MICRONUTRIENTS IN VEGETABLE CROPS

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PREFACE

Vegetables constitute a major part in Indian Agriculture in terms of providing food and nutritional security to the human being. In recent past, Indian Agriculture has made a quantum jump in vegetable production and produced 156.32 MT from an area of 8.99 M ha (Indian Horticulture Database, 2011-12). At present India is the second largest producer of vegetables next to China. However, the average productivity in India is only 17.4t/ha which is very less than many other countries. Therefore, large scope is available to enhance the production and productivity of vegetable crops to meet the demand of growing population and ensure the nutritional security. This can be achieved with the integration of available technologies incorporating integrated nutrient management.

The importance of micronutrients in Indian Agriculture has been realized during the course of 'Green Revolution' in the form of zinc deficiency caused *Khaira* disease of rice. After that the emphasis has been laid on the research and integration of micronutrients in agriculture. Intensive vegetable cultivation and development of nutrient responsive improved varieties/hybrids has created a problem of nutrient imbalance in soils due to extra nutrient mining. Imbalance between nutrient addition v/s removals, the later being on higher side, is a matter of great concern. Thus, it is imperative to maintain soil health for sustainable olericulture with adequate supply of micronutrients.

In the present compilation the authors have made an attempt to gather the available information on micronutrients in vegetable crops. This manual is a synthesis of available literature, personal experience and experience shared by the authors from extension personnel and progressive farmers. The main aim of this technical bulletin is to meet the challenges of micronutrient deficiencies and to develop suitable management strategies. It is hoped that this technical bulletin would provide sufficient information to help the researchers, the extension personnel and the progressive farmers engaged in vegetable cultivation so that micronutrient deficiencies may be corrected by adopting suitable management strategies.

The authors are highly grateful to Dr. S. Ayyappan, DG, ICAR and Secretary, DARE and Dr. N.K. Krishna Kumar, D.D.G. (Hort.), ICAR, New Delhi for their constant inspiration, encouragement and valuable suggestions to bring out this publication. The valuable suggestions given by Dr. S.K. Sharma, Director, CIAH, Bikaner for the improvement in the manuscript is highly appreciated.

(Authors)

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INTRODUCTION

The conventional practices of applying huge quantities of organic manures like FYM, compost, green manures to the vegetable crops maintain the soil with adequate quantities of micronutrients. With the restricted use of these bulky organic manures and use of high yielding short duration varieties and application of higher doses of macro elements resulted in stagnation of production and deficiency of micronutrients is likely to increase. Plants require altogether 35 elements, out of which 16 elements are considered as essential elements for their growth and development. The essential plant nutrients can be further divided into two groups, *i.e.* macro and micro nutrients. Micronutrients are elements which are essential for plant growth, but are required in smaller amounts than those of the primary nutrients *viz*., nitrogen, phosphorus and potassium. The essential micronutrients are iron (Fe), zinc (Zn), copper (Cu), boron (B), manganese (Mn), molybdenum (Mo) and chlorine (Cl). These elements are very efficient and produce optimum effects with minute quantities. Deficiencies of micronutrients drastically affect growth, metabolism and reproductive phase in plants. On the other hand, even a slight deficiency or excess is harmful to the plants. Soil pH is a key factor in regulating nutrient supply. The optimum availability of all macro and micronutrients is between weak acidic to neutral soils (pH 6.5-7.0).

Forms of micronutrients absorbed by plants

The micronutrients are being absorbed by the plants in both ionic and non-ionic forms which depend on the type of element. The details are given as under.

Micronutrient	Ionic form	Non-ionic form
Boron (B)	$B_4O_7^{2-}$, $H_2BO_3^-$, HBO_3^{2-}	-
Chlorine (Cl)	Cl^-	-
Copper (Cu)	Cu^{2+}	$CuSO_4$ with EDTA
Iron (Fe)	Fe^{2-}, Fe^{3-}	$FeSO_4$ with EDTA
Manganese (Mn)	Mn^{2+}	$MnSO_4$ with EDTA
Molybdenum (Mo)	MoO_4^{2-}	-
Zinc (Zn)	Zn^{2+}	$ZnSO_4$ with EDTA

EDTA=Ethylene diamine tetra-acetic acid

Mobility of micronutrients

The knowledge of the mobility of micronutrients in plants helps in finding the deficiency of particular nutrient. A mobile micronutrient in the plant moves to the growing points in case of deficiency and deficiency symptoms, therefore, appear on the lower leaves while immobile nutrients does not move to the growing points and hence, deficiency symptoms appears on the younger plant parts. Mobility of micronutrients in the soil has considerable influence on availability of nutrients to the plants and method of application.

Mobility in soil

i. **Mobile:** The mobile micronutrients are highly soluble and are not adsorbed on clay complex. e.g. $BO_3^=$, Mn^{++} and Cl^-.

ii. **Less mobile:** They are also soluble but adsorbed on clay complex and so their mobility is reduced. e.g. Cu^{++}.

iii. **Immobile:** These ions are highly reactive and get fixed in the soil. e.g. Zn^{++}.

Mobility in plants

Based on mobility of micronutrients in the plant system, they can be grouped as moderately mobile (Zn), less mobile (Fe, Mn, Cu, Mo, Cl) and immobile (B).

Chemical nature

The micronutrients can be classified into cations and anions and metals and non-metals based on their chemical nature.

Chemical nature	Micronutrients
Cations	Fe, Mn, Zn, Cu
Anions	Cl, B
Metals	Fe, Mn, Zn, Cu
Non-metals	B, Mo, Cl

Excess amount of micronutrients cause toxicity symptoms which are difficult to recognize visually and are usually mistaken by deficiency symptoms. The sufficient and critical levels of micronutrients in the leaf tissue of vegetable crops are as under:

Micronutrient	ppm of dry weight of leaf	
	Sufficient level	Critical level*
B	30-60	20-30
Cu	8-20	4-8
Fe	50-250	50-80
Mn	30-200	30-50
Mo	0.5-5.0	0.2-0.5
Zn	30-100	20-30

*Below critical level of nutrients in leaf tissue, deficiency symptoms in plant may occur.

The optimum range of micronutrients (ppm) in different vegetable crops is as under:

Vegetable	Fe	Mn	Zn	Cu	B
Beans	50-300	50-300	20-200	7-30	20-75
Beet root	50-200	50-250	20-200	5-15	-
Brinjal	50-300	40-250	20-250	8-60	25-75
Cabbage	30-200	25-200	20-200	5-15	25-75
Carrot	50-300	60-200	25-250	5-15	30-100
Cauliflower	30-200	25-250	20-250	4-15	30-100
Onion	60-300	50-250	25-100	15-35	22-60
Peas	50-300	30-400	25-100	7-25	-
Radish	50-200	50-250	19-150	5-25	25-125
Tomato	40-200	40-250	20-50	5-20	25-60
Turnip	40-300	40-250	20-250	6-25	40-100

Source: Anjaneyulu, K. and Raja, M.E. (1999). Micronutrient disorders in vegetable crops and their correction. *Indian Horticulture* (Jan.-March). pp 15-16.

Soil properties of the Thar Desert

The soil of the Thar Desert belongs to the order Aridisols and is sandy desertic, very poor in organic carbon, water holding capacity and deficient in zinc. The knowledge of soil properties helps the vegetable growers to raise a successful crop. The physico-chemical properties of desert soil are as follows:

i. Physical properties

Texture	Loamy sand
Sand content	80-90 %
Silt content	2-5 %
Clay content	2-10 %

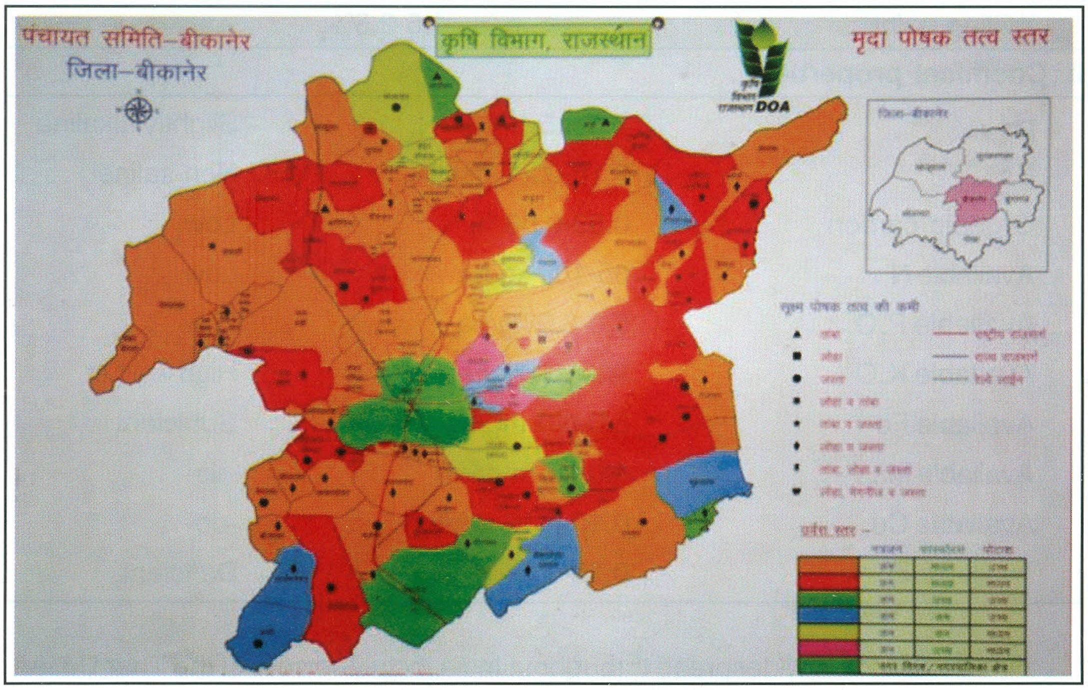
Structure	Single grain structure
Bulk density	1.58-1.60 mega gram/cubic meter
Soil moisture retention capacity	3.0-4.5% (w/w)
Wilting point	1.5-2.5%

ii. Chemical properties

pH	7.5-8.5	Slightly alkaline
Ec	0.16-0.21 dsm^{-1}	Non-saline
Organic carbon	0.03-0.08 %	Low
Available N	65-100 kg/ha	Low
Available P_2O_5	5.0-8.0 kg/ha	Low
Available K_2O	200-480 kg/ha	High
Available Fe	5.0-6.0 mg/kg	Sufficient
Available Mn	4.0-4.5 mg/kg	-do-
Available Cu	0.10-0.18 mg/kg	-do-
Available Zn	0.10-0.15 mg/kg	Deficient

Zinc deficiency is widespread throughout India including soils of the Thar Desert. The magnitude of boron deficiency is next to zinc. The soil health and organic content is not good and also deteriorating fast. The continuous deterioration of soil health does not allow harvesting optimum yield of vegetable crops. Management of micronutrients is a key factor in determining the production and productivity of vegetables in the era of intensive vegetable culture. Further the deficiency of micronutrients, if not properly taken care would threat the ecological sustainability of intensive cultivation of vegetable crops. Therefore, the main objective of this technical bulletin is to provide at glance information to the scientists, extension workers and progressive farmers to recognize the importance of micronutrients in vegetable crops under field conditions.

A detailed soil map with reference to micronutrient status of Indian soils is available in literature. However the information regarding micronutrient status of desert soils are scare and the soil map of *Panchyata Samiti*, Bikaner is given below.



Source: Department of Agriculture, Rajasthan

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FUNCTION

The micronutrients are involved in enzyme activation and electron transport. These elements act as catalyzers and activators in plant system. The important functions of micronutrients are as follows.

Micronutrient	Function	Deficient soils
B	i Involved in cell wall formation, cell division, fruit formation and seed development. ii Sugar transport in plants. iii Help in flower retention and pollen formation. iv Increase seed and grain production. v Involved in the synthesis of protein, carbohydrate.	i Acidic and sandy soils of high rainfall. ii Soils with low organic matter content. iii Deficiency also occurs during drought period.
Cl	i Helps in stomatal opening and electrical charge balance in plants. ii It indirectly affects plant growth by stomatal regulation of water loss.	Sandy soils in high rainfall areas or those derived from low-chloride parent materials.
Cu	i Necessary for carbohydrate and nitrogen.	i Mainly reported on sandy soils which are low in organic matter.

Micronutrient	Function	Deficient soils
	ii Required for lignin synthesis which is needed for cell wall strength and prevention of wilting.	ii Cu uptake decreases as soil pH increases. Increase in P and Fe availability in soils decreases Cu uptake by plants.
Fe	i Involved in the biosynthesis of chlorophyll. ii It is a component of many enzymes associated with energy transfer, N reduction and fixation, and lignin formation. iii Fe is associated with S in plants to form compounds that catalyze other reactions.	i Mainly in high pH soils, although some acid, sandy soils low in organic matter may also be Fe deficient. ii Cool, wet weather enhances Fe deficiencies, especially on soils with marginal levels of available Fe. Poorly aerated or compacted soils also reduce Fe uptake by plants. iii Uptake of iron decreases with increased soil pH, and is adversely affected by high levels of available P, Mn and Zn in soils.
Mn	i Necessary in photosynthesis and nitrogen metabolism. ii Helps in formation of carotene, riboflavin and ascorbic acid.	i Mainly occur on organic soils, high-pH soils, sandy soils low in organic matter, and on over-limed soils. It may be less available in dry and well-aerated soils. ii Uptake of Mn decreases with increased of soil pH and is adversely affected by high levels of available Fe in soils.

Micronutrient	Function	Deficient soils
Mo	i Involved in enzyme systems relating to nitrogen fixation by bacteria growing symbiotically with legumes. ii Affect N metabolism, protein synthesis and S metabolism. iii It has a significant effect on pollen formation.	i Mainly found in acid, sandy soils in humid regions. ii Mo uptake by plants increases with increased soil pH, which is opposite that of the other micronutrients.
Zn	i Essential component of various enzyme systems for energy production, protein synthesis, and growth regulation. ii Essential for the synthesis of tryptophan, a precursor of indole acetic acid (IAA). iii Helps in seed maturation and production.	i Mainly found on sandy soils low in organic matter and on organic soils. ii Zn uptake by plants decreases with increased soil pH. Uptake of Zn is also adversely affected by high levels of available P and Fe in soils.

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DIAGNOSIS

A number of abiotic and biotic factors may cause symptoms that resemble micronutrient deficiencies. The waterlogged soils are deficient in oxygen therefore; plants growing in such soils often develop small, yellow leaves and show the symptom of dieback just like the symptoms of iron deficiency. Under such conditions proper irrigation management would provide more effective results rather than application of micronutrients. Under drought conditions plants became stunted and the margins of their leaves may burn, especially during hot weather. Too much or too little of certain elements also cause the same symptoms. The root diseases also cause yellowing of foliage, which can resemble nutrient deficiencies. Improper use of certain herbicides, produce symptoms that could be confused with symptoms of zinc or iron deficiencies. Micronutrient deficiencies are often blamed when the real cause can not be identified. Therefore, during diagnosis of micronutrient deficiency symptoms one should have an appropriate knowledge of insect damage, disease symptoms, herbicide injury, drought, water-logging condition, *etc.* for proper identification of micronutrient deficiency symptoms in vegetable crops. Soil tests and plant analysis are excellent diagnostic tools to monitor the micronutrient status of soils and vegetable crops which are as follows:

Soil analysis

The availability of micronutrients depends on soil pH, texture and organic matter content. Availability of B, Cu, Fe, Mn and Zn generally decreases with increase in soil pH, while Mo increases with increase in pH. Mineral soils containing substantial organic matter may have an adequate supply of micronutrients due to mineralization of organic matter. The ideal soil pH for vegetable cultivation is between 6.5 and 7.0. Soil pH below 5.5 is not suitable at all for vegetable production. Deficiency of Mn and Fe occur most frequently in mineral soils having pH above 7.5.

Soil testing has immense value in establishing a sound vegetable cultivation program based on soil fertility. Soil testing is necessary to advocate judicious recommendation of micronutrients. Soil tests and their interpretations are based on the soil samples. Therefore, it is important that the soil samples should be properly collected. After scrapping the surface litter, uniform core of a thin slice of soil from the surface to plough depth (15-22 cm) from 15-20 spots of each sampled field should be taken. About a handful of soil sample should be taken and air-dried on plastic sheet before chemical analysis. The normal range of micronutrients found in mineral soils is as follows:

Micronutrient	Normal range (ppm)
B	5-150
Cu	5-150
Mn	200-10000
Mo	0.2-5
Zn	10-250

Source: Brady, N.C. (1980). The nature and properties of soils (8th ed.). MacMillan Publishing House Inc., USA.

Plant tissue analysis

The basic principle of this technique is that the nutrient concentration of plants is related to the amount of nutrient element available in soil. If the nutrient level in the plant tissues falls below the critical level, the soil may be deficient in that element for optimum plant growth. The most recently matured leaf serve well for routine crop monitoring and diagnostic procedures for most micronutrients. However, for the immobile nutrients like Ca and B younger leaves are generally preferred. The plant part to be sampled and growth stage of different vegetable crops for plant tissue nutrient analysis are as follows:

Crop	Plant parts to be used as sample	Growth stage/ time
Beans	2-3 fully developed leaves at top of the plant	Initial flowering
Bulb vegetables	Young mature leaves from centre	Prior to bulbing
Cabbage	First mature leaf from central whorl	Prior to heading
Cauliflower	Young mature outside leaves	Button stage of curd
Chilli	Young mature leaves	Early fruit set
Cucurbits	Mature leaves near the base portion of plant on main stem	Early growth prior to fruit set
Leafy vegetables	Youngest mature leaf	Mid-growth
Pea	Leaves from 3rd node down from top of the plant	Initial flowering
Potato	4th - 6th leaf from growing tip	Early growth (35-40 days after planting)
Root vegetables	Young mature leaves from central rings	Prior to root enlargement
Tomato	4th - 6th leaf from growing tip	Early bloom

Source:

1. Knott's Handbook for Vegetable Growers (1980). John Wiley & Sons, New York.
2. Donahue, R.L., Miller, R.W. and Shickluna, J.C. (1990). Soils: An Introduction to soils and plant growth. Prentice-Hall of India Pvt. Ltd., New Delhi.

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DEFICIENCY SYMPTOMS AND MANAGEMENT

Micronutrients play a vital role in metabolism of plant system. Generally, two elements rarely perform the same role in metabolism, therefore, element induces characteristic symptoms. Plants may not show visual symptoms up to a certain level of nutrient content, but growth is affected and this situation is known as hidden hunger. When a nutrient level still falls, plants show characteristic symptoms of deficiency. These symptoms though vary with crop to crop but have a general pattern. The deficiency of micronutrients can be categorized in the following two ways.

Primary deficiency: It refers to the low total content of micronutrients which depends on the type of soil and other agro-climatic conditions. Generally sandy and calcareous soils contain low amount of micronutrients, whereas clay loam and loam soils contain comparatively more micronutrients. Loose textured soil low in organic matter and soils of high rainfall areas are also deficient in micronutrients. Primary deficiency can be corrected by the application of chemical compounds containing micronutrient elements. It should be kept in mind that micronutrients should be applied only in deficient conditions otherwise they will cause phytotoxicity.

Secondary deficiency: It implies that total micronutrient content in the soil may be ample but their availability is affected due to soil pH, antagonism, *etc*. The availability of Zn, Mn, Fe, Cu and B is often reduced in soils exhibiting alkaline reaction whereas Mo is unavailable in acidic soils. Under such situation, proper soil management like liming and application of organic matter to the soil should be followed to avoid the deficiency symptoms.

How to understand micronutrient deficiency symptoms

The basic thing is first one should identify plant part and actual place where the symptoms mostly appeared. The most common hypothesis of micronutrient deficiency symptoms is that their deficiency symptoms are generally not appeared on older leaves. However, the deficiency symptoms can be broadly categorized in to three categories:

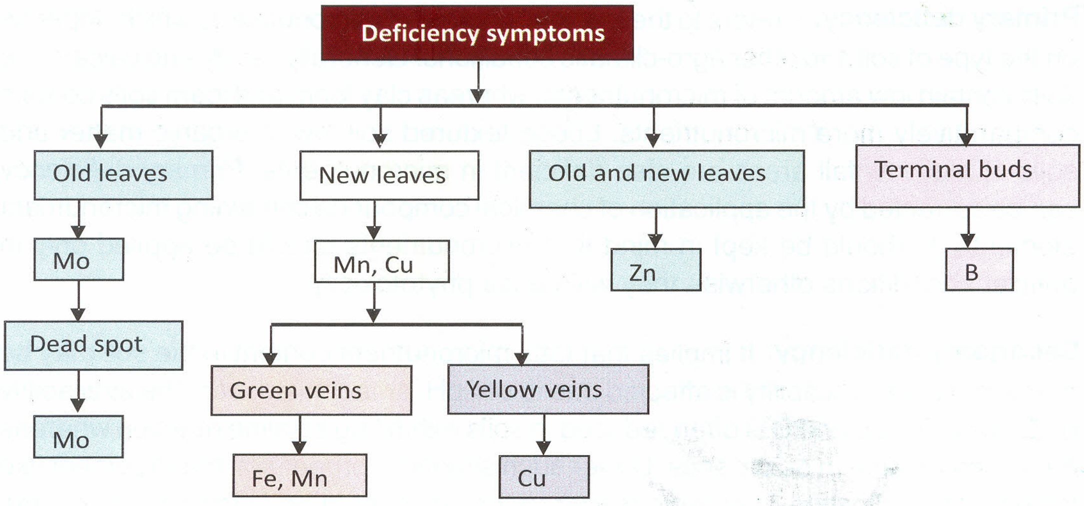
i. Symptoms mostly appeared on older leaves.

ii. Symptoms pronounced on younger leaves.

iii. Symptoms appeared on both younger and older leaves.

Identification of deficiency symptoms

The deficiency symptoms of micronutrients can be distinguished based on (i) region of occurrence, (ii) presence or absence of dead spots, and (iii) chlorosis of entire leaf or interveinal chlorosis.



The region of appearance of deficiency symptoms depends on mobility of micronutrient in plants. The deficiency symptoms of Mo appear in lower leaves because of their mobility inside the plants. It moves from lower leaves to growing leaves thus causing deficiency symptoms in lower leaves. Zinc is moderately mobile in plants and deficiency symptoms, therefore, appear in middle leaves. The deficiency symptoms of less mobile elements (Fe, Mn and Cu) appear on new leaves. Since B is immobile in plants, deficiency symptoms appear on terminal buds or growing points. In general, nutritional deficiency symptoms may appear on any part of a plant, but foliage symptoms are usually the most useful for visual diagnosis. The location of the symptoms on a plant may be a first helpful step in determining the cause of a nutrient deficiency: symptoms of nitrogen, phosphorus, and magnesium deficiency appear first on the lower leaves and progress upward; symptoms of boron and calcium deficiency begin at the apex of the plant and progress downward.

Micronutrient disorders, either a deficiency or toxicity are the most common fertility problem for successful vegetable cultivation. Even small variation from the optimum level may cause considerable loss in yield. So it is very important for the vegetable growers to have knowledge about the management of micronutrients. The main reasons of accelerated exhaustion of available micronutrients in the soil are as follows:

i. Introduction of hybrids and high yielding varieties of various vegetable crops which removes higher amount of micronutrients from soil and increase plant micronutrient demand.

ii. Application of more N, P and K fertilizers as it decreases the availability of micronutrients.

iii. Lack of organic input application in the soil.

iv. Adoption of intensive cropping system.

v. Application of compound fertilizers as generally they do not have micronutrients.

vi. Maximum application of phosphatic fertilizers decreases the availability of zinc.

vii. High acidity also aggravates micronutrient deficiencies (B, Mo).

viii. Leaching losses of few micronutrients (B) by high rainfall especially under coarse texture soil.

ix. Moisture stress condition decreases the availability of Fe and Bo.

Besides above factors antagonism also affect the availability of micronutrients as given below:

Micronutrient	Availability reduced by
B	Organic nitrogenous fertilizers and level of P
Cu	High level of Zn, N and P
Fe	High level of Cu, Mn, Zn and P
Mn	High level of K, P, Fe, Cu and Zn
Mo	High level of Mn and nitrate-nitrogen fertilizer
Zn	High level of Cu and P

Micronutrient deficiencies symptoms and their management

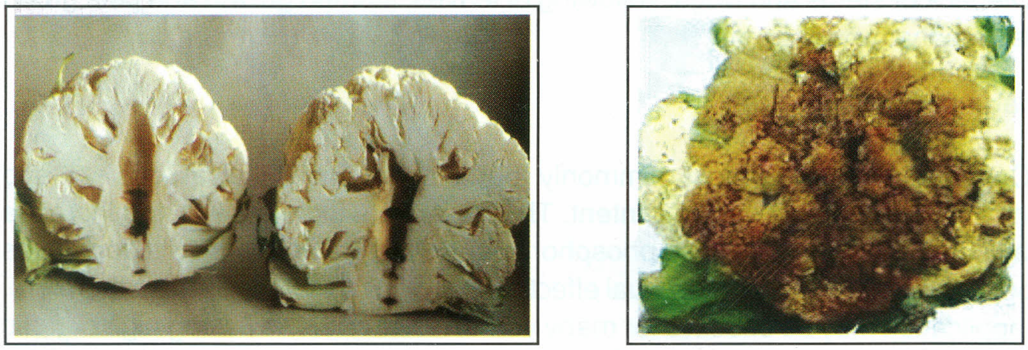
Micronutrient disorders have become widespread with diminishing use of organic manures, adoption of intensive cropping system, unbalanced use of NPK fertilizers and extension of vegetable cultivation on marginal lands. To get high quality produce and yield, micronutrient deficiencies have to be detected before visual symptoms expressed by the plants at hidden hunger stage. Thus vegetable cultivation needs judicious use of micronutrients to produce yield of high quality. The most common micronutrient disorders in vegetables are due to the deficiency of B, Mo, Zn and Fe.

Boron (B)

Breakdown of the growing tip resulting in death of shoot tip, rosette appearance of the plant due to shortening of terminal growth, young leaves of terminal buds are light green, thick, curled and brittle, root growth gets restricted and flower become barren. The crops like cabbage, cauliflower, sugar beet, potato, *etc.* are highly sensitive to B deficiency.

Typical symptoms

1. Browning of cauliflower curd.
2. Hollow heart in cauliflower.
3. Black heart of beet.
4. Internal browning of turnip.
5. Brown or black heart of potato.
6. Water soaked spots and hollow heart in radish.
7. Tomato fruits become pitted, corky and resulted in uneven ripening.



B deficiency in cauliflower

Management

Boron deficiency is mainly occurring in coarse textured soils and more pronounced during drought periods when root activity is restricted. Boron is highly immobile in the plant so frequent and a constant supply of boron to the young tissue or bud is must for proper growth and development of vegetable crops. Soils are considered deficient if the soil test value of B is less than 0.5 mg boron/kg soil. The most effective method of boron application is basal application in the soil at the time of land preparation or at transplanting. Spray @ 0.5-0.6% at early stage of crop is most effective. The rate of application varies from crop to crop being lowest in beans and highest in cole crops and beet. The common B fertilizers are borax (10.5% B) and boric acid (20% B), and these fertilizers can be applied @ 2-5 kg/ha, although the rate depends on the native availability of boron in the soil.

Copper (Cu)

Yellowing of young leaves, leaves may become elongated and tips may curl. Leaf edges may become ragged and plant top may wither.

Typical symptoms

1. Bulbs of onion become soft with thin pale young scales.

2. Dieback of stems and twigs, yellowing of leaves, stunted growth and pale green leaves that wither easily.

Management

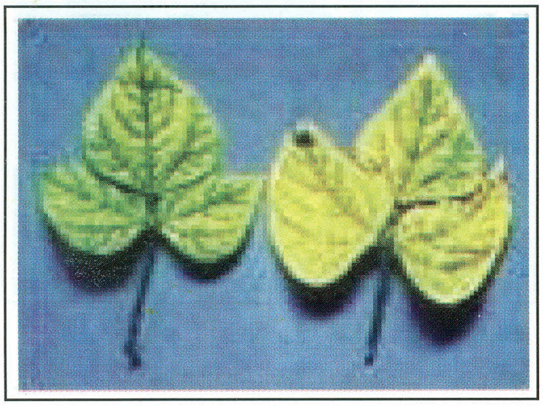
Cupper deficiency is most commonly found in sandy soil, calcareous soil and soil having high organic matter content. The level of Cu increase with the increase in clay content of soil. Increased phosphorus and iron availability in soils decreases copper uptake by plants. The residual effect of copper in the soil is very long therefore, one application may be effective for many years. However, soils having high organic matter require annual application of Cu. Some fungicides also contain Cu and their repeated use will increase the level of Cu in the soil. The main Cu containing fertilizers are copper oxide (75% Cu) and copper sulphate (35% Cu). Copper can be applied to the vegetable crops @ 5-10 kg/ha as soil application and 0.1-0.2% as foliar application.

Iron (Fe)

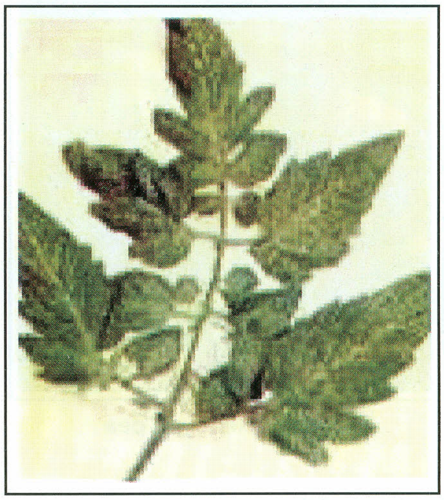
Typical symptoms are distinctive green vein colour and yellow interveinal areas on the young leaves. Points and margins of the leaves keep their green colour for long time. In severe cases, the entire leaf, veins and interveinal areas turn yellow which sometimes bleached. Fe deficiency is mainly manifested by yellow leaves due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves in interveinal tissues.

Management

Deficiency of iron occurs on soil with pH above 6.8, calcareous soil and soil containing considerable amount of sodium and calcium. Iron chlorosis is mainly corrected through foliar spray of iron containing micronutrients *i.e.* ferrous sulfate @ 0.4%. Soil application of Fe is not recommended as applied Fe quickly reverts to forms unavailable to the plants. Correction of iron chlorosis at early stage of crop growth is essential to prevent yield loss. A surfactant should be added in the solution to improve leaf adherence and absorption of Fe.



Fe deficiency in beans



Fe deficiency in tomato

Manganese (Mn)

Interveinal chlorosis is a characteristic symptom of Mn deficiency. Greyish areas may appear near the base of the younger leaves resulting in premature leaf drop. The leaves become smaller in size.

Typical symptoms

1. Interveinal chlorosis in pea called Marsh spot.
2. Narrow and yellow striping in the leaves of onion.
3. Chlorosis followed by necrosis and yellowing in the leaves of beans.
4. Small, yellowish leaves with interveinal yellow mottling in cabbage.
5. Chlorotic and forwardly rolled leaves in tomato.

Mn deficiency in pea

Mn deficiency in French bean

Management

Manganese deficiency is found in soils with pH above 6.7, calcareous and sandy soils. Uptake of Mn decrease with increased soil pH and is adversely affected by high levels of available iron in soils. In acidic soils, apart from low pH and toxicity of Mn may decrease the availability of P and Mo. Vegetable crops are sensitive to excess Mn. Interveinal chlorosis and its relation with over liming show a strong association of manganese deficiency with pH. Deficiency of Mn can be corrected by either soil application (5-10 kg/ha) or foliar spray (0.4-0.6%) of manganese sulphate with an adjuvant at first bloom stage in most of the vegetable crops.

Molybdenum (Mo)

Impairment of growth, deformation of shoot, older leaves show interveinal yellowing with necrotic margins and leaves may crinkle. The symptoms are identical with those of nitrogen deficiency.

Typical symptoms

1. Whiptail leaf (leaf lamina fail to develop) in cauliflower.
2. Mottling and whiptail in turnip.
3. Young leaves turn purple in tomato.
4. Discoloration of leaf and death of growing tip in radish.
5. Decomposition and granulation in veins of chilli.
6. Deep blue leaves with conspicuous yellow and green mottling in onion.
7. Leaves of cabbage become cup shaped and chlorotic mottling.

Whiptail in cauliflower

Management

Deficiency of Mo is associated with acidic soils having pH below 5.2 and highly leached sandy soils. The uptake of Mo by plants increases with increasing the soil pH, which is opposite that of the other micronutrients. The high level of Mn and nitrate-nitrogen fertilizers reduced the availability of Mo in the soil. The crops like cauliflower, broccoli, spinach, lettuce, radish and beans are highly sensitive to Mo deficiency. Ammonium molybdate (54% Mo) and sodium molybdate (38% Mo) are common Mo fertilizers available in the market and can be applied @ 2-5 kg/ha as soil application or 0.03-0.05% as foliar spray.

Zinc (Zn)

Deficiency symptoms mostly appear on the 2nd or 3rd fully mature leaves from the top of the plant. The most visible Zn deficiency symptoms are short internodes and decrease in leaf size. Zn deficiencies occur more often during cold, wet spring weather and are related to reduced root growth and activity as well as lower microbial activity decreases zinc release from organic matter. The crops like tomato, potato, beans and onion are highly sensitive to Zn deficiency.

Typical symptoms

1. Small reddish brown spots on cotyledonary leaves of beans.
2. Interveinal yellowing with marginal burning in beet.
3. Fern leaf disorder in potato.
4. Tomato leaves become smaller, chlorotic and inwardly curved.
5. Onion leaves turn yellow.
6. Whole plant turns yellow in garlic.
7. Middle leaves of cucurbits show golden yellow colour.

Zinc deficiency in tomato

Management

Neutral to alkaline sandy soils and calcareous soils are mostly suffering from Zn deficiency. It has been well documented that at least 50% of the Indian soils suffer from Zn deficiency. Indian soils are generally considered zinc deficient if the test value is less than 0.6 mg DTPA-extractable Zn/kg soil. Zn uptake by plants decreases with increased soil pH and the uptake of zinc also adversely affected by higher levels of available phorphorus and iron into soils. The common fertilizers are zinc sulphate (21 and 33% Zn) and zinc-EDTA (12% Zn). Zinc sulphate ($ZnSO_4$) is suitable for soil application @5-25 kg/ha (based on native Zn availability of soil) while Zn-EDTA is suitable for foliar application @ 1%.

Methods of Application

Vegetable crops respond very well to the application of micronutrients. Generally, micronutrients are applied in following ways:

i. Soil application

Micronutrient containing materials can well be applied to soil mixed with other fertilizers at the time of land preparation or transplanting of vegetables. Care should be taken to avoid excess application of micronutrients to avoid toxicity. Doses of micronutrients depend on soil type, crop, *etc*. On the basis of soil and plant analysis report, the foliar recommendation has been given for different micronutrients is as follows:

Rate of application varies with the type of soil. As a higher rate of manganese is required for both organic and sandy soils which are alkaline in reaction; high rate of zinc is applied when soil is neutral to alkaline in reaction.

Source and rate of micronutrients for soil application

Micronutrient	Source	Quantity required (kg/ha)
B	Borax- 10.5 % Boron	2-5
Cu	Copper sulfate- 35% Cu	5-10
Fe	Iron sulfate- 20% Fe	10-15
	Iron chelate (EDTA)- 12% Fe	15-20
Mn	Manganese sulfate- 28% Mn	5-10
Mo	Sodium molybdate- 38% Mo	2-5
	Ammonium molybdate- 54% Mo	2-5
Zn	Zinc sulfate- 21 & 33% Zn	5-25

ii. Seedling root dip

This method of application is not widely practiced in India. Generally, 0.2-0.3 per cent solution of zinc sulfate is used for root dipping of vegetable seedlings.

iii. Seed treatment

Seeds of vegetables can be treated with the chemical compounds containing Cu, Fe, Zn, B, Mn, *etc.* prior to sowing. Seed treatment of pumpkin and squashes with borax @ 0.5% increases number of female flowers and ultimately yield.

iv. Foliar spray

Foliar application of micronutrients is widely used. Most of the micronutrients, after foliar spray, enters the plant body though leaves within few hours to one day. They mostly enter the leaf via stomata. Since the stomata are mostly present on the undersurface of the leaf, the foliar spray should be applied to both under and upper surfaces of the leaf as evenly as possible for rapid and complete absorption of the nutrient solution. 2-4 foliar sprays at an interval of 7-10 days are sufficient to correct the deficiency symptoms. This method is most suitable because of the following reasons:

i. Convenience in application.

ii. Requirement of micronutrients in small quantity.

iii. Quick correction of deficiency symptoms.

iv. Avoidance of fixation of the micronutrients in soil.

Recommended concentration of micronutrients for foliar application

Micronutrient	Concentration
B	0.5-0.6% borax
Cu	0.1-0.2% copper sulfate + 0.5% lime*
Fe	0.4% ferrous sulfate + 0.2% lime*
Mn	0.4-0.6% manganese sulfate + 0.2-0.3% lime*
Mo	0.05% sodium or ammonium molybdate
Zn	0.4-0.6% zinc sulfate + 0.1-0.3% lime*

*Lime is added to neutralize the solution, otherwise leaves may get scorched. Minimum 450 litres of water must be used per hectare.

Vegetable crops being short duration and bio-accumulating crop which removes substantial quantities of plant nutrients from soil. Thus, the management of plant nutrients for vegetable production with improved quality traits demands integration of fertilizers with organics, green manures, bio-manures and bio-fertilizers to enhance overall nutrient use efficiency and reduce cost of production. Our plant nutrient management strategies should, therefore, be in tune with large nutritional requirement ensuring full replenishment of the nutrients depleted through intensive vegetable cultivation. Thus in the present scenario, micronutrients has great promise in increasing vegetable production and productivity, sustaining soil health and maintaining ecological balance.

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