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Micronutrients status and management in orchards soils: applied aspects

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Abstract

Average yields of our orchards (9 tones ha^{-1}) are much less when compared with the world average of 25 tones ha^{-1}, which is mainly blamed to imbalance fertilization. Technical Services Wing of Fauji Fertilizer Company is the pioneer one in fertilizer sector, which is providing macronutrients as well as micronutrients analysis and recommendations facilities to farming community throughout the country absolutely free of cost. During a period of seven months, 329 soil samples of various depths collected throughout Pakistan from citrus, mango, guava, banana and apple orchards were analyzed for available iron, copper, manganese, born and zinc status. The results reveal a wide spread deficiency of zinc, boron, followed by iron throughout the country while the deficiencies of copper and manganese have also been observed occasionally. Due to restricted mobility of iron, zinc and boron in plant tissues and keeping in view plant physiology, the authors are of the view that as orchard crops try to accumulate maximum amounts of essential nutrients before flower formation so micronutrients foliar sprays should be made preferably after fruit harvest and before flower formation in addition to recommended deficiency doses already applied through soil. To make up the deficiencies, various management strategies and future options have been discussed in detail in this paper.

Keywords: Micronutrients, orchards, management

Introduction

The essential micronutrients for plants are B, Cu, Fe, Mn, Mo, Cl and Zn. Other mineral nutrients at low concentrations considered essential to growth of some plants are Ni and Co. The incidence of micronutrient deficiencies in fruit crops has increased markedly in recent years due to intensive cropping, loss of top soil by erosion, losses of micronutrients through leaching, decreased proportions of farm manure compared to chemical fertilizers, increased purity of chemical fertilizers and use of marginal lands for crop production. Micronutrient deficiency problems are also aggravated by the high demand of modern fruit crops cultivars. Increases in orchard crops yields from application of micronutrients have been reported in many parts of the world.

Ion activities of most micronutrient metals in soil solution should be above 10^{-11} to 10^{-8} *M* in order for most agricultural crops (Welch, 1995). Soil and plant analysis show that more than 50 per cent of the cultivated soils of the country were unable to supply sufficient zinc and boron to meet the needs of many crops (Khattak, 1995). In a survey of 40 orchards, made by Haq *et al.* (1995), 50 per cent soils were found deficient in zinc and majority of the sites were deficient in B. According to Rashid *et al.* (1991) almost all the surveyed citrus orchards of Sargodha, 63 per cent of Sahiwal and 88 per cent of Faisalabad contained marginal to deficient zinc content.

In Pakistan fruit crops cover an area of 0.66 m ha with an estimated production of 6 m tones (GOP, 2003). Thus average yields of our orchards (9 tones ha^{-1}) are much less when compared with the world average of 25 tones ha^{-1}. In this country, despite of favorable climatic conditions, average yields of fruit crops are far below than potential yields, which depict that in many of the fruit crops, either nutrients use is below optimum or in unbalanced proportion. Even on world scale, it is estimated that Fe and Zn deficiencies are wide spread occurring in about 30 and 50% of the cultivated soils (Cakmak, 2002) while B deficiency, have also been reported in over 80 countries and on 132 crops (Shorrocks, 1997). Although a lot of awareness has been created for the use of macronutrients but a little work has been done to identify micronutrients disorders that are presently limiting fruit yield and quality. In this advanced technological era our farmers are still deprived of the micronutrients analysis and recommendations facilities. In this paper an attempt has been made in brief to identify the extent of problem, discuss and recommend micronutrients doses, their economical sources and application strategies for orchards growers.

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Materials and methods

The soil samples for this study were collected from through out the country for two depths i.e. 0-9 and 9-18 inches. The samples were air dried, ground and sieved through 2 mm sieve. Samples extracts were prepared by DTPA solution for iron, copper, zinc and manganese (Lindsay and Norvell, 1978), and dilute HCl for boron (Ponnamperuma *et al.*, 1981). The iron, copper, zinc and manganese contents were determined by atomic absorption spectrometry technique and boron by developing colour with Azomethane-H method. To make up the micronutrients deficiency, different application techniques were reviewed and maximum efforts were made to give examples of zinc, boron, and iron, as presently, out of 7 micronutrients the deficiencies of only these 3 nutrients are becoming problematic in Pakistan. In some cases examples have been quoted of macronutrients with an idea to give more awareness to the readers.

Results and Discussion

A) *Micronutrients Status of Orchards Soils in Pakistan*

Technical Services Wing of Fauji Fertilizer Company is the pioneer one in fertilizer sector, which is providing macronutrients as well as micronutrients analysis and recommendations facilities to farming community throughout the country absolutely free of cost. During a period of seven months, 329 soil samples of various depths collected throughout Pakistan from citrus, mango, guava, banana and apple orchards were analyzed for available iron, copper, manganese and zinc status. The results revealed a wide spread deficiency of zinc followed by iron throughout the country while the deficiencies of copper and manganese have also been observed occasionally (Table 1). On an overall Pakistan basis, 64, 19, 2, and 4 per cent soils had been found deficient for available zinc, iron, copper and manganese respectively. On province basis zinc deficiency was 60, 90, and 43 per cent in Punjab, Sindh and Balochistan respectively. While the corresponding deficiency figures for available iron were 22, 16 and 19 %, respectively. Similarly, 68, 60, 47, 89, and 40% zinc deficiency has been noted in citrus, mango, guava, banana, and apple orchards respectively. While the corresponding deficiency figures for available iron are 28, 3, 24, 16,and 12 per cent in above orchards respectively.

The main reasons for the deficiencies of above mentioned micronutrients especially zinc and iron may be attributed to nature of parent material, coarse soil texture, low use of organic matter and micronutrient fertilizers, alkaline pH and calcareousness of our soils. Moreover boron deficiency analyzed only in banana and apple orchards also seems to be wide spread. Relatively wider boron deficiency in the two orchards soils might be due to the fact that the samples were collected during July to September, which is termed *monsoon* period (i.e. high rainfall months) in the country. As boron is highly soluble under such conditions so, temporary deficiencies of boron might be expected. Moreover in banana, which is a nutrient exhaustive crop, too much irrigation is applied which may be responsible for boron leaching although its parent mineral tourmaline is highly insoluble in soil.

B) *Features to be considered for Fertilizer Management in Orchards*

The nutritional needs of fruit crops are different from those of annuals. In perennial crops, there is a need to supply nutrients for current fruit production as well as for the vegetative parts, which persist for several years. So following points should be kept in mind.

i. Certain nutrients get accumulated in various parts of the tree such as roots, trunk, branches etc., and they can be mobilized for future use since the plant responds in subsequent years to both direct and residual soil fertility apart from drawing nutrients from reserves.
ii. Establishment of optimal plant nutritional ranges at different development stages. For example studies in grapes have clearly demonstrated that yield potential is determined early in the season and is influenced by the nutrient status at the time of fruit bud initiation and differentiation (Bhargava and Chadha, 1993). It is the proportion of N, P, K and other micronutrients that induces the bud either to differentiate in to a fruit bud or in to a non-productive structure such as tendrils.
iii. Fertilizer application should match the growth pattern of root distribution. For example the root system of grapes, when properly fertilized and irrigated is confined to top 45 cm depth and up to 120 cm in lateral directions, whereas in banana, the roots are mostly on surface and, therefore, feeding top

Table 1. Micronutrients status of orchards soils in Pakistan

	Iron	Copper	Manganese	Zinc
Pakistan: Sample size 329				
	Iron	Copper	Manganese	Zinc
Average contents (ppm)	11.6	1.9	13.4	1.3
Range (ppm)	2.1-76	0.03-9.6	1.03-42.5	0.1-9.8
% Deficiency	19	2	4	64
% Deficiency (0-9 inches)	26	1	2	59
% Deficiency (9-18 inches)	30	3	5	87
Punjab: Sample size 158				
	Iron	Copper	Manganese	Zinc
Average contents (ppm)	12.7	2.0	13.8	1.3
Range (ppm)	2.1-50	0.03-9.6	1.03-42.5	0.1-7.8
% Deficiency	22	0	5	60
% Deficiency (0-9 inches)	16	2	0	54
% Deficiency (9-18 inches)	35	5	7	79
Sindh: Sample size 94				
	Iron	Copper	Manganese	Zinc
Average contents (ppm)	10.4	1.6	7.6	0.5
Range (ppm)	3.0-76.0	0.59-5.0	1.9-25.0	0.17-1.6
% Deficiency	16	0	2	90
% Deficiency (0-9 inches)	14	0	3	90
% Deficiency (9-18 inches)	21	0	0	100
Balochistan: Sample size 72				
	Iron	Copper	Manganese	Zinc
Average contents (ppm)	10.8	1.9	20.4	1.8
Range (ppm)	2.5-30.0	0.2-6.0	1.4-32.5	0.3-6.8
% Deficiency (0-18 inches)	19	1	4	43

Province wise deficiency (%)

	Iron	Copper	Manganese	Zinc	Boron
Balochistan	19	1	4	43	64*
Sindh	16	0	2	90	94**
Punjab	22	0	5	60	

% Deficiency* in soils (Orchard wise)**

	Sample size	Iron	Copper	Manganese	Zinc	Boron
Apple	68	12	2	2	40	64*
Banana	92	16	0	2	89	94**
Citrus	85	28	2	8	68	
Guava	45	24	7	2	47	
Mango	39	3	0	0	60	

* Sample size=56 (Apple orchards only)
** Sample size=48 (Banana orchards only)
*** Deficiency limits in soils: iron $\leq$ 4.5 ppm, copper $\leq$ 0.2 ppm, manganese $\leq$ 2.0 ppm, zinc $\leq$ 1.0 ppm

15 to 30 cm of soil provides the best result. During the dry season the active roots go to deeper layers in search of ground water and under such situations, foliar feeding can be opted.

iv. Application of fertilizer obtained from an appropriate nutrient source at appropriate growth stages is essential to get good returns. For example phosphorus is needed at the time of planting for root formation and also at the time of fruit bud differentiation. On the contrary, potassium is involved in movement of photosynthates inside the plant system and therefore, its optimum concentration in plant tissues should be ensured at the time of fruit development and sugar translocation. Moreover crops such as grapes are sensitive to Cl and therefore, recommendations are made to apply SOP fertilizer for better quality.

C) Strategies for the Correction of Micronutrients Deficiencies

i. Zinc Management

One of the important functions of zinc is the synthesis of auxin or indoleacetic acid (IAA) from tryptophan. Due to alkaline and calcareous nature, Pakistan's soils are more prone to zinc deficiency. Zinc solubility is highly soil pH dependent and decreases 100-fold for each unit increase in pH, and effective because the roots of some fruit crops occupy deep soil layers and zinc does not easily move in the soil towards beneath layers. The deficiency of micronutrients can better be controlled by making up deficiency doses through soil and later on maintenance doses through foliar feeding. On an average, zinc metal residual effect persists for three years. For correction of zinc deficiency, suggested fertilizers and their doses have been discussed in table 2 and 3.

Table 2. Commonly Available Micronutrient Fertilizers

Nutrient	Def. limit in soils (ppm)	Suggested fertilizers	Solubility in 100 L water
Zinc	$\leq$ 1.00	Zinc sulfate (23 % Zn)	44 kg
Boron	$\leq$ 1.00	Boric acid (17 % B)/ Borax (11 % B)	6.5 kg
Iron	$\leq$ 4.50	Ferrous sulfate/ iron chelates	15.7-48 kg
Copper	$\leq$ 0.20	Copper sulfate	32 kg
Manganese	$\leq$ 2.00	Manganese sulfate	105 kg

Table 3. Micronutrient Fertilizer Recommendations for Orchards

Nutrient	Mode	Dose	Fertilizer
Zinc	Soil	40-100 g zinc/tree	175-435 g $ZnSO_4$ (23% Zn)
	Foliar*	0.1 % zinc	440 g $ZnSO_4$ (23 % Zn)
Boron	Soil	10 g Boron/tree	35-70 g Granubor (15 % B)/45-90 g borax (11 % B)
	Foliar	0.05-0.1 % B	325-650 g Granubor (15% B) or 450-900 g borax (11 % B)
Iron	Soil	Fe-Sequestrene	Fertigation of Fe-Sequestrene @ 3-5 mg/L
	Foliar	0.5-1 % Ferrous sulfate (20 % Fe) or 1 % Fe-Sequestrene	0.5-1 kg Ferrous sulfate /1 Litre of Fe-Sequestrene

* Recommended fertilizer dose dissolved in 100 litre of water.

uptake by plants decreases as a consequence. Soil pH is more important than any other single property for controlling Zn mobility in soils (Anderson and Christensen, 1988). The low availability of Zn in high pH calcareous soils is due to the adsorption of Zn on clay or CaCO3 (Trehan and Sekhon, 1977). In addition, high concentrations of HCO_3^- inhibit Zn uptake and translocation (Dogar and van Hai, 1980).

Conditions under which fruit trees are most likely to respond to corrective Zn treatments in terms of growth, yield, and fruit quality are not completely understood. In citrus and apples, the occurrence of severe deficiency symptoms appears to be a prerequisite for tree responses. Due to wide occurrence of zinc deficiency in orchards, soil applications are generally recommended. Some times soil applications of zinc might not be much

High rates of phosphatic fertilizers applied to low Zn soils enhances the plant accumulation of P thereby increasing the internal plant Zn requirement because of Zn precipitation (Robson and Pitman, 1983). Therefore, high application rates of P fertilizer can induce Zn deficiency (P-induced Zn deficiency) and increase plant requirements for Zn (Robson and Pitman, 1983). Inappropriately high P applications have induced Zn deficiency in plants most likely because of increased P uptake and higher shoot growth, which has led to decreased Zn in shoots because of dilution (Loneragan *et al.*, 1979; Marschner, 1993). Zinc-deficient plants may also have high and potentially toxic P concentrations, and P toxicity symptoms have sometimes been mistaken for Zn deficiency (Fageria and Gheyi, 1999). High levels of P may also result in increased absorption and retention of

Zn in roots and decreased translocation to leaves (Iorio *et al.*, 1996).

ii. Boron Management

A primary function of boron is related to cell wall formation, so boron-deficient plants may be stunted (rosetting). In orchard crops, sugar transport, flower retention and pollen formation & germination are severely affected by boron. Boron deficiency causes cracking and internal & external cork development in fruit. Boron is the only micronutrient to exist in solution as a nonionized molecule over soil pH ranges suitable for the growth of most plants. Increasing soil pH decreases B availability by increasing B adsorption onto clay and Al and Fe hydroxyl surfaces, especially at high soil pH (Keren and Bingham, 1985). Boron deficiency is common for plants grown in arid, semiarid, and heavy rainfall areas in calcareous, sandy, light textured, acid, and low OM soils (Gupta, 1993). Positive responses to B application have been reported in over 80 countries and on 132 crops over the last 60 years (Shorrocks, 1997).

Boron is absorbed by roots as undissociated boric acid [$B(OH)_3$ or H_3BO_3], and it is not clear whether uptake is active or passive (Marschner, 1995; Mengel and Kirkby, 1982). Boron is supplied to roots primarily by mass flow. The factors affecting B uptake include soil type, B content, soil pH, amount of water soil receives, and plant species (Welch *et al.*, 1991). Boron is very vulnerable to leaching so its deficiency can temporarily be expected in Pakistan during and after *monsoon* rains especially on coarse textured soils. However, its major source mineral i.e. tourmaline is highly insoluble. In Pakistan Alfisols, appear to be the soil group most likely to produce B deficient crops. Boron deficiencies are also more pronounced during drought periods when root activity is restricted. Once boron has accumulated in a particular organ, it has restricted mobility in most plant species but not all.

Boron deficiency manifests itself in poorly developed stamens, blast of pear blossoms, inadequate fruit set, bark necrosis of apple, corking in the fruit, and cracking of fruit. Moreover B deficiency is also observed through its effect on calcium uptake. Symptoms of this are cork spot and cracking of fruit, both calcium related disorders. Flatness of fruit is also often attributed to B insufficiency. When leaf B levels are in the range of 20-25 ppm (desired is 35 ppm) on a dry-weight basis, supplemental B is needed. Boron is taken up from the soil only at higher soil temperatures than are other elements. Late bud break and small spur leaves in apple may be signs of incipient B insufficiency, and B sprays may be useful in such cases. Because of the narrow margin between boron sufficiency and toxicity, an excess dose can easily occur and harm plant growth (Marschner, 1995). Therefore, extreme care is needed to apply the correct dose of boron fertilizer and to distribute it uniformly. Boron may safely be recommended for orchards at a rate of 0.56 kg B/ha as a maintenance dose and at a rate of 1.12 kg B/ha as a deficiency dose. Its residual effect is generally reported for two years. Boron sources and their recommendations are listed in Table 2 and 3. In case of Borax (11 % B), application rates should not exceed 90 g per tree.

iii. Iron Management

The role of iron in photosynthesis, nitrite and sulfate reduction and N_2 assimilation is well established. Although it is the 4th most abundant element in soils, yet its deficiency (chlorosis) is wide spread in orchards and is by far the most difficult to correct especially in calcareous soils. The solubility of Fe decreases by~1000-fold for each unit increase of soil pH in the range of 4 to 9 compared to ~100-fold decreases in the activity of Mn, Cu, and Zn (Lindsay, 1979). Minimum Fe solubility occurs between pH 7.5 and 8.5, which is the pH range of many calcareous soils (Lindsay, 1991).

For the correction of iron deficiency, inorganic Fe sources have proved non-effective. Efficiency of soil applied Fe-chelates are somewhat effective to prevent chlorosis but it must be supplemented with repeated iron foliar sprays (Table 2 and 3). The 1st report on chlorosis correction was with inorganic Fe salt additions by Gris in France in 1843. Iron-containing synthetic chelates are usually quite expensive, but, generally speaking, they could indeed be effective in correcting leaf Fe chlorosis (Abadia *et al.*, 2002). However, Fe(II) salts are in many cases as effective as Fe(III) chelates. It is also interesting to mention here that some acidic treatments like 0.5 m*M* H_2SO_4, citric acid @ 2 g/l can release Fe immobilized within the plant by changing apoplastic pH.

Plants evolved on Fe-deficient calcareous soils have natural ability to develop adaptive mechanisms to overcome or minimize the effects of Fe deficiency stress. Marschner and his colleagues have identified two different types of adaptive root responses to Fe deficiency. The first strategy exists in all plant families other than graminaceous family, and is characterized by the mechanisms involving acidification of rhizosphere, activation of a membrane-bound ferric reductase enzyme and the release of reducing substances from roots (Marschner, 1995). These mechanisms are highly inducible in response to Fe deficiency; they improve solubilisation and uptake of Fe from sparingly soluble Fe compounds in soil. The other strategy (strategy II) is confined only to graminaceous species, and characterized by the release of the mugineic acid family phytosiderophores (MAs) to chelate Fe in rhizosphere. The resulting Fe (III)-MAs are taken up into root cells by an inducible specific transporter in the root cell plasma membrane (Marschner and Romheld, 1994).

D) Pros and Cons of Foliar Application of Micronutrients

There are several good reasons for foliar nutrition practice. Micronutrients such as zinc, boron, and iron are required in relatively small quantities by plants (i.e. less than 100 g to produce 1 ton of economic yield). Thus, foliar sprays can prevent or correct a problem with relatively small amounts absorbed by the foliage but at the same time it has also been recognized that root uptake must be maximized in order to obtain the most benefit from foliar sprays. For details about different aspects of foliar nutrition readers may refer to various reviews (Jyung and Wittwer, 1965; Wittwer etal., 1967; Franke, 1967; Haynes and Goh, 1977; Slowik and Swietlik, 1978; Kannan, 1980). Mineral nutrients enter into leaves in three steps (Frank, 1967) involving: (1) penetration through the cuticle and epidermal walls; (2) adsorption on the surface of the plasmalemma, and (3) passage through the plasmalemma into the cytoplasm. Discontinuities and cracks in the epicuticular waxes, however, open a pathway for penetration of leaf-applied nutrients.

Bukovac and Wittwer (1957) classified foliar-absorbed mineral nutrients in to three groups: mobile, partially mobile, or immobile. According to these authors, mobile nutrients are K, Na, P, Cl and S; partially mobile ones are Zn, Cu, Mn, Fe and Mo; and immobile one are Ca. Very little is known about the mobility of foliar-absorbed boron. Chamel *et al.* (1981) found that 24 hours after foliar application of boron (as H_3BO_3) to radish, 78 to 98 % of absorbed B was still present in the treated leaf, 4.5 to 7 % had migrated to the epicotyl, and 2.5 to 17.7 % had migrated to the hypocotyls. Considering these data, B may also be regarded as a partially immobile nutrient when foliar-applied.

Applying micronutrients to the foliage is widely practiced in fruit crop production to get quick response especially after the appearance of deficiency symptoms. Foliar applications of B, Cu, Mn, and Zn for controlling deficiencies of these elements in fruit trees have advantages over soil application. Those advantages are high effectiveness, rapid plant responses, convenience, and elimination or reduction of toxicity symptoms brought about by excessive soil accumulation of a given element. Several disadvantages/problems associated with foliar applications include low penetration rates in thick leaves, run-off from hydrophobic surfaces or being washed off by rain, rapid drying of spray solution, limited translocation from uptake site to other plant parts, limited amounts of nutrients that can be supplied and often do not meet plant demands, and leaf damage/burn (Marschner, 1995). Thus the effects of foliar sprays are temporary and are not transmitted into the next year so, annual sprays are necessary. In case of Cu and Zn foliar nutrition, there is reported danger of leaf and/or fruit injury. By proper timing, injury can be avoided but there is need for better means of supplying these elements to fruit trees (Navrot and Banin, 1982).

i. Boron

Batjer and Thompson (1949) were the first to report increased fruit set in pear after treatment with B sprays at bloom, even though the control trees did not express deficiency symptoms and fruit and leaf boron at harvest were high. The authors speculated that trees could experience temporary B insufficiency during bloom, which was not reflected by leaf and fruit analysis. Degman (1953) concluded that B sprays might improve fruit set only when deficiency symptoms were present. Later reports seem to support this idea (Horsfall and Shear, 1950; Dixon *et al.*, 1973). Boron deficiency causes cracking and internal and external development in fruit. Confusion between B-deficiency symptoms and bitter pit and cork spot probably led to many misinterpretations as to the effect of B sprays on the occurrence of bitter pit and cork spot (Faust and Shear, 1968). In addition to relieving B-deficiency symptoms, B applications may affect fruit quality through its effect on fruit Ca nutrition. Application of B to apple trees low in B was shown to increase the mobility of ca in the trees (Shear and Faust, 1971).

Chaplin *et al.* (1977) and Westwood and Stevens (1979) reported increased fruit set and yield resulting from fall B sprays applied to non-B-deficient prune and cherry trees. This effect was interpreted as a direct involvement of B in the reproductive physiology of the tree. It was also suggested that B absorbed from fall sprays was metabolized and available for flowers in early spring in suitable chemical form (Chaplin and Westwood, 1980). The research to date has failed to answer precisely under what conditions B sprays would result in beneficial response in fruit set and fruit yield. This task is complicated by the fact that availability of soil B is strongly dependent on soil conditions and as a consequence is subject to rapid changes. Thorough knowledge of B requirements at different stages of tree growth is essential. Excess of B, resulting from unnecessary sprays, may cause negative effects, i.e. premature fruit senescene on some cultivars (Yogaratnam and Johnson, 1982). Too frequent spraying with B after bloom may cause fruit drop, fruit breakdown of apples in storage, and possibly B toxicity (dieback of shoots and veinal chlorosis). Experiences have indicated that B sprays can be concentrated up to eight times with satisfactory results.

ii. Zinc

There are no advantages in using chelated products of zinc and manganese in sprays as compared to their inorganic salts. Foliar-absorbed Zn is not easily translocated in plants, which necessitates repeated spray applications. Increases in yields of apple trees after treatment with zinc sprays have been reported by some authors. However, the nutritional status of the trees in these studies is not reported. Stang *et al.* (1978) observed no effect on fruit set by Zn sprays applied to dormant apple trees with high leaf levels (117 ppm) of Zn. Although some research work indicates a positive effect of zinc sprays on fruit calcium that resulted in less bitter pit. However, the results of other investigations don't confirm these findings (Yogaratnam and Johnson, 1982). As some fungicides like *Dithane M-45* and *Zineb* also contain zinc so recommended foliar doses must be accordingly adjusted. During the dormant season, higher rates of Zn compounds can be applied. Injury from spring applications has been associated with oil sprays and/or cool temperatures at the time of application. Zinc sulfate is not recommended for application within 3 days before or after applying oil. The addition of urea to zinc sprays probably might improve zinc absorption.

iii. Iron

Iron fertilization with foliar sprays is usually carried out with products containing at least 200 mg of Fe per L of solution. The chelated forms of mineral nutrients are extensively used for foliar applications, especially Fe Chelates. For iron the literature contains conflicting reports as to whether the iron chelates or inorganic salts are more effective. Their effectiveness is probably related to their increased mobility within the plant compared with inorganic salt sources of Fe, since chelation of Fe with EDTA (ethylene-diamine tetraacetic acid) or EDDHA (ethylene-diamine di-O-hydroxy-phenylacetic acid) decreased absorption of Fe by leaves compared with $FeSO_4$ (Kannan and Wittwer, 1965). Basiouny and Biggs (1976) reported greater Fe uptake by citrus leaves from FeEDTA than from $FeCl_3$. According to Kannan and Mathew (1970), translocation of foliar-applied Fe may be enhanced by chelation and by treatments with GA_3 and kinetin (6-furfurylamino purine).

The technology of foliar application of nutrients must consider the time of application, most commonly used effective concentration, dose per acre, dilute vs. concentrated application, mixability with pesticide sprays, and, finally, pesticides as a source of foliar nutrients. Various surfactants like *detergent surf* and humactants (0.2 per cent $CaCl_2$) can enhance foliar nutrition efficiency. However, $CaCl_2$ should not be combined with boron foliar sprays (Williams *et al.*, 1983). Here below is a general listing of recommendations commonly followed by cooperative extension services in the United States of America (Table 4) extracted from a review work of Swietlik and Faust (1984). For chelates or organic complexes farmers should follow manufactures guidelines. Moreover, solubor as a source of boron should not be applied over 2.3 kg per acre per year.

iv. Timing(s) of Foliar Sprays

Best timing for foliar sprays should be one or more of the followings; i) at new flush, ii) after fruit harvesting, iii) pre-anthesis/2-3 weeks prior to fruit

Table 4. General recommendations for foliar application of micronutrients in orchards commonly followed by cooperative extension services in the USA

Nutrient	Time of Spray	Purpose	Materials	Dose per hectare	Concn. for dilute spray in 100 L water
Boron	Prepink, pink	maintenance	Solubor	2.8 Kg	0.06 Kg
	Foliar	maintenance	Solubor	2.8 Kg	0.06 Kg
	Prepink	correct deficiency	Solubor	5.6 Kg	0.1 Kg
	Foliar	correct deficiency	Solubor	5.6 Kg	0.1 Kg
Iron	Dormant	correct deficiency	Solubor	4.5-6.0 Kg	
	Foliar	control of chlorosis	Fe chelate or org. complex		As per manufacturer recomm.
Zinc	Dormant	maintenance	$ZnSO_4$ (36%)	4.5 Kg	1.5 L
	Dormant	maintenance	$ZnSO_4$ 47 g/L	18.9 L	0.5 L
	Post-harvest	maintenance	$ZnSO_4$ (36%)	6.8-28 Kg	0.1-0.8 Kg
	Post-harvest	maintenance	$ZnSO_4$ 47 g/L	18.9 L	0.25-0.5 L
	Dormant	correct deficiency	$ZnSO_4$ (36%)	112 kg	1.2 Kg
	Dormant	correct deficiency	$ZnSO_4$ 47 g/L	113 L	3 L
	Post-harvest	correct deficiency	$ZnSO_4$ (36%)	30.5 Kg	0.3-0.7 Kg
	Post-harvest	correct deficiency	$ZnSO_4$ 47 g/L	66 L	1-1.5 L

bud differentiation, iv) at full bloom, and v) at small fruit formation stage. Due to restricted mobility of iron, zinc and boron in plant tissues and keeping in view plant physiology, the authors are of the view that as orchard crops try to accumulate maximum amounts of essential nutrients before flower formation so micronutrients foliar sprays should be made preferably after fruit harvest and before flower formation in addition to recommended deficiency doses already applied through soil. However, after review of literature some general recommendations regarding application timings for individual nutrients are also listed below for the interest of readers.

Zinc foliar sprays applied before anthesis may be most beneficial in terms of fruit yield in citrus and grapes. Bicarbonate-induced chlorotic leaves are usually recommended to be sprayed with Fe Chelates twice during the growing season. The first spray is recommended about 4 weeks after bloom and the 2nd spray 3 weeks later. Johnson *et al.* (1955) consistently showed post harvest B sprays to be more advantageous than spring season sprays. In literature, effectiveness of early but not late boron sprays is evidence that B is critical for pollination or fertilization of flowers. In apples pink flowering timing for B sprays is often used because of the importance of adequate B for proper pollen tube growth, flower fertilization, fruit set, and early fruitlet development (Peryea, 2002). To improve the B status of the trees in early spring, B must be applied in late autumn season or early spring before bloom.

E) Efficacy of Chelates to Correct Micronutrients Deficiencies

True chelates are compounds containing ligands that can combine with a single metal ion (e.g. Zn^{2+}) to form a well defined, relatively stable cyclic structure called a chelation complex. These properties are particularly important and useful in agricultural regions with basic (i.e., high pH) and/or calcareous soils. In the chelated form, metals ions are less likely to react with and be immobilized by the soil and are more likely to be "delivered" to plant roots. Some products are called "organic chelates" but are actually organically complexed micronutrient sources. Organic complexes, sometimes called "organic chelates" are formed by reacting metallic salts with various organic, industrial by-products (e.g. by-products of the wood pulp industry; sucrose type materials like cane sugar molasses). The structure of these by-products is not well defined (hence the term complexes) and there is no evidence that the resulting product has true chelate structure or properties. Producers of organic sources generally claim a 10:1 advantage of organic sources vs. inorganic sources. However, most of the research work has depicted that there is approximately a 3:1

to 5:1 advantage for ZnEDTA, a "true" organic chelate. In case of iron chelates, Fe-EDDHA (marketed under the trade name of *Sequestrene* and *Feriplex and available in Quetta @ Rs. 800-1000 per litre*) is more stable in high pH, calcareous soils than Fe-EDTA. In Israel to alleviate iron deficiency in mango orchards, Fe-Sequestrene is recommended through fertigation @ 1-5 mg/l. According to Tandon (1995), higher efficiency of chelated micronutrients has only been well proven for iron.

F) Micronutrients Fortified Fertilizers: A Future Option

To promote micronutrients application to correct their wide spread deficiency, it would be the best option to incorporate them into popular chemical fertilizers like UREA and DAP. This will also help to apply small quantity of micronutrient fertilizers over a large field area in a uniform manner. To formulate micronutrient-enriched fertilizers, possible reaction pathways, reaction products and their complex nature as well as solubility properties need prior investigations in depth (McCollum *et al.*, 1966). More often, however, multiple reactions occur either in sequential alteration steps or as competitive reactions during formulation, subsequent storage periods, and the initial dissolution in soil. These reactions can broadly be divided into 6 categories, i) metathetical reactions ii) addition products iii) metal Complexing reactions iv) hydration and dehydration reactions v) reactions of incongruent dissolution, and vi) oxidation-reduction reactions. In brief, zinc source addition to DAP or UREA forms less soluble [$ZnNH_4PO_4$, $Zn_3(PO_4)_2.4H_2O$, or $Zn(NH_4)_3H(PO_4)_2.H_2O$] or explosive ($Zn(NO_3)_2.4NH_3$)/hygroscopic ($ZnSO_4.6CO(NH_2)_2$, $ZnSO_4.6CO(NH_2)_2.2H_2O$ etc) compounds respectively so possibility of its direct inclusion in to these fertilizers does not seem to be feasible (Mortvedt and Gilkes, 1993). Thus as an alternative, possible method to manufacture zinc-coated urea seems to be the only option. Little information is available for boron inclusion in to chemical fertilizers although strong possibility exists of its inclusion in to DAP fertilizer. However, it is desired that agronomic effectiveness of both the fertilizers be tested before entering in to commercial phase of the product.

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