Trace Element Nutrition: Revitalising Health and Agriculture

A study in the management of trace elements – their significance in sustaining community health, crop growth and farmer profitability.

A report for NUFFIELD AUSTRALIA FARMING SCHOLARS

by Evan Ryan

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Scholar Contact Details
Evan Ryan
RYANAG PTY LTD
473 Katamatite Rd
Yarrawonga, Vic, 3730

Phone: 0428 298 031
Fax: (03) 5744 3662
Email: ev_ryan@hotmail.com

Nuffield Australia Contact Details

Nuffield Australia
Telephone: (03) 54800755
Facsimile: (03) 54800233
Mobile: 0412696076
Email: enquiries@nuffield.com.au
586 Moama NSW 2731

Foreword

Trace Element Nutrition has been a constant source of fascination throughout my studies in Agricultural Science at secondary school and in Agronomy and Plant Nutrition at university. Generally speaking, broadacre farmers in Australia focus more fully on macro elements, such as Nitrogen, Phosphorus and Potassium in their crops. As a result, the importance of Trace Elements (TE's) for crop growth is overlooked. This is to the detriment of plant growth and ultimately to human health.

In contrast, crops **not** deficient in TEs grow efficiently and thus return yield and profit to the farmer's pocket. This study has confirmed my belief that we can further optimise plant production with the use of innovative methods to manage TE's.

My goal as a Nuffield scholar has been to expand knowledge in the area of TE nutrition and improve the productivity and profitability of Australian grain farms. TE Nutrition in Australia already encompasses many interesting, innovative and successful producers, advisors and leaders in the agricultural sector.

On our farm in South Eastern Australia, my parents and I have adapted our broadacre crop planting equipment to inject liquid TE's to the seed row during the crop planting operation. Initial observations of the improvements in crop growth and yields both on our farm and in other regions of Australia have been encouraging, inspiring us with enthusiasm to learn more.
In paying closer attention to TE's, farmers will gain a better understanding of the role TE's in their crop production and growth. By providing adequate essential mineral concentrations in optimum amounts to staple foods, farmers will also be able to offer more value to the consumer, resulting in healthier people.

Findings

TE's are an important part of human health and are required in adequate amounts for the healthy functioning of the human body. An alarming statistic is that half of the world's population is deficient in Iron and Zinc (Hotz & Brown, 2004) (Welch & Graham, 2004). This can be attributed to many factors including personal wealth, staple food diet products consumed, the source of the food products and the nutritional content of the soil that plant and animal produce is grown from.

The addition of TE's in some cropping situations will both increase the profitability to the farmer, as well as increase the quality and possibly the value of the product being produced. This is because the soil may be deficient in TE's due to the parent material it was derived from, which in turn means the produce grown is deficient in important elements causing a mineral deficiency in the humans who eat the produce. The key issue in realising both a benefit to the farmer/producer and the consumer is the recognition of the value of having elevated levels of minerals in plant and animal products. For this to be realised there needs to be consumer education through doctors, dieticians and health services together with government assistance to ensure food is nutritious. Producers and processors must derive an economic return from the extra effort, cost and attention to detail in fortifying the mineral nutrition of the grain which in turn produces high-value, nutritious, quality food.

Nuffield Australia and the Grain Growers Association of Australia made my travel and study possible for this project. The assistance provided by these two organisations to this study, to the development of leadership, knowledge transfer and guidance in both Australian and worldwide agriculture has been both visionary and practical.

Acknowledgements

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Abbreviations

Cd	Cadmium
Fe	Iron
FYM	Farm Yard Manure
IP	Identity Preserved
Mn	Manganese
QA	Quality Assured
RNI	Reference Nutritional Intake
TE’s	Trace Elements
Zn	Zinc

Glossary

Biofortification

Process of increasing the content ('density') of micronutrients such as zinc, in food crops - especially cereals. There are two types: agronomic biofortification involves using fertilisers to increase the density of zinc and other micronutrients in cereal grains; genetic biofortification uses specially-bred crops which have been selected on the basis of their ability to concentrate zinc and other micronutrients in their edible parts, such as grains.

HarvestPlus

A Global Challenge Program of the Consultative Group on International Agricultural Research (CGIAR) dedicated to reducing micronutrient malnutrition through the biofortification of staple food crops.

Reference Nutritional Intake

The level of mineral nutrition which is adequate for 97% of the human population.

Trace Element

Elements such as Zinc, Copper, Molybdenum, Iron and Selenium which occur in relatively low concentrations in plant and animal tissues (<100 parts per million) and in rocks, all trace elements together compromise <1% of total elemental composition on the earth.

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Executive Summary

Initially this study focussed upon the role of trace elements in broadacre farming. The "definition" of broadacre farming for this report is the expansive production of cereals (wheat, barley, and oats) and oilseeds (canola, soybeans). This Nuffield study broadened its focus as it progressed expanding to the global issues of produce quality and human health, these areas of importance are explored in this report.

The principle of crop nutrition across most plant types remains constant and is not exclusive to cereal and oilseed crops. Plants need adequate nutrition to perform to their optimum, which is also true for animals, humans and all other organisms on the planet. In the broadacre farming system, if there is a mineral nutrition deficiency, this has consequences for not only the current crop's yield and the farmer's income but also in the production/value chain to the consumer who eats the final food product. Trace element deficiencies in human diets are a current and urgently important issue globally. This is why TE's are important to agriculture and to humanity.

This report addresses factors that may benefit farmers, food processors, consumers and legislators. Issues pertaining to food affect everyone, and, depending upon whether your role is in the chain between the producer and the consumer or as someone who can affect broad-scale legislative change, the issues in this paper are significant.

As an agricultural scientist who has worked as an agronomic advisor the role of trace elements and their ability to help plants achieve their true genetic potential has been a great motivation for this study. Now as a full-time farmer my interest is keener than ever as the growth of my crops effects me directly. We only have control in agriculture over certain parts of our system and it is easy to become defeated by the apparent lack of control over the final outcomes of our system. There is no point dwelling on the effects of weather, prices, strikes etc, because we usually do not have direct control over these things as producers. **We do have control,** however, over more components of our production systems than we ever had before, such as the technologies of irrigation, precision farming, weather radar, efficient large scale machinery, futures contracts for grain pricing and the choice of an amazing array of inputs to make our crops grow to their potential. The focus of this report lies in a part of the system we are able to control, TE nutrition.

The aim of this report is to educate the reader as to the importance of TE's, how to apply them, and to then generate discussion around the use of them more widely within agriculture

and the food industry. Trace elements are required to improve consumer health, farmer's profitability and humanity as a whole. For this study I travelled for six months through 2009 to four continents during three trips attending conferences, interviewing farmers and their advisers and companies involved in nutritional produce production, observing first hand the best strategies and techniques farmers use to improve the quality and quantity of the produce from their farming system.

Many people in the developing world suffer from TE deficiency at chronic and severe levels. Some third world populations are worse off because they not only suffer a deficiency, they also suffer toxicities from another contaminants for example, arsenic and cadmium. These soil contaminants are taken up by plants such as rice when TE's like Zinc and Iron are not available because of soil deficiencies.

I recommend that farmers assess their crops for TE deficiencies that may be asymptomatic, limiting yield, production, profit and product quality.

It is recommended that the grain industry set up a standard for food products that are enhanced or enriched with minerals for improved human health outcomes. The Australian grains industry would benefit from an Identity Preserved (IP) value chain for grain which has been produced under an accredited Quality Assured (QA) system with TE's applied at critical stages of crop growth to **safely** elevate the nutrition of the end product. The elevated TE food product must be profitable for producers to grow it and consumers will need to see the value for their health and the grains industry will need to accept this parameter in their standards for success.

For the findings of this report to make a significant improvement to farming, grain farmers need to understand the importance of TE's to their crops performance and quality and use them where required. Farmers have an opportunity to improve and market the quality of their product to the processor and end user. Legislators would do well to recognise that the diets of people in Australia are lacking in essential TE's and this is probably negatively impacting health. Consumers who are becoming more sophisticated in their buying decisions and how this affects their health and well-being will recognise their need for nutritious food containing essential elements required for their good health and bodily function.

Introduction

Trace Elements (TE's) are essential for the proper functioning of every organism on the planet. The interaction between TE's in biological processes and their role in mediating biological and chemical reactions that are essential to life are still being discovered by biologists and scientists every year. Expanding knowledge regarding TE functions in commercial food crops and their importance for crop growth and genetic expression continues to be reinforced by research (Alloway B. J., 2009). The medical field is constantly being reminded of the important role that TE's have in human health.

As farmers and food producers we need to tell our story of how we grow the most nutritiously rich, healthiest, safest food in the world each day to the billions of people who eat it. This fascinating story of how plants and humans need TE's to reach their optimum genetic capacity should spur consumers to embrace TE consumption and farmers to enhance their farming system to provide the essential elements required for life.

Objective

The primary objective was to explore the role of TE's in broadacre farming, this objective led to the opening up of an interest in areas linked to TE's and human health.

Trace Elements

Trace Elements (TE's) are those nutrients required in extremely small quantities (less than 100ppm in plant dry weight). They are essential for the correct functioning of many plant, animal and human biological systems.

Why TE's are important to humans

Micronutrient malnutrition is a growing concern in the developing and developed world. It results in mental retardations, impairments of the immune system and overall poor health. Zinc deficiency, for example, represents a major cause of child death in the world and is a widespread global issue (Cakmak I. , Enrichment of fertiliser with zinc: An excellent investment for humanity and crop production in India, 2009). Zinc deficiency is predominantly prevalent where cereal-based foods are the main source of calorie and protein intake in diet, and is often exacerbated by the concentration of zinc in cereal crops being inherently low. The situation is often made worse by the growing of cereal crops on deficient soils. For example, 50% of India's soils are zinc deficient but agronomic biofortification (enrichment) of rice through plant breeding efforts may save the lives of 48,000 children in India each year (Cakmak I. , Enrichment of fertiliser with zinc: An excellent investment for humanity and crop production in India, 2009). Another consideration when Zn is deficient is that Zn and cadmium (Cd) are chemically very similar, competing for binding sites and transport proteins. This means that Cd will be taken up by plants and deposited in the grain where Zn is not available but Cd is. The high content of Cd in Asian grain is of a growing concern as Cadmium is a toxic element to humans in very low concentrations (Cakmak I. , Enrichment of fertiliser with zinc: An excellent investment for humanity and crop production in India, 2009).

Macronutrients, just like protein, are an important measure of grain quality. Why are TE's or mineral nutrition not measured as a quality parameter of grain for payment to the producer? The human race needs to look more closely at plants and how these supply humans with their requirements. Among all the mineral cations, Zinc is required the most in biological proteins and is essential for gene regulation and expression under stress, protecting against infectious diseases. Farmers need to look at how they can supply these TE's to consumers to add value to their business.

Human deficiencies in TE's are not exclusive to the developing world. The UK, Finland and Australia have documented evidence of widespread deficiencies based on a lack of adequate levels of TE's in their daily diets. In work done by (Ryan, Norton, Kirkegaard, McCormick, Knights, & Angus, 2002), wheat grain Zinc concentrations were documented to be routinely in the range of 19-27µg/g in Australian samples. Investigations done for this report indicate that 40µg/g would be closer to an ideal level to ensure sufficient Zn is in the diet (between 7,000-9,500µg Zn/day) Reference Nutritional Intake (RNI), especially where cereal grains are a major component of a diet. Zinc deficiency can also become an issue in developed countries due to highly refined diets where foods are highly processed excluding zinc in place of sweeteners and preservatives. Also of concern and importance is that Zn is a 'Type 2' nutrient, which means that its concentration in blood does not decrease in proportion to the degree of deficiency in humans and animals. As a result, physical growth slows down and excretion is reduced to conserve Zn. Most children suffering from Zn deficiency have stunted linear growth which is a symptom of this type 2 deficiency (Graham, 2008).

Zinc is also a critical micronutrient required for structural and functional integrity of biological membranes and for detoxification of highly aggressive free radicals (Cakmak I. , 2000). Any alteration in Zn homeostasis or any decrease in Zn concentration of human body will, therefore, result in number of cellular disturbances and impairments such as i) immune dysfunctions and high susceptibility to infectious diseases, ii) retardation of mental development and iii) stunted growth of children (Black, 2003).

Selenium (Se) deficiency in Scandinavia and Finland has been a significant problem impacting the population's cardiovascular health. This was remedied by the legislated addition of Se fertiliser on all crops grown in these countries. Major studies have been conducted in the United Kingdom (UK) by (Fan, 2008) reporting that the current average daily amount of Se eaten by people in the UK is half the RNI. This is an alarming statistic because Se is important in the human body in reducing the risk of cancer and cardiovascular disease (Combs & Gray, 1998) (Reilly, 1996).

The mineral content (TE content) of grains has unintentionally been decreased since the plant breeding efforts which started the "green revolution" in the 1960's. In work done by (Fan, 2008) it was discovered that the TE concentration in grain has decreased markedly since the semi-dwarf cereal varieties were introduced. It is thought that the reason for this is that the TE's re-distribution at grain fill (with photosynthates) from the leaves and stem to grain does not catch up with the much enhanced re-distribution of photosynthates in these semi-dwarf, short straw cereal crop varieties. There is currently a worldwide program called Harvest Plus (www.harvestplus.org) whose goal is to breed crop cultivars with elevated TE levels in the grain to address this issue.

Like most complex problems, the solution to these deficiencies must come from an integrated, multidisciplinary approach for improvement. High yielding varieties that require more nutrition to develop to their genetic potential are of little advantage if they are planted on TE deficient soils. This will also become a problem for the new generation of "Harvest Plus" varieties that are more efficient in extracting nutrition from the soil and depositing it in the plant's grain. A multi-prong approach whereby agronomic knowledge of soils and plants combined with plant breeding and observations of the nutritional status of the human population is the best way to improve health.Why TE’s are important to plants

Grain farmers role in lifting human nutrition

Farmers have the potential to increase their productivity and profitability through using trace elements. Consumers of the future will be demanding an adequate level of mineral nutrition in the food they eat and farmers must encourage this and in turn demand more monetary value for food that **is** enhanced with minerals. Organically grown produce contains no actual additional mineral nutrition benefit over non-organic produce (Alan D Dangour, 2009) and yet it commands more money from consumers. Farmers should be rewarded for food that is enhanced with mineral TE’s and is more nutritious, rather than an organic food which is sold by marketing spin with no additional nutritional benefits. Food processors have the potential to use raw food ingredients that have been enhanced with minerals naturally by farmers using fertilisers on their crops. This would reduce the instance of food contamination at toxic levels at the processing stage such as the melamine scare in milk in China during September 2008. Melamine was used in China to make milk appear higher in protein and is normally used in plastic products. The addition of melamine to milk powder killed at least four children and caused illness to 53,000 inhabitants in mainland China (AAP, 2010). Minerals are best added to plants rather than at the food processing stage to ensure the minerals are in plant products in forms that are able to be absorbed by humans and animals and in biologically metered amounts to lower the chance of a mineral toxicity.

The broadacre farming industry is a stakeholder in the issue of TE biofortification of food. The Australian and global agricultural industry should embrace trace element nutrition as a quality parameter for differentiation just as it did more than 50 years ago with product differentiation based on protein. More value could then be derived from this for the producer and throughout the entire grain product value chain. Policy makers, by understanding the value of having elevated and adequate levels of trace elements in food to combat the issues of heart disease, cancer and other preventable diseases based in part on inadequate TE nutrition will be better equipped in their decision making. Australia may also be able to create more benefit in its ongoing aid efforts to countries suffering food production shortfalls by assisting with food aid containing elevated levels of nutrition to assist health goals instead of just throwing money at problems of this type.

Why TE’s are important to plants

The very first 60 days are crucial to plant growth and are amongst the most important. These early days of crop growth can determine the final yield so it is important that plants are not stressed when they are sensing their environment and placing energy into root exploration and shoot growth. The challenge for plants is that most soils worldwide have deficiencies due to poor past management practices of the parent soil material from which they originated causing modern deficiencies and plant stresses. Farmers must manage the growth of their plants and crop according to the needs based on the type of plant and the soil it is growing in. Supplying TE’s to plants not only optimises plant growth when required, their role in assisting plants to survive and thrive through stressful growth periods that can reduce yield is also widely documented, especially the importance of zinc (Cakmak I. , 2008). TE’s are vital in mediating the production of plant hormones such as Cytokinins, Auxin’s and Gibberelic Acids as components of enzyme’s; these hormones are important for mediating growth and plant stress responses. This concept is illustrated in Figure 1 below. By providing an optimum environment for plant growth in the soil, with TE nutrition as a vital component, the crop is set up to thrive in good conditions and survive stress.

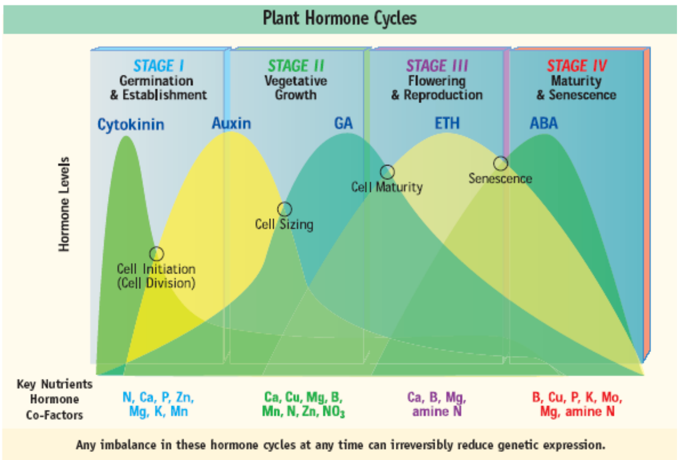

Figure 1: The Plant Hormone Cycle during plant growth and the key Nutrients that are Hormone Co-factors (Stoller, 2009)

Farmers in the Canadian prairies have been observing decreases in the fungal disease ergot where plant tissue test levels of copper are adequate or high. Ergot is also observed to be a problem along with copper deficiency in New Zealand and often associated with crops grown in soils with high levels of organic matter. Farmers in Iowa, USA have been observing less “sudden death” (*fusarium solani*), a fungal disease in soybeans, in fields where chicken litter (containing TE’s) has been applied compared to soybeans fertilised without chicken litter. Zinc in the UK is being used in wheat to increase early growth, it also was observed that it regulates hormones essential for flowering and strengthen the fibrous root mass of the plant (Fuller, 2009). This is supported by (Stoller, 2009) who produces plant enhancers containing TE’s and plant hormones for crop production. Each ton of wheat harvested extracts approximately 70 grams of Zinc. Where has or is this being replaced from? This is an important consideration for farmers as the TE’s taken off the farm are not replaced as diligently as the macro-elements of Phosphorus, Nitrogen and Potassium.

It is never advisable to let plants fall into a significant TE deficiency as up to 20% of plant yield can be sacrificed before visual symptoms are evident, this is called the “hidden hunger” of the plants where yield loss can occur undiagnosed by the farmer/advisor.

Global Discoveries

Ismail Cakmak from Sabanci University in Turkey has discovered that zinc and nickel can affect nitrogen metabolism in plants When they are deficient there is no avenue for amino acids manufactured in the leaf to be converted into proteins, rendering the plant’s leaves dysfunctional in protein syntheses (Cakmak I. , Trace Element Discoveries in Turkey, 2009). Molybdenum is vitally important for low temperature tolerance and in addition it is needed by enzymes to produce abscisic acid for stomatal regulation in plant leaves, resulting in implications for plant water use efficiency and drought survival when adequate molybdenum is absent.

Boron is important for early growth and cell wall strength in addition to its important role in pollen formation, survival and viability. Canola plants in Canada and Australia can have a demand for boron that outstrips the soils natural ability to supply enough to fulfil flowering requirements. A foliar application of boron or an upfront treatment at planting will ensure this does not hold back genetic expression and yield.

There are interactions which have been observed between plant manganese levels and take all disease in wheat, where manganese is deficient take all yield loss is greater. A similar trend is observed with crown rot damage in wheat being more pronounced when Zinc is deficient.

Additional Zinc will be beneficial to yield if crown rot is a risk factor, especially in susceptible cultivars such as Durum wheat.

Trace Elements in Australian Broadacre Cropping Systems

TE's applied in the seeding row ('row loading') to the plant are very important in drier years when the plant roots are not growing vigorously and they cannot intercept nutrition readily. Work done in the study by (Ozturk, 2006) which was reinforced by (Cakmak I. , Trace Element Discoveries in Turkey, 2009) revealed that seeds with relatively low Zinc concentrations showed poor seedling vigour and seedling establishment. Conversely, seeds with relatively high Zinc concentrations act to protect the germinating seedlings from infection by soil-born pathogens, and increase seedling tolerance to environmental stress factors such as drought, extreme temperatures and salinity. In Australia we are routinely subjected to all the above stresses so that having an elevated Zinc concentration in the developing seedling is an advantage. The above references also stated that Zinc should be provided to seeds at levels that exceed the optimum level for the crop itself to achieve optimum seed viability and seedling vigour, especially when planted under stressful conditions.

Biotech crop requirements for TE's

Concentrations of iron (Fe) and manganese (Mn) in glyphosate tolerant plant seeds and Mn in the plant tissue have been discovered to decline after application with the herbicide glyphosate (Cakmak, Yazici, Tutus, & Ozturk, 2009). This has broad implications for the suite of crops that are genetically altered to be resistant to glyphosate and it is recommended that a nutrient fertilisation and plant breeding strategy be determined to address this issue. The mechanism of this interaction appears to be quite specific and may affect seed quality for germination and the mineral content of the grain for human and animal nutrition. Work by the Stoller company in the USA indicates that the mechanism involves the way that glyphosate kills weeds by limiting the amount of auxin transport from the new leaves to the roots. Therefore, the roots of weeds do not have enough auxin for continuous new cell division.

On the other hand, glyphosate resistant plants appear to have the ability to move enough auxin from the leaves to the roots so that the glyphosate does not stop cell division in the roots.

It is becoming more apparent from Stoller's research that during certain periods of climatic stress or due to soil conditions (wet soil or dry soil) glyphostate resistant crops cannot move adequate auxin from the new leaves down to the growing root tips. Therefore, there is interference for a short period of time in cell division and new root hair formation. It is during this condition that glyphosate can cause manganese deficiency in soybeans and zinc deficiency in corn. More commonly copper deficiency has been noted (Stoller USA, 08).

Global Impact

The World Bank reports that by 2030, 50% more food will be needed, including an 85% increase in meat demand. The Pioneer seed company in the USA has a goal to increase corn and soybean yields by 40% by 2018. To double crop yields at current production trend increases there will need to be a 2.5% increase in crop yields each year for the next 30 years. We need to bend yield trend lines upwards to meet the world population's requirements.
With all of this new technology being used to produce plants with enhanced genetic potential there is relatively little work being done on fertiliser research and development.

"Seeds produced with the technology of 2009 are planted alongside fertiliser of 1959 technology" (Blair, 2009).

Breeding alone will not answer a requirement for higher yields. Plant densities need to be increased and more water and nutrition is needed to meet this challenge. As yields are increased, more nutrition is removed from the soil and nutrients are transported away from where they are required to grow nutritious, high yielding food crops.

Approximately 100 million tonnes of nitrogen is used globally each year and is only taken up and used by the plant at 50% efficiency. Agriculture's challenge this century is to produce more than ever before for a human population with an escalating food consumption. TE's role in this may be its ability to improve the utilisation of macro-elements like Nitrogen, Phosphorus and Potassium.

Politics and Crop Nutrition

In Australia crop nutrition does not often enter into politics, however in Europe it is being regulated at the farm user level across the European Union (EU). The current EU directive is to decrease the use of inorganic phosphorus and nitrogenous fertiliser by agriculture. The reductions in Nitrogen (N) are related to availability of organic N. Fertiliser N is deemed to be 100% available in the year it is applied.

From January 1st 2010 in Ireland, organic N is deemed to be between 30 and 50% available in the year of application depending on the organic product one uses. For example in pig and poultry manure the N content is deemed to be 50% available, in Farm Yard Manure FYM it is deemed to be 30% available and in Mushroom Compost the N is deemed to be 45% available. Organic P and fertilizer P are deemed to be 100% available in the year of application.

This directive will have a dramatic effect upon crop production systems throughout the EU. Efficiencies of Phosphorus use must be improved or farm grain production and profitability will plummet. The utilisation of TE’s to improve the efficiency of Phosphorus uptake, use efficiency and availability is an area that requires further research. In the current political environment in the EU, however, organic sources of nutrition and more efficient use of fertilisers are a necessity to maintain productive and profitable agriculture.

How leading farmers and advisers are using and recommending TE’s in broadacre field crops.

Just like people, plants without health stresses are more productive.

Kip Cullers, a farmer from Missouri, USA holds the world record for growing the highest yielding soybean crop in the world. He is a vegetable farmer who also grows soybeans and corn, using his expertise across vegetable and broadacre crop types to succeed. He nurtures his crops as much as possible, irrigating them when required, paying close attention to the planting arrangement and exact distances between plants and uses a meticulous fertilisation strategy together with the best crop genetics available. Kip’s mantra is: never let the crop you are growing ‘die and dry’. You need to make it ‘stay alive and yield’. One constant amongst the best farmers in the world was their attention to detail. TE’s are a part of the recipe to producing the highest yielding crops in the world and they are part of the attention to detail and the recipe that producers like Kip use. Just like a master chef who alters his recipe to enhance the result, a farmer needs to change his strategy and his inputs to maximise the end result of yield and quality.

Figure 2: Kip Culler's world champion yielding soybeans that yielded almost 10tonnes/hectare

Testing for trace elements

"In business what gets measured gets done"

Zinc deficiency is an ongoing issue in Australian agriculture and until it is tested for, or symptoms are recognised in plants, it will continue to go untreated. Most of the coastal land in the cultivated belt of Australia through Victoria, South Australia, Queensland, Northern New South Wales, the South West of Western Australia, and the coastal areas of Tasmania, have all been found to have zinc deficiency (Alloway B. J., Zinc in Soils and Crop Nutrition, 2008). Close to 50% of the world cereal cropping soils are deficient in zinc and an estimated 50% of the world's population is at risk of zinc deficiency that can lead to health problems (Cakmak, 2000) (Alloway B. , 2003).

Addressing Trace Element Deficiencies

Farmers and crop advisors need to understand that a **critical value** and the analysis for a deficiency performed on a plant tissue is really only applicable for that particular location of the study or experiment. Published critical values need to be taken as a rough guide in the context of the crop variety, crop type, field, farm, region and country that they have been taken in. Critical values derived from tissue and soil tests in individual experiments are often extrapolated and used as guides in situations where their relevance as a yardstick is questionable. The experimental error present when taking a tissue test renders the results usage as a guide questionable, even in small plots of horticultural crops. For example, in a typical broadacre cropping situation where 100 plants from a field of 65 hectares are samples for a tissue test, there are 1.75million plants/ha potentially (using wheat with a 1000grain weight of 40g and a planting rate of 60kg of seed/ha). This field of 65ha would have theoretically more that 113million plants of wheat in it.

Average plant tissue test values for nutritional guidance in fields such as the one described above are not adequate. Therefore critical values published in literature are not adequate when the average tissue test value for a field of plants is used.

If the average value of a group of plants being tissue tested is close to the critical value then MORE fertiliser is required to optimise plant growth. The affordability of this approach needs to be determined for the individual situation. Nutrient demand is determined by yield and the economics of the fertiliser application depend upon the return on investment or profitability of the exercise to the grower.

Lessons from Trace Element Management

One approach that may have merit in Australian cropping recommendation systems is to demonstrate to farmers and advisers a range of levels that confirm where the nutrition test level sits amongst other fields sampled with crops growing at a similar growth stage.

Visual symptoms observed by the grower and advisor are widely cited as one of the best means of diagnosing and then correcting a deficiency. The issue here is that often 20%, and up to 40%, of the yield may be lost without obvious symptoms. This is termed a transient or insipient deficiency. Farmers and their advisers educated with the knowledge of the visual symptoms as well as the soil and tissue values of a field are often the best means of diagnosis. Figure 3 illustrates the difficulty of visually assessing a deficiency with boron deficiency only obvious in the reproductive growth of the sunflowers displayed.

Figure 3, Varying levels of Boron deficiency in sunflowers affecting reproductive growth (flowering). The plant in the front left has no Boron available to it, the plant in the front right hand side has 50% of its requirement, the plant at the back left has 75% of its requirement and the one at the back right has 100% of its Boron requirement.

Once there are TE deficiency symptoms, the mechanics and processes of the plant cell may have already been damaged beyond their ability to recover and to produce effective growth. Plants are akin to a complex machine that needs to be adjusted through inputs (like TE's) to run efficiently. Specific examples of this are when Zinc, Manganese, Boron and Copper deficiencies, that are not detected and remedied before flowering, result in the pollen formation being adversely affected.

The largest returns on fertiliser used will nearly always come from situations where there is a pronounced deficiency and the crops are suffering large losses. However, there are additional profitable gains to be made also where yields are high and a deficiency is holding back further yield. Additionally where there is a biotic or abiotic stress that could affect plant growth, having adequate TE nutrition assists the plant to survive and thrive.

In California, USA advisers and growers in the horticultural industries are fertilising above recommended benchmarks, giving field average leaf tissue test values that are over and above recognised published critical values from research. This is done to fulfil the needs of all plants in a field to ensure none are deficient. However, this approach is not always possible in broadacre field crops where the cost of fertiliser can be a high proportional cost in production meaning that sometimes fertilisation for optimum agronomic performance may not be economically viable.

"The critical value in a soil test is where there is a 5-10% reduction in growth, this is an insipient deficiency." (Patrick Brown, 2009). Patrick Brown of UC Davis predicts that growers who fertilise with the aim to have 95% of their crop above a recognised critical value will result in a field mean nutrient concentration of at least two standard deviations above the established critical value derived from scientific research. In plain English this means farmers need to fertilise more once their average field tissue test is equal to the established critical value.

How much trace element fertiliser should we apply now given the discoveries above?

The established practice in production agriculture is that TE fertilisers should be applied to reach a critical value and then no further production gain is to be made to fertilise beyond this point. The above theory would appear to be correct on its own, however the variability inherent in sampling plant materials for analysis and the variability between plants within a field mean that a critical value used for guidance without knowledge of variability within plant samples will give a false impression of the plant's nutritional needs.

The YARA/PHOSYN company have taken the innovative step of benchmarking leaf tissue samples they have analysed and graphed, showing the "low", "normal" and "high" values for plant growth using the program MEGALAB. This analysis of information for a given region, crop type and TE type is powerful data enabling a farmer to benchmark his/her crop performance against. Currently most tissue test reports only tell the grower or agronomist whether the sample submitted is adequate or not. This information alone is not adequate for optimisation of the crop's growth through input management. A grower and his/her adviser need to know where their sample sits amongst a benchmark of crops within the region, crop type and for the specific element. Armed with nutritional benchmarking information the farmer and his/her adviser can then decide how far to push the production system's inputs given the profitability of specific inputs in question.

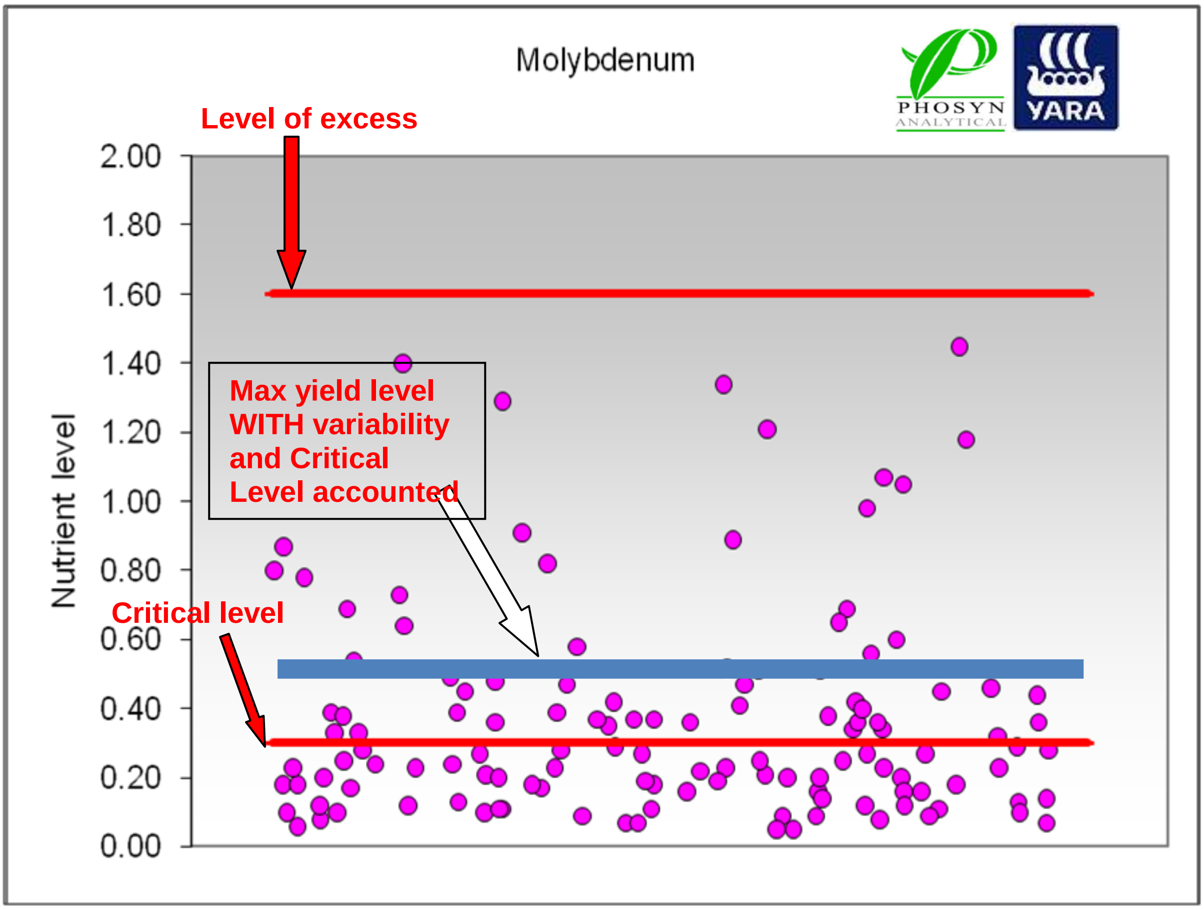

Figure 4: This graph illustrates the amount of molybdenum in Canola plant tissue samples in Victoria and the upper and lower limits associated with the tests. (Hancl, 2009)

Fertiliser applied to soil is a good investment as long as the soil has the ability to give the nutrition to a plant when it requires it. Foliar applications of fertiliser have a place where soils are hostile or strongly absorb a given nutrient. This can often occur with TE's applied to soils, particularly if there is a macro-element that binds it. Common interactions like this are Selenium and Sulfur and Zinc and Phosphorus. A general philosophy in terms of ameliorating a plant nutritional deficiency is to "keep a steady hand on the tiller", in other words it is not advisable to make rash changes in the fertiliser program until the correct reason why the plant is deficient is determined. Generally, leading advisers and growers advise taking a measured and logical approach until a comprehensive view of the nutrient interactions can be gauged.

Producers and advisers need to be mindful of the interactions between elements when deciding how much to apply to correct a deficiency. This balance between nutrients in the soil and the plant described simply by (Mulder, 1953) demonstrate the effects that elements have on TE nutrient availability.

Most nutrients interfere with the availability or uptake of another which is called antagonism. In Figure 5 below, the lines colored green indicate an antagonistic relationship between each connecting element. Also, some elements can stimulate the uptake or increase the availability of another. These lines are indicated by the color purple.

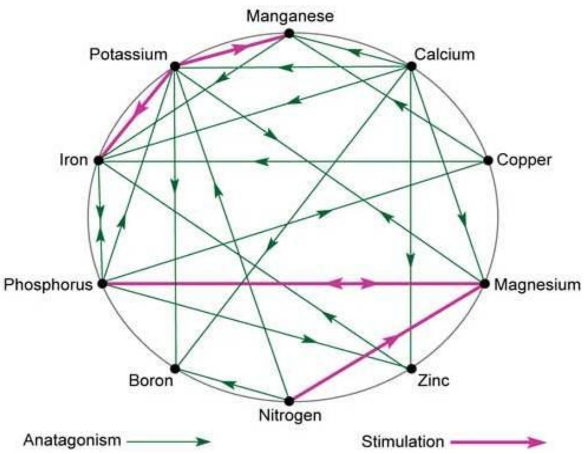

Figure 5: Mulder's Chart of Nutrient Interactions (Larocque, 2010)

Examples of the antagonistic and synergistic effects between nutrients are:

- where excessive, phosphorus applications will reduce the availability of iron, calcium, potassium, copper and zinc which increase in sterile florets, ergot, lodging and disease
- high levels of calcium will reduce the availability of phosphorus, zinc, magnesium, iron, potassium and manganese. This reduces seedling vigour, tillering, standability and maturity
- high nitrogen fertilization can reduce the availability of boron, potash and copper. This Increases sterility, ergot, flowering, increasing lodging and increasing transpiration
- increased levels of boron will increase the availability of nitrogen. This Increases chlorophyll, protein and amino acid production (Larocque, 2010).

Crop types and species also have varying responses to TE application based on their genetics. Table 1 below highlights the differences that require consideration when testing for and treating a deficiency.

Table 1 (Alloway B. J., Zinc in Soils and Crop Nutrition, 2008)

Genetic response of crops to treatment with Trace Element fertilisers					
	Zinc	**Copper**	**Boron**	**Manganese**	**Iron**
Barley	Medium	Medium	Low	Medium	High/Medium
Canola	Medium	Low	High	Medium	-
Oats	Low	High	Low	High	Medium
Wheat	Med/Low	High	Low	High	Low

Farmers need to assess their crop production in each paddock on their farm separately from other farmers in their area and critical levels for TE deficiency need to be determined for their system. Farmers may think their levels of fertilisation are adequate based on published critical levels of leaf tissue analysis or soil testing. However, the critical level for each farm needs to be determined by the farmer to afford him the greatest profitability. Each field, crop type and variety has a slightly varying requirement for nutrition. No biological system is identical. To achieve an average optimum an overview of the system is required and is best done by the farmer with the right information.

Innovations in TE application equipment and technologies, globally

Applications of TE's via a foliar application early in the crop's growth above ground can be wasteful in a broadacre situation as there is little leaf area for uptake. It is more efficient to apply TE's in a foliar form once there is 70% or more ground cover by plants. Foliar applications of zinc (Zn) have been found to improve grain zinc concentrations by 2-3 fold (Cakmak, Yazici, Tutus, & Ozturk, 2009). An alternative means of application is with Zn-enriched urea applied to rice and wheat. This has been found to significantly improve both crop yield and grain zinc concentrations also. This has merit in situations where it is not practical or easy to apply foliar TE's.

Figure 6, Some of the liquid application equipment used in Ireland to “row load” nutrients at planting

In order to ensure there is not a deficiency in the plants prior to a foliar application at 70% canopy cover, it is advisable to have nutrients in the furrow with or on the seed for early growth. TE fertiliser needs to be applied with, on or near the seed at planting. Success has been gained in some broadacre systems by coating seeds or soaking them in a nutrient solution containing TE’s prior to planting. In studies by (Ozturk, 2006) and (Cakmak I. , Enrichment of fertiliser with zinc: An excellent investment for humanity and crop production in India, 2009) foliar treatments applied late in the seed development were found to be effective in causing distinct increasing seed Zinc concentrations. These increases became more pronounced with the frequency of zinc application.

It is currently thought that the best timing of application for TE foliar applications is under higher humidity conditions when leaf uptake is also optimised. Generally the same rules for applying foliar applications of pesticides should also apply to applying TE fertilisers in a foliar delivery system. The main elements of this are to monitor for higher humidity, lower plant moisture stress and optimal temperature during and immediately post application.

Alternative Trace Element Fertilisers

Organic materials from industry (paper pulp) or intensive animal waste (from cattle feed-lots and chicken broiler farms) are a worthwhile source of TE’s if they can be economically sourced. Users need to monitor contaminants such as heavy metals that can cause issues such as arsenic in chicken litter and heavy metals such as Cd in paper pulp. Farmers who use wastes as alternatives to conventional fertilisers successfully, like Kip Cullers, apply 3 tonnes of poultry manure per acre each year and find that the nutrition from this is over a slow and extended period and the best type of starter fertiliser. An analysis from a large commercial processing egg facility in Iowa equates values to the following amounts of nutrition applied per hectare per year in Table 2.

Table 2: Mineral content of broiler chicken litter at Freemont Farm's Iowa

Trace Elements	**Nutrient Concentration PPM (dry basis)**	**Grams nutrient / ton of Chicken litter**		**Kilograms of nutrient applied/ha**
Boron	20	13.6		0.102
Iron	492	386		2.90
Manganese	808	630	**The chicken litter is applied at 7.5tonnes/ha**	4.73
Copper	29	23		0.173
Zinc	684	535		4.01
Macro Elements	**Mg/kg**	**Grams/ton**		
Nitrogen	16248	18872		14.7
Phosphorus	21904	25441		19.9

Figure 5: Freemont farms, Iowa

"Nutrition creates yield potential, all other inputs into plant growth preserve or keep it."

Purchasing TE fertilisers

It is easy to be confused by the myriad of products available to farmers when they decide to apply a fertiliser to remedy a deficiency.

The latest technology now available in premium products in the market ensures that a formulated quality product combines the essential elements of fertiliser chemistry and additives to produce a product that works.

Several important components in a high quality TE formulation product include: a consistent particle size, the use of quality raw materials, high solubility and availability in the plant post application.

When “row loading” trace elements the formulation of the product is not as important as when the TE’s are applied as a foliar spray application because the mechanism of uptake and exterior influences are different. However, a high quality source is essential so contamination with toxic minerals often found in conjunction with raw TE’s in their natural state does not happen.

In product selection for broadacre crop foliar applications of TE fertiliser there are several factors to consider:

Product Chemistry

The basic solubility of the elemental formulation of a TE fertiliser being used is critically important for successful use as a fertiliser. Products in their raw state can cause issues in foliar applications especially when partnered with a pesticide in their application due to unwanted reactions. Chelated products generally have a low elemental analysis and can be expensive. This can cause issues with application volumes needing to be large and transport cost can contribute a substantial proportion of the product cost.

Nitrates and Sulphates also have relatively low elemental analysis, increased phytotoxicity risks and a need for repeat applications sometimes rendering them more costly in a foliar application program. Nitrate and sulphates also are more likely to have issues in tank mixes with pesticides by reacting and causing blockages if the formulation is not adequately produced.

Formulation

Modern advances in formulation technology with the use of chemical buffers, solubility agents, wetting agents, sticking agents, absorption agents and stabilising agents enable many types of product to be combined to utilise the positive attributes of each chemistry in a complete product. Insoluble nutrients can be made soluble and available to plants through formulation technology. This technology allows higher analysis products to be applied, improving crop safety, improving availability of the product over a longer period of time through controlled particle size, enhancing leaf and root uptake and minimising phytotoxicity to the plant. Controlled particle sizes in flowable suspension fertilisers during manufacture is essential, especially for foliar applications as small particle sizes mean the surface area of the fertiliser is maximised for plant uptake and utilisation. In addition, a spectrum of relatively small and large particles is necessary to feed the plant with nutrition over the short, medium and long term periods of the growing season. Chemistry to stick the TE fertiliser (Stickers) in the formulation are important to keep the product on the leaf and to stop it from being lost due to rainfall. Wetting agents are also important to increase the surface area of the product applied onto the leaf and reduce leaf damage due to sunlight being focussed onto the leaf through a water "lens" effect post application.

Recommendations

The Future

"Change isn't essential, survival is optional"

As farmers, we periodically need to try different techniques, ideas and innovations to survive. Latecomers to a technology usually are too far behind an innovation to gain a technological advantage that will reward them with impressive returns. The adoption of technology that in turn increases efficiencies and profitability can mean the difference between success or failure in a farming system. For producers to continually stay where they currently are in their production system puts them at risk of being superseded by others. It is a wise investment to assess where your farm and production system sit in terms of TE's and use them where required.

Using TE's correctly will result in improved plant growth and yield and also improved health and less disease in humans and animals. In addition to this a growing world population will drive a strong demand for grains, for both human food and animal feed. In developed countries such as Australia, the time-poor, more quality conscious and ageing population will provide market opportunities for product differentiation such as enhancement with TE's through biofortification. The added consumer benefit when TE's are biofortified in grain rather than supplemented as a food product ingredient is that they are an intrinsic part of the food available by being incorporated in a protein that is readily absorbed by the body through natural mechanisms. There are many opportunities to be seized in this area.

The key recommendations of this study are:

- for the grains industry of Australia to set up a mineral nutrition standard for raw grain delivered to storages so that products with enhanced mineral nutrition can be extracted for added value where possible

- assess your own diet's intake of essential Trace Elements to ensure you are not starving your body of essential nutrition that nourishes and protects your body

- benchmark broadacre crops based upon the best performing areas of crop fields and their corresponding soil and tissue Trace Element values

- understand what a 'critical value' is and use its definition to manage yield in response to TE applications at economically sensible levels

- set-up a liquid system in planting equipment to "row load" Trace Elements in the furrow at planting time and give crop plants the best possible start to growth.

- be ready to apply Trace Elements through foliar applications if found to be necessary

- learn to visually assess crops for Trace Element deficiencies so they can be treated and corrected before widespread yield and profit loss occurs

- look for alternative Trace Element fertilisers like animal wastes that have benefits and advantages beyond their TE nutrition that will give an economic advantage above formulated TE products

- for farmers to use quality TE formulation products, not snake oils with promises and no back-up

- explore ways to gain an improved economic return on grain production with elevated mineral TE concentrations in grain being produced by farmers to elevate human and animal nutrition.

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APA format

Plain English Compendium Summary

Project Title:	Trace Element Nutrition: Revitalising Health and Agriculture
Nuffield Australia Project No.:	0911
Scholar:	Evan Ryan
Organisation:	RYANAG PTY LTD
Phone:	0428 298 031
Fax:	03 5744 3662
Email:	ev_ryan@hotmail.com
Objectives	To assess the importance of trace elements in broadacre farming and to study methods to manage their application and benefits
Background	Currently few Australian broadacre farmers are using trace elements to increase their productivity and profitability
Research	Travel across North America and Europe interviewing farmers, researchers and advisors who use and recommend trace elements
Outcomes	Trace elements are important both to plant growth and to human health. Trace element use can improve productivity and profitability for farmers and improve health outcomes for consumers.
Implications	The broadacre cropping industry needs to invest in trace element research to lift yields and improve the mineral nutrition of grain for consumer health and to add value to broadacre commodities.
Publications	