Importance of Micronutrients in Sustaining Crop Production

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Micronutrient disorders still occur in the field!

- In spite of the availability of micronutrient fertilizers in many countries, deficiencies in the field continue to be reported

- Symptoms of micronutrient disorders commonly occur in many parts of Asia

Recent examples for B:
Tomato - Nigeria
Sunflower - Italy
Cauliflower - Brazil
Rice - India
Tobacco - China
Eucalypts - Vietnam
Coffee - Thailand

Fe

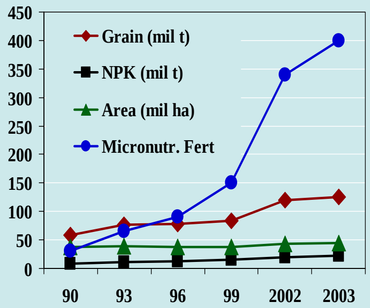
Fe

B

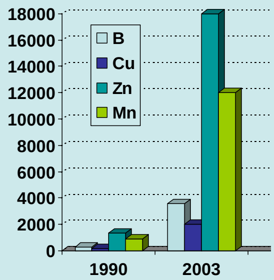
Cu

Micronutrient consumption

- Micronutrient consumption has increased in some countries resulting in increased yields and some improvement in soil fertility e.g. Brazil (Yamada, New Delhi 2004)
- Balance sheets are, however, lacking for many countries



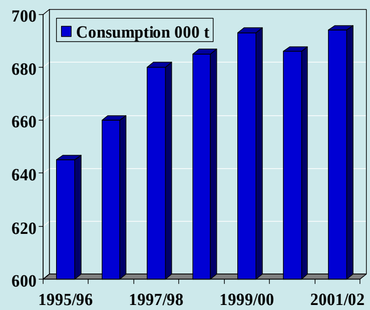
Brazil (Yamada 2004)



2003	B	Cu	Fe	Mn	Mo	Zn
Output as % input	59	69	21	30	45	33

Micronutrient consumption

- But this appears not to not universal.



World (Wijaya 2004)

2. Current challenges

Land degradation

- reversing soil loss
- reversing the loss of soil organic matter
- reversing deleterious changes in soil chemistry

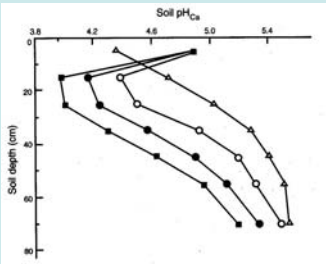
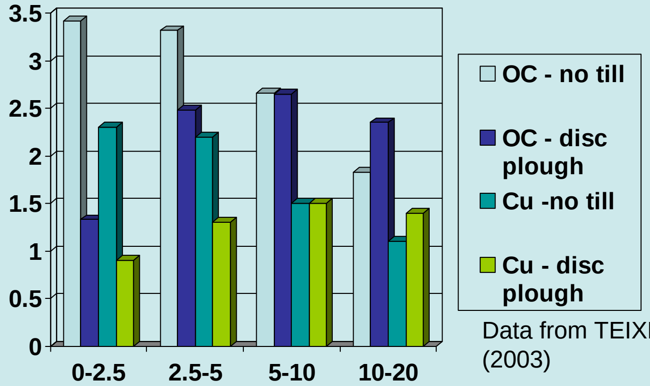


Figure 5.1.1 Effect of depth and time since clearing on soil pH_{Ca}[1] (△ mean of uncleared sites; ○ 12, ● 50, and ■ 74 years after clearing; from Figure 1, Dolling and Porter 1994).

- **The management of micronutrients has not kept pace with changes in agricultural practices, including no-till, water-saving crops and increased biomass harvesting.**
- **More research on soil micronutrients under key crops and cropping systems is desirable to underpin future micronutrient application.**
- **In Australia, for example, determinations of RVs for micronutrients were made when crop yields were far less than they are today and when the land was heavily cultivated**
- **Will no-till lead to increasing concentration of micronutrients in the surface soils? Does this matter?**

Managing soil organic carbon (amount and depth)

• Tillage and micronutrient distribution in soils – one of the few studies in this area



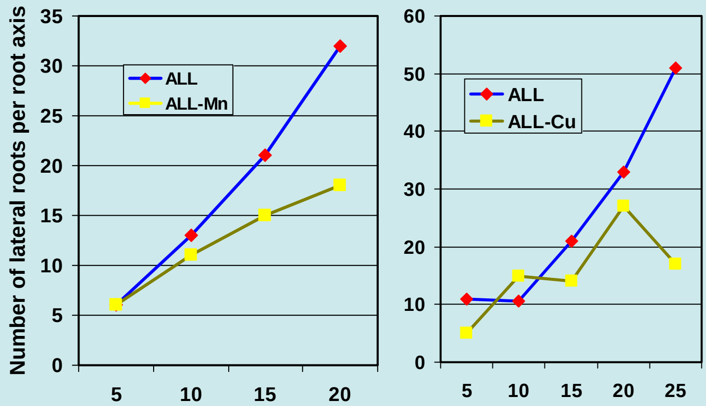
Data from TEIXEIRA et al. (2003)

• Sometimes a positive correlation between soil OC and DPTA extractable Zn, Mn and Cu (e.g. Sharma et al. 2004)

• How should micronutrients be applied in the future under no-till conditions?

• Are there implications for root penetration in subsoils low in micronutrients?

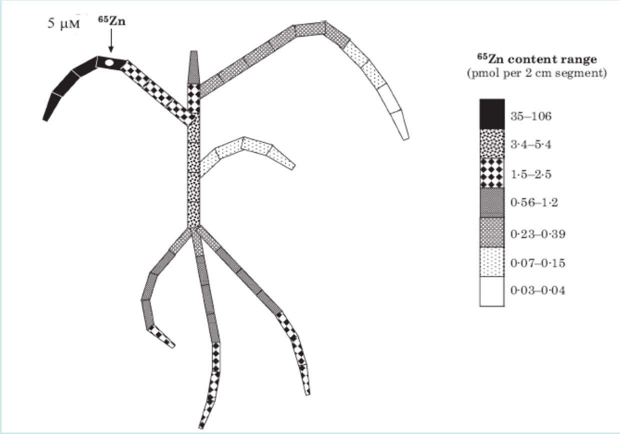
Do roots require an external source of micronutrients for sustained new root growth?



Wheat seedlings with a split-root system grown hydroponically in the presence of ALL nutrients, then one half of the root system transferred into ALL-Mn or ALL-Cu for 20 days. Data from Webb (unpub.).

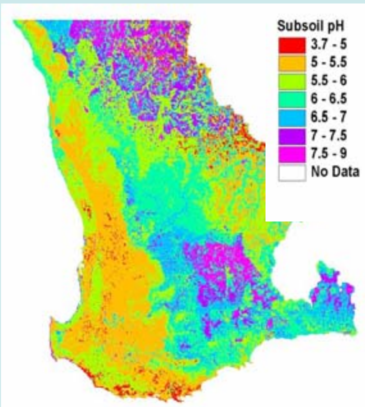
Can foliar application meet demand for root growth?

• 5 week-old wheat seedling roots are sufficiently supplied with phloem-delivered foliar Zn. From Haslett et al. (2001).

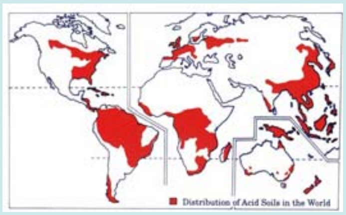


• Field experiments are required to determine if root-derived micronutrients from the near-surface soil horizon can be redirected to sustain growth of roots as they seek water in subsoils that are low in micronutrients.

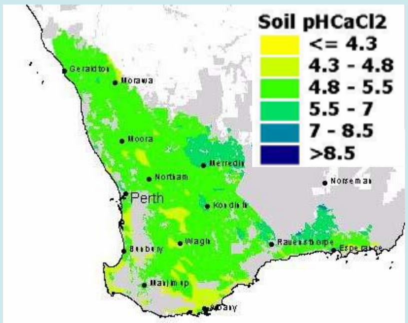
<u>Managing micronutrients in acid soils</u>



Sub-soil pH in south-western Australia. 23 m ha Australia.
Data from National Land and Water Audit.



Distribution of surface acid soils in Western Australia



Courtesy of Land and Water Audit

- Advantage of legume – cereal rotation: yield and cereal grain quality

Crop	Wheat t/ha	Wheat % protein
Continuous wheat	1.37	9.5
Wheat: lupin	2.00	10.6

From Shackley (2000)

- Disadvantage: reduced soil pH (Mo deficiency, Mn toxicity)

Increased risk of Zn deficiency in wheat on soils limed to correct soil acidity (Brennan et al. 2005)

Virgin sand

pH $_{(Ca)}$ 4.9

Limed to 5.8

Limed to 7.4

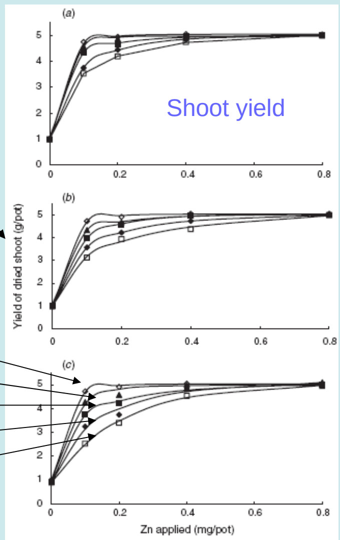
not incubated

30 days

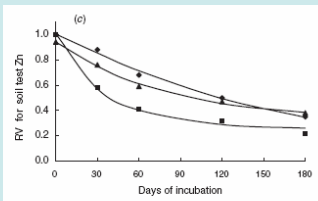
60 days

120 days

180 days



Residual values of Zn for the 3 soils



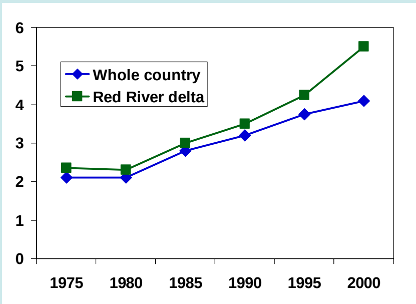
How frequent does Zn need to be applied in the field?

Intensive cropping and high yields

- Crop demand for micronutrients will increase as crop yields increase

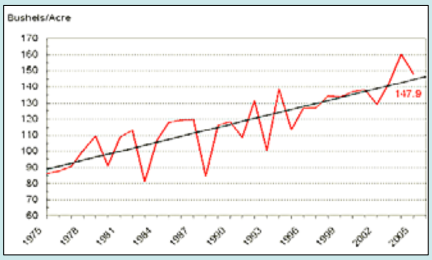
Rice yields (t/ha) in Vietnam

(Nguyen et al. 2003)

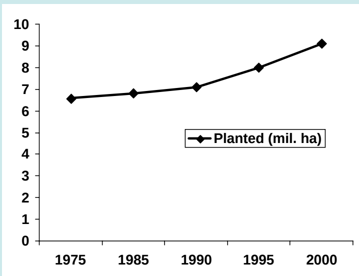


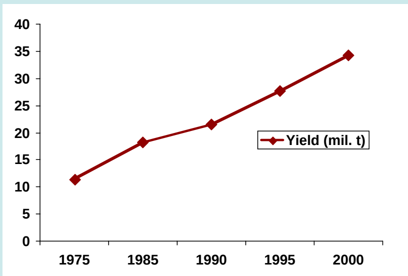
Corn yields in U.S.A

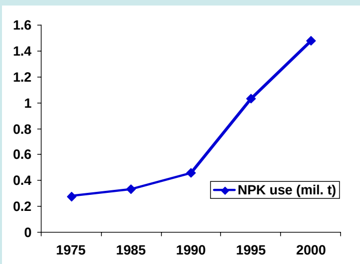
(USDA-NASS)



- Factors contributing to crop yield increases include farming practices and crop improvement e.g. Vietnam







• Micronutrient removal in crop harvest

Significant amounts of micronutrients are removed in the harvest.
An issue for marginal soils or all soils?

Crop species	Micronutrient concentrations in grain (mg/kg dwt)*		Estimated micronutrient removal (g/ha)	
	Cu	**Zn**	**Cu**	**Zn**
***Triticum aestivum Yield* 3 – 5 tons/ha@**				
	1.2 – 8.6	**8.0 - 46**	**4 - 43**	**24 - 230**
***Oryza sativa* brown (husk removed) Yield 7 – 9 tons/ha #**				
	1 - 13	**6 - 28**	**7 - 117**	**42 - 252**

* Range taken from Rengel 1998; @ the data is the yield range in China, courtesy of Dr Zhao Bingqiang, Chinese Academy of Agricultural Research; # Rice yield range is cited from Peng et al. 2004

• Mn in paddy rice – wheat rotation

- Lower Mn in paddy topsoil (rice – wheat) (total Mn 42%, active Mn 11 %) of upland soil of same soil series
- Mn loss due to leaching and excessive uptake by rice
- Mn deficiency in wheat when Mn low in subsoil
  - Sustaining soil fertility under water-saving rice?

Table 3. The difference in manganese distribution in soil profile between the rice–wheat rotation and the upland soil

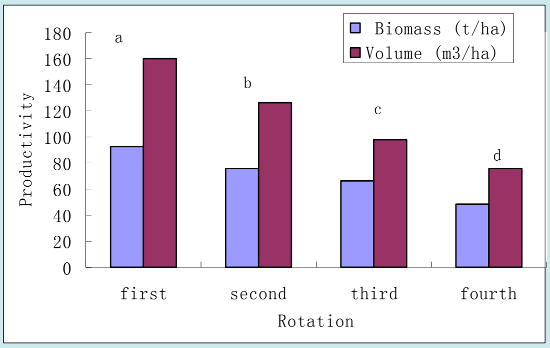
Site	Soil depth (cm)	DTPA-Mn (mg kg^{-1}) R–W[a]	DTPA-Mn Non R–W	DTPA-Mn S	Active Mn (mg kg^{-1}) R–W	Active Mn Non R–W	Active Mn S	Total Mn (mg kg^{-1}) R–W	Total Mn Non R–W	Total Mn S
1[b]	0–20	3.3	7.7	*	20	112	**	267	515	*
	20–40	6.8	6.2	NS[c]	75	118	*	380	495	*
	40–60	11.1	6.1	*	144	125	NS	426	508	NS
2	0–20	6.0	50.9	**	15	210	**	207	342	*
	20–40	30.7	39.6	NS	512	195	**	624	434	*
	40–60	11.6	20.4	*	294	163	*	533	401	*
3	0–16	16.3	5.2	*	76	266	**	259	585	**
	16–21	20.2	3.8	**	141	268	*	329	610	**
	21–55	13.6	3.8	*	388	215	*	656	634	NS
4	0–20	1.2	7.8	*	19	185	**	426	774	**
	20–40	3.8	6.6	NS	62	171	*	509	709	*
	40–60	17.8	7.8	*	681	161	**	1539	616	**
5	0–20	6.1	21.0	**	20	541	**	368	1446	**
	20–40	5.6	16.2	*	29	564	**	388	1454	**
	40–60	22.3	16.9	NS	632	577	NS	1432	1455	NS

[a] R–W, Non R–W, and S refer rice–wheat rotation, upland cropping system without rice, and difference significance, respectively.
[b] Sites 1, 2, 3, 4 and 5 refer to Tianfu town of Wenjiang county, Guihu town of Xindu county, Fujiang town of Mianyang city, Anshun town of Shimian county, and Tianping town of Shimian county, respectively.
[c] NS, * and ** refer not significant, significant at 5 and 1% levels by the *t*-test, respectively.

in Shimian County all on Chengdu Plain in Sichuan province, southwest China.

Lu et al. (2004)

Biomass production in south China
Preventing declining productivity between rotations



(Source: Xu et al. 2002)

Scenario under low NP and zero B inputs

- Applications of compound fertilizer+B have doubled yield in the last decade
- B needs to be reapplied for each rotation

Changing land use

Crops/pasture to eucalypt fibre in coastal south-western Australia

- Soil N, P and K adequate for plantation establishment
- Crops/pastures: 1-3 kg Cu ha^{-1} applied 20-30 years ago
- Cu deficiency was problematic for eucalypts

Crops/pasture to eucalypt fibre in coastal south-western Australia

- Cu is less available to eucalypts than annual crop/pasture species
- Eucalypts produce much greater biomass than crops they replace

Table: Comparison of Cu export – wheat v. plantation forestry

Crop	Cu (g) removed/ha/yr
Wheat[1]	3.5 - 7.0
Eucalypt[2]	25 - 30 28 - 34

[1] in grain, source Bolland et al. (1991)

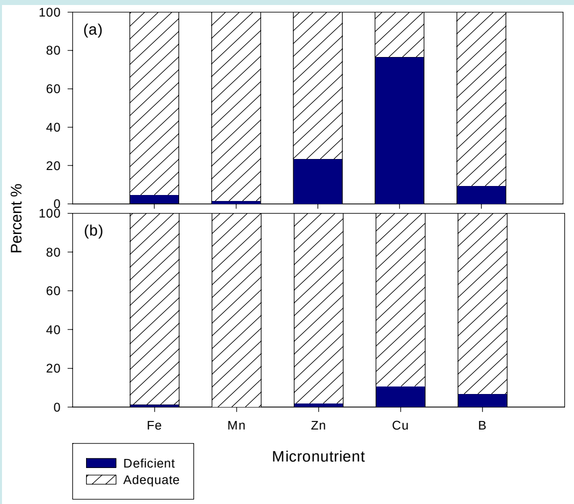
[2] harvest at year 10 averaged across years

[3] debarked on-site

[4] debarked off-site and residue not returned

Crops/pasture to eucalypt fibre in coastal south-western Australia

- Prevention of yield loss due to micronutrient deficiency was reduced by establishing a foliar nutrient monitoring program for micronutrients, and corrective treatments (ground and by air)



pre application of Cu

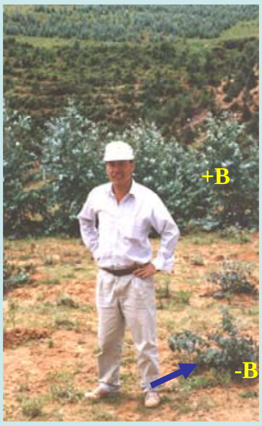
2 years post application of Cu

Land expansion

• Land expansion – developing countries – for crop production predicted to be >180 m ha (2000 – 2030) (FAO)

Thailand

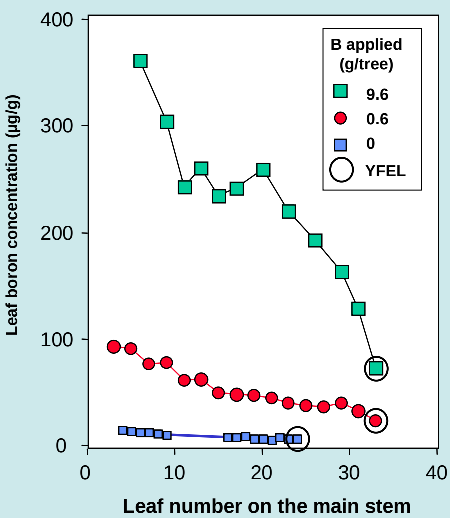
Yunnan



B deficiency near Chuxiong, Yunnan

Maintaining soil nutrient supply for the crop cycle

• Eucalypts in Yunnan on low B soils

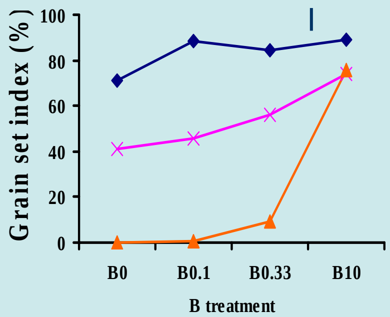


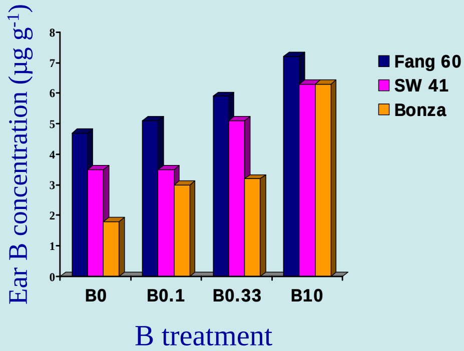
Year 1 Leaf B concentrations exceeding 100 mg kg^{-1} resulted in toxicity symptoms of marginal and tip burn.

Solutions: frequent soluble B applications (not practical); reduce soil B loss; apply slow-release B fertilizer at establishment; breed B-efficient trees

Distinguishing nutrient disorders from climate constraints

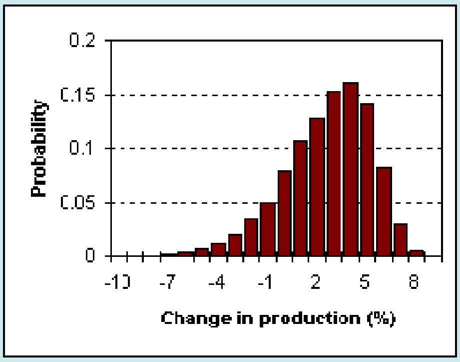
- Male sterility is a serious problem in cereals in many parts of Asia
- Pollen development can be impaired by low temperature, drought or low B supply during critical stages of microsporogenesis.
- B-efficient wheat maintains grain set in low B soils by distributing enough B into the ear to maintain pollen development (Nachiangmai 2004).





Climate change

- The world's weather pattern is increasingly erratic and unpredictable, fluctuating from warm days to cold days within the same season.
- Climate change models for Australia predict negative and positive impacts on cereal producing areas depending on location.



Projected change in Australian wheat production for the year 2030 from current levels as a result of increase in CO_2 and change in temperature and rainfall. (From Howden & Jones 2001)

• Lobell et al. (2005), using a combination of mechanistic and statistical models, contributed much of the 25% increase in wheat yields in Mexico over the past two decades to climate change (cooling of night temperatures).

• Lin et al. (2005) China – yields of cereals will decrease due to increase in temperatures alone!

• How could climate change affect micronutrient requirements of crops?

- Increased growth due to elevated CO_2, increased rainfall, etc. creating greater demand on soil micronutrient reserves

- Altered internal demand e.g. low root zone temperature increases the B requirement of some plants of tropical/subtropical origins (Huang et al. 2005)

- Lynch & St.Clair (2004): "An integration of quantitative genetics with mechanistic and conceptual models of plant response to mineral stresses is needed if we are to understand plant response to global change in real-world soils."

Food quality

• Increased micronutrient content

- Genetic improvement and biofortification: what are the consequences for micronutrient inputs in agriculture?

    1. Increased uptake by the plant?
    2. Greater allocation to the grain?
    3. Soil application of micronutrients?
    4. Foliar application (Zn) for enhanced grain content?

- Will we need to recalibrate plant and soil tests?

Nutrient efficiency

• One approach to manage crop production on soils low in micronutrients is to select for NE genotypes in breeding programs

• Nutrient efficiency is the ability to produce a high yield in a soil that is limiting for that genotype (Graham)

• Huang & Graham: "The lack of compelling arguments for breeding micronutrient efficiency traits is the reason that little effort has until now been made deliberately to adapt crop plants to micronutrient-deficient soils"

• Can MicroNE crops be generated and will they require less nutrient inputs?

• B - Wheat is more prone to B deficiency than rice or maize, and some dicotyledons including soybean and mungbean (Rerkasem & Jamjod 2004).

- International germplasm from CIMMYT on which most developing countries depend for their new wheat cultivars is largely B inefficient. Increasing B efficiency is feasible as a few B efficient advanced breeding lines have already been identified and B efficiency is under the control of major genes (Rerkasem & Jamjod 2004)

- Progress with selecting B-efficient lines of some other major crops e.g. canola in China

Nutrient efficiency

• By contrast to B, Zn efficiency in modern wheat genotypes has already been exploited to improve production on soils with Zn supply constraints (see I. Cakmak, this meeting)

• Synthetic wheat hexaploids (*Triticum turgidum duram* x *Aegilops tauschii* crosses) have the potential to improve current levels of Zn efficiency in modern wheat genotypes. From Genc & McDonald (2004)

- These efficient cultivars have lower external B or Zn requirements, being able to extract the low levels of B or Zn efficiently. At the same time, they are also able to utilise the micronutrients more efficiently through timely remobilisation into new growth.

- So these efficient cultivars can at least complete their reproductive growth and yield reasonably in soils of low B or Zn.

- Even with nutrient efficient cultivars we must protect against exporting too much soil fertility!

- Much needs to be done!

3. Concluding remarks

1. Crop requirements for micronutrients are relatively small, but qualitatively micronutrient deficiencies greatly limit the effectiveness of macronutrients.
2. Land management that reverses soil degradation and ameliorates unfavourable soil pH must embrace issues of sustainable micronutrient supply for crop growth.
3. Crop demand for micronutrients will increase due to higher yields, high total output per unit land, greater export off-farm and the introduction of micronutrient-dense cultivars.
4. Micronutrient requirements for new crops, especially woody crops, are poorly documented and research is required to support micronutrient fertilizer programs.
5. As micronutrients continue to limit yields in many parts of the world, sustained effort is required by extension personnel to bring micronutrients to the farmer's attention. We should strengthen local knowledge of micronutrients in many cropping systems.

6. Micronutrient efficiency breeding strategies need to be incorporated in high yield selection programs. In remote regions of developing countries, breeding for micronutrient efficiency may be the most effective solution for stable and reliable yields rather than high yields, due to inaccessibility to many fertiliser products and technology.