Zinc essentials and subtleties

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ZINC AT A GLANCE

Use soil tests, paddock history, soil characteristics, crop demand and tissue tests to determine the likelihood of a zinc (Zn) response.

Soil tests get a 4/10 and tissue tests a 7/10 for predicting response to extra Zn.

Water-soluble Zn content is a good indicator of agronomic effectiveness, but no formulation can provide more Zn that the amount supplied.

In acidic soils, water-insoluble fertilisers such as ZnO can be equally effective in improving plant growth when soil is Zn deficient.

When incorporated into acidic fertiliser, ZnO and $ZnSO_4$ can be similarly effective in providing Zn to the plants.

The best way and time to apply Zn is mixed or blended with dry or fluid fertilisers at seeding.

Using Zn-fortified seed can reduce the need for added Zn.

Where there is a moderate deficiency crops are able to take up and respond to Zn applied before stem elongation. Later applications – up to flowering – can increase grain Zn content but will do little in terms of yield response.

Using soil-applied Zn ahead of the most responsive crops seems a good strategy that balances cost and risk.

Zinc, one of the 16 essential nutrients for plant growth and reproduction, is a micronutrient that is required in smaller amounts than some other nutrients but is still essential.

If zinc (Zn) is limiting or in short supply, crop yields will suffer and crop use of water and nutrients will decrease.

Seedling vigor is related to grain Zn content and Zn has an important link to human health, with grains a major source of dietary Zn.

Zinc was one of the first micronutrients recognised as essential for plant growth and Zn deficiency is considered the classic deficiency on alkaline soils such as vertosols and calcarosols. It is still the major micronutrient deficiency in cropping systems in Australia, particularly since the change from single superphosphate (0.04% Zn impurity) to MAP and DAP (Holloway et al. 2008).

Information from a range of researchers working in this area suggests that chronically Zn deficient sites are not common, and while Zn responses are often seen in the form of increased grain Zn concentration, significant yield benefits are less common (Peck et al. 2008).

TISSUE TESTS CAN GIVE A GOOD INDICATION OF POTENTIAL RESPONSE TO APPLICATION OF ZINC BUT LEAVES LIKE THIS ONE, WHICH IS SHOWING CLEAR SYMPTOMS OF ZINC DEFICIENCY, ARE NOT THE ONES TO SAMPLE. SAMPLING THE YOUNGEST FULLY EXPANDED LEAF WILL PROVIDE THE BEST RESULTS.

Zinc supply for susceptible crops can be low on many soil types, but soil properties commonly associated with Zn deficiency are pH>7.5, high sand content, cold, wet conditions and compaction. Zinc can also bind to iron and manganese, so red acidic soils can be Zn responsive. Liming can alter root zone pH and so induce Zn (and manganese) deficiency if the lime is not applied well ahead of seeding.

Plants growing on soils testing very high in phosphorus (P) commonly suffer Zn deficiency. This syndrome is sometimes mistakenly considered to be due to a P tie-up of Zn in the soil but competition for nutrient transporters is more likely. Applying P to a soil with adequate Zn levels will not produce a Zn deficiency.

Much of the available Zn is associated with the organic matter in the topsoil. Land leveling and erosion can cause Zn deficiencies in crops by exposing subsoils low in organic matter, low in native Zn, or higher in pH.

Zinc deficiencies tend to occur early in the growing season when soils are cold and wet and shoot growth is more rapid than root growth. The slow-growing root system is unable to take up enough Zn to supply the shoot. Plants sometimes appear to outgrow this deficiency but the damage has already been done, with yields often significantly reduced. Root pruning herbicides such as SUs can give a similar response.

Soil test values from the National Variety Trial (NVT) sites showed that 15% of samples had low topsoil diethylene triamine penta acetate (DTPA) Zn and 15% of wheat grain samples had low grain Zn (<15mg/kg), even though quite a few sites received supplementary Zn. A larger data set of soil tests indicated that about 30% of soil samples from NSW had DTPA Zn <0.5mg/kg.

Typical grain Zn concentrations for Australian cropping regions are around 20mg/kg for wheat (Table 1), so Zn off-take in a 4t wheat crop is less than 100g/ha. However, soil has a strong capacity to bind Zn and balancing removal is not a useful concept for this nutrient.

TABLE 1. MEAN VALUES (± STANDARD ERRORS) OF SOIL PH, CLAY (%), ORGANIC CARBON (OC%), DTPA EXTRACTABLE ZN IN THE TOP 10CM, FROM NVT SOIL TESTS 2008-2012.

ASC Order	pH ($CaCl_2$) (0-10 cm)	Clay % (L1)	OC%	Mean critical Zn (mg/kg)	DTPA Zn (0-10 cm) (mg/kg)	Wheat grain Zn (mg/kg)
Calcarosol	7.3±0.1	18±9	1.7±1.6	0.25	1.1±0.7	18.6±0.9
Chromosol	5.6±0.1	14±7	2.1±1.3	0.20	2.1±0.3	22.6±1.1
Dermosol	6.8±0.1	29±9	2.5±1.5	0.26	0.8±0.6	16.7±3.0
Ferrosol	6.6±0.2	15±8	*		1.7±0.9	23.3±3.0
Kandosol	5.3±0.1	12±4	1.8±1.0	0.21	1.4±0.4	17.3±0.9
Sodosol	6.7±0.1	14±7	2.9±1.4	0.21	0.8±0.4	17.8±0.5
Tenosol	6.0±0.2	11±6	2.0±0.8	0.19	0.6±0.9	21.7±1.3
Vertosol (pH<7.0)	6.3±0.1	44±4	1.7±1.1	0.32	0.8±0.4	23.6±0.8
Vertosol (pH>7.0)	7.8±0.1	44±4	1.4±0.6		0.6±0.3	22.4±0.8
Means	**6.7±1.2**				**0.9±2.0**	**20.0±0.4**
% below critical	**22%**				**15%**	**15%**

Based on this risk assessment, all soil orders evaluated seem to have a moderate to high risk of Zn deficiency, and wheat grain analysis does show low Zn concentrations. Soil tests are quite variable and show low Zn, but the relationship between grain Zn and soil test Zn is weak, even with the inclusions of other soil factors such as pH and organic carbon. Many of the Zn recommendations in the eastern states have been developed for alkaline cropping soils, with few published reports of Zn responses in high rainfall zones.

Soil tests

Soil tests for Zn, most commonly either DTPA or ethylene diamine tetraacetic acid (EDTA) extractable Zn, and other micronutrients are available. Tests for DTPA or EDTA extractable Zn give similar numeric values (Norton, 2013).

Soil tests have been correlated to crop responses in properly conducted trials but the trials have been limited and the confidence limits can be quite large. As a result, the critical levels developed are often very low in absolute terms and are subject to sampling errors and analytical reliability. As with all soil testing, it is important to use accredited laboratories that use ASPAC-accredited methods for assessing nutrients, since these tests have critical values established for Australian conditions.

The current recommendations for critical DTPA Zn are variously given as 0.5 to 1.0mg/kg, but this value is strongly influenced by soil pH, soil texture and organic carbon content (Brennan 1992).

Table 1 gives estimates of critical values for various soil types that in most cases are between 0.2 and 0.4mg/kg. Dang et al. (1993) proposed that using the Zn buffering power of the soil in combination with DTPA-Zn values would improve the reliability of this soil test on vertosols.

These values are generally sufficient to meet Zn demand by crops and, despite indications from recent US research with high-yielding maize crops (Ciamoitti and Vyn 2013), there is little evidence to support the idea that high-yielding cereals in Australia have a higher critical DTPA-Zn value.

There is genetic variation in Zn efficiency between wheat varieties but the detail of this interaction is not known and a comparison of grain Zn levels from NVT trials showed no differences between the Elmore, Gregory, Gascoyne and Scout varieties. An earlier survey showed that Yitpi was more Zn-efficient than Gladius (Norton 2013).

It is uncertain how root associations such as those with vesicular-arbuscular (VA) mycorrhizae may affect critical soil Zn value, because infected roots are more efficient at accessing Zn (and P) than poorly colonised roots. Ryan et al. (2002) showed that VAM colonisation did not affect early crop growth, P and Zn uptake prior to anthesis or grain yield, but did find in one experiment that colonised plants had higher grain Zn contents.

TABLE 2: CRITICAL TISSUE ZINC CONCENTRATIONS FOR A RANGE OF SPECIES (REUTER AND ROBINSON, 1997). ALL VALUES ARE FROM AUSTRALIAN RESEARCH, EXCEPT THAT MARKED WITH AN ASTERISK.

Species	Sampling time	Tissue	Critical or deficient value
Barley	5 leaf	Youngest expanded blade	<14 mg/kg
	Maturity	Grain	<8 mg/kg
Canola	3-5 leaf	Youngest mature leaf	<12 mg/kg
	3-5 leaf	Youngest open leaf	<27 mg/kg
	Start stem elongation	Youngest mature leaf	<8 mg/kg
	Start stem elongation	Youngest open leaf	<16 mg/kg
	Maturity	Grain	<29 mg/kg*
Chickpea	45 days after sowing	whole shoot	<34 mg/kg
	Vegetative	Youngest mature leaf	<22 mg/kg
	Maturity	Grain	<28 mg/kg
Faba bean	First flowers	Youngest open leaf	<19 mg/kg
	First flowers	Whole shoot	<26 mg/kg
	Maturity	Grain	<14 mg/kg
Field pea	First flowers	Youngest mature leaf	<22 mg/kg
	Maturity	Grain	<20 mg/kg
Lupin	Pre-flowering	Youngest mature leaf	<13 mg/kg
	Maturity	Seed	<19 mg/kg
Sorghum	GS 3	Youngest mature blade	<10 mg/kg
	Maturity	Grain	<10 mg/kg
Sunflower	R2	Youngest mature leaf	<12 mg/kg
Wheat	23 days after emergence	Whole Shoot	<15-25 mg/kg
	Mid-late tillering	Youngest expanded blade	<14 mg/kg
	Mid-late tillering	Youngest emerged blade	<16 mg/kg
	Mid-late tillering	Whole shoot	<9 mg/kg
	Maturity	Grain	<15 mg/kg

Plant tissue tests

While soil tests provide a guide, the literature indicates that tissue tests provide a more reliable indication of potential Zn response.

It is critical to take the correct tissue at the correct time, as uptake and redistribution differ with time and tissues. Zinc has low mobility so the usual tissues to sample are the youngest fully expanded leaf (youngest expanded blade – YEB).

Table 2 gives the critical values for Zn in a range of tissues.

Younger, more rapidly-growing tissues are more responsive to changes in Zn supply so are better indicators of deficiency than older leaves or whole plants. Plant stage is also critical because Zn is redistributed and diluted as the plant matures. Consequently, critical levels decline with plant age. YEB samples are also suitable for other micronutrient tissue tests.

Of all the tissue tests for micronutrients, Zn measurement using the correct tissue at the correct time is one of the best diagnostics. Even so, there can be problems with positional unavailability of Zn in soil profiles or low temperatures reducing uptake. These conditions need to be taken into account when interpreting the tissue test results.

Also included in Table 2 are values for Zn in grain. These can be used to track trends in paddock supply over time and have some diagnostic value within cropping systems. Grain Zn content is particularly important for seedling vigour, especially in cereals, and it is the seed content, not concentration, that is important. A supply of less than 500mg of Zn per seed – a concentration of about 16mg/kg in a 32mg seed – is considered limiting (Rengel and Graham 1995). Larger seed could have a lower concentration but still supply the 500mg Zn.

Addressing deficiency

If the indicators used suggest a Zn response is likely, there are several options available.

Irrespective of the strategy chosen, there are several important aspects to using supplementary Zn.

- Zinc does not move very far in soil, so to increase the chance of roots intercepting it, distribution needs to be even. Banded fertiliser should spread Zn evenly along the drill row, which requires consistent zinc content in each granule. Soil mixing (e.g. via cultivation) can dilute Zn concentration but make the distribution more uniform through the soil. If placed too shallow, Zn can be 'stranded' in dry soil.
- Crops differ in their response to Zn, so it is more important to apply Zn ahead of or to responsive crops within a rotation. Canola is generally relatively more efficient than cereals at accessing soil Zn (Brennan and Bolland 2002), while lupins, faba beans and chickpeas need less than wheat and lentils have a higher demand (Brennan et al. 2001). Maize and sorghum have higher Zn demands than wheat or barley. This suggests Zn demand should be addressed in the cereal phase of a crop rotation, rather than a pulse or oilseed phase.
- Foliar Zn can be used for rescue operations but has little residual value. Soil-applied Zn (with macronutrient) has a residual value of two to five crops depending on soil texture and pH.
- Yield increases with added Zn are less common than increases in grain Zn (Peck et al. 2008).

Sourcing zinc

There are numerous Zn products that can be blended or coated with dry fertilisers, used as a seed dressing or applied as foliar spray in-crop. The source can be inorganic, synthetic chelates or natural organic complexes. The cost and efficiency of these different products vary significantly and the final decision comes down to cost versus efficiency. Table 3 gives some properties of different Zn sources.

The source selected will depend on the desired solubility and the type of soil to which it is to be applied.

The agronomic value of the source depends on the solubility and concentration of Zn in the product, although less soluble sources have greater residual value. The efficiency of sparingly-soluble Zn sources such as ZnO, $ZnCO_3$, Zn fritts in fine-textured soils that rapidly fix Zn soils was equal to that of highly-soluble Zn-sulfate heptahydrate. When sparingly-soluble and soluble Zn sources are compared in coarse textured soils, soluble Zn sources give the best performance.

Zinc sulphate is more effective than Zn oxide on alkaline soils but both are equally effective on an acid soil (Brennan and Bolland 2006).

Cost can vary ten-fold between products and is a major consideration, especially with chelated products. To estimate the cost per kg of Zn supplied, use the formula

\$/kg zinc =
Cost per tonne of product/%Zn/10

TABLE 3. SELECTED ZINC FERTILISERS (FROM ALLOWAY 2008).

Compound	Zinc content	Formula	Water solubility	Cost
Zinc sulphate monohydrate	36%	$ZnSO_4.H_2O$	High	Low
Zinc sulphate heptahydrate	22%	$ZnSO_4.7\ H_2O$	High	Low
Zinc oxysulphate	20-50%	$ZnSO_4.xZnO$	Variable	Low
Zinc oxide	50-80%	ZnO	Sparingly-low	Low
Zinc chloride	50%	$ZnCl_2$	High	Low
Zinc nitrate	23%	$Zn(NO_3)_2.3\ H_2O$	High	Medium
Zinc phosphate	50%	$Zn_3(PO_4)_2$	Low	?
Zinc fritts	10-30%	Fritted glass	Very low	?
Ammoniated zinc sulphate	10%	$Zn(NH_4)SO_4$	Solution	High
Sodium zinc EDTA	9-13%	Na.ZnEDTA	High	High

The uptake of Zn from compound fertilisers depends on the pH of the carrier (among other things).

Mortvedt and Gilkes (1993) concluded from a literature survey that Zn incorporated into DAP-based fertilisers is unlikely to be a fully effective Zn source, especially in neutral to alkaline soils.

Coating MAP granules with ZnO transforms all the applied ZnO to Zn ammonium phosphate, which limits expected Zn solubilty and diffusion in the soil. Coating ZnO on urea granules reduced Zn solubility more than coating it on MAP granules (Milani et al. 2010). More recent research has shown that Zn diffuses more slowly from DAP than MAP because of the higher pH (stronger sorbtion), and there appears to be more Zn-P minerals precipitated from a DAP source than from a MAP source (deGryse et al. 2012).

Other work has shown that distribution in the granule and then in the seed row is also important. Reduced pH due to root exudates in the rhizosphere or acidic fertiliser granules is thought to assist with the solubilisation of soil Zn under alkaline conditions.

GUESS WHERE THE ZINC WAS APPLIED. CHRONIC ZINC DEFICIENCY IS NOT COMMON, BUT WHERE IT DOES OCCUR, APPLYING A ZINC FERTILISER CAN HAVE STRIKING RESULTS. ZINC DEFICIENCIES GENERALLY TEND TO OCCUR EARLY IN THE GROWING SEASON WHEN SOILS ARE COLD AND WET.

In some situations there have been good responses to deep-placed micronutrients in SA (Holloway et al. 2008) and in the northern grains region (Bell, pers. comm.). No more than about 3% Zn (as Zn sulphate heptahydrate) can be added to P fluid fertilisers. (There is a limit to the amount of Zn that can be added to P solutions. – Holloway et al. 2008).

Brennan (1991) found Zn chelates 1.4 to 1.7 times more effective than Zn sulphate when applied as a foliar spray to wheat at GS14, but all the products trialled were equally effective when applied at GS23-24. In the same experiment, Zn sulphate banded with the seed at sowing produced the highest grain yields.

For more information: http://anz.ipni.net

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