# Micronutrient Deficiencies in Global Crop Production

Brian J. Alloway
Editor

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*Cover photos*

***Top Photos from left to right:***
1. Three leaves of a zinc-deficient citrus tree (in Turkey) showing chlorosis. *Photograph supplied and reproduced by kind permission of Dr. V.M. Shorrocks*
2. Zinc-deficient citrus tree (in Turkey) showing chlorotic leaves. *Photograph supplied and reproduced by kind permission of Dr. V.M. Shorrocks*
3. Zinc-deficient maize plant (in England) showing characteristic chlorosis ("white bud") and stunting. *Photograph by Prof. B.J. Alloway*

***Bottom photos from left to right:***
1. Ears of copper-deficient wheat plants in France showing empty grain places at the tip and base ("rat-tail" symptom). *Photograph by Prof. B.J. Alloway*
2. Zinc-deficient wheat plant (in Australia) showing chlorosis and stunting. *Photograph supplied and reproduced by kind permission of Dr. V.M. Shorrocks*
3. Ears of copper-sufficient wheat plants, showing all grain places filled (on the left to the photo), and ears of copper-deficient wheat plants, showing empty grain places and some melanism (on the right). These wheat ears are from a field experiment on copper-deficient site in France where the copper-sufficient ears were taken from plants in the copper-treated plots. *Photograph by Prof. B.J. Alloway*

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# Preface

There are eight micronutrient elements which are essential for the healthy growth of higher plants. If one or more of these elements is deficient, crops will fail to achieve their optimum yields and the quality of their food products is likely to be impaired. In order to provide adequate food for the world's rapidly increasing population, micronutrient deficiencies in agricultural and horticultural crops should be identified and treated wherever they are found. Micronutrient deficiencies occur all over the world but variations in soil conditions, climate, crop genotypes and management result in marked variations in the incidence of these problems. In addition to yields, the contents of micronutrients in crop products, such as staple grains, are also of great importance to the health of human and livestock consumers.

This book covers the occurrence of deficiencies of the plant micronutrients, their causes, effects and treatment in different countries, regions and continents around the world. Eight chapters deal, respectively, with micronutrient problems in Australia (Chapter 3), India (Chapter 4), China (Chapter 5), the Near East (Chapter 6), Africa (Chapter 8), Europe (Chapter 9), South America (Chapter 10) and the United States of America (Chapter 11). Of the remaining four chapters, Chapter 1 provides an introduction to the plant micronutrients and their deficiencies, and the soils associated with these problems. Chapter 2 follows on with a wide-ranging overview of the causes of deficiencies, the agronomy of micronutrient fertiliser use, the links between deficiencies and human nutrition and the biofortification of staple foods with elements essential for humans. This latter theme is further developed in Chapter 12, which concentrates on the links between the trace elements essential for humans in crops and human health problems, such as iron and zinc deficiencies, and explores ways in which the micronutrient content of food crops can be increased and their bioavailability to humans improved. Chapter 7 differs from the other chapters in that it provides an in-depth case study of an investigation into zinc deficiency in wheat in Central Anatolia, Turkey. This resulted in the widespread adoption of zinc fertilisation of wheat crops in the region, leading to greatly increased yields and consequent improvements in human health.

Apart from covering the occurrence, causes and treatment of deficiencies in the respective countries, each chapter deals in greater detail with one or more related topics, adding depth to the treatment of this broad subject. Examples include soil testing and plant analysis, field experiments, innovative treatments, micronutrients in the subsoil, nutrient interactions, changes in cropping systems, micronutrient budgets and hidden deficiencies.

In addition to local names for soil types, the equivalent soil group in either the FAO–UNESCO/World Reference Base for Soil Resources, or the USDA Soil Taxonomy classification is also given. The equivalent soil groups in both of these classifications are listed in Appendix II. The botanic names of the crops are given in the chapters, but are also listed in Appendix 1. Average world and national yields of maize, rice and wheat are given in Appendix 3, to put the yield data given in the chapters into a broader perspective.

The book is primarily based on chapters developed from papers presented at the Special Symposium on "Micronutrient Deficiencies in Global Crop Production" held in May 2005 at the 8th International Conference on the Biogeochemistry of Trace Elements (ICOBTE) in Adelaide, South Australia. This symposium was organised by the editor with sponsorship from the International Copper Association Ltd (ICA), the International Council on Mining and Metals (ICMM) and the International Zinc Association (IZA). However, due to the limited number of papers which could be presented, additional authors were subsequently sought for chapters on Africa and the Near East. Their contribution has ensured that the crops, types of management, climate and soil conditions representative of the most of the world's agricultural land have been covered.

The editor wishes to acknowledge the following, who have assisted him in the task of bringing the book to completion. Firstly, thanks to Murray Cook, formerly of IZA (now of the Galvanisers Association), for help with organising the sponsorship for the ICOBTE symposium, and to the ICA, ICMM and IZA for providing funds to enable most of the team of authors to be brought together at the ICOBTE Symposium. Secondly, thanks are extended to Professor Iain Thornton (Imperial College, London), Professor Michael McLaughlin (University of Adelaide, Australia), Professor Ronald McLaren (Lincoln University, New Zealand) and Professor Volker Römheld (University of Hohenheim, Stuttgart) for help with reviewing chapters. Finally, and most important of all, the editor would like to thank the authors of all the chapters for the high quality of their contributions.

# Contents

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# List of Abbreviations

| | |
|---|---|
| $a^{-1}$ | per year |
| AAPFCO | American Association of Plant Food Coordinators |
| AB-DTPA | ammonium bicarbonate-DTPA extraction |
| ADAS | ADAS UK Ltd – research, consultancy and knowledge transfer in the cropped environment (formerly Agricultural Development and Advisory Service of Ministry of Agriculture, Fisheries and Food, UK) |
| AE | agronomic efficiency (i.e., kg of seed produced per kg of micronutrient (e.g., Zn) applied) |
| APP | ammonium polyphosphate (fluid fertiliser: 10% N and 34% $P_2O_5$) |
| ARC-ISCW | Agricultural Research Council, Institute for Soil, Climate and Water (South Africa) |
| ASC | Australian Soil Classification System |
| CGIAR | Consultative Group on International Agricultural Research |
| CIAT | International Centre for Tropical Agriculture (Centro Internacional de Agricultura Tropical) (in Cali, Columbia) |
| CIMMYT | International Maize and Wheat Improvement Centre (Centro Internacional de Mejoramiento de Maiz y Trigo) |
| DAP | diammonium phosphate (fertiliser – 18% N and 47% $P_2O_5$) |
| DM | dry matter, or dry weight (DW) (in plant tissue analysis) |
| DMT1 | divalent metal transporter 1 – the major transferrin-independent iron uptake system of intestinal cells |
| DTPA | diethylene triamine pentaacetic acid (chelating agent – used in some soil tests and sometimes also as a fertiliser ligand) |
| DRIS | Diagnostic and recommendation integrated system |
| EDTA | ethylene diamine tetraacetic acid (chelating agent used in some soil tests and in some fertilisers) |
| EU | European Union (27 constituent countries, since January 2007) |
| FAO | Food and Agriculture Organization of the United Nations |
| FYM | farm yard manure (cattle urine and faeces mixed with straw) |
| GAEC | Good agricultural and environmental condition (farmland) (Scottish Exec', 2004) |
| ha | hectare (equivalent to 2.471 acres) |
| HWE | hot water extraction soil test for boron (see also HWS) |

| | |
|---|---|
| HWS | hot water soluble (soil test extractant for boron), i.e., HWS B |
| HYV | High yielding varieties programme ("Green Revolution") |
| ICARDA | International Centre for Agricultural Research in Dry Areas |
| ICP-MS | Inductively Coupled Plasma Mass Spectrometry (multi-element analytical method, generally more accurate with a lower detection limit than ICP-OES) |
| ICP-OES | Inductively Coupled Plasma-Optical Emission Spectrometry (multi-element analytical method) |
| IFPRI | International Food Policy Research Institute (Washington, DC, USA) |
| IITA | International Institute for Tropical Agriculture (in Nigeria) |
| IRRI | International Rice Research Institute (the Philippines) |
| MAP | monoammonium phosphate (fertiliser 11% N and 49% $P_2O_5$) |
| mg $kg^{-1}$ | milligrams per kilogram (equivalent to micrograms per gram $\mu g g^{-1}$, or parts per million – ppm) |
| mg $L^{-1}$ | milligrams per litre (equivalent to ppm in liquids) |
| MIR | Mid infra-red (spectroscopy) technique, which enables soil minerals and organic matter species to be identified |
| NATO-SFS | North Atlantic Treaty Organization, Science for Stability Program |
| ng | nanogram ($10^{-9}$g) |
| NP | combined nitrogen and phosphorus fertilisers |
| NPK | nitrogen, phosphorus and potassium compound fertilisers |
| NSW | New South Wales (State of, in Australia) |
| NUE | nutrient-use-efficiency |
| NVZ | nitrate vulnerable zone |
| OC | organic carbon |
| OSP | ordinary superphosphate (fertiliser, 21% $P_2O_5$) |
| Qld | Queensland (Australia) |
| QTL | quantitative trait loci (for traits which are influenced by multiple genes) |
| RDA | recommended daily allowance (of nutrients for humans) |
| RDI | recommended daily intake (of micronutrients by humans) |
| ROS | reactive oxygen species |
| SA | South Australia (State of, in Australia) |
| SAC | Scottish Agricultural Colleges – agricultural advice, consultancy and research in Scotland |
| SOD | superoxide dismutase |
| TEA | triethanolamine (chelating agent) used with DTPA in a soil test at pH 7.3 |
| TFI | The Fertilizer Institute (USA) |
| t $ha^{-1}$ | tonnes per hectare (equivalent to 1.1 tons per acre) |
| TSP | triple superphosphate (fertiliser 47% $P_2O_5$) |
| UNESCO | United Nations Educational, Social and Cultural Organization |
| USDA | United States Department of Agriculture |
| WA | Western Australia (State of, in Australia) |
| WHO | World Health Organization |
| YEB | youngest emerged leaf blade (for plant tissue analysis) |
| YOB | youngest open blade (for plant tissue analysis) |
| $yr^{-1}$ | per year |
| Z | Zadoks Scale (see glossary for more details) |

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