Copper as a nutrient for agricultural crops in southern Australia

Scope

This review of the literature focuses on the function, importance and management of copper (Cu) for wheat production in dryland cropping systems of south-eastern Australia. The review draws on a selection of cornerstone journal articles and book chapters that provide foundation information about the role of and importance of Cu for wheat production. Information is sourced from the international literature and, where available, literature that provides specific Southern Regional content. The selected research and extension literature focuses at the regional level but is underpinned by the basic universal principles of Cu nutrition provided by the cornerstone articles and texts. Region-specific literature may be in the form of conference papers, fact sheets, technical reports or decision support systems (DSS).

These information sources are selected to assist advisers and growers to improve their understanding of Cu to provide the basis for improved decision making for managing Cu nutrition.

Outcome

This literature review seeks to assist advisers and growers to make better decisions about Cu management including whether Cu supply will be adequate or additional quantities of Cu need to be applied, and if so, where, when, in what form and at what rate. The review summarises the function, importance and use of Cu by plants in dryland cropping systems and provides a bibliography of reliable information sources. This literature review will be combined with reviews of other agronomic topics to provide growers and advisers with a carefully targeted source of information that will assist them to make more informed decisions about agronomic management.

Function of Cu in broad-acre grain crops

Nature of Cu in plants

Copper is an essential micronutrient required for the growth of wheat (Brown and Clark 1977) with crucial roles throughout the plant including chlorophyll formation, enzymatic reactions and pollen formation (Graham 1975, Sauchelli 1969). Copper mobilises from old leaves to younger parts of the plant to some extent with the degree of mobilisation greater when Cu is more available to the plant and movement is related to leaf senesce (Hill et al 1978, Loneragan 1981). Wheat deficient in Cu during the vegetative phase appears wilted and progresses to plants being short and thin-stemmed with twisted leaf-tips that senesce (Grundon 1987, Wurst et al 2010). Mature plants deficient in Cu have delaying heading, and empty or partially-filled heads due to lack of viable pollen and also senesce (Graham 1975).

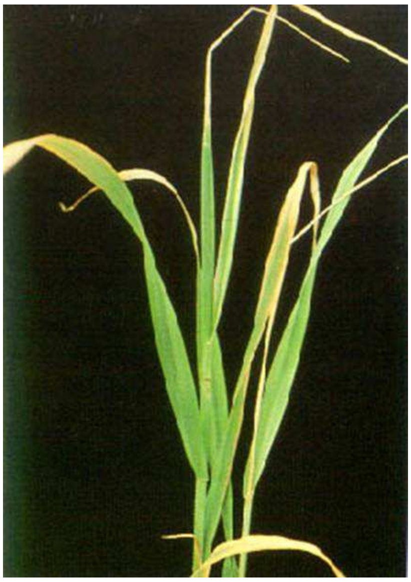

Figure 1: Wheat with with twisted and senesced leaf-tips. Sourced from: http://www.spectrumanalytic.com/support/library/ff/Cu_Basics.htm

Nature of Cu in soil

Copper is naturally present in soil in several soluble (hydroxy and carbonate) and insoluble (oxide and sulphide) forms and with the soluble form differing in its availability to plants dependent on other soil properties predominantly soil pH, clay content and the presence of organic matter (Fernandes and Henriques 1991, Harter 1991, McBride 1981).

Access to Cu by plants

Plant roots take up Cu from soil solution as water soluble Cu2+ in the soil or from fertiliser. Uptake of Cu from the soil and into the plant depends on (Fernandes and Henriques 1991, Gartrell 1981):

- limited movement of the nutrient via mass flow or diffusion (from the soil to the root)
- the chemical availability of the nutrient
- growth of roots through the soil (root interception)
- active and passive uptake of the nutrient at the root surface itself

Cu in context of south-eastern Australia

The calcareous sands of south-eastern Australian (commonly known as 90-mile Plain) was one of the first regions in the world where a deficiency of Cu in soil was recognised as reducing growth and yield of wheat, other cereals and permanent pastures (Riceman et al 1940). A broader history of the diagnosis of micronutrient deficiencies in wheat and other crops throughout the arable lands of Australia is summarised by Donald and Prescott (1975). Their summary includes a map of Australia indicating the regions with Cu-deficient soils as principally the coastal areas of southern Australia, Wimmera and large tracts of arable land in South Australia and Western Australia. Individual field experiments demonstrate inconsistent and isolated grain yield responses to copper on duplex acid soils in the southern Wimmera (Dickmann et al 1987, Flynn and Gardner 1987, Gardner and McDonald 1988) but not on other soil types in the Wimmera or acid soils in Northern Victoria (Haines 1987). Initial field observations and field experiments compliment soil testing in Victoria showing copper deficiency is more prevalent in the Wimmera and Western Districts (30% of tested soils) than the Mallee (7%) and Central Victoria (9%) (Norton et al 2012). An analysis of wheat grain sourced from the National Variety Trials in Australia shows that Cu concentration is well above critical values in Victoria and New South Wales (Norton 2012, Reuter et al 1997a).

Local tools available to help Cu fertiliser decision making

The bulk of advisory literature is focused on the symptoms and detection of Cu deficiency rather than on correcting the problem (BCG 2009, Wilhelm 2007, Wurst et al 2010). Plant testing is promoted as the preferred technique for diagnosing Cu deficiency (BCG 2009, Wilhelm 2007). BCG (2009) draws on information from Western Australian experiments to make a generalisation that Cu fertiliser applied to soil will be effective at preventing Cu-deficiency is cereal for about 10 years. This is a conservative timeframe if results from Western Australian are applicable in south-eastern Australia (Brennan et al 1986).

Guidelines are available for Western Australia and Eyre Peninsula that provided additional information about timing and rates of Cu fertilisers needed to correct Cu deficiency in cereals (Brennan 2001, Brennan 2005, Cordon and Ashton 2006). There are similarities in the advice for correcting Cu deficiency given for both regions despite the differences in soil types between regions and conclusions are supported by the broader research literature. This shows that the timing and rates of Cu required to correct Cu deficiency in wheat does not differ greatly between regions in southern Australia. Assessing the need for Cu fertiliser is the more important step and the guidelines provided by Norton et al (2012) can aid in that assessment. Norton et al (2012) advocates using a subjective assessment of Cu availability by considering relevant soil factors; soil pH, soil moisture, organic matter and soil texture.

Principles of better crop nutrition

The principles for effective fertiliser use are right source, right place, right time and right amount (Norton and Roberts 2012). Effective use of Cu fertilisers are similar to some other micronutrients, especially Zn. This is due to both micronutrients having similar ionic properties, interactions with other elements, and modes of movement in soil and into plants (Chesworth 1991). The efficiency of Cu fertilisation is only discussed here in situations when Cu is either known to be deficient due to plant symptoms or thought to be deficient due to low values from soil tests. There is no advantage of applying Cu to soil or plants for nutrition purposes when Cu is not deficient (King and Alston 1975). This applies to much of the wheat grown in south-eastern Australia as there are no symptoms of Cu deficiency in plants and soil testing shows that Cu is adequate (Norton 2012, Norton et al 2012).

Right source

There are three different types of Cu fertilisers used in wheat production; seed dressing, fertiliser applied to soil and foliar fertiliser. Copper fertiliser is mainly applied to the soil at seeding in a solid form. There are few direct agronomic comparisons of the efficiency of these three fertiliser types on grain yield production for Australian wheat. GRDC (2008) only discriminates between them in terms of their immediate costs and residual effect. Soil-based fertilisers are used as a long-term strategy to increase Cu availability whilst seed dressing and foliar applications only resolve the immediate deficiency.

Variable responses to soil and foliar fertiliser types result often from different soil moisture. Under moist soil conditions, wheat produces the same grain yield response with both soil and foliar Cu fertiliser (Flynn and Gardner 1987, Grundon 1980). However, foliar Cu application is more effective than soil-applied Cu at increasing grain yield when the soil dries out during plant growth (Grundon 1980).

Copper fertiliser is principally applied to soil in the form of copper sulphate (CuSO4) and to a lesser extent, copper oxide (CuO). The raw material, CuSO4.5H2O, is soluble in isolation however it becomes insoluble on interaction with some other fertilisers, such as superphosphate once blended (Gilkes and Sadleir 1978). Comparisons of different solid forms of soil-based Cu fertilisers show no difference in their efficacy on wheat grain production when the soil is continuously moist (Gilkes and Sadleir 1978). No comparisons are in the literature for solid and liquid Cu fertiliser applied to the soil. The overall conclusion for various solid forms of soil-based Cu fertiliser is they are equally agronomically effective when applied with correct placement (Gilkes 1981).

Foliar application of Cu is an alternative to soil-applied Cu fertiliser. Foliar application has the advantage of allowing Cu to be applied strategically based on seasonal progress and the occurrence of visual symptoms. The most common form of foliar fertiliser is CuSO4 (25% Cu). Alternative forms are copper oxychloride (52% Cu) and chelated-Cu (15% Cu) (Brennan 1990). Comparing foliar Cu fertiliser types for wheat shows that chelated-Cu is the most effective foliar form of Cu for increasing grain yield and copper oxychloride is least effective form (Brennan 1990).

Copper applied as a seed dressing has not been researched in Australia and is considered less effective than soil and foliar fertilisers due to Cu being lost from the seed as dust (Gartrell 1981). This lack of research also applies to both comparisons between seed dressing and other types of Cu fertiliser.

Right place

Soil-applied fertilisers can be placed shallowly or at depth. However, copper has very limited mobility in soil hence fertiliser and seed need to be in close proximity (McBride 1981). The practical application of this basic principle is that fertiliser placed within 2cm of the seed increases copper uptake and biomass of young wheat in well-watered Cu-deficient soil (Gilkes and Sadleir 1979).

The alternative is to place Cu fertiliser at depth. Ma (2009) reviewed the effectiveness of deep placement of fertilisers in Mediterranean environments, including south-eastern Australia. Deep placement of fertiliser generally means applying fertiliser at least 30mm below the seed. Placement of fertilisers containing elements with low mobility, including Cu, improves grain yields in situations where the top soil is prone to drying out and subsequently nutrients are immobilised (Grundon 1991, Ma et al 2009). Environments prone to dry topsoil during the growing season include the sandy soils of Eyre Peninsula and low rainfall environments (Wilhelm 2005). Australian research specifically examining the benefits of placing Cu away from the seed is rare (Gilkes and Sadleir 1979) and no field experiments to our knowledge has examined the placement of Cu were found in the course of this review.

Right time

Copper needs to be available throughout the life of the plant (Loneragan 1981). The agronomic advantage of applying Cu at depth in soil prone to drying means that in practice Cu fertiliser must be applied before or during seeding in those environments. Theoretically applying Cu as a seed dressing and as a soil-based fertiliser at depth could provide adequate Cu nutrition in Cu-deficient soil however, no research is available to assess this option. Under glasshouse conditions, Cu applied as a liquid to the soil between seeding and early booting is effective at increasing grain yields (Graham 1976).

The timing of application for foliar Cu fertilisers is operationally more flexible than solid fertiliser but must match plant demand. Graham (1975) concludes that early booting stage (GS41) is the most critical time for Cu supply as this is when pollen is formed. Grain yields are increased when Cu is applied anytime between sowing and GS41 (Graham 1975). More recent research is focused on determining the optimal timing of foliar applications within Graham’s (1975) broad range. Improvement of grain yield occurs with a single application of foliar Cu early in the season at GS16 (Brennan 1990) but not necessarily to maximum yield potential. Grain yield is maximised when copper sulphate is applied as a foliar application twice during the season; at late tillering (GS 24-29) and just prior to booting (GS 35-39) (Grundon 1980). There is variation of optimal timing of CuSO4 application between cultivars with some needing Cu fertilisation prior to mid-tillering to avoid yield reduction (Nambiar 1976).

Right amount

The amount of major nutrients required for a crop is given by GRDC (2011) in terms of kilograms required for a target grain yield but no equivalent for micronutrients is provided. Based on concentrations of copper in wheat grain (4.8 +/- 1.2 mg/kg) grown as part of the National Variety Trials in 2009 (Norton 2012), the amount of Cu removed is 11-18g for every 3 tonnes of grain/ha. This amount is very small compared to the amount of N, P, K and S removed by grain (GRDC 2011, Norton 2012). The amount of Cu considered 'adequate' for normal growth in whole shoots at commencement of ear emergence (GS51) is 5-25 mg/kg (Reuter et al 1997a). This is equivalent to 25 – 125g for a crop with an above ground biomass of 5 t/ha. In addition to these general Cu requirements, the amount of Cu required increases overall as soil fertility increases through application of higher rates of N and P fertilisers or use of N fixing species (Gartrell 1981).

Foliar application rates needed for wheat to achieve 90% maximum grain yield varies with Cu source, soil type and year (Brennan 1990). The amount of foliar-applied Cu required for a 2 – 2.5 t/ha grain yield in Western Australian acidic sands ranges from 125g/ha for chelated-Cu to 950g/ha for copper oxychloride. The more commonly used form of foliar Cu, CuSO4 requires application at 250 – 350g/ha (Brennan 1990). The results of this research form the foundation for the overall recommendation to apply 1kg Cu/ha once per season in a foliar form to wheat crops grown in Western Australia (Brennan 2005). This recommendation differs little from an earlier generic recommendation to apply 1- 2kg/ha of foliar Cu as a split application (Grundon 1987). The recommendation for Western Australia is similar to Cu requirements for Eyre Peninsula where 11 out of 14 sites known to be deficient in Cu were corrected by applying 300 g foliar-Cu/ha along with other micronutrients (King and Alston 1975).

The amount of Cu required for a single crop when applied as a soil fertiliser is less well-defined (Brennan 2001). Instead, the amount of Cu required for wheat is stated as a requirement to ensure adequate supply over a number of years as only a small amount of Cu is removed in any one season compared to the amount applied ie. There is a significant 'residual value'. Thus the amount to apply depends on how many years of residual effect is desired and the nature of the soil to 'fix' Cu.

Predicting crop requirements

There are three general approaches to determining whether a nutrient needs to be applied soil testing, historical records and plant testing.

Soil testing

Soil testing in a pre-emptive indicator for the amount of major nutrients (nitrogen (N), phosphorus (P) and potassium (K)) available to a planned crop. Soil samples are tested for Cu as a cheap adjunct to testing for major elements. Placement of soil-sampling points influences soil test results with higher Cu values occurring if all samples are taken on existing rows rather than between rows (Bolland and Brennan 2006). Sampling randomly both in and between rows provides an overall Cu value for the sample area. Soil testing of the top 10cm layer is promoted for the major cropping soils in Australia as being relevant for making decisions about immobile plant nutrients such as P (GRDC 2009). Testing only the 0-10cm soil layer is also appropriate for Cu as most Cu in soil occurs in that soil layer and Cu as fertiliser remains in the vicinity of placement even except in highly leached soils (McBride 1981).

Soil testing by DPTA-Cu

Extractable Cu is commonly measured in cropped soils (0-10cm layer) by extraction with DTPA as described in Method 12A1 by Rayment and Higginson (1992). The principle behind the DTPA extraction technique is that DPTA extracts solubilised and insoluble Cu from the soil similar to the extraction expected by plants. Given availability of Cu in soil is reduced as soil pH increases (McBride 1981), pH of the solution is standardised at pH7.3 for the extraction. Critical Cu values relevant to wheat by DTPA extraction vary with soil type and on some soils in Queensland extraction values cannot be related to grain yield response (Brennan and Best 1999). Only a limited number of Australia soil types are calibrated for Cu-deficiency in wheat thus interpretation of Cu values for other soil types relies on extrapolation. Critical Cu values by DTPA extraction for soil growing wheat are 0.2 mg/kg on the Eyre Peninsula, and gravel and duplex sandy soils in Western Australia (Brennan and Best 1999, King and Alston 1975). Further calibration of soils in Western Australia is unlikely to occur as Cu-deficiency has largely been recognised and corrected by Cu application thus there are few soils with which to develop a calibration (Brennan and Bolland 2006).

A less commonly used method extracts Cu using EDTA (Method 12B1 in Rayment and Higginson 1992). Few soil calibrations for this method are published for wheat (King and Alston 1975).

Historical records

Past responses to Cu fertiliser and a lack of prior Cu fertiliser application are not a reliable guide for Cu fertiliser requirements. Cu uptake is dependent on the presence of water in soil (Grundon and Best 1981) and is adversely affected by waterlogging (Flynn and Gairdner 1987); thus a response to Cu fertiliser in one year does not necessarily mean a response can be expected in subsequent crops. This interaction between Cu and seasonal conditions supports Norton’s et al (2012) conclusion that past Cu deficiency in crop should not be used as the sole criteria for determining if Cu fertiliser application is warranted for a particular crop.

Further, depletion of naturally occurring Cu in soil does not appear to be an issue in wheat production but there is a distinct lack of research on this topic. The response of wheat to Cu fertilisers is only considered in soils inherently deficient in Cu (Brennan 1990, Riceman et al 1940). Thus an extended period of omitting Cu fertiliser from a cropping program does not necessarily indicate that Cu reserves are depleted and Cu fertiliser is required for the next crop. This differs from other micronutrients like Zn (Brennan and Bolland 2006).

Crop testing

Cations like Cu^{2+} can be absorbed by plants through the leaves (Eichert and Burkhardt 2001). Therefore limited calibrations for soil Cu coupled with the technical possibility of foliar application of Cu makes tissue testing viable for diagnosing and correcting Cu deficiencies as the plant grows. Importantly, plant testing is considered to be a reliable method for detecting Cu deficiency (Brennan 2006). Copper is a micronutrient thus plant samples must be taken with care to avoid contamination with Cu from other sources such as soil or cutting tools (Reuter et al 1997b). Testing of the youngest emerged blade of wheat at GS23-30 for Cu may show that Cu concentration is below the range deemed minimal (1.3 to 3.0 mg/kg) by Reuter et al (1997a); a range supported by Brennan and Bolland (2004).

Other factors affecting availability of Cu to crops

Residual value

Copper is largely immobile in soil with mass movement limited to highly leached podzols (Isbell 2002) and even under those conditions Cu remains within the root zone (McBride 1981). Podzols (mostly reclassified as podosols in Australia) are rare in south-eastern Australia and tend to be in Gippsland, an area more focused on pasture production than grain production (Isbell 2002). Locally, a laboratory study with soils from the south-east of South Australia shows that Cu leaches up to 3cm in sieved sands when subjected to the equivalent of 12 months simulated rainfall (Jones and Belling 1967).

In the field, Cu fertiliser applied to soil has a residual effect on crop growth for several years depending on the rate applied (Brennan et al 1986). A review of Australian and overseas literature concluded that 1 – 1.5 kg Cu/ha applied to soil with the seed has a residual effect for at least 5 years after application (Brennan et al 2006). The residual effect of Cu fertiliser on acidic sandy earth in Western Australia is estimated to be higher at about 18 years for a single application at 0.7 kg Cu/ha and about 44 years for a single application at 2.1 kg Cu/ha applied as $CuSO_4.5H_2O$ (Brennan et al 2006). Similar studies have not been conducted in south-eastern Australia.

Soil water

Lack of soil water reduces the response of wheat to Cu fertiliser (Grundon and Best 1981). One reason this occurs is because the lack of soil water restricts the ability of Cu to move into the roots by diffusion (Gartrell 1981). Further, Cu is immobile and plant uptake relies on the roots seeking out the Cu in the soil. However, dry conditions reduce root growth and therefore the ability to access soil Cu. Waterlogging can also adversely effect plant growth resulting in a similar negative outcome for Cu fertilisation.

Parent material of soil

A soil characteristic of major interest in south-eastern Australia is the origin of soil when the parent material is inherently low in Cu. Such parent materials are acid igneous rocks (e.g. granite) and marine-based calcareous rocks (Gartrell 1981, McBride 1981). Soils based on these parent materials occur in the 90-Mile Plain, an area known to be naturally deficient in Cu (Riceman et al 1940) and south-west

Victoria and south-eastern South Australia where some soils are volcanic and Cu-deficiency in wheat has been reported (Flynn and Gardner 1987, Norton et al 2012).

Organic matter and clays

Fulvic acids and humic acids present in organic matter bind Cu and thus reduce its availability (Stevenson and Fitch 1981). Similarly, clays and oxides also bind Cu and reduce availability of the nutrient. A Cu deficiency due to high organic matter content is most likely to occur in peat soils, which are rarely used for cropping in south-eastern Australia. Other regions most likely to be affected by this relationship in south-eastern Australia are the higher rainfall areas in south-west Victoria, Tablelands of southern New South Wales and the south-east of South Australia.

Soil pH

The amount of Cu in soil solution decreases as soil pH becomes increasingly alkaline (McBride 1981). However, this does not always reduce the availability of Cu to wheat as shown by Cu uptake (Brennan et al 1983).

Effects of other nutrients on response to Cu

Wheat's requirement for, and use of, Cu is influenced by supply of other essential nutrients. As fertilisation with the major nutrients, particular N, increases grain yield potential, the demand for Cu increases (Brennan 1993, Gartrell 1981). Conversely, since plant roots must actively grow into soil that contains Cu fertiliser to enable Cu uptake, limited availability of the major nutrients N and P that restricts root growth also restricts Cu uptake. Uptake of Cu from soil by wheat also effects, and is affected by, the uptake of other micronutrients. For instance, adequate zinc in soil coupled with inadequate Cu leads to Cu deficiency due to competition between the two elements (Loneragan and Webb 1993). The movement of Cu within wheat from old to young parts of the plant is slowed when N is deficient (Hill et al 1978).

Genetics for Cu efficiency

Wheat cultivars vary in their expression of the symptoms of Cu deficiency during the early growth stages, at ear emergence and in grain production (Nambiar 1976). Correction of Cu-deficiency by foliar application prior to booting stage (GS 22-26) is more effective at preventing a reduction in grain yield in relatively longer season cultivars (85 days to ear emergence) than shorter season cultivars (65 days to ear emergence). This genetic variation is not being pursued as a desirable trait for selection by breeders in Australia (Richards 2006).

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