficiencies are considerably higher than the metals, the main concern is localized toxicity around the point of granule application, thus an even application of small particles is desirable.

Further research is required to improve the uptake efficiency of metal micronutrients.

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