Zinc Application and Its Availability to Plants

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I declare that this thesis is my own work and contains as its main content, work which has not been submitted for a degree at any other tertiary institution.

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Summary of thesis

Globally, low zinc (Zn) soils are widespread, but one of the largest expanses of such soils is in south west Australia (WA). Early Zn research in the region determined how much fertiliser Zn was required for profitable production of spring wheat (*Triticium aestivum* L.) and subterranean clover (*Trifolium subterraneanum* L), the major crop and pasture species at the time. The research showed that Zn sulfate and ZnO were equally effective Zn fertilisers, but ZnO was cheaper and so was widely used. The research indicated that in the year of application, depending on soil type, between 0.5-1.5 kg Zn/ha provided adequate Zn for the production of wheat and subterranean clover. The length of time that a single application of Zn fertiliser remains fully effective in maintaining the production of crops and pasture in future years (residual value; (RV)) had not been determined. This knowledge of the RV of Zn fertilisers is required for soils of WA. The experiments that measured the RV of fertiliser Zn for spring wheat and subterranean clover form the bulk of this thesis.

The soils in the region were also initially acutely phosphorus (P) deficient requiring the application of fertiliser P for profitable production. Single superphosphate was the P fertiliser initially used. It was manufactured locally using phosphate rock imported from Nauru and Christmas Islands. This phosphate rock also contained much Zn, and the single superphosphate manufactured from it contained 400-600 mg Zn/kg. At amounts of application needed to provide adequate P, the Zn-contaminated superphosphate also supplied about 90 g Zn/ha. Therefore, early field experiments measured the RV

of ZnO applied to soil when single superphosphate was applied annually at >150 kg/ha. In these experiments, the RV of Zn was measured when different amounts of fertiliser nitrogen (N) was applied. This was because it has recently been very profitable to apply fertiliser N to wheat crops, which greatly increased grain yields and so may have increased the demand for Zn, thereby probably decreasing the RV of the original ZnO application. In these experiments, there were many nil-Zn plots. In subsequent years, freshly-applied ZnO amounts were applied to measure the RV of the original ZnO treatments relative to the fresh Zn treatment. No Zn deficiency was detected for up to 23 years after applying ZnO while applying superphosphate at >150 kg/ha per year and for all amounts of N applied.

Subsequently cheap imported DAP fertiliser was used for wheat crops instead of locally produced Zn-contaminated single superphosphate and urea. The imported DAP contained about 50 mg Zn/kg ($^{1}/_{12}$ that of single superphosphate). This new fertiliser strategy induced Zn deficiency in many wheat crops. This led to further field studies to determine the RV of ZnO fertiliser when DAP was applied. The experiments also included 2 Zn-contaminated single superphosphate treatments. In one, no ZnO was applied, and superphosphate was applied at >150 kg/ha per year to match the amount of P applied as DAP to the other treatments. The other treatment was the same, except 1.5 kg/ha Zn as ZnO was applied in the first year only. In subsequent years, freshly-applied ZnO amounts were applied to measure the RV of the original ZnO treatments relative to the fresh Zn treatment. Relative to freshly-applied Zn in each year, the RV of the original ZnO treatments decreased as the length of time that the Zn was in contact with soil increased. However, the rate of decline in the RV was also found to differ with soil type, and was affected by soil pH, clay and organic carbon content of soil, and in alkaline soils with the calcium carbonate content of soil.

Parallel glasshouse studies measured the RV of Zn, as Zn sulfate, for wheat and subterranean clover, using many soils from WA and other Australian States. The glasshouse studies also showed that the rate of decline in the RV of the original Zn application varied markedly with soil type and was strongly influenced by soil pH, clay and organic carbon content of soil, and in the alkaline soils, the amount of calcium carbonate in soil.

In the above studies, the RV of fertiliser Zn was measured relative to freshly-applied Zn using yield of plants (shoots and grain for wheat, shoots for clover), Zn content in shoots and grain, and soil test Zn using the ammonium oxalate and DTPA procedures. In addition, Zn concentration in young tissue and rest of shoots (glasshouse studies) and young tissue and whole shoots (field studies) was measured, and Zn concentration related to 90 % of the maximum yield (critical Zn in plant parts) was determined. The studies showed that the DTPA soil test procedure, together with soil pH, and clay and organic matter content of soil, was an accurate prognostic test for indicating when Zn deficiency was likely in the next clover or wheat crop. The study confirmed that young tissue (youngest fully expanded leaves) provided critical plant test values for diagnosing Zn deficiency in plants. The plant and soil tests for Zn are now used by commercial soil and tissue testing laboratories.

When Zn deficiency was diagnosed early in field grown wheat, Zn sprays can be applied to the crop foliage to prevent or minimise decreases in grain yields at the end of the growing season. Zn sulfate and Zn chelate are the most widely used compounds. This thesis reports the results of a field study to compare the effectiveness of the two compounds when the spray was applied at two growth stages of wheat (Gs14; seedling growth and Gs24; tillering). In addition, Zn applied with the seed while sowing the wheat crop was also included. Zinc applied to the soil while sowing was the most effective treatment. Zn chelate was more effective as a spray than Zn sulfate when applied at the earlier growth stage, but Zn sulfate was cheaper, and both sprays were equally effective when applied at the later growth stage.

Recently in the region, durum wheat (*T. durum* L.), narrow-leafed lupin (*Lupinus angustifolius* L.), yellow lupin (*L. luteus* L.), white lupin (*L. albus* L.), canola (*Brassica napus* L.), chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.) and lentil (*Lens culinaris* Medik) were all increasingly grown in rotation with spring wheat. Consequently, the Zn requirement of the new crops was compared with the Zn requirements of spring wheat. Species requiring less Zn than spring wheat to produce the same relative yield were faba bean, chickpea, albus lupin and canola; species requiring more Zn were lentil and durum wheat.

Spreadsheet models were developed to determine when re-application of fertiliser Zn was required for low and high production systems. Relative to freshly-applied Zn, the rate of decline in the RV of Zn applied in a previous year varied depending on the amount of Zn applied, time the Zn was in contact with soil since application, properties of the soil (soil pH, % clay, % organic carbon, % free calcium carbonate), plant species, and the amount of Zn removed in harvested grain or hay.

The thesis has culminated in a better understanding of Zn in the agricultural production systems of WA. The distribution and correction of Zn deficiency is now predictable for the many soil types and cropping systems of WA. Accurate identification of Zn deficiency for a range of crop and pasture species by plant analyses, typically the youngest mature leaf, is now possible for local conditions. With the calibration of the DTPA Zn soil test for soils of WA, particularly for wheat the major crop species grown in WA, prognosis of potential Zn deficiency can now be predicted before the appearance of Zn deficiency or loss in plant production.

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Chapters 2 to 6 are based on a series of papers that have been accepted by a range of scientific journals during the course of this work. The principal author of each of these papers is myself and I am joined by a number of co-authors. These people provided advice on the writing, editing and review of these papers. The individual experimental procedures, data processing and

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Publications

The publications listed below form the basis for the major part of this thesis.

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