Fertiliser Technology Research Centre

Technical Bulletin: Fertilizer Zn is not of environmental concern

EXECUTIVE SUMMARY

- Zinc is an essential plant nutrient, but if added to soil in excessive amounts may cause concern from an environmental viewpoint.
- Loadings of zinc to soil from fertilizer use are small in comparison to situations where animal manures or sewage biosolids are applied to agricultural land.
- Most concern regarding applications of zinc to soil is therefore related to disposal/re-use of animal/human wastes, or where zinc is added to soil from industrial/consumer sources e.g. runoff from galvanised structures.
- To our knowledge, there are no instances reported where zinc added to soil via fertilizers has caused environmental harm.
- A simple mass balance model was developed to examine potential scenarios for how zinc application in fertilisers causes accumulation of zinc in soil, and how this relates to critical toxicity concentrations for zinc in soil.
- The model was parameterized for a typical mid-western (United States) corn production system and assumed farmers keep adding fertilizer Zn even though available Zn in soil increases to sufficiency levels (an unlikely scenario). The time for Zn to accumulate in soil to concentrations approaching toxicity thresholds was more than a millenium.
- Data from a long-term field trial in Virginia on a neutral soil, where high rates of Zn fertilizer were applied to corn over a 20-year period (rates equivalent to more than 500 years of normal rates of Zn application), indicated no adverse effects on crop growth.
- The environmental risk of Zn in fertilizers is therefore extremely low.

BACKGROUND

Zinc (Zn) is an essential element for both crops and humans, and many soils around the world are potentially Zn deficient (Alloway 2008)(Figure 1).

Zinc is one of the key factors affecting human health in developing countries and UNICEF has a program of Zn supplementation of child diets to overcome these deficiencies either directly by dietary intervention (adding Zn compound powders directly to foods) or through biofortification (enhancing Zn concentrations in food crops by breeding and/or fertilization) (Brown et al. 2009; Hotz 2009).

Deficiency of Zn in soil can therefore adversely affect not only crop production through reduced yields, but also affect the health of humans eating food produced from those soils because they do not consume enough Zn. Hence many farmers now require (and request) Zn-enriched fertilizers for use in crop production.

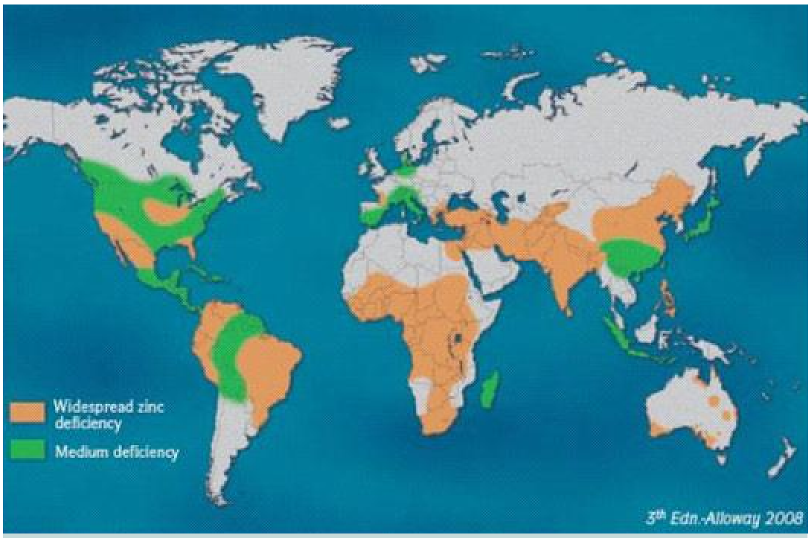

Figure 1. Map of Zn-deficient soils in the world (from Alloway 2008).

ADDITIONS OF ZINC TO SOILS IN FERTILIZERS

Rates of Zn addition to soil through fertilization vary from <1 kg Zn/ha (0.9 lbs/ac) up to 25 kg Zn/ha (22.3 lbs/ac) depending on the crop type and soil and environmental conditions (Alloway 2008). In very deficient soils these rates may need to be re-applied for several years until the available Zn status in soil has increased, and then rates of Zn application can be reduced, or the frequency of Zn application reduced.

MESZ contains 1% Zn, so a typical application of MESZ to corn in the mid-US (100 lbs P2O5/acre or ~49 kg P/ha) would add ~2.5 kg Zn/ha (2.5 lb Zn/ac). For comparison, the addition of 5 tonnes of animal manure or sewage biosolids to soil could easily add (1.5–10.0 kg Zn/ha, ~1.5-10.0 lbs Zn/ac) or more (Benke et al. 2008).

WHAT IS THE FATE OF FERTILIZER ZN ADDED TO SOIL?

Fertilizer Zn added to soil does not diffuse far from the point of application (Hettiarachchi et al. 2008), as most soils bind Zn very strongly and this reduces movement of fertilizer Zn (Figure 2) from the granule (or fluid injection point). Binding of Zn in soil is predominantly governed by soil pH (Sauve et al. 2000; Tiller and Hodgson 1962), with alkaline soils binding Zn more strongly (hence alkaline soils are more prone to be Zn deficient and require Zn fertilization).

Zinc that diffuses into the soil can either be taken up by crop plants (and the Zn removed in produce) or may be lost from soil by leaching - in the soils most likely to require fertilizer Zn addition (alkaline/calcareous soils) leaching losses are minimal. Losses of Zn through runoff will generally be small as Zn binds so strongly to soil particles (Brümmer et al. 1983). Any Zn added in excess of crop removals and leaching will accumulate over time in soil building up the total Zn concentrations, and the available Zn concentrations. Once available Zn is built up to a specific level (dependent on soil and crop type and climatic conditions), further addition of Zn will not be required for several years (Brennan 2001) as the soil becomes "non-responsive" to Zn fertilizer.

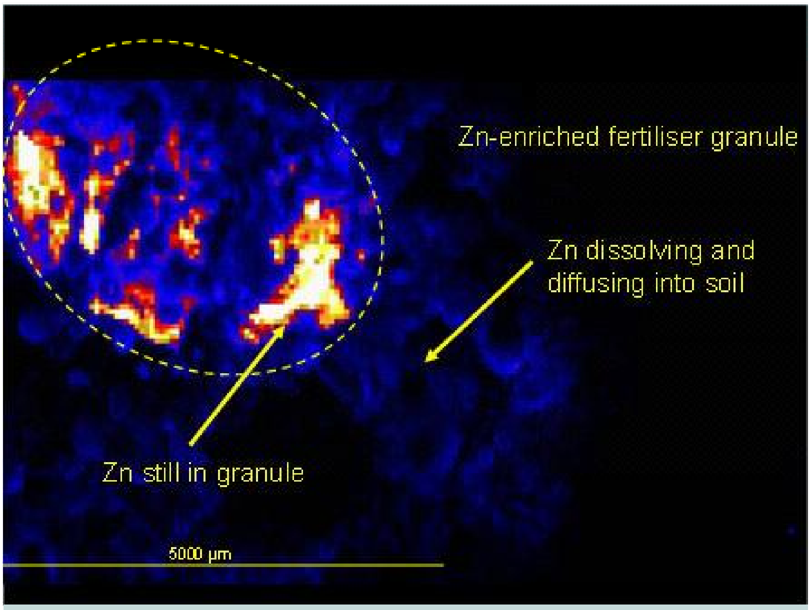

Figure 2. Map of Zn concentrations in soil around a Zn-enriched fertilizer granule 5 weeks after application to soil (Hettiarachchi et al. 2008, used with permission of the Soil Science Society of America).

ZINC TOXICITY IN SOIL

If Zn accumulates to high enough concentrations in soil, it may cause toxicity to plants or to soil microorganisms (Chaney 1993). This phenomenon was first observed in soils contaminated with runoff from galvanized structures (Millikan 1947) and is most commonly observed only in contaminated urban/industrial soils or where wastes have been applied to land e.g. biosolids (Chaudri et al. 1993).

Much research has been conducted to set "safe" levels for Zn in soil, and naturally these are not single values across all soils but vary (due to variable ability of soil to bind Zn) depending on soil pH and other soil properties (e.g. cation exchange capacity (CEC)) (Smolders et al. 2004; Smolders et al. 2009; Warne et al. 2008).

COULD FERTILIZER ZN EVER CAUSE TOXICITY IN SOILS?

This is highly unlikely for several reasons:

1) Amounts of Zn added to soil in fertilizers are very small;

2) Zinc is removed in agricultural produce and as Zn concentrations in soil increase, so too does the Zn concentrations in produce removed from the land (which is good for human and animal nutrition); and

3) Fertilizer Zn has residual value i.e. once Zn levels in soil have been increased through repeated application of Zn fertilizers, there is no need for farmers to continually add more Zn to soils and applications are often reduced in frequency or rate to match crop removals.

A simple model of fertilizer Zn behaviour in soil was developed to model inputs in fertilizer, crop offtake and losses through leaching to predict forward for the next 1000 years. This model also calculates the maximum concentration in soil likely to lead to toxicity to compare to soil concentrations resultant from fertiliser addition. Note the model does not include the likely reduction in Zn inputs once Zn concentrations in soils have increased to sufficiency levels (point 3 above). Normally farmers would not apply Zn if the extractable Zn concentrations in soil reach sufficiency levels.

Naturally, accumulation of Zn depends on fertilizer management regime, crop type, soil type, etc. Results for a typical corn cropping system in mid-western USA are presented in Figure 3.

It is evident from Figure 3 that, even assuming farmers do not reduce the rate or frequency of Zn applications as Zn concentrations and availability in soil increase over time (which they normally would), it takes many centuries for Zn concentrations in soil to increase significantly, and soil Zn concentrations do not exceed toxicity thresholds at "equilibrium" under this scenario. Other scenarios can be assessed using the model.

The modelling results are confirmed by results from a long-term field trial where up to 900 kg Zn/ha (~900 lbs/ac) was cumulatively added to a neutral (pH 7.0) silty clay soil over a period of 19 years (Payne et al. 1988). Yields of corn and silage were unaffected even though soil Zn concentrations reached >250 mg/kg. Movement of Zn to depth was minimal also. Given that normal rates of Zn application are ~1-2 lbs/ac/yr, this trial confirms that in the long-term (500-1000 years) there is a low risk of fertiliser Zn posing environmental problems.

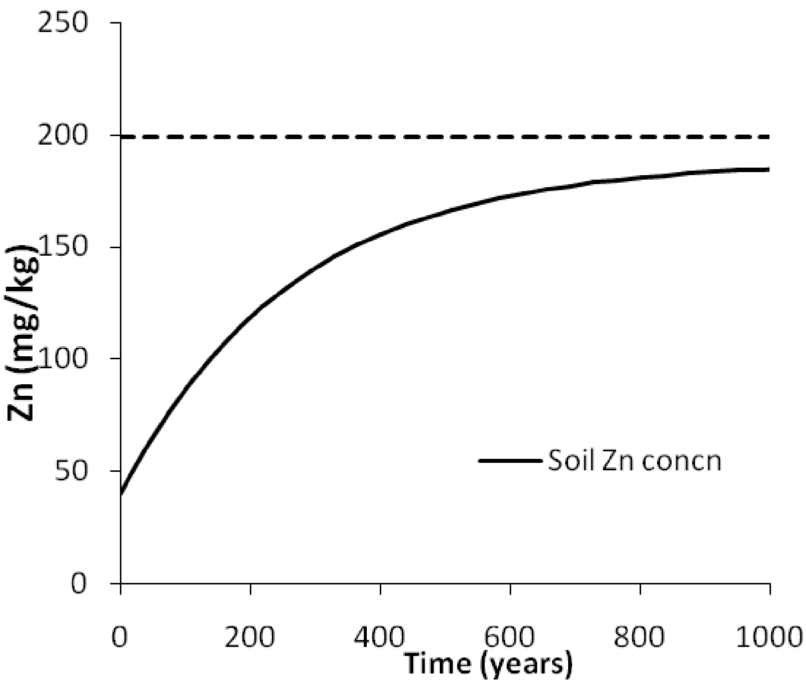

Figure 3. Predicted increase in Zn concentrations in soil in relation to the concentration expected to cause toxicity. Assumptions for each yearly cycle are: addition of fertilizer Zn of 2 kg/ha (2 lb/ac, equivalent to >200 lbs MESZ/ac), atmospheric deposition of 1 g Zn/ha (0.035 ounces/ha), corn yield of 10 t/ha (160 bushels/ac), and deep drainage of 300 mm (11.8 inches); and for the soil properties: soil pH 6.0, CEC 15 cmolc/kg (sandy loam soil), and initial total soil Zn concentration of 40 mg/kg. Partitioning of Zn between soil and soil solution according to the relationship determined by (Degryse et al. 2009), toxicity thresholds for plants determined according to soil pH and CEC (Warne et al. 2008) and toxicity thresholds for nitrifying bacteria determined according to soil pH (Broos et al. 2007).

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Further information

The Fertiliser Technology Research Centre was established in 2007 via a partnership between The University of Adelaide and The Mosaic Company. The scope of the centre was further expanded in 2009 via a partnership between The Mosaic Company and Australian Grains Research and Development Corporation (GRDC). The centre has expertise in soil chemistry, fertiliser technology and plant nutrition. Specifically, in developing novel fertiliser formulations, advanced isotopic and spectroscopic investigations of fertiliser efficiency, and field scale agronomy trials.

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