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MICRONUTRIENTS: BEYOND CROSSROADS – ON THE HIGHWAY

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Micronutrients: Beyond Crossroads – On the Highway

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Introduction

The description 'micronutrients', sometimes referred to as 'trace elements', belies the importance and essentiality of this group of nutrients for plants, as well as their role in human and animal diets.

The prefixes 'micro' or 'trace' refer only to the relatively small amounts which are required by plants, usually as a few kilograms per hectare (kg/ha), or parts thereof, compared to the primary and secondary nutrients which are usually required in hundreds or tens of kg/ha respectively (Moran, 2004).

The primary nutrients comprise nitrogen (N), phosphorus (P) and potassium (K); the secondary nutrients are calcium (Ca), magnesium (Mg) and sulphur (S); and the main micronutrients are boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn).

It has been suggested that chlorine (Cl) should be included in the group of micronutrients (Shorrocks, 1994) and recently evidence has been forthcoming that nickel (Ni) should also be in the list (Brown, 2003). Cobalt (Co), along with molybdenum, is established as an essential micronutrient for the symbiotic bacteria found in the root nodules of both leguminous plants and alder (Mengel and Kirkby, 1978).

Furthermore, Co as well as selenium (Se) and iodine (I) are essential micronutrients in the diets of humans and animals (Schwarz, 1970) in addition to those listed above.

However, this paper will focus on the six main micronutrients B, Cu, Fe, Mn, Mo and Zn required by plants.

The metabolic function of B in plants is primarily in sugar translocation as well as involvement in sugar/starch inter-conversion, the production of nucleic acids (DNA and RNA) and growth regulation via cytokinin and auxin synthesis.

Cu, Fe, Mn and Zn are all associated with the activity of a vast array of enzymes which control plant metabolism, function and development. All are transition metals which can readily change valency / charge states and therefore they have an indispensible role in the electron / energy transfer processes of photosynthesis and respiration.

In addition, these four micronutrients have a fundamental role in the plant's ability to assimilate and metabolise the primary (N, P, K) and secondary (Ca, Mg, S) nutrients which, along with Mo and it's essential role in nitrate-N reduction, and the role of B in sugar transport, will form the main driving theme of this paper and the presentation associated with it.

To conclude this introduction to micronutrients Katyal (2004) elegantly demonstrated the relatively small amounts required compared to those of primary nutrients, but their equal importance for plant metabolism, by estimating that a deficiency of 1 Mo atom will impair the biological advantage of 10^6 N atoms.

Occurrence of Micronutrient Deficiencies and their Effect on Yield and Quality

A comprehensive study by Sillanpaa (1982) observed that micronutrient deficiencies were common in many parts of the Asia-Pacific region and that they were becoming more extensive. More recently these observations have been confirmed by Fairhurst (2003) in South East Asia, Rijpma and Fokhrul Islam (2003) in Bangladesh, Dar (2004) in many districts of India, Jin (2006) in China and most recently by Srinivasarao et al (2007) in the semi-arid areas of Central India.

Although they are required in relatively small amounts, moderate to severe micronutrient deficiencies will significantly reduce crop yields and quality with visible symptoms, such as leaf chlorosis (yellowing) and shoot die-back, appearing on crops which may ultimately lead to complete crop failure.

However the much more common occurrence are sites where soil micronutrient levels are below the optimum required by plants and though not severe enough to cause the appearance of visible deficiency symptoms they will cause significant losses of crop yield and quality. This is commonly referred to as "hidden hunger" and currently for micronutrients it is estimated that this represents the most serious "robber" of crop yield and quality throughout the Asia-Pacific region.

Liebig's 'Law of Minimum' – Past, Present and Future

The 'Law of Minimum' proposed in 1843 by Justus von Liebig is frequently demonstrated by the 'barrel analogy' which has achieved almost cliché status in crop nutrition circles though it never fails to engender an unforgettable seminal image which contrasts abundance when you get it right with scarcity when something critical is missing! Perhaps it should be replaced with a more contemporary or even futuristic analogy like a series of shiny steel crop silos or rocket fuel tanks which all need filling to reach the desired goals?

The law states that 'If one plant nutrient is deficient, plant growth is limited, even if all other vital nutrients are adequate and plant growth is improved by increasing the amount of the deficient nutrient'. More recently Lammel (2005) reflects that 'Although this law of minimum was already detected in 1843, a shortfall of specific nutrients is still the major reason – with limited water supply – for low crop yields and poor quality throughout World Agriculture'.

The latter highlights that in modern agricultural production, filling the 'barrel' goes well beyond yield to achieving marketable quality standards, and increasingly in future to improving the nutrient content / density of crops and therefore their contribution to human and animal diets; all of which can be achieved by appropriate and balanced micronutrient fertilizer inputs (Graham and Welch, 2007).

So, whether it is a shortfall of a primary, secondary or micronutrient the magnitude of the effect on crop yield and quality is the same irrespective of the relative quantities required as Katyal (2004) has demonstrated.

Recently the 'barrel analogy' has come under some scrutiny in terms of the mere incremental benefits as each limiting nutrient is added and that this may be an over-simplification of the effects on the metabolism and physiology of plants at the molecular level. For example, Summer and Farina (1986) constructed an interpretative model based on the 'law of minimum' and Mitscherlich's 'law of physiological relationships' to suggest that the higher the yield the more sensitive a crop becomes to nutrient imbalance; and therefore the more responsive it is to adding a deficient nutrient; an effect which has been demonstrated by Phillips (2006) in rice/wheat systems in Bangladesh. And very recently Elser et al (2007) postulated that alleviation of one nutrient limitation produces a synergistic, rather than a simple additive effect, when another limiting nutrient is introduced into the system. Although Elser et al (2007) focussed on N and it's close metabolic relationship with P and the micronutrient Mo and it's critical role in N fixation, the other well documented 'synergisms' between P and Zn as well as between Ca and B may add weight to their hypothesis and yet again Katyal's (2004) deduction on the relationship between N and Mo has a strong bearing in the matter.

From the 'Barrel' to the 'Global' Challenge!

Having established the fundamental essentiality of micronutrients, particularly in the metabolism and assimilation of dominant primary nutrients like N in plants at the molecular level and through the 'barrel analogy', the important role they have to play in the balanced fertilization of crops in current and future agricultural production at the 'global' level can now be illustrated and discussed.

More specifically I want to show for the Asia-Pacific region some powerful indicators that micronutrients must become a critical component of balanced fertilization programmes in the region now and that the requirement for them will increase in the future. So, if all you wanted was a simple reply to the question "Where are we now?" then you have it here, but please stay with me a little longer to allow reinforcement of my declaration of this "crossroads to highway" position that micronutrients now find themselves in - out of absolute necessity!

Pereira (2003) elegantly summarised the main achievements of agricultural production over the past four decades and sets the objectives that must be achieved, and possibly surpassed, in the next four. Some of his data have become quite familiar particularly those of population growth and the requirement for increased food production up to the 2030-2040. However it is important to note the understandable emphasis on the increased use of N and P fertilizers to support the increase in agricultural production needed to secure sufficient quality food, fuel and fibre for the growth in the human population and it's live-stock.

Fresco (2003) alludes to the potential for 'soil depletion', particularly of micronutrients, with the levels of N, P and K that will be necessary to drive these future production requirements, and states that micronutrients need to be looked at in a systematic fashion with priority to provide 'balanced nutrient management' to avoid this and further 'degradation' from happening.

The pernicious process of 'soil depletion' which is more commonly referred to as 'nutrient mining' has been taking place over the past decades of very successful increases in food production with only a relatively small increase in productive soil areas to achieve it. Therefore the potential for 'nutrient mining' of these soils has always been there and is currently becoming much greater and I will demonstrate that this is happening widely in the Asia-Pacific region.

Hartemink (2006) highlighted the changes of land use in China with around 35 million hectares (M ha's), representing a 33% increase, being brought into cultivated production between 1949 and 1996. Perhaps more significantly is the 840%, a ten-fold, increase in orchards and plantations from around 1 to 10 M ha's and these crops do demand relatively high fertilizer (and water) inputs as well as micronutrients for maximum yields and optimum quality. Therefore the potential for 'nutrient mining' of micronutrients has been running at a very high setting and undoubtedly, over the last decade, significant additional areas of these crops, as well as a wide array of 'new' vegetables and 'exotic' fruits, have come into production with increasing use of irrigation to secure higher yields.

Zhang (2006) illustrated the steady increase in N, P and K fertilizer consumption for grain production in China since 1975 though he notes that the yield/ha has either levelled off or even decreased slightly. He argues convincingly that this is due mainly to poor nitrogen (and other primary nutrient) use efficiency (NUE) particularly from their injudicious use and over-application of N (P and K) fertilizers but also alludes to other factors such as low soil micronutrients as ‘culprits’ in this dilemma.

That shortages and imbalances in micronutrients are part of the problem of primary nutrient use efficiency) PNUE in China comes from the analysis of Jin (2006) who demonstrates that the extent of soil deficiencies has increased significantly in recent decades.
Although he notes that B deficiency has decreased somewhat, probably as a result of cogent communication programmes (Phillips, 2006), it still occurs as commonly and extensively today as the other micronutrients in Chinese soils.

That ‘nutrient mining’ of micronutrients is on the increase is also starkly illustrated by Rijpma and Fokruhl Islam (2003) and Srinivasarao (2007) in India with a greater number of Zn and B, and most recently Mo, deficient soils being identified. This has also occurred with secondary nutrients, such as S and Mg, and primary nutrients, notably K, and the use of appropriate and balanced fertilizer programmes are now being promoted and implemented in an attempt to re-balance soil fertility levels in these areas.

All of these studies cogently predict that if ‘nutrient mining’ is not addressed with judiciously balanced fertilizer applications including micronutrient applications then this will result in the progressive and possibly irreversible degradation of soils and therefore a significant loss of productive land in the future with potentially dire social, political and economic consequences.

Fairhurst (2003) proposed that ‘nutrient mining’ is compounded by the removal in crops exported from their region of production and that this is very significant for both sugar-cane and cassava in Indonesia, as well as rice in Thailand and Vietnam. He also demonstrates that although the area planted with rice has increased in recent decades, yields have reached a plateau which he then attributes to unbalanced fertilization.
Furthermore he predicted that the irrigated rice area will decrease in future which, as will be shown later, increases the requirement for micronutrient inputs (Gao et al, 2007). Fairhurst also describes the ’downward spiral into the poverty trap’ through the progressive processes of nutrient depletion, yield reduction, income loss and finally soil degradation that will occur without nutrient replenishment through balanced fertilizer inputs.

Looking to future demands for global food, fibre and bio-energy production, Ringler (2006) presented several scenarios for each of these sectors but highlights the projected models of growth in bio-fuel crops all of which show that 50% or more of this increase will be in the Asia-Pacific region. This growth in the bio-energy sector will inevitably lead to competition for available land for food production and the only solution to this conflict will be that yields/ha of all agricultural crops are increased to meet these additional demands (Contini, 2007). More pertinently, with the information provided so far illustrating the extent of ‘nutrient mining’ that has already taken place in the Asia-Pacific region, the importance of balanced fertilization including micronutrients to enable the sustaining of the higher yields/ha, becomes amplified.

There are other changes taking place in the Asia-Pacific region which indicate that larger amounts of micronutrients will be required in future. For example, Gao et al (2007) confirmed the prediction of Ferguson (2003) in Indonesia that there is a current movement from ‘flooded’ to ‘aerobic’ rice production, and demonstrated that in China this has significantly reduced the Zn content of grain. This has implications for both reducing crop yield/ha, PNUE of applied N, P and K (Zhang, 2006) and the lower contribution of micronutrients to human diets (Graham and Welch, 2007).

Another example comes from the work of McGrath et al (2007) who demonstrated the trend in recent decades with short-straw wheat varieties of high ‘harvest index’ to have lower Zn contents. This can be interpreted that traditional fertilizer practices for wheat would benefit from fortification with micronutrients.

Placed into the context of the analysis so far, figures provided by Moore (2007) illustrating crop areas in Indonesia are cogent reminders of the potentials for ‘nutrient mining’, lost yield potential and below-optimum quality of many crops without micronutrients to balance traditional fertilizer programmes.

Some elegant work in rice / wheat systems in Bangladesh demonstrating the benefits of balancing traditional N, P and K fertilizer practices with appropriate micronutrient inputs has been reported by Phillips (2006). Not only were there significant yield and economic benefits from simply adding Zn to the traditional NPK programmes in both rice and wheat but the effect of the same amount of Zn became amplified when NPK inputs were increased on both crops. This indicates that PNUE became greater at the higher NPK levels and this is consistent with the interpretative model of Summer and Farina (1986) predicting that, at higher yields, crops become more sensitive to other limiting factors and therefore become more responsive when limiting nutrients are added. This ‘synergism’ was also predicted by Elser et al (2007) in their analysis of N, P and Mo relationships at the metabolic level in plants.

Greater focus on quality, marketability and nutrient content / density is now demanded by importers, wholesalers, retailers and consumers and though this currently might be more applicable to high-value fruits and vegetables, to retain fresh-ness and visual appeal, in future it will begin to apply more and more to ‘staple’ crops as well.
That micronutrient inputs have a significant role in crop quality was demonstrated by Silalahi and Marpaung (2007) on Mandarin oranges in Indonesia. These workers selected three sites with growers who had never used micronutrients before but were now seeking a solution to the ‘falling yields’ at two of the sites and ‘very low yields’ at the third. The micronutrient input was provided by a proprietary formulation called ‘Tri-pholate’ which was applied as a foliar spray in addition to the traditional soil treatments with NPK.
The responses to the ‘Tri-pholate’ were outstanding with the two ‘falling yield’ sites showing a 20% and 28% increase in yield per tree and a 17% and 32% lift in Grade A fruits respectively over the untreated. Furthermore at the third ’very low yield’ site there was a146% increase in yield and over a 500% lift in Grade B fruits. These data clearly indicate that these were very responsive sites suffering from multiple micronutrient deficiencies. Nevertheless they do illustrate how micronutrient additions can profoundly affect both yield and quality with significant economic benefits when used to balance traditional NPK inputs.

For ‘staple’ crops the use of foliar applied micronutrients may be either inappropriate or not economical and for this reason a good deal of focus has been given to micronutrient seed treatments in the Asia-Pacific region in recent years with extensive trials-work to demonstrate the value and benefits of what have become bench-mark proprietary products known as the ‘Teprosyn’ range (Moran, 2006).
Work at the prestigious Philippine Rice Research Institute in 1998 showed a significant lift in yield from 4.7 to 6.5 tonnes/hectare (t/ha) in ‘flood-irrigated’ rice; and an extensive programme at 33 trial-sites throughout India in the same year conducted by the Rallis Corporation delivered average yield increases in ‘paddy’ rice from 3.97 to 4.31 t/ha. Notably in the Indian work quantification of ‘root-ball’ volume was undertaken and as a general rule this was increased where ‘Teprosyn’ seed treatments were applied as illustrated with these trials data.
In all the above work with rice the traditional NPK applications were made at the trial-sites so again an increase in PNUE is observed with micronutrient inputs delivered by the ‘Teprosyn’ seed treatments.

The benefits of increased ‘root-ball’ volume with micronutrient treatments may be pertinent to the work of Dar (2004) in the three districts of Andhra Pradesh in India which demonstrated that rain-water use efficiencies (RUE) of soybean, groundnut, mungbean and sorghum were all significantly increased where micronutrient inputs were made in addition to normal farmer NPK inputs.

Dar’s work is important in illustrating that micronutrients have a key role in the water economy of crops and as both fertilizer and water usages become more closely linked in future and with the increasing use of irrigation in the Asia-Pacific region as predicted by Alexandratos (2003) then innovative and relevant micronutrient products must be available to meet the requirements of this growing sector.

To meet this challenge in the Asia-Pacific region recent advances in chelate technology, availability and applications are now providing solutions and economic benefits from micronutrient inputs in fertigation and hydroponic systems, protected-crop production and soil applications, including the only effective treatment for chronic Fe deficiencies in fruit and vine crops as illustrated by Bugter and Zhang (2006) .

Micronutrient deficiencies also affect human and animal health throughout the Asia-Pacific region with the World Health Organization (2002) placing lack of Zn and Fe in diets at 5th and 6th on the list of ‘Leading 10 Risk Factors as Causes of Disease Burden’. Graham and Welch (2007) argue that one of the main causes of micronutrient shortages in crops, including Zn and Fe and those not required by crops but needed in human and animal diets such as selenium (Se) and iodine (I), is the increasing use of primary (macro) nutrient fertilizers. They also state that all of these ‘deficient’ micronutrients can be applied to crops as part of a balanced fertilizer programme and Moran (2007) demonstrated several different methods for their delivery, including foliar sprays, seed treatments and fertilizer impregnation (coating), as practical and effective means of ‘fortifying’ crops and consequently the food chains they will enter.

In conclusion, it has been demonstrated that micronutrients have now moved ‘beyond the crossroads’ and are now truly ‘on the highway’ of mainstream fertilizers, alongside the primary (N, P and K) and secondary (Ca, Mg and S) nutrients, in the Asia-Pacific region.
Micronutrient applications must now become essential components of balanced fertilizer programmes to enable the achievement of maximum yield potential/ha as well as to optimize crop quality for both domestic consumption and export markets.
Furthermore, fortification of food crops with micronutrients as part of balanced fertilizer programmes can assist in improving food chain quality and dietary intake of these essential nutrients by humans and their live-stock.

The use and application of micronutrients is normally based on reliable soil and/or leaf tissue testing which can identify which of them are deficient as well as their severity (Moran, 2004). Accurate interpretation of the data is best achieved using computer programs, which have been specifically designed for the purpose where these are available and accessible, or more practically by well trained and experienced field advisors who will ensure the right product is applied at the correct rate to treat micronutrient deficiencies effectively as part of a balanced fertilizer programme.

And finally, I hope you are now more aware of micronutrients and their fundamental role in increasing and sustaining future agricultural production in the Asia-Pacific region to balance traditional NPK fertilizer programmes. Also you have seen products and methods that can be used to treat them effectively, as well as results which demonstrate, in the words of Dar (2004), ‘Macro-benefits from Micronutrients’.

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