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## Foliar nutrition in vegetables: A review

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### Abstract

Vegetables being a rich source of vitamins, minerals and non-nutritive phytochemicals play a vital role in our diet. According to World Health Organization, lower intake of vegetables is one of the main risk factors for mortality. To make a healthy diet affordable to all, the gap between actual and potential yield of vegetables should be reduced. Foliar application of water soluble fertilizers can boost production in vegetables thus attaining the goal of food security. Foliar applied nutrients absorbed through stomata and cuticle. For better results, foliar application of nutrients at proper growth stage of crop is important. It is not an alternative to soil application, but supplement soil application especially when secondary and micro nutrient deficiencies arise. In spite of a few limitations foliar nutrition serves as an efficient means of nutrient management in vegetables. To combat the wide spread deficiencies of nutrients especially arising at the critical stages of crop growth foliar nutrition can be successfully adopted.

**Keywords:** Foliar fertilization, major nutrients, micro nutrients, vegetables

### Introduction

Foliar application is the most effective method of application of water-soluble fertilizers. Application of suitable concentrations of fertilizers on leaves of growing plants is termed as foliar fertilization. Foliar nutrition was found to be six, four and twenty times more beneficial than soil application for N, B and Zn respectively Dixon (2003) [13]. Shortage of a single nutrient usually becomes bottleneck for achieving potential production of a crop, since metabolic pathways get seriously affected. For every plant, there are critical values for each nutrient, below which it becomes deficient. Such lacking nutrient can be supplemented through foliar fertilization and the problem can be corrected. Currently foliar fertilization is gaining significance, while soil application is the basic method (Alam *et al.*, 2010) [6].

### Mechanism of Foliar Fertilization

Plants are able to absorb essential elements through their leaves. Cuticle is the first route for uptake of water and water-soluble salts into plants. Absorption of ions is governed by kind of charge and ion radius. Accumulation of ions takes place against a concentration gradient by leaves (Franke, 1967) [18]. It was also reported that, ion uptake by leaves is completed in three stages. In the first stage, particles penetrate the cuticle and cell wall by active or passive diffusion. Diffused particles are adsorbed to the surface of plasma membrane and in the third stage adsorbed particles are taken up by the cytoplasm by way of active diffusion. Nutrients can also enter plants through stomata, other specialized epidermal cells and leaf hairs. Absorption is faster through the stomata but the net quantity is greater for epidermis (Shabnam and Kuruwanshi, 2015) [44].

### Situations Favouring Foliar Nutrition

Nutrient deficiencies in a crop arising at the critical stages of their growth adversely affect yield and quality of produce. In such situations, foliar nutrition can quickly correct nutrient inadequacies. Availability of soil applied nutrients is subjected to various soil factors but foliar applied nutrients quickly penetrate leaf cells and directly reach cytoplasm of cells. High degree of nutrient fixation in soil reduces the on-season availability of nutrients to plants. Sandy soils which are prone to leaching losses of nutrients reduce the efficacy of soil applied nutrients. Low as well as high soil temperature impede nutrient uptake by plants. Lack of soil moisture results in complete wastage of soil applied nutrients; rather it will result in wilting of plants. At the later stages of plant growth developing fruits turn to be the major sinks for assimilates, which make roots deprived of energy for nutrient uptake. This will in turn reduce crop growth and yield. Foliar nutrition at these stages can benefit the crop.

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**Table 1:** Commonly used liquid fertilizers

Nutrient	Compounds
Nitrogen	Urea (46% N), Di ammonium phosphate (18%N), calcium ammonium nitrate (26%N), ammonium nitrate (35%N), ammonium sulfate (21%N), ammonium chloride (26%N)
Phosphorus	Di ammonium phosphate (46%P <sub>2</sub> O <sub>5</sub> ), single super phosphate (18-22% P <sub>2</sub> O <sub>5</sub> )
Potassium	Muriate of potash (58%K <sub>2</sub> O), potassium nitrate (44% K <sub>2</sub> O),
Calcium	Calcium nitrate (19% Ca), mono calcium phosphate, calcium chloride, calcium ammonium nitrate.
Magnesium	Magnesium sulphate hydrate (epsomite) (9.6% Mg), magnesium sulphate
Iron	Ferrous sulphate (20% Fe), ferrous ammonium sulphate (20% Fe), FeEDTA (9-12% Fe)
Manganese	Manganese sulphate (26-28% Mn), manganese oxide (41-68% Mn), manganese chelate (12% Mn)
Copper	Copper sulphate (25% Cu), cupric oxide (75% Cu) cuprous oxide (89% Cu), copper chelate (13% Cu)
Zinc	Zinc sulphate (34. 46% Zn), Zinc oxide (77- 80% Zn)
Boron	Borax (11% B), sodium pentaborate (18% B), solubor (20% B), boric acid (17% B)
Molybdenum	Sodium molybdate (39% Mo), ammonium molybdate (54% Mo)
NPK fertilizer	19:19:19

### Factors Affecting the Efficiency of Foliar Applied Fertilizers

Efficiency of foliar applied fertilizers depends on crop type, leaf coverage, weather conditions and product quality. 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 (Shabnam and Kuruwanshi, 2015) <sup>[44]</sup>. Growth stage is one of the most critical factors that determine the efficacy of foliar fertilization. Foliar application should be timed to provide needed nutrients at the yield determining stages of plant development. Multiple, low rate applications may show the most favourable responses within these time frames. Size and shape of leaf determine the quantity of spray solution intercepted by the foliage. Composition of cuticle and surface wax architecture influence the ease with which foliar applied nutrients reach the cell wall. Leaf hairs often catch and hold spray droplets on the leaf surface. But when it becomes crowded it reduces the contact of spray solution with the leaves. Physical and biological aspects of foliar application are influenced by environmental factors, such as, temperature, humidity and wind velocity. The fertilizer used for foliar application should be completely soluble in water. It should not leave any residue on plant surface. The concentration of spray solution should be such that it should not cause any harm to leaf tissue while permitting sufficient uptake of applied nutrients. Point of deliquescence is the humidity at which nutrients dissolve in water vapour from air. A lower deliquescence is preferred and hence adjuvants called humectants are added to spray solution to lower the deliquescence point.

### Advantages of Foliar Feeding

Foliar feeding of nutrients is a way of rapid correction of nutrient deficiencies and physiological disorders of crop plants (Kerin and Berova, 2003) <sup>[29]</sup>. Jaskulski (2007) <sup>[25]</sup> pointed out the economic viability of foliar fertilization in vegetable production. It is an effective mean of reducing soil and ground water pollution (Fageria *et al.*, 2009) <sup>[15]</sup>. Plant response to soil application is observed in five to six days whereas; it is three to four days in foliar application. Regardless of soil condition foliar nutrition helps in rapid and effective absorption of nutrients and also stimulates the capability of roots to absorb nutrients from soil (Kannan, 2010) <sup>[27]</sup>. 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 (Haytova, 2013) <sup>[23]</sup>. Foliar fertilization can be adopted throughout the growing season of

crop which facilitates application of adequate amount of nutrients at the right time. Fertilizers can be mixed with compatible pesticides. This reduces plant protection costs. Foliar fertilization can be used as a tool in integrated pest management for the production of vegetables.

### Foliar Application of Macro-Nutrients

Foliar application of N can supplement soil application (Ling and Silberbush, 2002) <sup>[36]</sup>, but it is presumably impossible to meet the full N requirement of a plant (Singh *et al.*, 2016) <sup>[46]</sup>. Urea is the most common fertilizer used for foliar application of N due to its high solubility. Owing to its low salt index urea is less likely to cause leaf burn. Combination of two molecules of urea results in formation of biuret, which is toxic to plants at concentrations greater than 2 per cent. Hence it is recommended not to exceed the concentration of foliar applied urea by 3 per cent. In lettuce 0.6 per cent urea as foliar spray significantly enhanced the growth and yield attributes (Guvenc *et al.*, 2006) <sup>[20]</sup>.

Foliar application of P confirms higher fertilizer use efficiency. Girma *et al.* (2007) <sup>[19]</sup> observed that P use efficiency increases with the leaf area of the plant. Soils with low soil P show higher response to foliar applied P. Foliar P application induced higher pod number in *Phaseolus vulgaris* L. (Don Santos *et al.*, 2004) <sup>[14]</sup>.

Availability of K in soil is influenced by soil moisture, texture, pH, aeration, temperature, competition from other cations etc. As a result, plants grown on such soils may show K deficiencies even though soil analysis shows adequate K. Under such situations, foliar application of K corrects deficiencies quickly (Singh *et al.*, 2016) <sup>[46]</sup>. In a plant system K uptake is more prominent during vegetative and developmental stages compared to reproductive stages (Marschner, 1998) <sup>[37]</sup>. In tomato, fruit firmness increased as a result of foliar application of K (Chapagain and Wiesman, 2004) <sup>[12]</sup>. Lester *et al.* (2006) <sup>[34]</sup> revealed that basal application of K followed by foliar application at flowering stage enhanced the quality of fruit in musk melon due to the improvement in firmness, sugar content, ascorbic acid and carotene content.

Calcium is important for maintaining the quality of fruits and vegetables. Foliar application of Ca improves fruit firmness, vitamin C content and decreases rotting and browning in fruits and vegetables (Singh *et al.*, 2016) <sup>[46]</sup>. Foliar application of Ca also prevents blossom end rot in tomato, tip burn in lettuce and cabbage. The most commonly used compound for foliar application is calcium chloride. Soil pH, CEC and concentration of K and Ca in the soil solution influence the absorption of magnesium.

Foliar application of magnesium sulphate hydrate (epsomite) significantly improved the growth, yield and quality of tomato and pepper (Nannette, 2011) [40]. Harris *et al.* (2018) [22] opined that foliar spray of 150 mg L<sup>-1</sup> Mg enhanced the number of fruits per plant and fresh fruit weight per plant in chilli. Soil application of elemental sulphur decreases soil pH while foliar application did not influence this soil characteristic and foliar application of sulphur does not influence the sulphur content in the soil (Kulczycki, 2010) [30].

### Foliar Applications of Micro-Nutrients

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 (Kaya *et al.*, 2005) [28].

In neutral and alkaline soils Fe is present as Fe<sup>3+</sup> ions which are unavailable to higher plants (Shaw *et al.*, 2007) [45]. Foliar application of water-soluble iron compounds is recommended in alkaline soil conditions. Repeated foliar application of ferrous sulphate (0.5 per cent) solution at 10-15 days intervals are recommended if chlorosis symptoms persist in crops. This can be attributed to the limited remobilization capacity of Fe in plants.

At higher soil pH, soil application of Mn loses its effectiveness and also higher availability of Fe in the soil decreases the Mn uptake, under these situations foliar application is preferred (Singh *et al.*, 2007) [46]. Heckman (2010) [24] reported that the cost-effective way for Mn nutrition in plants is foliar feeding. The most common rate recommended for foliar feeding is 0.045- 0.9 kg Mn per acre. Sandy and loamy soils are found to be deficient in copper when compared to heavy textured soils. Organic matter content, pH, soil N and P also affect availability of Cu to plants. Organic matter firmly binds copper and decreases the Cu availability. One unit increase in soil pH (between pH 7 and 8) brings 100 fold reductions in Cu availability (Singh *et al.*, 2016) [46]. High soil N values indicate the probability of Cu deficiency in soils. These problems can be overcome by foliar feeding of Cu. When copper sulphate is used for foliar applications it is to be buffered with calcium carbonate (0.5 kg ha<sup>-1</sup>) to reduce the scorching effect on leaves. For foliar sprays, oxides are safer than sulphates owing to its lower salt index. But the cheapest source is copper sulphate.

Zinc deficiency is observed in crops raised in soils with high pH. Zinc deficiency is also observed in soils low in organic matter content. High levels of phosphorus also render Zn unavailable to plants (Forth and Ellis, 1997; Chang, 1999) [16, 11]. To overcome the Zn deficiency arising out of various reasons foliar nutrition is the most recommended practice. Teixeira *et al.* (2004) [49] revealed that foliar nutrition of Zn significantly increased the pod yield in common beans.

Boron deficiency is prominent in highly calcareous soils, sandy leached soils, lime acid soils and reclaimed yellow or lateritic soils. Boron must be available to the plant throughout the crop growing period. It is not translocated within the plant body and is easily leached out from soil. Hence foliar application is an appropriate approach for correcting its deficiency. Kuruppaiah (2005) [32] opined that foliar application of 0.5 per cent borax at 35 and 65 days after transplanting (DAT) increased the number of flowers per plant, number of productive flowers per plant, number of fruits per plant, individual fruit weight and yield in brinjal.

In cauliflower, deficiency of Mo is manifested as “whiptail”. To correct the Mo deficiency, foliar spray of Mo at the early stages of the crop is recommended. In acid soils or under dry conditions, foliar application is more beneficial than soil

application of Mo (Hamlin, 2006) [21]. Generally, 0.025- 0.1 per cent solution of sodium molybdate or ammonium molybdate (200g Mo ha<sup>-1</sup>) is recommended (Singh *et al.*, 2016) [46].

### Foliar Feeding In Vegetables

#### 1. Okra

Mini and Mathew (2019) [39] developed a multi nutrient mixture to address the wide spread deficiencies of Ca, Mg, B and Zn in Onattukara region. The multi nutrient mixture is having a nutrient composition of Zn (9.5%) + B (2.6%) +Cu (1.2%) +Mg (2.4%) +N (0.46%). Results of the experiment conducted to evaluate the effect of multi nutrient mixture on okra revealed that foliar application of micronutrient mixture (0.5%) at 15 and 30 DAS along with soil test based package of practices (POP) recorded higher pod yield with good keeping quality compared to soil application of multi nutrient mixture. Mehraj *et al.* (2015) [38] reported that foliar feeding of 100 ppm Zn, B, Fe, Cu, Mo and Mn at 20 DAS and 35 DAS significantly improved number of pods per plant, pod diameter and pod yield per plant. Abbasi *et al.* (2010) [11] opined that soil application of fertilizers was more effective than foliar application of fertilizers alone. However, soil application of fertilizers + foliar application resulted in significant improvement in growth and yield traits in okra.

#### 2. Solanaceous vegetables

Tomato is well known for its nutritional importance and antioxidants especially lycopene and salicylate [2]. Potassium enhances the vitamin C content of fruits (Perkins-Vecznie and Roberts, 2003) [43]. Foliar K application is a low- cost approach to maximize the fruit lycopene content (Lester *et al.*, 2005; 2007) [33, 35]. Chapagain and Weisman (2004) [12] observed that K content in the leaves of tomato got depleted at the time of fruit development and detrimentally affected the fruit quality and plant growth. Studies conducted by Afzal *et al.* (2015) [3] revealed that foliar application of 0.7 per cent potassium significantly enhanced the ascorbic acid content of two varieties of tomato *viz.*, Nagina and Roma. Among the two varieties, Nagina showed higher ascorbic acid content than Roma. Tejashvini and Thippeshappa (2017) [50] studied the effect of different sources and levels of calcium on the nutrient content and uptake of nutrients by tomato and it was found that 0.5 and 0.8 per cent calcium ammonium nitrate (CAN) recorded higher nutrient content and uptake compared to CaCl<sub>2</sub> and CaNO<sub>3</sub>.

Chilli (*Capsicum annum* L.) is the world's highly preferred solanaceous spice crop valued for its pungency, colour, aroma and phytochemical constituents. Boron is required for the maintenance of structural integrity of cell wall and cell membranes (Zhang *et al.*, 2014) [52] and development of flowers, fruit and seed set (Borghini and Fernie, 2017) [10]. Boron deficiency at the time of flowering resulted in reduced fruit and seed set. Harris *et al.* (2012) [22] reported that two foliar sprays of B (100 mg L<sup>-1</sup>) + Mg (100 mg L<sup>-1</sup>) at flower bud initiation stage and 14 days after first application registered the highest number of flowers per plant in chilli. Kumar (2013) [31] reported that four applications of 19:19:19 NPK (7.5g L<sup>-1</sup>) + KNO<sub>3</sub> (5g L<sup>-1</sup>) at monthly intervals starting from one month after transplanting significantly increased the fresh as well as dry pod yield in chilli and it was also observed that yield was limited beyond 7.5g L<sup>-1</sup> of 19:19:19. Studies conducted at College of Horticulture, Vellanikkara to find out the effect of foliar feeding of water-soluble fertilizers in brinjal hybrid 'Neelima' revealed that foliar application of

water-soluble fertilizers had significant effect on the growth and yield. Results also revealed that the highest yield was obtained with five sprays of potassium nitrate given at an interval of 10 days starting from 30 days after planting (AICRP, 2006) [5]. An experiment conducted by Pandav *et al.* (2016) [41] reported that fruit and yield characters of brinjal were significantly enhanced by the foliar application of micro nutrients than the control. Anburani (2018) [7] reported that the highest number of leaves per plant, leaf area and chlorophyll content were recorded in brinjal hybrids which received 7 sprays of 19:19:19 at 1.0% concentration starting from 30 DAT at 10 days interval.

### 3. Cucurbitaceous vegetables

Studies conducted by Bharati *et al.* (2018) [9] revealed that foliar spray of 100 mg L<sup>-1</sup> boric acid at 30, 40 and 50 days after sowing (DAS) recorded higher length of vine, fruit weight per vine and yield due to increased photosynthetic and metabolic activities. Fozia *et al.* (2018) [17] also reported that foliar application of 6 mM boric acid at two leaf stage reduced the number of days taken for first flowering in bitter gourd. Ashraf *et al.* (2019) [8] conducted an experiment to evaluate the effect of foliar application Zn, Fe and B in sponge gourd revealed that foliar application B (3 g H<sub>3</sub>BO<sub>3</sub> L<sup>-1</sup>) at 30, 45 and 60 DAS significantly improved the fruit length, diameter and yield per plant compared to foliar application of Fe and Zn.

### 4. Leguminous Vegetables

Foliar application of nutrients had significant effect on the yield and quality of leguminous vegetables. Field experiment conducted to evaluate the effect of foliar spray of Mg and B on yard long bean at College of Agriculture, Vellayani revealed that foliar application of MgSO<sub>4</sub> (2%) and borax (0.25%) at fortnightly intervals along with soil test based POP recommendation of NPK recorded the highest crop duration (96 days) and yield (1569 g plant<sup>-1</sup>) (Jose, 2015) [26]. Studies conducted by Singhal *et al.* (2015) [47] revealed that one per cent banana pseudostem enriched sap recorded higher pod yield per plant and was found to be on par with 19:19:19 NPK 0.5%, urea 1%, MOP 0.5%, DAP 2%, owing to the supply of more nutrients at the critical stages (flowering and fruit setting). Foliar nutrition of water-soluble NPK fertilizer (19:19:19) at 30, 45 and 60 DAT recorded significantly higher protein content in vegetable cowpea seeds compared to control (Singhal *et al.*, 2016) [48]. Studies conducted by Pandey *et al.* (2017) [42] reported that foliar application of 2 per cent urea at flowering stage increased the number of green pods per plant, fresh weight of green pods per plant and pod yield in vegetable pea (*Pisum sativum* L.).

### 5. Cruciferous Vegetables

Foliar feeding of nutrients had significant effect on the growth and yield of cruciferous vegetables. In cauliflower, the highest curd yield (168.33 q ha<sup>-1</sup>) was recorded with five sprays of 19:19:19 NPK mixture which was significantly better than the control (130.00 q ha<sup>-1</sup>) (AICRP, 2006) [5]. A significant increase in yield was observed in cauliflower due to the foliar application of Mo at 30 and 45 μg L<sup>-1</sup> (Ahmed *et al.*, 2011) [4]. It was also observed that foliar application of Mg at 0.50 and 0.75% increased total yield, total chlorophyll, N, P, Mg and vitamin C contents of curds. Yadav *et al.* (2014) [51] recorded reduction in days to curd initiation, maturity and higher yield in cauliflower owing to the foliar application of 1.5 per cent N and 40 mg L<sup>-1</sup> Zn individually at 30 and 45 days after

transplanting (DAT). Earliness in curd initiation might be attributed to the fact that N enhances the vegetative growth and Zn facilitates rapid translocation of photosynthates towards curd.

### Limitations of Foliar Application

For foliar application, water-soluble fertilizers can only be used which are comparatively costlier. If fertilizers were applied in higher concentrations causes burning symptoms on plant tissues. To avoid scorching, lower concentration is usually recommended and hence repeated applications are needed. Compared to soil application, it is labour intensive. If the sprayed nutrient has limited remobilization capacity, flushes developed after application may show deficiency symptoms. Plant response to foliar application is temporary. Foliar fertilization cannot be employed in crops at the early growth stages, when sufficient leaf area has not been developed. In some crops foliar nutrition after flowering may result in inflorescence discoloration [15].

### Precautions to be followed in Foliar Feeding

Hot and dry mid- days should be excluded for foliar application of nutrients. To avoid drift into adjacent fields, foliar application should not be done in a windy weather. Care must be taken to avoid any kind of damage to foliage when spray applicators are employed. Thoroughly clean the sprayer before application. Select appropriate nozzle and to be operated within the desired pressure range of pump capacity. In ground applicator, wide angle, hollow cone nozzles can be used. Calibrate each spray nozzle for the desired ground speed. Adjust nozzles on boom to spray at 90° angle for uniform spray pattern. High volume spray with 500 litres of spray fluid per hectare is recommended for foliar application. Ensure flushing out of all hoses, pumps and pipelines using water to make them free of undesirable residues. Flush the equipment with water after use as well to prevent corrosion and damage. Stainless steel and plastic components are ideal in sprayers. Additional care is required for the application of copper sulphate as it is corrosive on spraying equipment. Addition of surfactants to the spray solution enhances its efficacy. Safety can be ensured by standardizing the concentration of spray solution.

### Conclusion

Foliar nutrition is the technique of feeding plants by applying water-soluble fertilizers directly on their leaves. Right choice of fertilizer material for application at the right concentration, during the right growth stage of crop along with the right method of application confers maximum benefits. Foliar nutrition adequately fits into nutrient management schemes owing to fast response to applied nutrients with no loss. The concept that foliar nutrition should be practiced after the expression of deficiency disorders has to be changed, since decline in yield and quality precedes the appearance of visual symptoms. Foliar feeding of nutrients can be standardized as an insurance against specific deficiency disorders and uncertain weather conditions.

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