Review Article

Role of Foliar Nutrition of Micronutrients in Vegetable Production: A Review

ABSTRACT

Vegetables are potential source of vitamins, minerals and dietary fibers. Proper plant nutrition is essential for successful production of vegetable crops. Integrated supply of micronutrients with macronutrients in adequate amount is an important approach to sustain the soil health and crop productivity besides maintaining the nutritional quality of vegetables. Micronutrients (Fe, Zn, B, Cu, Mn, Cl, Mo, Ni) are required by plants in small or trace quantities. They are essentially as important as macronutrients for better growth, yield and quality of plants. Deficiencies of micronutrients may induce several physiological disorders in plants and drastically affect growth, metabolism and reproductive phase in plants. The successful tasks carried out by various micronutrients include plant metabolism, nutritional management, chlorophyll production, reproductive growth, flower retention, fruit and seed development, *etc*. Judicious use of micronutrients is essential for vegetable cultivation to get maximum yield of high quality produce. Foliar nutrition is the one of the most efficient method of applying micronutrients. Spraying of nutrient solutions on the foliage of growing plants is known as foliar nutrition. Foliar nutrition of micronutrients at right concentration and at right growth stage is important for better results. Micronutrients applied by foliar application are more effective than those applied through soil application because soil application requires longer time for micronutrient absorption and assimilation. Foliar application of micronutrients plays a dynamic role and has been found beneficial for improving growth, yield and quality attributes of vegetable crops. In general, this review shows an immense potential of foliar nutrition of micronutrients in vegetable production.

Keywords: Vegetable crops; micronutrients; foliar nutrition; spraying; concentration

1. INTRODUCTION

Vegetables are one of the major constitute in terms of providing food and nutritional security to the human being. Therefore, a 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. Micronutrients are one of the important constitute of integrated nutrient management. In the modern era of 21st century, the cultivation of vegetables is very intensive and highly responsive to the fertilizers and improved varieties or hybrids which created the problem of nutrient imbalance in soils due to extra nutrient mining. Thus, it is imperative to maintain soil health for sustainable crop production with adequate supply essential plant nutrients.

According to the criteria of essentiality of nutrients by Arnon and Stout (1939), there are total sixteen (present seventeen) essential nutrients which are required by plants for their successful completion of life. Out of them, nine nutrients (C, H, O, N, P, K, Ca, Mg and S) are considered as macronutrients as they are required by plants in large quantity and the nutrient elements which are required comparatively in small quantities are called as micro or minor nutrients or trace elements (boron, iron, copper, zinc, manganese, chloride, molybdenum and nickel). For better growth, yield and quality in plants, micronutrients are equally important as macronutrients [1]. Micronutrients are extremely important in agriculture and horticulture, and their application has greatly enhanced the yield of a number of crops [2]. Numerous vegetable crops have been reported to benefit from the addition of micronutrients like ferrous, zinc, boron, and manganese in terms of growth, yield, and quality [3].

Micronutrients are known to work as catalysts in encouraging a variety of biological reactions in plants, which improves the chemical composition and general health of vegetable crops [4]. Micronutrients play an eminent role in plant growth, development and plant metabolism. However, their deficiencies may induce several physiological disorders or diseases in plants and later, can reduce the quality as well as quantity of vegetable crops [5].

As time goes on, the deficiency of micronutrients in the soil has been increased severely (Fig.1). Due to intensive cropping, soil erosion, nutrient losses through leaching, liming of acid soils, unbalanced fertilizer application and lack of replenishment, the incidence of micronutrients deficiencies has sharply increased in recent years [6]. The practices of applying massive amounts of organic manures like FYM, compost and green manures to the vegetable crops can help to maintain the adequate quantities of micronutrients in the soil. But, the restricted use of these bulky organic manures and use of high yielding short duration varieties with higher doses of macro elements resulted in stagnation of production and shortage of micronutrients. On the other hand, these micronutrients can also be proven toxic effect when present at accelerated concentrations and such toxicity level endangers the plant growth. Sometimes, access of one nutrient reduce or hinder the activity of another nutrient and creates antagonistic effect. The toxicity symptoms are difficult to recognize visually and are usually mistaken by deficiency symptoms. Growers should carefully follow recommendation for micronutrients to avoid unnecessary costs and possible toxic effects or deleterious interaction in other nutrients [7].

The micronutrients are being absorbed by the plants in both ionic and non-ionic forms which depend on the type of element. Micronutrients can be classified into cations (Fe, Mn, Zn and Cu), anions (Cl and B), metals (Fe, Mn, Zn and Cu) and non-metals (B, Mo and Cl) based on their chemical nature. The mobility of micronutrients in plant plays an important role for finding the deficiency of particular nutrient. Mobility of micronutrients in the soil also has considerable influence on availability of nutrients to the plants and method of application. 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) [8]. Other factors such as redox potential, biological activity, cation-exchange capacity and clay contents are also important in terms of determining the availability of micronutrients in soils.

The vegetative development and yield of crops are improved by adding micronutrients to the soil or supplementing them by foliar application [9]. Micronutrients applied by foliar treatment are more effective than those applied through soil because soil application requires longer time for micronutrient uptake and assimilation [10]. When the roots are unable to supply the necessary nutrients, foliar spraying with microelements is very beneficial [11]. According to Kolota and Osinska (2001) [12] foliar feeding is a productive way to deliver nutrients at a time of intense plant development, when it can enhance the plant's mineral status and boost crop output.

Nowadays, micronutrients are gradually gaining momentum among the vegetable crops because of their beneficial nutritional support and at the same time ensure better harvest and returns. The demand for increasing vegetable production will require a thorough knowledge of micronutrients in vegetable crops. But the available information regarding the impact of foliar nutrition of micronutrients on vegetable crops is scanty. Therefore, in current review an attempt has been made to summarize the literature pertaining to overall significance of foliar nutrition micronutrients in vegetable crops.

Table 1. Mobility of micronutrients in soil and plant

Mobility	Soil	Plant
Mobile	B, Mn, Cl	-
Moderately mobile	-	Zn
Less mobile	Cu	Fe, Mn, Cu, Mo, Cl
Immobile	Zn	B

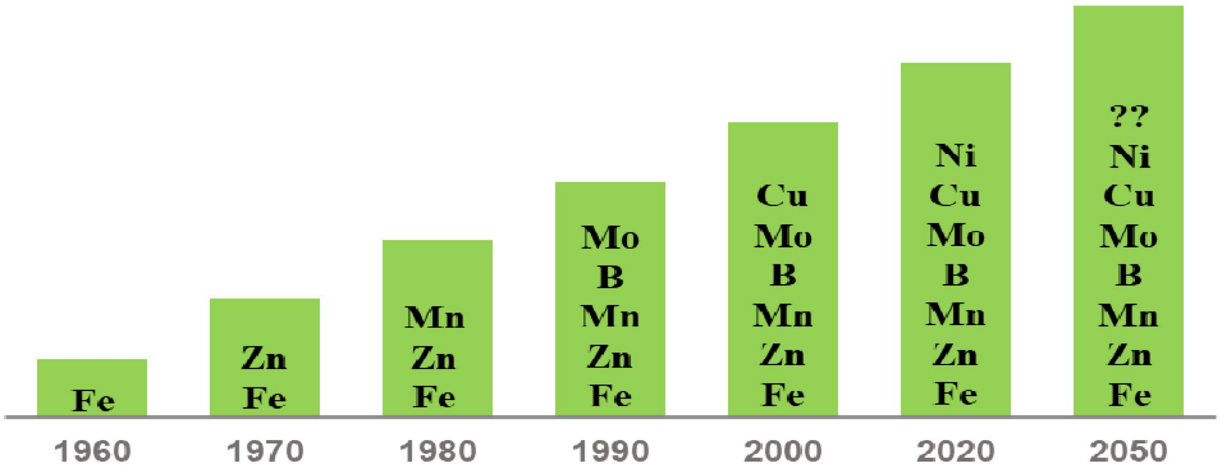

Fig. 1 Emergence of micronutrients deficiencies on time scale (Singh and Bahadur, 2014)

2. MICRONUTRIENTS

There are total eight micronutrients which required by plants in small or minute quantity *viz.,* iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo) and nickel (Ni). It has been determined that some plants use four extra elements, including silicon (Si), cobalt (Co), vanadium (V) and sodium (Na) as helpful micronutrients are known as beneficial nutrients [13].

2.1 Role of Micronutrients

Among micronutrients, boron plays a vital role in growth, development and several other physiological processes such as N metabolism, protein formation, cell division, *etc.* [14]. Boron is necessary for cell wall formation, development of fruit and seed. It helps in pollen formation, pollination and flowering of plants [15]. The main function of boron in plants is to increase the solubility and metabolism of calcium. It also facilitates the uptake of nitrogen. Iron (Fe) is the structural component of porphyrin molecules like cytochromes, hemes, hematin, ferrichrome, and leghemoglobin. In respiration and photosynthesis, these substances take part in various oxidation-reduction reactions [16]. The synthesis of the chlorophyll molecule is accelerated by iron and it also aids in the uptake of other elements. Zinc (Zn) is an indispensable for normal growth and development of plants. The production of plant hormones like auxin and the creation of carbohydrates can both benefit from it. Many enzymes, including proteinase, peptidase, aldolase, dehydrogenase and phosphohydrolase require zinc (Zn) as a component [17]. Copper (Cu) plays a pivotal role in regulating multiple biochemical reactions in plants. In their research with tomato plants, Arnon and Stout (1939) stated that copper was a crucial component for plants. Copper is a crucial regulator of multiple metabolic and physiological processes in plants because it is a stable cofactor of numerous enzymes and proteins. It aids in the usage of iron during the production of chlorophyll [18]. Both photosynthesis (reduction of CO_2 to carbohydrates) and respiration (oxidation of carbohydrates to CO_2) involve the transfer of electrons that requires copper (Cu). Numerous enzymes that aid in respiration and photosynthesis are activated by manganese (Mn). During photosynthesis, manganese facilitates electron transport, which accounts for the majority of the oxygen (O2) in the atmosphere [19]. Chlorine (Cl) is most commonly used as sanitizer, due to its low cost for maintaining the fruit quality like appearance, soluble solids content, acidity, pH, texture and flavour, shelf life and also control microbial growth [20]. It is required for photosynthesis, controlling stomata and elevating the osmotic potential of cells. Molybdenum (Mo) is required for the fixation of atmospheric nitrogen as well as assimilation of nitrates. It also helps in protein synthesis, sulphur metabolism and absorption of iron in plants. Nickel (Ni) stimulated the activity of urease enzyme which is essential for nitrogen metabolism and control senescence. It also acts as substitute for zinc and iron as a cofactor for some enzymes.

2.2 Deficiency of Micronutrients

Micronutrients are essential to the metabolism of the plant system. Successful vegetable cultivation is most frequently hampered by micronutrient problems, either a deficit or toxicity. Any deviation from the ideal level, no matter how slight, can result in a substantial yield loss. The region of appearance of deficiency symptoms depends on mobility of micronutrient in plants. A mobile nutrient in the plant moves to the growing points in case of deficiency. Therefore, deficiency symptoms appear on the lower leaves. While, immobile nutrient does not move to the growing points and hence, its deficiency symptoms appear on the younger plant parts. 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. So, it is very important for the vegetable growers to have knowledge about the management of micronutrients.

Older leaves develop interveinal chlorosis due to zinc (Zn) deficiency, which causes the leaves to turn grey-white, drop off early or die. Short internodes and a reduction in leaf size are the two most noticeable signs of Zn deficiency. Zinc deficiencies occur more often during cold, wet spring weather and are related to reduced root growth and activity. Zinc is also inaccessible to plants due to high phosphorus levels [21]. The crops like tomato, potato, beans and onion are highly sensitive to Zn deficiency. Mottling and rosseting in vegetables and fern leaf in potato are the major disorders of zinc deficiency. In coarse textured soils, where root activity is constrained by dryness, boron shortage is more prevalent. Its insufficiency is frequently linked to sterility and deformity of the reproductive organs**.** Boron does not easily move around the plant and therefore, the deficiency appears first in young tissues and growing points. Sterility, poor fruit set, small fruit size and eventually poorer yield can all result from boron deficiency. Additionally, a lack of boron results in the breaking and deformed development of fruits. The vegetable crops like cabbage, cauliflower, sugar beet, potato *etc*. are highly sensitive to boron deficiency. Browning and hollow stem in cauliflower, brown heart in turnip and beetroot, knob splitting in knol-khol, akashin in radish, cracked stem in celery and fruit cracking in tomato are the major physiological disorders caused due to boron deficiency.

Iron deficiency is common with interveinal chlorosis of young leaves and veins remain green except in severe cases. Its deficiency is mainly manifested by yellow leaves due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves. Deficiency of iron observed in soil with pH above 6.8, calcareous in nature and containing considerable amount of sodium and calcium. A lack of copper results in stunted growth, distorted young leaves, necrosis of the apical meristem, curled tips, dieback of stems and twigs, ragged leaf edges and a probability of plant top withering [22]. Copper deficiency is most commonly found in sandy soil, calcareous soil and soil having high organic matter content. One unit increase in soil pH (between pH 7 and 8) brings 100 fold reductions in copper availability [23].

A lack of manganese can results in interveinal chlorotic patches that turn a dull green or yellowish colour and a light green mottle between the main veins**.** Marsh spot of pea, yellow striping in onion, chlorosis and necrosis of leaves in beans, interveinal yellow mottling in cabbage and speckled yellow in beetroot are the major disorders caused by manganese deficiency. Manganese (Mn) deficiency is found in soils with pH above 6.7, calcareous and sandy soils. Increased soil pH and high quantities of accessible iron in soils have a negative impact on the uptake of manganese. In acidic soils, P and Mo availability may be reduced in addition to low pH and Mn toxicity. Molybdenum (Mo) deficiency can be common in nitrogen-fixing legumes. Deficiency of Mo is associated with acidic soils having pH below 5.2 and highly leached sandy soils. In contrast to other micronutrients, Mo is more readily absorbed by plants as soil pH rises. The high level of manganese and nitrate fertilizers reduced the availability of molybdenum in the soil. The crops like cauliflower, broccoli, spinach, lettuce, radish and beans are highly sensitive to molybdenum deficiency. Whiptail in cauliflower is the most common disorder caused due to molybdenum deficiency.

The common signs of a chlorine deficit include chlorosis in young leaves and overall plant wilting. Chlorosis of younger leaves and overall wilting of the plant are the most common symptoms of chlorine deficiency. The sensitivity of chlorine deficiency is higher in vegetable crops like potato and beans [24]. The deficiency of nickel also delayed nodulation and reduced efficiency of nitrogen fixation in leguminous vegetable crops. Nickel is an important micronutrient in cowpea at reproductive phase.

3. FOLIAR NUTRITION

It was discovered around three centuries ago that plant leaves can absorb nutrients and water. In the early 19th century, the application of nutrient solutions to plant foliage as an alternative means of fertilizing grapevines was noted [25]. Spraying of fertilizer solutions containing one or more nutrients on the foliage of growing plants is known as foliar spray. Application of nutrients through foliar spray is known as foliar nutrition. Several nutrient elements are readily absorbed by leaves when they are sprayed on them. Foliar Spray is highly effective for the application of minor nutrients like iron, copper, boron, zinc, molybdenum and manganese. Foliar nutrition will enhance the efficiency of the use of nutrients which plants need to increase ungently for maximum growth and yield. Foliar nutrition is the most efficient method for placing fertilizers under problems of soil fixation which normally needs reduced amounts of nutrients compared to soil application. Foliar application of micronutrients is widely used in vegetable crops. Most of the micronutrients are enter in the plant body though leaves within few hours to day of foliar spray. In arid and semi-arid regions, foliar application is widely recommended to overcome the deficiencies of micro nutrients *viz.*, Fe, Cu, Mn, Zn and B [26].

3.1 Factors Affecting the Efficiency of Foliar Nutrition

In relation to the optimal effectiveness of the foliar nutrition, growth stages are one of the most critical factors that determine the efficacy of foliar nutrition. The effectiveness of foliar feeding is affected by a number of endogenous (related to leaf anatomical structure), exogenous (nutrient concentration, soil type, pH of solution) and environmental factors. Environmental factors including; day time, humidity, temperature, wind speed, *etc.* The ability of plant tissues to absorb nutrients is crucial for plant growth. The largest amount of tissue permeability is favoured in warm, humid and tranquil environments. These conditions most frequently seen in late-night hours and often in early morning hours [27]. Since plant tissue does not immediately absorb all nutritional materials, rainfall may reduce the efficiency of foliar treatment within 24 to 48 hours of administration. Efficiency of foliar applied fertilizers also depends on crop type, leaf coverage and quality of fertilizers. Efficiency of foliar fertilizers can be improved by using wetting agents and stickers. Wetting agents improve coverage and stickers prevent nutrients being washed off by rainfall [28]. The fertilizer used for foliar application should be completely soluble in water. The concentration of spray solution should not leave any residue on plant surface and cause any harm to the leaf tissue. The humidity level at which nutrients dissolve in atmospheric vapour is known as the point of deliquescence. Adjuvants called humectants are added in the spray solution to lower the deliquescence point since a lower deliquescence is preferable. Controlling the concentration of spray solution (pH) is necessary to prevent the leaves from being scorched, which could cause catastrophic harm. Lime is most commonly used to neutralize the spray solution.

3.2 Benefits of Foliar Nutrition

Foliar feeding of nutrients is a way of rapid correction of nutrient deficiencies and physiological disorders of crop plants [29]. Jaskulski (2007) [30] pointed out the economic viability of foliar fertilization in vegetable production. It is an effective mean of reducing soil and ground water pollution [31]. Plant response to soil application is seen in five to six days, whereas foliar application takes three to four days to show results. Foliar feeding supports efficient and quick nutrient uptake regardless of the state of the soil and encourages roots to be more effective at absorbing nutrients from the ground [32]. It ensures improved nutrient balance in crop. Foliar feeding is environment friendly when compared to soil application as it avoids accumulation of toxic concentration of nutrients in soil [33]. Foliar fertilization is a practice that can be used to apply the proper amount of nutrients to crops at the right time throughout the entire growth season [34]. Pesticides that are compatible with fertilizers can be combined. This reduces the cost of plant protection. Only small quantity of fertilizer is required in foliar spray as nutrients are utilized properly and efficiently in foliar spray. Foliar nutrition of micronutrients is convenience in application as compared to soil applications. Moreover, foliar nutrition has a great potential to give higher yield under intensive cropping system and also side- by-side enhance the quality, economic aspect and crop tolerance to various biotic and abiotic stresses [35]. Foliar nutrition can be used as an important tool in integrated nutrient management for the production of vegetables.

Table 2. Commonly used micronutrient fertilizers for foliar spray

Micronutrient	Fertilizers
Boron	Borax (11% B), Solubor (20% B), Boric acid (17% B)
Iron	Ferrous sulphate (19% Fe), Ferrous ammonium sulphate (14% Fe), Chelated Fe (12% Fe)
Manganese	Manganese sulphate (30% Mn), Manganese oxide (41-68% Mn), Manganese chloride (17% Mn), Chelated Mn (12% Mn)
Copper	Copper sulphate (25% Cu), Cupric oxide (75% Cu), Cuprous oxide (89% Cu), Chelated Cu (13% Cu)
Zinc	Zinc sulphate (33% Zn), Zinc oxide (55-70% Zn), Chelated Zn (12% Zn)
Molybdenum	Sodium molybdate (39% Mo), Ammonium molybdate (54% Mo)
Chlorine	Potassium chloride (47% Cl), Ammonium chloride (66% Cl)

3.3 Application of Foliar Nutrition in Vegetable Crops

Foliar application of micronutrients has a dynamic role in vegetable production in order to increase the growth, yield and quality attributes. Here, some important past studies related to foliar nutrition of micronutrients in vegetables are summarized in Table 3.

Tablet 3. Effect of foliar nutrition of micronutrients on vegetable crops

Crop	Foliar nutrition	Improved characters	References
Cabbage	Zn 1000 ppm + B 200 ppm + Mo 50 ppm	Plant height, number of leaves per plant, leaf area, head diameter, head volume, head weight, head yield and chlorophyll content	Patel *et al.* (2021) [36]
Cauliflower	FeSo4 0.5 % + Borax 0.2 % + ZnSo4 0.5 %	Leaf length, number of days required for curd initiation and curd maturity, total biomass production, curd size, curd yield, ascorbic acid content, net income and B:C ratio	Moklikar *et al.* (2018) [37]
	Boric acid 0.2 % + Ammonium molybdate 0.1 % + Zinc sulphate 0.5 % + Manganese sulphate 0.5 %	Plant height, number of leaves per plant, days to first curd initiation, days to 50 % curd maturity, curd diameter, gross curd weight, net curd weight and curd yield	Punam *et al.* (2020) [38]
Broccoli	Zinc sulphate 0.60 %	Plant spread, stalk length, root length and ascorbic acid content.	Singh *et al*. (2018) [39]
	Borax 0.2 % + $ZnSO_4$ 0.5 %	Plant height, number leaves per plant, stem girth, plant spread, leaf area, head diameter, head weight and head yield	Tudu *et al*. (2020) [40]

Eggplant	Borax 0.5 %	Fruit length, fruit diameter and average fruit weight	Pandav *et al.* (2016) [41]
Coriander	$FeSO_4$ 0.5 %	Number of umbels per plant, root length, shoot length, essential oil content, seed yield and seed quality	Sinta *et al*. (2015) [42]
Water spinach	Borax 1500 ppm + ZnSO4 1500 ppm	Vine length, no. of nodes per plant, Average internode length, days to 50 % flowering, days to fruit harvest and chlorophyll content	Sarkar *et al*. (2017) [43]
Onion	Micronutrient mixture 0.5 % (Fe - 2.5 %, B - 0.5 %, Zn - 3 %, Cu -1 % and Mn - 1 %)	plant height, number of leaves per plant, polar diameter, equatorial diameter, average weight of bulb, bulb yield and B:C ratio	Biswas *et al*. (2020) [44]
Chilli	FeSO4 0.2 % + CaNO3 + Boron 0.1 %	plant height, number of primary branches per plant, plant spread, number of fruits per plant, average fruit weight, fruit length, fruit width, fruit yield, seed yield, oleoresin content and vitamin c content	Malik *et al.* (2020) [45]
Tomato	Boric acid @ 100 ppm	Plant height, number of branches, number of fruits per plant, fruit weight, fruit weight, fruit yield, net returns and B:C ratio	Patil *et al*. (2008) [46]
	FeSO4 0.2 % + CaNO3 0.2 % + Boron 0.1 % + ZnSO4 0.2 %	Plant height, days to first flowering, days to first fruiting, days to maturity, number of fruits per plant, fruit weight and fruit yield	Dixit *et al*. (2018) [47]
Potato	ZnSO4 @ 300 ppm	plant height, number of haulms per plant, number of leaves per plant, fresh weight of plant (340.23g), dry weight of plant, total number of tuber per plant, weight of tuber and yield of tuber.	Singh *et al.* (2018) [48]
Okra	MgSO4 0.5 % + MnSO4 0.5 % + FeSO4 0.5 % + ZnSO4 0.5 %	Weight of fruits, length of fruit, diameter of fruit and fruit yield	Dubalgunde *et al.* (2017) [49]
Cowpea	Fe @ 2 ppm	Nutrient uptake and protein percentage of seed	Salih (2014) [50]
Sponge gourd	Boron @ 0.75 g/L	Fruit length, fruit diameter, fruit weight, fruit set percentage and fruit yield per plant	Ashraf *et al.* (2019) [51]
Bitter gourd	Boric acid 100 ppm + Zinc sulphate 100 ppm + Ammonium molybdate 50 ppm + Copper sulphate	Length of vines, fruit length, fruit girth, fruit weight per vine, fruit yield, vitamin C, TSS and B: C ratio	Bharati *et al*. (2018) [52]

	100 ppm + Ferrous sulphate 100 ppm + Manganese sulphate 100 ppm	

5. CONCLUSION

Micronutrients play a crucial role in growth and development of vegetables crops. The nutritional value of crops is becoming a major issue in recent times. Therefore, application of micronutrients has a great importance to sustain the soil health and crop productivity besides maintaining the nutritional quality of vegetables. Application of micronutrients at right concentration and at right growth stage with the right method of application confers maximum benefits. Foliar nutrition is the one of the most efficient method of applying micronutrients directly on the plant leaves. Thus, it can be concluded that foliar nutrition of micronutrients proves beneficial for improving growth, yield and quality attributes along with increasing post-harvest life of vegetable crops.

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