J. Hortl. Sci.
Vol. 4 (1): 1-27, 2009

FOCUS

Importance of micronutrients in the changing horticultural scenario in India

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ABSTRACT

Sustenance and well-being of humankind are linked to the stocks of essential nutrients in the bio-geosphere and the capacity for cycling and manipulation. Micronutrients play a major role in crop production due to their essentiality in plant metabolism and adverse effects that manifest due to their deficiency. Besides affecting plant growth, micronutrients also play a major role in disease resistance in cultivated crop species. A hitherto lesser-understood phenomenon is their role in determining quality and the post harvest life of harvested produce. In the Indian context, this situation has become alarming due to the widespread occurrence of micronutrient imbalance throughout the country. Though soil application of soluble forms of micronutrients has been widely practiced in the past, it calls for introspection, considering the nature of occurrence of micronutrient related maladies. Novel approaches include application of crop-specific foliar formulations of micronutrients, application of chelated forms of micronutrients and the genetic biofortification of crops. In view of the importance of micronutrients in human diet, it is felt that biofortification of horticultural crops will play a definite and major role in addressing nutritional security of the nation in the coming years.

Keywords: Micronutrient, horticultural crops, deficiency, foliar nutrition, organic farming

INTRODUCTION

In the recent past, there has been massive investment in horticulture both in public and private sectors with the expectation that it would increase profitability of farmers, besides enhancing employment opportunities for the rural poor, while simultaneously providing consumers with good quality products. But, the above expectations remain largely unfulfilled due to several research gaps. Effective use of micronutrients in horticulture is one such research gap. Micronutrients can tremendously boost horticultural crop yield and improve quality and post-harvest life of horticultural produce. The purpose of this article is to highlight areas where the potential of micronutrients has not been fully realized.

According to Stout (1962), "If plants are considered as biological machines, their bodies are constructed from macro-elements, their working parts consist of proteins and enzymes revolving about N atoms and the '**MICRONUTRIENTS**' provide the special lubricants required for a variety of energy transfer mechanisms within the plants". This statement from a scientist who was involved in identification of Mo as essential micronutrient, succinctly portrays the importance of micronutrients in plant metabolism.

Micronutrients assume significance in horticultural crop production due to their ability to:

- Improve quality, size, colour, taste and earliness, thereby enhancing their market appeal
- Improve input use efficiency of NPK fertilizers and water
- Provide disease resistance, thereby reducing dependence on plant protection chemicals
- Increase post-harvest/shelf life of horticultural produce thereby avoiding wastage
- Prevent physiological disorders and increase marketable yield
- Enhance nutritional security by biofortification

In the 20th Century, revolution in crop yield increase began with the discovery of micronutrients starting with iron (Fe) in 1868, and ending with molybdenum (Mo) in1938. This led to a paradigm shift from "scientific discovery" to

"scientific management", which included three scientific components to increase productivity, viz.,

- Genetic components (improvement in heterosis, disease and pest resistance)
- Physiological components (better photosynthetic efficiency, decreasing photorespiration, etc.)
- Management components (precision in fertility, avoiding nutrient deficiency or toxicity, improvement in organic matter status, etc.) and appropriate use of information on climate, soil, water and specific characteristics of cultivars, etc.

In the crop production system, there are about 16 non-controllable, limiting factors (light intensity, day-night temperatures, etc.) and around 40 controllable, limiting factors (soil-available NPK, micronutrients, soil pH, organic matter, etc). Limiting factors translate to inputs. Some inputs have a cost component like, nutrients and compost while some do not, like, timeliness of operation, crop rotation to avoid allelopathy-related problems, etc. Judicious management of controllable and non-controllable factors is necessary for successful crop production. Controllable stresses are of two types: Liebigs type and Mitchserlich type. In the former, unless a limiting factor is corrected, no response to other inputs will be seen (eg., soil acidity, soil salinity and nitrogen deficiency). But, in the Mitchserlich type, limiting factors do not hinder correction of other factors.

Micronutrients in crop production

In the early stages, micronutrient disorders were described as diseases (Stiles, 1946). Subsequently, their essentiality as nutrients was confirmed and great strides were made in horticultural crop production by the use of micronutrients. Heart rot of root vegetables in Europe was cured by B application; "Pecan rosette" of Pecan trees was cured by Zn in Florida, and, Mottle leaf of Citrus by Zn, and Exanthema of Citrus in California and Australia by Cu. In Australian soils, Anderson (1956) proved the essentiality of Mo for N_2 fixation and increased clover yield from 1 to 5 t/ha by addition of 30 g of the micronutrient per hectare. This effect equalled the effect of a thousand kilograms of lime application, since, lime releases soil Mo. Stout (1962) wondered at the power of a tiny amount of Mo. By comparing it with uranium, he observed that "a gram of Mo may harness more energy by greater conversion of sunlight into plant materials than can be obtained from a gram of uranium'. We, in India, are unable to replicate the dramatic response to micronutrients observed in Australia. The first important reason is the soil wealth of India. A majority of soils do not exhibit extremes in important physical and chemical properties like pH, texture, water-holding capacity, organic matter, NPK fertility and micronutrients. Another reason is that we do not have vast expanses of B deficient soils similar to those found in Eastern and Southern China, nor do we have tracts of Fe deficient soils as occur in Australia, Spain and Italy. Micronutrient deficiencies in India, by themselves, do not restrict yield drastically but do so by acting additively with other stresses, reducing yield substantially.

Micronutrient scenario in India

About 40-55% of Indian soils are moderately deficient in Zn, while 25-30% are deficient in B. Deficiency of other micronutrients occurs under 15% of soils (Takkar and Kaur, 1984). These deficiencies/limitations by themselves do reduce yield significantly but, combined with 2 or 3 of the other 40 controllable yield-limiting factors/stresses, these act additively and reduce yield substantially. In the Indian scenario, micronutrient deficiencies are of the Mitscherlich type. Almost all micronutrient deficiencies or toxicities in India fall in the mild to moderate category, with exception of B deficiency in mango and cauliflower in Konkan and Chota Nagpur regions, respectively. Since skilled manpower and infrastructure to identify the micronutrient disorders/toxicities especially at hidden hunger stage itself by leaf/soil analysis are limiting in India, the damage done to Indian horticulture is enormous. Unfortunately, this is not fully recognized by decision makers and scientists. As 80-90% of Indian soils are deficient in nitrogen and phosphorus, their deficiencies are visible in terms of leaf colour, size, growth-habit, flowering and yield. Correction of these disorders is therefore more visibly convincing. But, 70-80% of micronutrient disorders in horticultural crops occur as hidden hunger. Leaf and soil analysis alone can detect it at the right stage. In a country of around 2 to 3 million farm-holdings with horticulture as the main enterprise, it is next to impossible to carry out leaf or soil analysis of micronutrients to detect hidden hunger. This is another reason why we do not take advantage of micronutrient correction.

The changing horticultural scenario

In 1860, the air and water systems were so pure in the world that it was necessary to add chlorine in the form of sodium chloride for healthy growth of plants. Whereas, by 1954, purification of air and water became a Herculean task, to prove Chloride as an essential micronutrient by T.C. Broyer. At present, chloride content has reached "toxic" levels from being "deficient". There is a tremendous change in yield-potential of crops, and soils health and its nutrient supplying potential. Hence, farmers need to be made aware of this changed scenario. Increasing the density of banana plants from 2500 to 4400 plants/ha, and mango from 100 plants/ha to 250 plants/ha (with use of dwarfing rootstocks and hormone sprays for regular-bearing) has resulted in severe depletion of soil nutrients. In India, traditional tomato varieties with yield potential of 30t/ha and F1 hybrids with a potential of 150t/ha, are being grown in the some soil type. With the help of fertigation, cropping intensity has increased from 100% to 300% in several parts of the country. The quantity of nutrients removed and the rate, at which these are removed, are vastly different. Physical, chemical and biological health of soil was not a major problem prior to "Green Revolution" of 1960's, whereas, in the present horticultural scenario of heavy NPK fertilizer use, fertigation and precision-farming, soil health and balanced nutrition has become a casualty. There is 30 to 40% decline in organic matter, with adverse effect on micronutrient availability. Decline in availability of organic manures due to greater use of inorganic fertilizer, has made micronutrient supply precarious. Replacing micronutrients that have been removed, or, increasing organic matter to make native nutrients available, has not received sufficient attention. Need-based input management of fertilizers, pesticides and water is more of an option than a necessary practice by farmers of the country owing to the poor dissemination of information generated in research. The widespread micronutrient disorders are believed to be a reason for stagnation in agricultural productivity.

How to get "Macro" effect out of "Micronutrients" ?

a. Identifying and eliminating Liebig stresses : Liebig Law of Minimum states that only an increase in the factor most-limiting will result in an increase in yield. Otherwise, the inputs are wasted. Moisture stress, salinity, soil acidity, extreme deficiencies of NPK, if left uncorrected, cannot result in a response to micronutrients. Overcoming soil-salinity in grape by using salt-resistant rootstock 'Dogridge' paved the way for response to other inputs in horticultural practices in Maharashtra.

b. Enhancing response to micronutrients by the Law of Maximum : Since micronutrient disorders in India are predominately of the Mitschertich type, correcting another stress is not a pre-requisite for obtaining response from micronutrient application. This law states that the largest net response to an input comes when there are no other limiting factors. The magnitude of response (to micronutrients) will increase as more and more limiting factors (abiotic and biotic stress) are corrected. The corollary to this law is that the attained yield is greater than the sum of individual parts because various parts interact to multiply the value of others.

c. Inter-disciplinary approach, a must : Only by following an interdisciplinary approach, we can maximize returns from micronutrient application. Identification and simultaneous correction of other stresses, along with micronutrient stress, can give a highly significant, profitable and visible response. Hence, the present practice of evaluating micronutrient response by applying it alone will limit magnitude of the response. A blueprint approach of identifying and correcting all possible limiting factors including micronutrients has to be done. In India, micronutrients have been so far used for increasing only crop yield, while, other quality parameters like colour, size, and firmness are seldom taken into consideration. Another important area where micronutrients can play an important role is disease resistance, since they function as enzyme activators and play an important role in lignin biosynthesis and other diseases resistance mechanisms.

Predominant micronutrient disorders and their management in horticultural crops

Though deficiencies of micronutrients were initially referred to as "diseases" in fruit crops, that lead has been lost. A non-exhaustive list of common micronutrient disorders that are observed in horticultural crops is furnished in Table1. Apart from handling sporadically-visible deficiencies, a systematic research in this area is only a recent development. This paper highlights the intricacies of micronutrients like B, Fe and Zn, which have a great potential in all areas of horticultural crop production mentioned earlier.

BORON (B)

B nutrition in horticulture crops

B deficiency and response to it have been recorded in 132 crops in more than 80 countries over the last 60 years. It is estimated that over 15 million ha worldwide are annually fertilized with B. It is through field bean, a vegetable-cum-pulse (*Vicia faba*) that essentiality of B was proved. The fact that B is needed for successful fertilization is of critical importance. Though monocots need less B than dicots, they also suffer from B deficiency due to low B at seed set. Since B is the only micronutrient that affects all components of horticulture (yield, quality, post-harvest life, disease resistance and use-efficiency of other inputs), it is to be

Table 1. Relative sensitivity of selected horticultural crops to micronutrient deficiencies

Crop	Sensitivity to micronutrient deficiency					
	B	Cu	Fe	Mn	Mo	Zn
Bean	Low	Low	Medium	Medium	Medium	Low
Broccoli	Medium	Medium	High	Medium	High	—-
Cabbage	Medium	Medium	Medium	Medium	Medium	—-
Carrot	Medium	Medium	——-	Medium	Low	Low
Cauliflower	High	Medium	High	Medium	High	—-
Celery	High	Medium	——	Medium	Low	—-
Cucumber	Low	Medium	——	Medium	——	—
Lettuce	Medium	High	——	High	High	Medium
Onion	Low	High	——	High	High	Medium
Pea	Low	Low	——	High	Medium	Low
Radish	Medium	Medium	——	High	Medium	—-
Spinach	Medium	High	High	High	High	High
Table beet	High	High	High	High	High	Medium
Tomato	Medium	Medium	High	Medium	Medium	Medium
Turnip	High	Medium	——	Medium	Medium	——

Source: Lucas and Knezek (1991

given highest importance, to derive maximum benefit. A number of soil and environmental factors affect boron uptake horticultural crops. Knowledge of these will improve assessment of B deficiency and toxicity under various conditions.

Chemistry of boron availability

B is mobile in soil and immobile in plants. It is the only micronutrient lost to leaching. When B is released from soil minerals, or is mineralized from organic matter or added to soils through irrigation water / foliar application, part of it remains in the soil solution, while, part is adsorbed by soil particles. Minerals that contain B are either very insoluble (tourmaline) or very soluble (hydrated boron minerals). These do not usually determine solubility of B in the soil solution, which is controlled mainly by boron adsorption reactions. Equilibrium exists between soil solution and the adsorbed B (Russell, 1973). Since plants, including papaya, obtain B from the soil solution and the adsorbed pool of B acts as a buffer against sudden changes in level of B in the soil solution, it is important to know how boron is distributed between the solid and liquid phases of soil. Factors affecting the amount of B adsorbed by soils, and, availability of boron in soils include: pH, soil texture, soil moisture, temperature and management practices such as liming.

Parent material

In general, soils derived from igneous rocks and soils in tropical and temperate regions of the world, have much lower B content than soils derived from sedimentary rocks, or those in arid or semi-arid regions. Soils of marine or marine shale origin are usually high in B. Low B content can be expected in soils derived from acid granite and other igneous rock, fresh-water sedimentary deposits and in coarse-textured soils low in organic matter (Liu *et al*,1983). Plant availability of B is also reduced in soils derived from volcanic ash and soils rich in aluminium oxides (Lebeder, 1968).

Soil reaction (pH)

Soil reaction is one of the most important factors affecting availability of B in soils and its uptake. When the soil solution has high pH, B becomes less available to plants. Therefore, applying lime to acid soils can sometimes result in B deficiency symptoms in plants. The level of soluble B in soils has close correlation with pH of the soil solution (Berger and Troug, 1945). B uptake by plants growing in soil with the same water-soluble B content was greater when pH of the soil solution was lower (Wear and Patterson, 1962). Boron adsorption from soils increased when pH rose to the range of 3-9.

Soil texture and clay minerals

Coarse-textured soils often contain less available B than fine-textured soils. For this reason, B deficiency often occurs in sandy soil (Fleming, 1980; Gupta, 1983). The level of native B is closely related to clay content of the soil (Elrashidi & O' Connor, 1982). At the same water-soluble B content, B uptake was highest in plants growing in the soil with the coarsest texture (Wear & Patterson, 1962). It increased as the clay content increased. Of the clay types commonly found in soil, illite adsorbed more B than either kaolinite or montmorillonite. Kaolinite in acid red soils absorbed the least. It was found that B adsorption was greater for Fe and Al coated kaolinite or montmorillonite than for uncoated clays. They concluded that hydroxy Fe and Al compounds present as silicates or as impurities were dominant over clay mineral species *per se* in determining B adsorption characteristics.

Soil moisture

Boron availability generally decreases as soils become dry, so that boron deficiency is more likely in plants suffering from water deficit. This may be because plants encounter less available B when they extract moisture from soil at a lower depth during dry conditions. Wetting and drying cycles increased the amount of B fixed. Flood irrigation resulted in leaching of B.

Temperature

Boron adsorption rises with higher soil temperatures and reduces availability. However, this may reflect on interaction between soil temperature and soil moisture, since B deficiency is often associated with dry summer conditions. High sunlight and low temperature also aggravate B deficiency.

Organic matter

Many researchers have suggested that levels of soil organic matter influence availability of B to plants. The strongest evidence that organic matter affects availability of soil B is derived from studies that show positive correlation between levels of soil organic matter and amount of available B and uptake by plants (Gupta, 1983, Chang *et al* 1993). The association between B and soil organic matter is caused by assimilation of B by soil microbes. Although B present in soil organic matter is not immediately available to plants, it seems to be a major source of available boron when released through mineralization.

Irrigation water

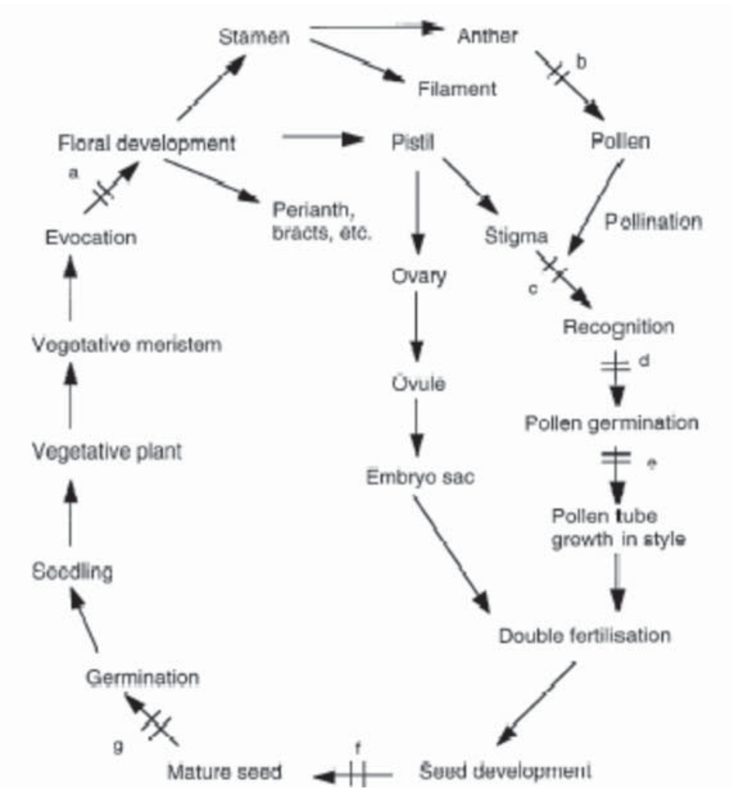
Water used for irrigation also has B content and water from semi-arid regions or saline soils has boron content of 0.001 ppm to 0.01ppm

Low boron concentration and its impact

What makes B unique among all other micronutrients in horticultural crops is its effect on reproductive physiology. Low B affects the plant right from seed-set to fruit-set and formation (Fig 1). This is because of its role in cell wall development, cell elongation and membrane stability.

Higher B content needed for reproductive parts

Sexual reproduction is more sensitive to low B than vegetative growth, and a marked reduction in fruit-set can



Source: Dell and Huang (1997)

Fig 1. Life-cycle of an angiosperm emphasizing stages when inadequate boron supply may directly or indirectly impact reproductive development. Consequences of B deficiency shown at (a)–(f) are: (a) impaired inflorescence/flower formation; (b) infertile or aborted pollen; (c) reduced recognition of pollen by the stigmatic surface; (d) impaired pollen germination; (e) impaired pollen tube growth in astylar tissue leading to reduced seed and fruit set; (f) impaired seed development, eg, hollow heart, shrivelled seed; (g) abnormal seedlings, reduced seedling vigour

occur without expression of B deficiency symptoms in vegetative parts. The most intricate aspect of B nutrition is highlighted by the fact that reproductive parts in both monocots and dicots require 2-4 times more B. The vast difference in B in low supply and adequate supply needs to be kept in mind while supplying B for optimum yield. Maintaining high B levels in reproductive parts is a vital component of efficient B management for yield in horticultural crops.

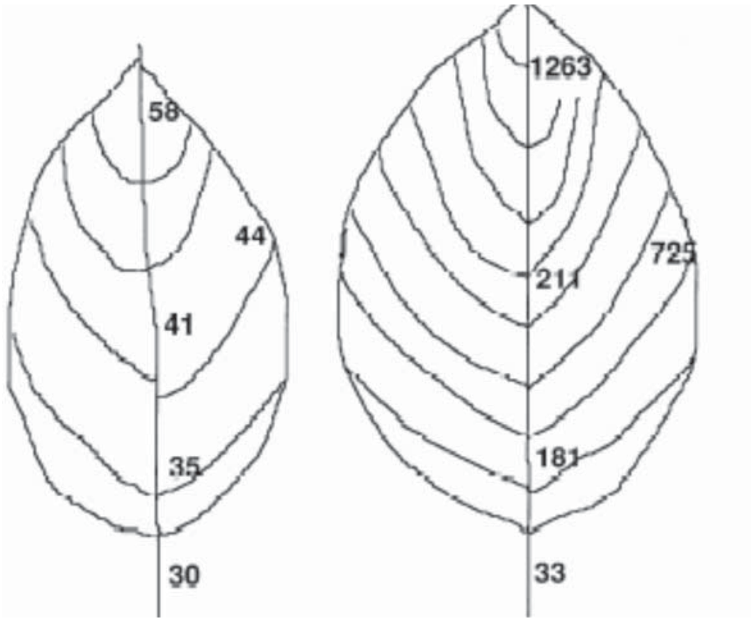
Boron mobility in horticultural crops: Horticultural crops vary widely in their boron mobility in phloem**;** hence, B deficiency is more widespread than any other micronutrient deficiency (Gupta, 1983). Occurrence of brown heart in turnip, radish and storage roots of rootabaga and hollow stem in cauliflower and broccoli are due to B deficiency (Shelp and Shattuck, 1987a; Shelp *et al*, 1987, 1992a). Poor fruit and seed set in nut crops, even when there is no symptom on leaves, indicates that B deficiency is physiological in nature (Nyomora *et al*, 1997). For tissue analysis, growing tissues are sampled in B immobile plants; whereas, in plants where B is mobile, even fruits and mature leaves are sampled. For B management in anticipated B deficiency, foliar spray is adequate in B mobile plants (apple), whereas, in B immobile (mango) plants; correction is difficult. Both soil and foliar spray, especially at flowering, are essential in B immobile plants.

Prognosis and diagnosis of B deficiency

Prognosis by B analysis is done for ascertaining B deficiency for preventive management, whereas, diagnosis is done for curative management. Critical B concentration for different crops varies between 3-7 mgkg^{-1} (for wheat) to 50-75 mgkg^{-1} (for mango), indicating the vast difference in crop requirement for B and the need for a sensitive prognosis programme for optimum fruit and vegetable production. Young, Fully Expanded Leaf (YFEL) seems to be ideal for forecasting the response to B application.

Table 2. Boron distribution (mg B kg^{-1}) in shoots of field-grown apple and walnut

Leaf age	Crop	
	Apple (*Malus domestica*)	Walnut (*Juglans regia*)
Old	50	304
Mature	57	225
Young, expanded	56	127
Expanding	73	62
Meristematic	70	48



Source: Brown and Shelp, 1997

Fig 2. Leaf-B concentration (mg kg^{-1} dry wt) in field-grown apple and walnut. Leaves were collected at the end of the growing season in 1995 in the pomology orchard, Davis, California, USA. The two species were grown in close proximity and received the same irrigation. B distribution in leaves also highlights B mobility and its effect. In a B mobile plant (apple), the meristem has more B than do old leaves, but, is low in meristem in immobile plant (walnut)

Table 3. Critical boron concentration (mg B kg^{-1}) or concentration range in leaves of plants for prognosis for B deficiency

Species	Leaf and plant-age or growth-stage	Critical B concentration or range (mg/kg)	Country and Source
Bean (*Phaseolus vulgaris*)	YFEL – 37 daysafter sowing	20–24	Columbia; Howeler *et al* (1978)
	YFEL – 75 days after sowing	16–18	
Broccoli (*Brassica oleracea*)	YFEL blade when 5% heads formed	9–13	Canada; Gupta and Cutcliffe (1973, 1975)
Brussel's sprout *(B. oleracea)*	YFEL blade when5% heads formed	7–10	
Cauliflower (*B. olreacea*)	YFEL blade when 5% heads formed	8–9	
Potato (*Solanum tuberosum*)	YFEL – 7 weeks after sowing	24	Australia; Pregno andArmour (1992)
Rutabaga (*Brassica napobrassica*)	Youngest mature leaf blade at 5–6 leaves	37–44	Canada Gupta and Cutcliffe (1972)
Wheat (*Triticum aestivum*)	YEB – booting	3–7	Thailand; Rerkasem and Loneragan (1994)
Mango *(Mangifera indica)*	Young leaves	50-75	India; Agarwala (1988)
Tomato F1 Hybrid (*Lycopersicon escule1*	Young leaves	35-40	India; Iyengar and Edward Raja (1988)

Effect of B on yield

Metabolic requirement for B varies with plant and plant species. The data (Table 4) highlight that vegetative parts exhibit B deficiency symptoms at low B levels, while, the reproductive parts show symptoms at higher B levels. Monocots like wheat are known to exhibit symptoms at lower B concentrations than dicots like sunflower, which need 10 times more B. The fastest response to any nutrient deficiency is observed in the case of B. Within 3 hours of withholding B, root growth stops, and, deficiency symptoms are visible even when adequate B is present in the soil but is unavailable, due to low soil-mixture or poor transpiration (Dell and Huang, 1997).

Plant factors and prognosis for B deficiency

Plant species differ in their capacity to take up B even when grown in the same soil. These differences generally reflect different boron requirements for growth. In most dicotyledonous species such as papaya, the requirement is 80-100 mg. Difference in B demand of graminaceous and dicotyledonous species is probably related to difference in their cell wall composition. Interestingly, these two plant groups also differ in their capacity for silicon uptake, which is usually inversely related to B and Ca requirement (Loomis and Durst, 1992). All three elements are located mainly in the cell wall. Reports on Ca/B interaction are thus far inconclusive (Gupta, 1979). However, these interactions are likely to have a physiological basis. Both elements are likely to have similar structural functions in the cell- wall and at cell-wall plasma membrane interface, and, similar interactions in uptake & shoot transport, and in IAA transport. These common features also explain certain similarities in symptoms of calcium and boron deficiency in peanut seeds and lettuce (Crisp and Reid, 1964).

Revolution in mango yield in India by B nutrition using the Brazilian experience

In India, mango is grown in about 1.6 milion ha, with productivity of 6-7t/ha, compared to 20-25 t/ha in Mexico/Brazil and 25-30 t/ha in South Africa. Poor micronutrient nutrition, especially B, is one of the causes for such a huge yield gap (Edward Raja *et al*, 2005). Deficiency of B results in poor and non-uniform flowering, low fruit-set, increased fruit drop and poor quality produce. Mango is a B loving crop and the critical level ranges between 75-100 ppm (Agarwala, 1988). Rossetto *et al* (2000) recorded tremendous response to B by application of 300g borax/tree as soil application. This response varied from 200% for cv.Tommy Atkins to 500% for cv. Haden 2H and Vandyke, but one cultivar Winter did not respond to B(Table 5). This highlights the tremendous potential of B for increasing yield in mango. But another point to note here is that Brazilian soils have low pH and hence availability of applied B is high. Edward Raja *et al* (2005) observed a significant yield response to B in cultivar Alphonso in Konkan, which has climate and soil similar to that in Brazil.

Why is widespread B deficiency seen in mango in Konkan region (India)?

1. Since B is the only micronutrient lost to leaching, heavy rainfall (2200mm/yr) in the region results in low soil B status (<0-3 ppm)

Fig 3. Young fruits of mango cv. Van Dyke. Fruit with leathery-color typical of low boron (left) and normal green fruit (right)

Source: Rossetto *et al* (2000)

Table 4. Boron concentration in plant parts exhibiting B deficiency symptoms

Species	Plant organ showing deficiency symptom	B in affected plant part(mg-1kg)	Reference
Wheat *(Triticum aestivum)*	Youngest emerged leaves	< 1	Huang *et al* (1996)
	Ear at booting	3–7	Rerkasem and Loneragan (1994)
	Carpels at booting	<6	Rerkasem and Lordkaew (1996)
	Anthers at anthesis	<9	
Rutabaga *(Brassica napobrassica)*	Youngest mature leaves	2–7	Gupta and Cutcliffe (1972)
Mango *(Mangifera indica)*	Fruit	<20	Ram *et al* (1989)

Table 5. Average yield of four mango cultivars, expressed in kilograms per hectare, over a six year period (1993-1998), showing the effect of soil boron application in half the blocks in the last three years, plus, the medium leaf-content of boron; Each figure is the mean of 27 observations (3 rootstocks, 3 blocks, 3 years) in Votuporanga, SP, Brazil

Boron	Cultivar	kg ha $^{-1}$ 1993-94-95	Leaf boron mg kg $^{-1}$ July 95	kg ha $^{-1}$ 1996-97-98	Leaf boron mg kg $^{-1}$ Dec.98	Yield Increment
Blocks without boron	Winter	8,379 a*	8.2	19,489 a*	7.7	2.3
	TommyAtkins	6,816 a	9.0	9,807 b	7.6	1.4
	Van Dyke	6,608 b	8.4	2,697 c	8.2	0.7
	Haden 2H	1,951 b	8.7	3,375 c	8.1	1.7
	Mean	5,188	8.5	8,842	8.1	
		'Without boron' effect		**'With boron' effect**		**Yield increment**
Block showing boron effect, from 1996	Winter	6,426 a*	8.2	17,114 a*	26.2	2.6
	Tommy Atkins	4,288 a	9.1	16,272 a	29.9	3.8
	Van Dyke	1,288 b	7.6	16,874 a	23.9	13.1
	Haden 2H	1,406 b	10.0	14,820 a	29.6	10.5
	Mean	3,352	8.7	16,270	27.4	

Mean, followed by the same letter, does not differ by Tukey test at 5%

Source: Rossetto *et al* (2000)

2. Since B uptake by xylem occurs through passive uptake, high humidity (60-80%) in the region also reduces B uptake by mango trees
3. Probable mismatch between need and availability; Boron is needed in Nov/Dec when flowering and fruit-set occurs (as, it is important in pollination). Since 90% of mango is grown as rain-fed crop, the soil becomes dry in December when available is B low and B demand is highest. This mismatch between availability and need is probably another major reason for hidden hunger and visible deficiency of B in India, and in Konkan in particular

Occurrence of boron deficiency and response in papaya

Among fruit crops, papaya is extremely susceptible to boron deficiency common in latisols and old slate alluvial soils in upland areas of Taiwan (Wang and Ko, 1975; Chang, 1993). This is more likely when papaya trees are planted in sandy soils during dry season. One of the earliest signs of boron deficiency is mild chlorosis in mature leaves which become brittle, and tend to curl downwards. A white "latex" exudate may flow from cracks in the upper part of the trunk, from leaf stalk, and from the underside of main veins and petiole. Death of the growing points is followed by regeneration of side-shoots that ultimately die. In fruiting plants, the earliest indication is flower-shedding. When fruits develop, they are likely to secrete white latex. Later, the fruit becomes deformed and lumpy. The deformation is probably a result of incomplete fertilization, as most of the seeds in the seed-cavity are either abortive, poorly developed or absent. If symptoms begin when the fruit is very small, it does not grow to full size. Papaya fruits having a rugged surface and secreting latex are typical symptoms of boron deficiency. In studies on boron deficiency in papaya in Taiwan, samples were taken from the 10th leaf blade (without petiole), counted from the 1st leaf (the most-recently-matured leaf, with a leaf blade that has only just fully-developed, and which has a brownish colored petiole). Standard sampling of this kind can effectively reflect variations in boron content in different orchards. Boron content of the tenth blade of papaya trees with deformed fruits was always found to be lower than 20 ppm, while that of leaves from normal trees was generally 25-155 ppm.

Curative management of boron deficiency

For tree crops application of B as Borax at planting is suggested for example, Borax @ 10g/banana plant, 50-100g/mango plant, 20-25g/papaya plant should be applied, supplemented with foliar spray at 25% flowering. At flowering, Solubor (20% B) is an ideal source of B for foliar spray, followed by boric acid (17% B). Boron is a phyto-toxic element and care should be taken to avoid toxicity. Older leaves show toxic symptoms of necrosis of margins. Slow-release B source in soil, with foliar spray of Solubor, is an ideal approach to avoid toxicity and deficiency in high-rainfall areas.

ZINC (Zn)

Zinc nutrition in horticultural crops

Among micronutrients, Zn occupies an important place due to its ability to positively influence plant growth and development. Zinc enhances seed-viability, seedling-vigour and imparts resistance to biotic and abiotic stresses (Cakmak, 2008). Zinc is highly immobile in soil and its deficiency is common in mango, banana, guava, litchi, apple, grape and pomegranate. Little-leaf and rosette symptoms are the most common visual indicators of Zn deficiency.

Chemistry of Zn availability in horticultural crops

a. Soil reaction (pH)

Among soil chemical factors, soil pH plays the most important role in Zn solubility in soil solution. In pH range between 5.5 and 7.0, Zn concentration in soil solution decreases 30 to 45-fold for each unit increase in soil pH, thus increasing the risk of Zn deficiency in plants (Marschner, 1993). Increasing soil pH stimulates absorption of Zn to soil constituents (eg. metal oxides, clay minerals) and reduces adsorption of the adsorbed Zn. Lindsay (1991) reported that at pH 5.0, concentration of Zn^{2+} in soil solution is sufficiently high, about 10^{-4} M (6.5 mg/ kg). When soil pH increases from 5 to 8, concentration of soil solution Zn^{2+} reduces by nearly 1000 times and becomes nearly 10^{-10} M (approx. 0.007 mg kg^{-1}). Consequently, increase in soil pH is associated with very sharp decrease in concentrations of Zn in plant tissues (Marschner, 1995).

b. Moisture

Transport of Zn to root-surface in soils occurs predominantly by diffusion, and this process is highly sensitive to soil pH and moisture (Wilkinson *et al*, 1968). Soil moisture is a key physical factor providing suitable medium for adequate Zn diffusion into plant roots. The role of soil moisture is very critical in soils with low Zn availability (Marschner, 1993). Zinc nutrition in plants is, therefore, adversely affected under water stress conditions, particularly in regions where topsoils are usually dry during later stages of crop growth. Occurrence of Zn deficiency stress and consequent decrease in crop yield were found to be more severe under rainfed (compared to irrigated) conditions (Bagchi *et al*, 2007).

c. Organic matter

Soil organic matter plays a critical role in solubility and transport of Zn to plant roots (Marscher, 1993). In a study with 18 different soils, there was a strong inverse relationship between content of soil organic matter and soluble Zn concentration in the rhizosphere (Catlett *et al*, 2002). These results indicate that the pool of readily available Zn to plant roots may be extremely low in soils with high pH, and, reduced levels of organic matter and soil moisture (Takkar, 1999; Cakmak *et al*, 1999). Removal of micronutrients by different crops indicates that removal of micronutrients is not substantial compared to soil reserves of both available and total micronutrients (Graham, 2002). Available Zn levels in mango orchards of peninsular India indicate adequate soil reserves of Zn, but leaf Zn status indicates deficiency in a majority of the soils, due to a combination of low moisture, low organic matter and high pH (Agarwala, 1988).

Zinc deficiency correction in tree crops

Confusion prevails in the minds of growers and scientists regarding the right choice for Zn amendment [$ZnSO_4$ or ZnEDTA (chelate) and its mode of application]. All studies have indicated that 0.5% $ZnSO_4$ as foliar spray is better than other treatments for correction of Zn deficiency, and this method is more efficient in economic and environmental terms. But, 2 – 4 foliar sprays are essential for consistent correction and to obtain leaf zinc concentration of 25 – 75 ppm, required for optimum yield. Apart form foliar spray, applying composted manure is essential for making soil Zn too available to the plant. Hence, no exclusive, single method is advisable. Use of chelated Zn sources for soil or as foliar spray is not needed, since these are par with $ZnSO_4$. Zn-solublizing bacteria can mitigate the widespread zinc deficiency in fruit grapes. Subramaniam *et al* (2006) observed that a strain of *Pseudomonas fluorescens* solubilized soil-Zn. Along with Zn-solubiling bacteria, foliar spray of B, Mn and Fe resulted in increased yield and quality in grapes.

IRON (Fe)

Iron nutrition in horticultural crops

Iron deficiency is easy to identify but difficult to correct. Iron is chemically unavailable in the soil, and physiologically unavailable in the plant. The paradox is that soil has about 10000-100000 ppm total iron, but the plant needs only 30-50 ppm. It is not the quantity of Iron that is important but the quality. Description of the thirsty sailor crying in the midst of the seawater, "water, water everywhere, not a drop to drink" aptly describes availability of soil-iron to the plant. Another paradox in iron nutrition is lime-induced iron chlorosis in plants, wherein, deficient leaves have more Fe than healthy leaves, making leaf analysis for Fe unreliable for judging iron-nutrition.

Diagnosis of iron chlorosis in tree crops

Prognosis of Fe deficiency is a challenging task, since iron deficiency (iron-chlorosis) is an important nutritional disorder in horticultural crops, in general, and tree crops, in particular. It does not occur due to low level of Fe in the soil but from impaired acquisition and use by plants. The most prevalent cause of iron chlorosis is bicarbonate levels in soils (Pestana *et al*, 2003) or the bicarbonate present in irrigation water (Tagliarani and Rombola, 2001). Prognosis of iron deficiency is important, since correction is a costly and tedious process.

Soil tests

For annual crops, soil tests are useful but, for tree crops, it is of limited value since the roots are deep and unevenly distributed. Soil tests for lime-induced chlorosis need to focus on

a. Use of extractants capable of chelating the metal

b. Determination of active lime-content

c. Lime in silt-clay and fractions of soil

Plant analysis

a. Visual scoring: This is a fast and economical method (Samz and Montanes, 1997). The score ranges from 0 (without symptom) to 5 (trees with dead branches and pale young leaves). It can be quantified by SPAD apparatus that measures leaf transmittance at two wavelengths, 650 and 950 nm, and is a measure of chlorophyll. But the limitation is that by the time chlorosis appears, correction is no longer possible.

b. Plant analysis: Leaf analysis is still the common method and is based on growth rate of plants and their nutrient content. But, it has several limitations in lime-induced chlorosis, viz.,

i. **Chlorosis Parad**: This is the phenomenon of absence of correlation between leaf Fe concentration and degree of chlorosis. Iron concentrations on dry weight basis are frequently more in chlorotic leaves than in green leaves, which is due to inactivation of Fe.

ii. **Analysis of active iron :** Analysis of active iron [(Fe (II)] is carried out using extractants like acetic, nitric and hydrochloric acids, O-phenanthrolone (*Rashid et al*, 1990). But these methods also have limitations as they remove Fe from phytoferrin, which is part of the pigment and make Fe not available for other metabolic role. More over by the time the active Fe is estimated, it may be too late for correction.

iii. **Flower analysis :** Flower analysis is the currently more acceptable method for deciduous fruit trees and citrus, since correction is possible before fruit set. The Fe content in flowers is well correlated with leaf chlorophyll status in deciduous trees with the exception of sweet orange where it is negatively correlated (Pestana *et al, 2003*).

iv. **Nutrient ratios in flowers :** Since Fe analysis of flowers is not acceptable for both deciduous and evergreen tree crops, some phenomena like increase in K in flowers due to iron chlorosis is used for prognosis. The K: Zn ratio in the flowers is fairly consistent and a value above 450 indicates the potential for preventive correction of iron chlorosis.

v. **Enzyme assay :** Inspite of all the refinements in mineral analysis, the difficulty in differentiating metabolic / active Fe from non-active Fe is still difficult. The assay for enzyme chlorophyllase activity is another useful option for assaying for chlorosis for its prevention especially hidden hunger. This form of iron chlorosis is looming large over tree crops like grapes, mango, citrus and banana grown in winter months in calcareous soils.

Correction of Fe chlorosis

Though Fe is one of the most abundant elements in soil, its deficiency in plant tissues is a major challenge. Short-term correction by organic manures (produced in India) is not suitable due to inadequate quality standards (CN ratio, humification, pH, exchange capacity). A wide CN ratio induces Fe deficiency rather than correct Fe deficiency, by producing bicarbonates from the CO_2 released from undecomposed carbon. Citrus, mango, grape and apple are known for their susceptibility to Fe deficiency, but prognosis is at its infancy. Presently, applying organic manure and use of multi-nutrient sprays are the only feeble attempts in iron deficiency management. The estimate of loss by hidden hunger for Fe has not been done, since, it is not recognized.

Iron deficiency prevention by use of ideal rootstocks

About 1/3rd of Indian soils are calcareous, and iron deficiency is a major nutritional problem in such soils (Ray Chaudry and Govindarajan, 1969). They are highly buffered, with pH 7.5 to 8.2, and have bicarbonate affecting soil and plant Fe availability. Chlorophyll content decreases and carotenoid pigment increases in such soils. The iron deficiency occurs as visible and hidden hunger. This lime-induced chlorosis delays fruit-ripening, resulting in impaired quality in peach and orange (Pestna *et al*, 2001). Mandarins, limes and lemons are moderately tolerant to Fe deficiency. Work of Pestana *et al* (2000) indicated that Troyer citrange rootstocks are very tolerant. Nikolic *et al* (2000) observed differential foliar tolerance to iron chlorosis in grape. Kadman and Gazit (1984) identified mango rootstocks tolerant to Fe deficiency. Edward Raja (2009) identified mango cultivars tolerant to Fe deficiency. Correction of Fe deficiency is the most difficult if suitable rootstock is not available.

Iron chlorosis in ornamental crops

Ornamental crops like rose, gerbera, gladiolus, and chrysanthemum are susceptible to Fe deficiency. Crops like jasmine *(Jasminum auriculatum* and *J. sambac* and *Crossandra* suffer Fe deficiency. Free calcium carbonate and high pH are the reasons for the incidence of iron chlorosis. *Jasminum grandiflorum* is tolerant to iron chlorosis (Kannan and Ramani, 1988). Remedial measures like soil or foliar application are only temporary. Identification of high yielding, efficient cultivars of crop plants should be the goal to manage iron chlorosis on a long-term basis. Edward Raja (1990) screened 22 chrysanthemum cultivars for tolerance to iron and observed that only four cultivars were tolerant to chlorosis. Since chrysanthemum is highly susceptible to Fe deficiency, crossing these tolerant cultivars with susceptible ones may help manage chlorosis by transferring the tolerance. In polyhouse grown rose, Fe deficiency is a serious problem, resulting in 20 – 30% of roses getting rejected as unmarketable. Of the ten cultivars screened for tolerance, cv. Kanfetti and First Red were found to be moderately tolerant. Chen and Barak (1983) observed that foliar spray of $FeSO_4$ with a non-ionic surfactant L-77, and, application of Fe-1 EDDHA, were effective in correcting iron chlorosis in soil at pH 7.7.

Chemical degradation in soil / irrigation water and iron deficiency

Due to increasing use of chemical fertilizers, the quality of irrigation water is deteriorating. Monitoring irrigation-water quality in grape orchards around Bangalore indicated increasing level of bicarbonate (HCO_3) 1.1 to 4.6 meq/l and NO_3-N from traces to 0.8 meq/l over a period of 10 years from 1998 (Table 6). NO_3-N enhances rhizosphere pH by physiological alkalinity and HCO_3 makes Fe inactive in the leaf and results in chlorosis- paradox. This is danger in all horticultural crops, especially grape, since hidden hunger for Fe deficiency will only increase in future.

A study on build-up of heavy metals like Zn and Cu in grape orchards of Rural Bangalore revealed that heavy metal content increased by 60 to 120% over a period of 10 years. These heavy metals, when present in excess induce iron chlorosis. Hence, balanced nutrition with adequate humified organic manures, alone can reduce the dangers of widespread iron chlorosis. Therefore, foliar correction of micronutrients, especially Zn, is recommended. Else, Zn toxicity induced Fe deficiency, coupled with poor quality irrigation, will further aggravate Fe-deficiency in horticultural crops.

Table 6. Change in quality of irrigation water over a period of 10 years in grape orchards in Bangalore district

Parameter	Unit	Value	
		In 1998	In 2008
pH	—	6.50	7.12
EC	dSm-1	0.44	0.909
Cl	meq/l	1.88	2.572
NO_3	meq/l	Traces	0.820
SO_4	meq/l	0.160	0.180
CO_3	meq/l	0	0
HCO_3	meq/l	1.102	4.590
Ca	meq/l	2.200	2.699
	meq/l	1.822	1.922
Na	meq/l	1.89	2.464
RSC	meq/l	Traces	Traces
SAR	meq/l	0.660	1.666

MANGANESE (Mn)

Occurrence of Mn deficiency in acid lime in orchards of southern India have been reported by Edward Raja (1992). Mn deficiency in older trees (25-30) of mango has also been recorded (Edward Raja, unpublished data).

COBALT (Co)

The beneficial effect of cobalt in nodulation is well-known and hence it is imperative that adequate cobalt supply is made to lignin vegetables like French bean, garden pea, pea and other vegetable beans, and take advantage of their capacity for symbiotic N_2 fixation. Economy in N also assures better soil-health due to reduced NO_3 pollution and better organic matter status even in marginal soils.

NICKLE (Ni)

Ni as a micronutrient

It is becoming apparent that Ni is likely a far more limiting factor in agriculture than previously supposed (Bai *et al*, 2006; Wood and Reilly,2006). Thus potential sources of Ni fertilizers are likely to be increasingly required, depending on usage situations. Discovery of field-level nickel deficiency in agriculture provides an opportunity to correct micronutrient deficiencies using biomass of hyper-accumulating plants. Ni is increasingly recognized as an essential mineral nutrient element for higher plants. Ni deficiency was discovered to be the cause of a mysterious malady of pecan, termed “mouse-ear”, and of an increasingly common replant malady in old or second generation, pecan orchards. This has established a need for commercial Ni fertilizers (Wood *et al*, 2004). Deficiency can also have a major impact on primary and secondary metabolism (Bai *et al*, 2006) and can also potentially influence plant resistance to certain diseases (Wood and Reilly, 2006). Walker *et al*

(1985) observed that Ni was needed in cowpea in reproductive stages. According to Brown *et al* (1984), Ni has a wide range of functions in plant growth, plant senescence and N metabolism.

DIAGNOSIS OF MICRONUTRIENT DISORDERS

Micronutrient management at the field level involves prognosis and diagnosis, followed by correction of the disorder. For diagnosis of hidden hunger, leaf analysis is being practiced. According to Loneragan (1997), expertise in diagnosis of micronutrients is the most challenging aspect of micronutrient management, since, it poses more difficulties than macronutrients. Most of the difficulties arise from experimental material (seeds, fertilizers and sampling / analysis of farmers' crops) and experimental trials. The concept of 'critical level' by Cate and Nelson (1962) and optimum leaf nutrient norms by Beaufils (1967) have been used by many research workers to develop leaf nutrient norms to diagnose leaf tissue to check whether it is deficient or healthy. Though these efforts are an improvement over the earlier diagnostic methods, we need to exercise circumspection in using these data. A perusal of Table 7 indicates leaf nutrient norms developed for mango for commercial cultivars of India and South Africa. The former is for a yield of 7-10/ha and the latter for a yield level of 30 t/ha. Productivity of mango in India is the lowest (6.8 t/ha) in the world. Therefore, development of leaf nutrient norms for such low yields is a point worth considering and hence the question. Is it relevant to analyze the leaf for low and unprofitable yield ? One more caution to be exercised is checking variability in leaf nutrient norms. The optimum value of manganese for Alphonso (Table 7) ranges between 13-408 ppm. Can a plant be healthy at this vast range ? Also, the Fe value for Alphonso is vastly different from Fe value for Totapuri. In this context, only diagnosis based on some metabolic function like photosynthesis or, any enzyme in which the nutrient is structurally associated, is relevant. Valenzuele and Romero(1988) recommended the use of biochemical indicators like penexidare, catalane, chlorophyll, carotenoid and anthocynain to analyze Fe deficiency. Success in diagnosis is fundamental to success in correction and profitable yield/quality.

DRIS and micronutrient diagnosis

DRIS is one of the important methods for diagnosing the limiting nutrient and its strength lies in diagnosis by ratio norms. Though research work on DRIS as a tool for nutrient diagnosis, was initiated as early as in 1988 (Bhargava and Chadha, 1988) no leaf analysis lab in the country uses nutrient ratio norms for providing service to farmers. Leaf nutrient standards for low, optimum and high ranges in high yielding orchards (using standard deviation from the mean) also need to be validated in the field before being used in leaf analysis service. Identifying limiting nutrients without analyzing B content, the most important micronutrient for horticultural crops is also is of limited use. If the leaf is not analyzed for B, even if another nutrient is identified as most limiting may not help in the response to that nutrient, since B figures in the Liebig stress category.

Soil test values and tree micronutrient status

Since leaf analysis is more useful than soil test for making nutrient management decisions in perennial crops, not much work has been done on this aspect. But, work conducted earlier indicated poor relationship between soil test and plant micronutrient status. Conventional soil tests are generally done to predict soil capability for supplying micronutrients during growth. The fundamental requirement of a soil test is that it should extract all or proportionate amount of plant-available nutrient which should correlate with or predict crop-response to application of the nutrient tested. Viets (1952) opined suggested that micronutrients are found in five chemical pools :

1. Water soluble
2. Exchangeable
3. Absorbed, chelated or complexed
4. Secondary clay minerals and metal oxides
5. Primary minerals

Edward Raja and Iyengar (1986) fractionated alfisoils (red soil), vertisoils (black soil) and high altitude soils for native and applied Zn, and found that only the first 3 fractions (watersoluble, exchangeable and complexed Zn fractions) contributed to uptake by tomato, but more than 80-90% of applied Zn accumulated in the last two fractions. The incubation study on fate of applied Zn in seven different soil types established that bulk of the applied Zn became unavailable within 48 h of application to soil (Iyengar and Edward Raja, 1988). In calcearous and clayey soil, about 70-80% applied Zn became unavailable (DTPA extractable), whereas, in the acidic and high organic-matter rich coffee soils of Kodagu, 30-40% of the applied Zn was still available. Hence, soil application to correct Zn deficiency is recommended mainly in acid soils rich in organic matter. Since use-efficiency of applied micronutrients (Zn, Mn, Fe and Cu) is very low (3-5%), it is better to resort to foliar spray than soil application to correct micronutrient disorders in perennial fruits (Alloway, 2008).

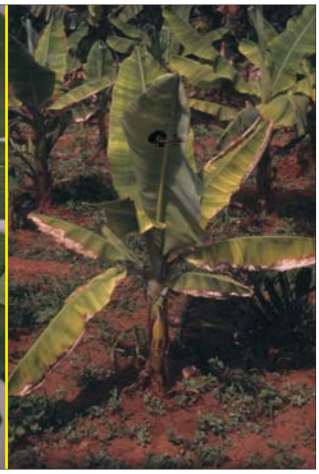
Micronutrient deficiency/exess symptoms on various crops

Iron deficiency in Guava

Zinc deficiency in Banana

Iron deficiency in Rose

Boron deficiency in Banana

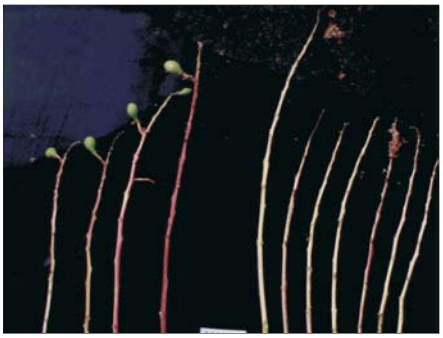


Manganese Toxicity in Banana

Boron deficiency in Mango

Boron toxicity in Tomato

Boron deficiency in Mango



Poor fruit set due to Boron deficiency in Mango

Iron deficiency in Mango

Table. 7. Optimum leaf nutrient norms for important mango cultivars

Parameter	Alphonso (India)	Totapuri (India)	All varieties of South Africa
N % (Range)	0.78 - 1.65	0.84 - 1.53	1.0 - 1.2
P % (Range)	0.02 - 033	0.064 - 0.147	0.08 - 0.1
K % (Range)	0.77 - 1.73	0.52 - 1.10	0.8 - 1.1
Ca % (Range)	0.76 - 1.63	1.67 - 3.20	2.0 - 3.3
Mg % (Range)	0.40 - 0.65	0.40 - 0.65	0.2 - 0.3
S % (Range)	0.035 - 0.131	0.0147 - 0.215	0.1 - 0.2
Fe mg/kg (Range)	657 - 963	48 - 86	190 - 310
Mn mg/kg (Range)	13 - 408	57 - 174	170 - 150
Zn mg/kg (Range)	7.8 - 18.3	25 - 33	30 - 75
Cu mg/kg (Range)	14.3 - 17.8	3.10 - 8.00	9 - 18
Boron mg/kg (Range)			40-80 (3-0.6 Mo)
Yield (t/ha)	6	10	30

Source: South Africa mango growers Year Book 2003 / IIHR, Folder No-45-0 2007

Photosynthesis and micronutrient deficiency

Micronutrient deficiencies affect carbohydrate pools and photosynthesis. Reduction in chlorophyll content leads to chlorosis in leaves, ultimately affecting the chloroplast system and photosynthesis (Balakrishnan *et al*, 2000). Fe, Mn and Zn levels affect the chlorophyll content. Micronutrient disorders exercise their influence by affecting photosynthesis and carbohydrate accumulation/translocation and there is a need for determining adverse effects of micronutrient disorders by effect on photosynthetic apparatus and photosynthesis. This approach would give a better idea of adverse effects of deficiencies.

Micronutrients and quality of horticultural crops

Horticultural crops differ in quality, which can affect profitability for the same level of productivity. Micronutrients have the capacity to improve quality, size, colour, taste, and earliness of horticultural produce. Sufficient data are available to show the positive effect of boron on juice purity in sugar beet. This occurs due to decrease in excess nitrogen content in roots. It has been suggested that B might be involved in regulation and uptake of nitrate ions. Part of the effects of deficiency are due to toxic accumulation of nitrates in the plant. It has been amply demonstrated that increased doses of nitrogen in boron deficient condition (which may happen in intensive orchards among different European countries) may reduce B uptake and suppress yield. With an aim of studying the role of boron on sugar transport in grapes, and its effect on the coloration of red wines, Borax carried out field trials in L Rioja in 1999. Application of B resulted in better coloured red wine.

As mentioned earlier, mango is a B-loving crop and, therefore, continuous adequate quantity of B is essential for yield, quantity and post-harvest life. Soil application in July at 100-150g Borax/plant followed by foliar spray in Dec. Jan. and March is essential for high yield, quality and post-harvest life. Trials conducted in Konkan and Maharashtra indicated that adequate B resulted in reduction in spongy tissue from 35% to 10%. Work conducted in farmer-fields indicated that 1% Solubor resulted in higher yield (8t/ha) and enhanced post- harvest life from 4 days to 14 days in B-sprayed plants (Edward Raja, 2009). Flowering was early by 3 weeks and, therefore, harvest was advanced by 3 weeks, enabling farmers to market their produce early to get a better price. The quality of horticultural produce in terms of colour, size, TSS and nutrients/nutraceuticals are important factors in deciding consumer acceptance and marketability, ultimately deciding the profitability to the producer. Micronutrients have a definite and significant effect on quality. Fruit-cracking due to cuticle damage is a serious problem in tomato grown under protected cultivation in South Africa. The study by Jobin *et al* (2002) indicated that B+Ca spray on the fruit resulted in reduced fruit-cracking. Application of micronutrients (Zn, Fe and B) by spray on Kinnow mandarin increased yield, juice and ascorbic acid content besides reducing acidity and improving TSS (Mishra *et al*, 2006). Boron is needed for cell-wall synthesis and reduction in cracking in tree fruits. Studies by Singh *et al* (2003) indicated that B application by spray @ 0.1 to 0.4% along with GA_3 (10 to 100 ppm) resulted, in increase in yield and reduced cracking of fruits in pomegranate. The marketable yield increased by 10-15% and profit by 20%. A study conducted in Mexico on the effect of Ca, B and Zn on quality and storage of peach indicated that pulp firmness, TSS, titrable acidity and storage life improved with B applied as pre-harvest spray. In greenhouse production systems, yield and quality of tomato was a problem. In a study on the effect of B on tomato, Smith and Comtrink (2004) observed that B application increased Ca, Mg & Zn content, besides improving firmness, colour, total solids, and shelf-life in tomato.

Micronutrients and input-use efficiency

All studies on response to micronutrients involve application of macronutrients, and, any yield increase due to application of micronutrient necessarily indicates that the efficiency of applied NPK fertilizers is enhanced. Indian farmers use about 2 million tons of fertilizers, valued at Rs.4,00,000 crore and a subsidy of Rs.48,000 crore is borne by the government, for fertilizers. If micronutrient application can save even 20% on fertilizers, the benefit is substantial, besides the added benefits to environment. More important is the fact that in B-deficient soils, water stress can damage crops more fiercely than in B-sufficient soils. In some studies on oilseed rape (*Brassica napus*) in B-deficient soils (without added boron), water stress treatment significantly increased root dry weight, but decreased shoot dry weight, resulting in decreased shoot/root ratio. Applied boron may improve the translocation of N compounds (Miley *et al*, 1969).

French bean is a poor nodulating legume, hence, inorganic N fertilizer is applied (due to inadequate symbiotically-fixed N). Low availability of Fe and Zn in the soil were identified as one of the causes for poor nodulation. Supplying Fe and Zn resulted in better nodulation and N fixation, according to Hemantaranjan and Garg (1986). It is well-established that Fe is an integral part of the nitrogen-fixing complex i.e, nitrogen-fixing enzyme (nitrogenase), leg hemoglobin and terridoxin (Evans and Russell, 1971). Subsequent study by Hemantaranjan (1988) indicated that application of chelated iron as Fe-EDTA and Fe-EDDHA at 5-10 ppm increased functional nodules and N-fixed symbiotically and total dry matter in French bean. Dry matter yield increased from 25 g to 46.3 g with Fe-EDDHA, nitrogen content from 360 mg N/pot to 673 mg N/pot, an increase of above 60% N fixed. Rai *et al* (1984) also recorded increased N fixation in lentil due to Fe application. But, excess Fe decreased N fixation, indicating a need for the correct dose of micronutrients and a possibility of toxicity. Application of 5 to 10 ppm Zn and Fe individually, and together, resulted in better 'functional nodulation' and seed in Varanasi soils pH 7.5. These findings encourage us to focus on micronutrient nutrition of legumes in general, and French bean in particular, for reducing inorganic N use in vegetable cultivation.

Molybdenum is also involved in functional nodulation and N fixation in legumes along with Fe and, hence, adequate Mo supply is also needed to encourage symbiotic N fixation and reduce dependence on fertilizer nitrogen. Molybdenum is needed in a very low quantity. In bold-seeded legumes like French bean, pea, cowpea and garden pea, the seed itself can be enriched, since seed legumes have the capacity to accumulate molybdenum to a very high level. When garden pea had 0.17 ppm molybdenum (which is low), it responded to soil application of Mo, whereas, it failed to respond to external application of Mo when the seed had 0.65 ppm of Mo. Gurley and Gidden (1969) corrected Mo deficiency in soybean by seed enrichment to 20-30 times the normal seed-Mo level, thereby avoiding the deficiency. Cobalt too has been involved in enhancing nitrogen fixation and improving N economy.

Micronutrients and disease resistance / tolerance in plants

Importance of adequate nutrition for disease resistance in humans is something most people accept from personal experience. Although this vital principle is also well-recognized in plant science, it is often ignored in practical agriculture. This is especially true of micronutrients. Of the many reviews dealing with plant nutrition and disease (Graham, 1983), few have seriously considered micronutrients. However, the role of Mn was treated at length (Huber and Wilhelm, 1988), and the flurry of research on siderophores in disease control (Swinburne, 1986) has brought Fe to prominence in plant pathological literature.

Manganese

Of the micronutrients, Mn may prove to be the most important in development of resistance in plants to both root and foliar diseases of fungal origin. Availability of Mn to plant roots and soil microorganisms varies mercurially over time, depending on many environmental and soil biotic factors. Consequently, Mn availability is subject to manipulation by both higher plants and microorganisms. As Mn is required in larger concentrations by higher plants than by fungi and bacteria, there is an opportunity for the pathogen to exploit this difference in requirement. The role of Mn in mitigating diseases in horticultural crops has been presented in Table 8. Whereas, effects of nutrition on disease are normally limited to the deficiency range (Graham, 1983), there are a few indications in literature that suppressive effects of Mn operate well into the sufficiency range of the host plant. This would appear to indicate either that (i) Mn requirement of the host plant for disease resistance is higher than for yield (ii) that Mn is somehow involved in lowering the inoculum potential of soil-borne, pathogens.

Several mechanisms have been proposed for the role of Mn in disease resistance, but lignification was found to be the most prominent. Some of the possible roles of manganese are outlined below:

- Manganese is involved elsewhere in the biosynthetic pathway of phenols and lignin. Mn deficiency leads to a decrease in soluble phenols (Brown *et al*, 1984),

Table 8. Effects of Mn deficiency reported on plant diseases in horticultural crops

Horticultural plant	Disease	Pathogen	Effect
Grapes	Phylloxera	*Phylloxera*	Decrease
Palm	Leaf spot	*Excerohilum rostratum*	Decrease
Cucumber	Mildew	*Erysiphe*	Decrease
Cow pea	Mildew		Decrease
Onion	Rot	Storage fungi *Erysitre polygone*	Decrease
Legume vegetables	Canker	*Rhizoctonia*	Decrease
Potato	Late Blight	*Phytophthora infestans*	Decrease
	Stem Canker	*Rhizoctonia solani*	Decrease
Swede	Mildew	*Erysiphe cruciferarum*	Decrease
Tomato	Bacterial speck	*Pseudomonas syringae*	Decrease
	Wilt	*Fusarium oxysporum*	Decrease
	Wilt	*Verticillium asbo-abum*	Decrease
	Virus	Tomato Mosaic virus	Decrease
Pumpkin	Mildew	*Erysiphe sclerotiorum*	Decrease
	Scab	*Streptomyces scabies*	Decrease
	Late Blight	*Phytophthora infestans*	Decrease
Sugar beet	Insect	Root borer	Decrease
Sugar beet	Leaf spot	*Cercospora* sp.	Decrease

Source: Huber and Wilhelm (1988)

which are frequently implicated in disease resistance (Bell, 1981)

- Photosynthesis is severely inhibited by Mn deficiency. It has been argued that decrease in root exudation of organic materials may follow and result in weaker rhizofloral population, less able to compete with potential root pathogens in the rhizosphere (Graham and Rovira, 1984). However, while photosynthetic capacity in Mn-deficient leaves responds quickly to foliar-applied Mn, evidence of ineffectiveness of foliar applied Mn in controlling take-all (Reis *et al*, 1982; Huber and Wilhelm, 1988) suggests that this mechanism is not important in this disease
- Direct inhibition of the pathogen is commonly suggested as a mechanism of Mn action. Although Mn is essential for microbial growth (Bertrand and Javillier, 1912), the requirement is nearly 100 times lower than requirement in higher plants. Both organisms exploit this marked difference in requirement between host and pathogen

Copper

Control of foliar pathogens by topical applications of Cu salts was been well-established by the turn of the 20th Century. This was almost 30 years before Cu was recognized as an essential nutrient in both higher and lower plant life. Whereas Cu is required by lower plant forms in minute amounts (Bortels, 1927), it is particularly toxic in higher concentrations (Keast *et al*, 1985). Copper has been used extensively as a fungicide at concentrations 10 to 100 times greater than those normally needed as a foliar spray, to cure Cu deficiency (0.1-0.2kg ha^{-1}). Most of its fungicidal properties have been used against foliar pathogens, since Cu added to soil is quickly adsorbed, and only a low concentration remains in the soil solution.

Zinc

Zinc is important for integrity and stability of biological membranes (Chvapil, 1973; Bettger and O'Dell, 1981). In plant root membranes specifically, it has been suggested that Zn may be important in preventing root membranes from leaking (Graham *et al*, 1987). This hypothesis has particular relevance to the finding that zoospores of *Phytophthora cinnamomi* were attracted to Zn-deficient *Eucalyptus marginata* and *E. sieberi* roots than to Zn-adequate roots. Many studies showed that Zn reduced plant diseases, which probably may be related to the toxic effects of Zn directly on the pathogen, rather than through the plant's metabolism. Thus, studies on artificial media (usually agar) in the absence of host plants have shown that high concentrations of Zn can inhibit growth or development of microorganisms. Somashekar *et al* (1983) demonstrated that 50 ppm of Zn resulted in growth reduction in *Penicillium citrinum* by 28%, *Cachliobolus miyabeanus* by 89% and *Cladosporium cladosporoides* by 12%. Cripps *et al* (1983) showed that 3 ppm of $ZnSO_4$ inhibited growth in *Trametes versicolor* and *Stereum strigosazonatum* by 100%, *Trichoderma* and *Alternaria* by 64%. *Epicoccum* by 43%, but did not inhibit the growth of *Curvularia* or *Penicillium*. Hooley and Shaw (1985) determined that more than 7.5m M Zn was required to inhibit one strain (6500P) of *Phytophthora dreschsleri* by 50%, but only 5.5 mM Zn was required to inhibit strain 6503IMI to the same degree. All these results showed that Zn could have a similar effect on pathogens that attack horticultural crops. In a survey, it was observed that level of Zn in the soil was lower in soils conducive to root rot (*Phymatotrichopsis omnivorum)* of cotton (Smith and Hallmark, 1987) and infection of ginseng by *Pseudomonas cichorii* (Gvozdyak and Pindus, 1988). Although these reports are correlative, the interpretation is that Zn is important in reducing *Fusarium* root rot of chickpea, *Cicer arietinum* (Gaur and Vaidya, 1983) and *Rhizoctonia bataticola* rot of groundnut, *Arachis hypogea* (Murugesan and Mahadevan, 1987).

Boron

Boron has also been reported to have beneficial effects in reducing plant disease; many of these effects have previously been reported by Graham (1983), as have the lack of effects. These are (i) its role in formulation of carbohydrate-borate complexes controlling carbohydrate transport and cell membrane permeability or stability (ii) its role in metabolism of phenolics, with its primary role in synthesis of lignin (Lewis, 1980). Since then, B has also been shown to reduce diseases such as clubroot of cabbage, caused by *Plasmodiaphora brassicae* in Sweden (Vladimirskaya *et al*, 1982) and other crucifers (Dixon and Webster, 1988); *Fusarium solani* in bean *Phaseolus vulgaris* L. (Guerra and Anderson, 1985); *Verticillium albo-atrum* in tomato (Dutta and Bremner, 1981); *Rhizoctonia solani* in mungbean, pea and cowpea (Kataria, 1982; Kataria and Grover, 1987); *Rhizoctonia bataticola* in groundnut (Murugesan and Mahadevan, 1987) and tomato yellow leaf curl virus in tomato (Zaher, 1985). Boron has been shown to decrease expression of the potato wart disease *(Synchytrium endobioticum)* of potato (Hampson and Hard, 1980) and club root of crucifers. In both cases, the disease is expressed by formation of a tumor or a gall; and in both reports, B decreased the severity of disease-expression. Boron did not, however, diminish initial infection of the host.

One consequence of B deficiency is increase in indoleacetic acid (IAA) concentration because of inhibition of IAA oxidase activity (Coke and Wittington, 1968), presumably by accumulation of phenolics. Similar conditions may occur in tumors and galls. Potato wart tumors have elevated levels of auxin-like substances (Reingard and Pashkar, 1959). This increase in auxin (or auxin-like) activity has been explained by an increase in auxin protectors (Tandon, 1985). It is worthwhile to note that, in a variety of tomato in which tumors were not found following successful infection, tomatine, an auxin antagonist, was present (Hampson and Haard, 1980). The auxin protectors from potato wart have been isolated, and shown to contain ferulic acid and caffeic acids covalently bound to a protein and chlorogenic acid. Interestingly, both chlorogenic and caffeic acid have been identified in the necrotic areas of B-deficient celery, *Apium graveolens* L (Perkins and Aronoff, 1956), and ferulic and vanillic acid in B-deficient oil palm (*Elaeis guineensis)* (Rajaratnam and Lowry, 1974). In addition, it is common to use borate as a buffer during plant tissue extraction to prevent conjugation of phenolics with proteins. These observations suggest that B may suppress gall or tumor formation by suppressing high concentrations of auxin or auxin-like substances. Gall formation itself is not a defense mechanism of the plant *i.e.,* galls are incited by the pathogen (Dixon, 1984). Thus B, by suppressing high levels of auxin or auxin-like substances, may also suppress gall formation.

There is no conclusive evidence that explains how B decreases disease caused by vascular pathogens. The association of B with lignin synthesis (Lewis, 1980) makes it tempting to suggest that B may suppress infection of the stele by a lignified physical barrier at the endodermis. It may be argued that this barrier would be of little consequence if, as suggested by Mai and Abaci (1987), *Fusarium* enters just behind the root cap, a region of the root with little lignification. However, if B deficiency weakens the lignification of other parts of the root system, successful infection may be more likely at other locations on the root axis. Indeed, Dutta and Bremner (1981) observed that B depressed the symptoms of *Verticillium* wilt in tomato, and roots of B-supplied plants showed no vascular discoloration. This suggests that B inhibited invasion of xylem by the pathogen.

Iron

Older literature sheds little light on the role of Fe in disease resistance, since it is relatively sparse compared with that of Cu, Mn and B. However, the sophistication of microbial Fe-acquisition systems suggests that microbes have a high requirement compared to higher plants and higher utilization efficiency. In this respect, Fe appears to stand in contrast to Cu, Mn and B, for which microbial requirements are relatively low. Addition of Cu, Mn and B to deficient soils generally benefits the host, whereas the effect of Fe fertilization in disease resistance cannot be predicted. Copper was antagonistic to Fe in the *F. oxysporum f. sp. lycopersici,* although lycomarismin has no known function in *Fusarium* wilt disease. Fe decreased tolerance of *Fusarium* wilt in tomato without affecting development of the fungus (Waggoner and Dimond, 1953).

Iron stimulated and Cu inhibited spore germination (Strakhov and Yaroshenko, 1959; Halsall and Forrester, 1977; Vedie and Le Normand, 1984). Though its key role in oxidative phosphorylation is known, Fe is directly or indirectly involved in all plant synthesis, but especially high Fe requirement for syntheses of the phytoalexin wyerone is of interest in the present context (Swinburne, 1986). Iron is essential for production of the host-attacking exoenzymes of fungi, such as pectin methylesterase of *Fusarium oxysporum* (Sadasivam, 1965) and endo- and exo-glucanase by *Phoma herbarum*, a leaf spot pathogen of peanut (Shinde and Gangawane, 1987).

Molybdenum

There have been few reports associating Mo with response of plants to disease and no reports have been found to specifically address effects of Mo deficiency (Graham 1983). However, Dutta and Bremner (1981) demonstrated that Mo applied to tomato roots reduced the symptoms of *Verticillium* wilt. Miller and Becker (1983) also reported that Mo suppressed *Verticillium* wilt in tomato. Molybdenum had a direct effect by reducing production of roridin E, a toxin produced by *Myrothecium roridum* (Fernando, 1986) and in slightly inhibiting zoosporangia formation by *Phytophthora cinnamomi* and *P. dreschleri* (Halsall and Forrester, 1977). Soil-application of Mo decreased nematode populations (Haque and Mukhopadhyua, 1983). It is not known whether Mo within the host plays any specific role in protecting plants from disease. Because of the requirement for Mo by the enzymes nitrogenase and nitrate reductase, any effect of Mo deficiency on pathogenesis may be indirect through an effect on N metabolism (Shkolnik, 1984).

Silicon (Si)

Although Si is not regarded as a full-fledged essential element for growth of higher plants, it is evident from recent work that it plays a critical role in biochemical pathways leading to resistance to certain pathogens. Adatia and Besford (1986) observed that cucumber powdery mildew that could not be controlled by repeated application of fungicide, could be controlled by silica. Meyer *et al* (2008) observed that silicon helped in powdery mildew control in grape, strawberry and cucumber, but in gerbera, the reduced uptake limited its role in disease. In view of this, judicious use of silicon (separately, or along with biopesticides) and balanced nutrition can control diseases in horticultural crops in an integrated way.

Role of micronutrients in improving post-harvest life and marketability of horticultural produce

Low storability of horticultural produce is well-known in a tropical country like India, but, the energy intensive cold-storage units escalate cost of storage. However, the capabilities of some micronutrients in complementing these techniques are well-known. Boron has a synergistic role with Ca in fruit-tree nutrition, since both are needed for fruit quality. Brown heart disease of pear is a serious storage disorder affecting the storage-life when controlled atmosphere storage is done. Studies conducted in South Africa indicated that storage life of mango, citrus, avacodo and grape improved with increased Ca and B content in the fruit (Kruger *et al*, 2003). Wojcik and Wojick (2003) indicated that pre- and post-harvest B spray on the fruit supplemented with soil B, resulted in better Ca status in pears and increased storage life, higher firmness and titrable acidity. The fruits also had lower membrane permeability and were less sensitive to internal browning than control fruits. Poor storability of melons in Brazil was solved by pre harvest spray of Ca and B from fruit-set to harvest. Storage life could be increased by higher Ca binding to the cell wall which, increased methoxylated pectin in cells of the melon skin (Chitara and Praca, 2004).

India paid a heavy price by losing export market for Alphonso mango to spongy tissue. Micronutrients can prevent occurrence of some of the disorders, in that cause reduction in marketable yield, while simultaneously increasing the profit of farmers and exporters. Zinc and B play a direct role in reducing physiological disorders. Zinc stabilizes membrane permeability and B (by increasing the mobility of Ca to the fruits. Mn, Cu and Fe) also plays a positive role by increasing photosynthesis and providing carbohydrates supply for good Ca uptake. Internal browning (chocolate) of grape in Brazil was associated with plants having abnormal yellowing and malformed clusters, with small berries and dark- brown pulp. This was corrected by supplying B (0.1% spray at flowering). Edward Raja (2009) observed that spongy tissue in mango cv. Alphonso, a calcium-related disorder observed in acid soils of Konkan, India, could be rectified by correcting severe B and Zn deficiencies by foliar and soil application. Improving root health by dolomite application (to eliminate Al toxicity), and facilitating better light-penetration by pruning, resulted in enhanced carbohydrate accumulation, and translocation and better Ca uptake by roots.

Bitter pit, a serious physiological disorder in apple, was reduced by sprays of Zn and Cu (Schmitz and Engel, 1973). The immobile calcium oxalate in fruits is solubilised by Zn and Ca is released to the fruit. Chvapil (1973) reported that Zn is tightly bound to cell membranes in leaves and it has the greatest affinity for cell membranes, followed by Cu, Fe, Ca and Co. This points out to the possibility of Zn and Cu sprays releasing Ca from various chelating and complexing agents. Smith and Green (1982) observed fewer cork spots in apples with higher B in the fruit-flesh and more of higher quality fruits. According to Shear (1975), both soil and foliar spray of B can increase fruit Ca and reduce Ca-related physiological disorders. Shear and Faust (1971) showed increased movement of Ca into leaves sprayed with B. Proper and timely application of micronutrients can help correct several physiological disorders of fruits, thereby increasing their marketability.

Role of micronutrients in enhancing nutritional security through horticultural crops

Horticulture products are protective tools which have to be nutrient-dense, since, nutritive value of the cereals is deteriorating due to growth-dilution and declining soil-health. Horticultural crops have minerals in better available-form compared to cereals like wheat and rice. Enhancement of nutritional security by biofortification and organic farming is gaining ground in the present agricultural paradigm. Fe and Zn deficiencies are becoming public- health issues. These can be addressed to a great extent by consumption of fruits and vegetables. Seventeen minerals are needed for human health and even boron has qualified for 5 out of 6 criteria for essentiality in human nutrition (3rd International conference on Boron, 2005). Phloem-immobile micronutrients like Fe, B, V and Cr cannot be increased in food crops by spray-application. According to Welch (1997), macronutrient treatment can influence concentration of beta-carotene and micronutrients in carrot. Root vegetables from acid soils have adequate Fe, Zn, N, Cu, Mo and Se for better human health. Biotechnology can play a major role in human nutrition by producing tangerines rich in micronutrients. Horticulture must change in ways that will closely link food production to human health and nutritional requirements. Holistic food system models hold promise in providing sustainable interventions to these complex nutrition and health problems. Sustainable solutions to micronutrient malnutrition can only be found in forming a nexus between agricultural production and human health. The magnitude of the problem is so great that we must use every tool at our disposal to eliminate this scourge from the world.

Crop phenology and micronutrients

The mean crop removal of all micronutrients does not exceed 600 g/ha, whereas the total micronutrients exceed more than several tons/meter depth, the maximum feeding zone of any horticultural crop. This opens up great potential for solving the problem of micronutrient disorders of horticultural crops in India, since micronutrient reserves in Indian soils are adequate for thousands of crops. When 5 ppm Zn can be adequate for 2500 crops of wheat in Australia, it is definitely adequate for 10000 crops of mango (considering its very low removal at 44 g/ha). It should be clear from Table 9 that perennial fruit crops like mango and grape remove much less micronutrients than to vegetables which, in turn, remove much less than a wheat crop does, since, dry matter produced by a cereal crop is much higher than that by fruits or vegetables.

Though all micronutrients are essential for the entire crop growth, each nutrient is needed at some phenological stage of growth in larger quantity, to maintain crop productivity. Boron is needed both at the time of planting or sowing for root growth, at the reproductive stage for pollination and, at maturity stage, to avoid fruit-drop, cracking and, also, for mobilization of calcium for better shelf-life. Since it is highly immobile in the plant, it is continuously needed. But, reproductive parts need more B than do vegetative parts (Rerkasem *et al*, 1996). It is better to give a foliar spray at pre-bloom for pome fruits and, a pre-bloom and post-bloom spray for other fruits. Since B is phloem-mobile, in some fruits like apple, one spray at flowering is sufficient, whereas, for B immobile crops like mango, pre-bloom and post-bloom sprays are essential (Edward Raja *et al*, 2005).

Though Fe is needed throughout the plants life, Fe nutrition becomes a problem at flowering due to poor photosynthate supply to roots. Root-health is very important in iron and calcium nutrition, since these are taken up in the

Table 9. Micronutrient removal (g/ha) by major horticultural crops

Crop	Zn	Mn	Fe	Cu	B	Mo
Mango	44	68	150	13	28	2
Papaya	68	110	140	22	48	3
Banana	110	380	190	14	68	4
Grape	130	240	180	22	62	4
Tomato	110	180	210	48	64	7
Cabbage	140	220	240	22	68	7
Beans	95	128	120	48	48	4
Mean	99	189	176	27	55	4

Source: Cakmak (1993), South Africa Mango Growers Handbook (2002, 2003) root-tip region only. Spray of Fe as 0.5% $FeSO_4$ at flowering, along with B, is always helpful. For leguminous vegetables, it is needed at seed-sowing for nodulation (Hemantranjan, 1998). Since Mn is also phloem- immobile, it needs to be continuously available to the plant, more so, at fruit-set (since it is essential for photosynthesis). Leaves adjacent to fruits are important for fruit growth and their Mn level needs to be at an optimum. An acidified rhizosphere always ensures enough Mn. Nitrate N should be avoided at flowering. Since Mn is important for disease resistance, a continuous supply keeps the plant healthy. Copper is also needed, more at the reproductive stage than at the vegetative stage. It is immobile. Protection of plants with copper fungicide at flowering ensures copper availability for reproductive growth. Molybdenum is partially mobile and is needed for nodulation in legume vegetables. It is needed more in the early stage of crop-growth and in crops that need high N, like banana/ tomato that need it more in acid soils. If seeds are enriched with Mo or seed-dressing is done, there is less need for Mo at the late stage of a crop. Zinc is also a partially mobile; it is required at an early stage of crop growth or during early establishment of tree crops. In sensitive crops like grape, mango and citrus, a spray (0.3% $ZnSO_4$) at pre-bloom, followed by a spray at the reproductive phase, is helpful, since it can protect leaves and fruits from reactive oxygen species (Cakmak, 2000). In situations where topsoil is removed by leveling during cold season, Zn deficiency affects crop establishment. Hence, Zn is needed more at the early and late stages for fruit membrance stability and to mobilize Ca for preventing physiological disorders.

Micronutrient toxicity

Micronutrient excess is as much a problem as deficiency and skill is needed in micronutrient correction. Since farmers are prone to using excess micronutrients, this creates a problem rather than solving a problem. Some of the common toxicity problems encountered with micronutrients are discussed below. Boron toxicity occurs due to saline irrigation water and saline soils. Citrus and beans are extremely sensitive to B toxicity. Copper toxicity occurs due to natural pollution by mine ores or anthropogenical reason due to use of fertilizers and fungicides. Copper accumulates more in the root and damages it more than the shoot. It induces K, Ca, Mg and Fe deficiencies and causes Fe chlorosis.

New approaches in micronutrient nutrition

According to Marshner (1995), rhizosphere modification in some crop species by Type I and Type II mechanisms is a Fe-stress response for better iron nutrition. In this process, a plant spices very susceptible to Fe deficiency may be grown adjacent to a Fe efficient genotype, to benefit from the rhizosphere modified with higher available iron. A banana cultivar with high available Mn in its rhizosphere can benefit an acid lime crop susceptible to Mn-deficiency. Thus, rhizosphere modification can help in micronutrient nutrition of crops by complementary existence.

Bio-fortification in horticultural crops

Nearly 40 – 50% of world population suffers from Fe and Zn deficiencies (Welch, 1999, 2002). Bio-fortification of food crops by breeding is one of the priority research areas of breeders (Welch and Graham, 2004). But bioavailability of Fe and Zn in grains is low due to the presence of phytic acid, which reduces their uptake in the digestive system (Cakmak, 2002). Due to low phytic acid content in fruits and vegetables, horticultural crops lend themselves for bio-fortification. Iyengar and Edward Raja (1988) observed some vegetables like okra getting enriched with Zn in pods (edible portion) when zinc level in soil was high. Hence, exploiting fruits and vegetables not only for vitamins but also for critically deficient Fe and Zn, has a great potential in addressing nutritional security of the nation. It is well- known that plants differ in their efficiency for uptake of nutrients from soils and in certain situation, options other than fertilizer-application (to correct micronutrient disorders) are considered. In tackling iron chlorosis (especially, induced chlorosis), breeding resistant varieties in soybean and sorghum is on for the past 25 years. Breeding is considered in the following situations :

1. When the cost of correction is high
2. When the method of correction is difficult
3. When the deficiency affects yield and quality very severely (Liebig stress)
4. When agronomic correction may result in environmental pollution
5. When agronomic correction produces produce with low nutritional value

Discussing the present technologies and future prospects it can be observed that sustainable and cost effective correction of Fe deficiency is possible by developing Fe efficient cultivars or rootstocks for sensitive crops. Breeding for tolerance to zinc deficiency has been well-identified for managing Zn deficiency in beans (Hacisalihoglu *et al*, *2004*). Another alternative is development of transgenic crops. The Zn transporter protein of *Arabidopsis* was transferred to barley, which resulted in correction of zinc deficiency (Ramesh *et al*, 2004). For enriching Fe content of rice seeds, transgenic rice was developed with ferritin gene, but increase in Fe content was inadequate (Qu *et al*, 2005).

Micronutrient management in Acid Soils

The western coast of peninsular India and parts of eastern and northeastern India has acidic soils, which need to be managed differently for micronutrient disorders. In these soils, aluminium and manganese are present at toxic levels (Pandey *et al*, 1994), while Mo and B are usually deficient (Edward Raja *et al*, 2005). Other micronutrients like Zn, Fe, Cu, are adequately available in these soils. Since B is the only mobile micronutrient in soil, it gets lost by leaching (like nitrogen). Since acid soils are distributed in high-rainfall regions, its deficiency is a perennial problem. But, the fact is that B-uptake by plants at identical water-soluble B content was greater at lower soil solution pH (Wear and Patterson, 1962). Hence, plants can manage with lower soil B in acid soils, than in high pH soils (calcareous soils). But, due to loss by leaching of fertilizer, slow release B sources like colemanite have a large potential for B-loving crops like, mango. Vegetables like cauliflower, carrot and turnip need to be supplied with adequate B. Deficiency of molybdenum is a problem in acid soils. But, liming for eliminating Al-toxicity can increase available Mo in soil and solve the problem. Use of molybdenum-rich seeds of legume vegetables, or seed treatment at sowing, also mitigates the problem.

Foliar nutrition in micronutrient: An option or management compulsion in horticultural crops

Hamilton *et al* (1943) were the first to establish potential of foliar nutrition in field- level nutrition management, by proving the influence of urea spray the N-nutrition in apple. Initial research on the potential of this technique was confined to supplying macronutrients like NPK, since, deciduous crops like apple (whose root systems are inactive throughout winter and early spring) have to be compensated for the time lost. This became all the more important when high-yielding clones were introduced and advances in horticultural technology doubled the yield of apple and there was a need for providing the extra nutritional requirement. Controlling physiological disorders by directly spraying on the fruits is also widely followed in apple. But, in India, foliar sprays are still optional as their vast potential is yet to be recognized in terms of increased yield, quality and post-harvest life.

Crop-specific micronutrient foliar formulations

Each crop is specific in its micronutrient requirement, based on its metabolic requirement, capacity to modify its root-soil interface, exploit the rhizosphere-soil nutrients, better root geometry, faster specific rate of absorption at low concentration (low Kw), improved internal root-distribution and superior utilization or low functional-requirement for the nutrient (Graham *et al*, 1992). In the alfsoils of IIHR, Bangalore, abundant in available Mn, three crops growing side-by-side exhibited contrasting response to Mn application. While acid lime exhibited deficiency, guava exhibited sufficiency and banana exhibited toxicity for Mn (Edward Raja, unpublished data). The most scientific approach would be to identify micronutrient disorder at the micro-farming level by leaf and soil analysis and suggest a farm/site specific recommendation. In the Indian context, with more than 2 million farm holdings in horticulture, it is impossible to provide farm-specific advice, due to lack of infrastructure for leaf/soil analysis and lack of manpower to interpret it. Hence, crop-specific foliar micronutrient strategy was proposed as one of the strategies to overcome this problem (Edward Raja, 2009) This involves identification of the predominant micronutrient disorder of a crop in agro-ecologically similar regions, developing a micronutrient formulation, incorporating the deficient nutrient in proportion to intensity of the deficient nutrition. This is similar to iodine-fortified common-salt promoted for public health. This concept is totally different from the existing market for micronutrient foliar formulations in India, which have following basic inadequacies :

1. All the existing market micronutrient formulations in India are meant to correct Zn deficiency, which is the predominant disorder in rice, wheat and maize, whereas, the predominant micronutrient disorder affecting both vegetative and reproductive growth in horticultural crops is that of Boron deficiency. This is a basic and fundamental flaw in the existing foliar micronutrient correction strategy in India
2. Reproductive parts need 2-3 times more B than do vegetative parts. Hence, foliar spray of B is a must
3. In rainfed crops like mango, foliar spray is the only efficient method for correction of micronutrient disorders
4. In view of chemical, physical and biological soil degradation, root health will become a problem in the future and foliar nutrition will gain significance
5. Soil-applied micronutrients like Zn, Fe, Cu and Mn have

low efficiency (3-5%), whereas, foliar nutrients have an efficiency of 20-40%. In view of this foliar nutrients having micronutrients are more of a compulsion than an option, especially in crop- specific foliar formulations

Micronutrient management in organic farming of horticultural crops

Organic farming has an in-built advantage of providing balanced nutrition especially for micronutrients, since, presence of adequate organic matter makes them available to the plant. Except copper, all micronutrients are available adequately in organically-farmed soils.

Why micronutrient disorders are not common in organic farming ?

1. Moderate and severe micronutrient disorders are uncommon in organic farming since crop growth rate is not as fast as in conventional farming. In the latter, application of fertilizers of high nutrient content (urea: 44% N; DAP: 46% N) results in accelerated growth rate.
2. High organic-manure (FYM+ Vermicompost) application results in many organic acids, which complexes micronutrients in the soil (especially Fe, Mn, Cu, and Mn) and makes available to plants. Humic acid and fulvic acid levels are very high, resulting in adequate available micronutrients.
3. In organic farming, balanced nutrition is achieved by avoiding extreme nutrient deficiencies like P-induced Zn deficiency, N-induced B deficiency and heavy-metal induced Fe deficiency. Due to crop residue recycling and application of composts like vermicompost, nutrient reserves are recycled and made available to the plant. Soils have Zn, Cu, Mo Fe and Mn in abundant quantity. But since crop residue recycling is the basic credo of organic farming, micronutrient depletion does not occur. Deficiency of B is likely to be encountered in organic farming practiced in high-rainfall areas, with coarse soil texture and an undulating topography.
4. The rhizospheric pH is maintained near neutral (<>) in organic farms due to crop rotation, avoiding some organic inputs which form acid in soils, thereby resulting in better micronutrient nutrition.
5. Microbial activity, is very high and this also releases minerals from soil.
6. Root health is very good in organic farming, and therefore, nutrient uptake is higher.
7. Toxic elements like Al, Mn and Na are generally absent.
8. Less leaching-loss or run-off loss of B due to better soil structure.
9. Root-penetration upto deep sub-soils, which thereby supplies micronutrients.

Techniques to enhance micronutrient uptake in organic farming

1. Use of mycorrhiza (VAM) for mobilization of Zn and P
2. Enriching FYM with rock phosphate releases Zn, Ca and Mg/ s into soil
3. Use of gypsum for supplying calcium and sulphur
4. Use of dolomite provides Ca and Mg wherever needed and increases availability of molybdenum
5. Since mango is highly susceptible to Fe deficiency, use 13-1, Fe-deficiency resistant rootstock from Israel when mango is grown in calcareous soils
6. Use of Boradeaux mixture/Burgundy mixture should be encouraged for controlling diseases in soils of high pH, so that copper deficiency is eliminated
7. By leaf analysis, the limiting micronutrient is identified and a spray of such micronutrients can be given (Zn, Mn, Fe, Ca, B and Mo) in consultation with an organic certifying agency
8. Use of neem cake is recommended in high pH calcareous soils, since it can recycle soil Fe, Mn, Zn, and Cu and make them available to the plant by rhizosphere acidification. Fe deficiency in fruits and flower crops has been corrected by this method. Neem decoction can be used for drenching, if chlorosis is seen

When a farm is converted from a conventional one to organic-farming system certain modifications have to be made in nutrient management to overcome problems caused by the earlier system. A 3-year period is required to correct the system. Conventional farms have depleted organic matter and high available-phosphorus, which creates problems of availability, uptake and translocation of micronutrients. Increasing N and K to the level of P is one method; another is to encourage availability, uptake and translocation of micronutrients by increasing organic-matter status. The key for exploiting the enormous micronutrient reserves of Indian soils is to increase the organic matter status through on-farm and off-farm bulky, organic inputs *viz*., crop residues and green manures. Crop residues like fallen leaves, pruned crop-wastes etc., are to be used for increasing soil organic matter status. Instead of adding inorganic P fertilizer to soil, FYM can be enriched with rock phosphate at 20% ratio (so that excess P in the soil is avoided) thereby reducing the risk of P-induced zinc deficiency. The increase in organic-matter status itself increases availability of soil micronutrients owing to the chelating ability of humic and fulvic acids in the compost.

Micronutrients and future challenges in horticulture production

Though some more essential micronutrient is added to the existing list, it is doubtful if they will have as much importance as the already identified ones. Hence, it is essential to tap expertise in diagnosis and treatment of micronutrient deficiencies and toxicities. Experimental techniques for detecting micronutrient disorders need to be refined. Analysis of leaves for manganese and boron deficiency detection presents a severe problem, since old leaves accumulate B and Mn in the margins and give a wrong picture. Delayed sampling of deficient leaves also presents a problem in diagnosis. Fertilizers and additives affect availability of micronutrients indirectly and these problems are attributed to other factors. The present strategy on micronutrients revolves only around increasing the yield of horticultural crops. Farmers' interest will be taken care of when micronutrients are used not only to increase biological yield, but also marketable yield, by improving quality and post- harvest life, ultimately bringing profits to the farmer. As discussed earlier, the role of B. Zn, Mn and Fe is paramount in realizing this objective. Public interest will be adequately taken care of if it receives horticultural produce of high quality, since worldwide, clinical and sub-clinical deficiencies of these micronutrients have been noticed (Cakmak, 2008). Besides, pesticide residues are increasing to harmful levels due to exclusive dependence on curative management by chemical pesticides. A shift to preventive management, using balanced lignin biosynthesis and preventing oxidative stress nutrition and using Mn, B, Zn and Cu, as part of Integrated Disease and Pest Management will go a long way in implementing "value addition" at the farm level. To operationalize the strategy, following action is required:

1. Micronutrient correction should be done by mobilizing soil reserves of Fe, Zn, Mn, Cu and B by humidified organic manures (vermicompost)
2. Use of Zn-enriched NPK fertilizers (like iodized common salt) as was done in Turkey (Cakmak *et al*, 1999). This will also simultaneously enhance the use-efficiency of NPK fertilizers due to removal of Zn deficiency on mild or moderate stress [Mitscherlich type or Bevere stress (Lieberg type)]
3. Use crop-specific foliar formulations for correction of predominant micronutrient disorders as a complementary strategy to supply from soil and also as disease tolerance strategy due to balanced nutrition
4. Agronomic bio-fortification by foliar spray and increasing soil availability of Fe and Zn so that consumers get fortified value-added food at reduced cost (Cakmak, 2002)
5. Increased shelf-life/post-harvest life by directly enriching fruits with Ca and B to reduce dependence on energy consuming cold-storage systems. It can be also part of integrated post-harvest management

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