

Foliar fertilization

for balanced nutrition in rainfed crops

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For attaining optimal yields, the essential plant nutrients are primarily applied through the soil and foliage, but the most common and effective approach for it is soil application. Contrarily, foliar nutrition is, sometimes, more economical and beneficial. The soil application of fertilizers is usually carried out on the basis of soil tests while foliar application is pre-dominantly done by virtue of visual symptoms or plant tissue tests. The foliar nutrition could be complementary to fertilization. Among the dryland technologies, foliar spraying of nutrients is also effective in mitigating drought stress during cropping seasons. Foliar fertilization is a climate resilient technology, which not only increases the nutritional quality, but also increases the yield of the crops under rainfed conditions with the ability to tackle malnutrition and global hunger.

Keywords: Dryland, Foliar nutrition, Nutrient concentration, Soil application, Yield

RAINFED agriculture covers more than 80% of world's cultivated land and accounts for more than half of global crop production, however the drought and soil moisture stress conditions have been identified as major constraints for limited production. The efficient use of nutrients by the crops is essential for sustainable crop production. With the increase in global population, the fulfillment of raising demands for food and energy has become an ever-increasing priority. Globally, about 190 million tonnes (MT) of nutrients were used for crop production in 2020 out of which more than two-third was used in developing countries.

Need of foliar nutrition

Fertilizers are costly to produce and many environmental aspects are associated with their use. Hence, there is an urgent need to maximize their use efficiency. Foliar fertilization is the rapid and economical way to improve the nutrient use efficiency under intensive agriculture. This phenomenon includes apportioning the supplemental doses of essential plant nutrients and other beneficial substances which results in an increment in yield, resistance to diseases and insect/pests, improved drought tolerance and enhanced crop quality. Application of nutrients through foliar

spray at appropriate growth stages is essential for efficient absorption by plants to fulfill nutrient demands and improve yield outcomes. New generation special fertilizers are now available exclusively for foliar fertilization. Foliar application of macronutrients is usually not able to meet the nutrient requirement of crops; hence foliar application is generally recommended for micronutrient application in crops. The increasing cost of commercial fertilizers and relatively low nutrient use efficiency of fertilizers in soil application have elevated the importance of foliar fertigation in agriculture. Foliar feeding is gaining importance because of soil and ground water pollution issues concomitant with soil application of fertilizers. Foliar fertilization cannot completely replace soil application and is usually a nutrient corrective technique, when soil application is ineffective due to immobilization of soil applied nutrients. Under drought conditions, foliar application also plays an important role in plant metabolism. The main objectives of foliar fertilization are to apply the plant nutrients at deficit and critical stages in crop production, to improve the nutrient use efficiency, to reduce the use of chemical fertilizers and ultimately increase in crop growth and yield under stress conditions.

Entry of nutrients into plants through foliar application

In foliar application, the mechanistic process involves the nutrient penetration in the cuticle of the leaf or stomata which then enter the cells, however in soil application, plant roots absorb the nutrients and translocate to aerial parts of plant. Hence, crop response occurs in short time in foliar application compared to soil application. Pure water cannot penetrate to stomata unless a surfactant is added to lower its surface tension. The waxy covering of aerial plant parts called cuticle acts as a barrier for bidirectional exchange of water, solutes and gases between the plant and the environment. The various processes for foliar nutrient uptake are foliar adsorption, cuticular penetration and uptake and absorption into the metabolically active cellular compartments of leaf. Cuticular cracks in leaf surface, stomata and trichomes or lenticels as modified epidermal structures play important role in the uptake of foliar applied chemicals. Cuticular permeability and stomatal uptake are the major plant surface penetration pathways which affect the diffusion of substances on the leaf surface.

Factors affecting penetration of foliar solutions into plants

The absorption of foliar-applied nutrients by the plant surface involves a series of complex processes and events. The principal processes include nutrient solution formulation, mode of transport of spray droplets to plant surfaces, wetting, spreading and retention of solution on plant surfaces, penetration and distribution of the nutrient to a reaction site. These processes are not only interlinked, but are also affected by plant growth factors, environmental conditions and application parameters. The physico-chemical properties of the specific nutrient solution, such as solubility, pH, point of deliquescence and molecular weight have a significant impact on the rate of absorption of element by the leaf. The rate of retention, wetting and spreading of a nutrient in foliar spray is governed by the physico-chemical properties of the formulation. When an aqueous solution is applied to a leaf, initially there is a high rate of penetration which decreases with time from the drying of the applied solution. This drying is influenced by the prevailing environmental conditions and by the formulation of the applied foliar spray solution. Plant responses to foliar fertilizers may be affected by the properties of the spray solution. The concentration of a nutrient solution for foliar spray should always be substantially higher than its concentration within the plant organ and this will potentially lead to the diffusion of the nutrient across the surface. The higher penetration rates in plants are directly associated with increased concentrations of nutrient solutions. The ideal concentration range of mineral nutrient solutions for foliar application varies with the kind of nutrients (e.g. macro or micro nutrient), plant species, plant age, nutritional status and weather conditions (Table 1).

Table 1. Adequate concentrations and ranges of nutrient elements (dry weight basis) in plants (Source: Raun 2007)

Nutrient	Range of concentration	Adequate concentration
Nitrogen	0.5–6.0%	1.5%
Phosphorus	0.15–0.50%	0.20%
Potassium	0.80–8.0%	1.0%
Calcium	0.10–6.0%	0.50%
Magnesium	0.05–1.0%	0.20%
Sulphur	0.10–1.50%	0.10%
Iron	20–600 mg/kg	100 mg/kg
Zinc	10–250 mg/kg	20 mg/kg
Manganese	10–600 mg/kg	50 mg/kg
Copper	2–50 mg/kg	6 mg/kg
Boron	0.2–800 mg/kg	20 mg/kg
Chlorine	10–80,000 mg/kg	100 mg/kg
Molybdenum	0.10–10 mg/kg	0.10 mg/kg
Nickel	0.05–5 mg/kg	0.05 mg/kg
Cobalt	0.05–10 mg/kg	0.10 mg/kg
Silicon	0.10–10.0%	0.10%

Relative humidity and temperature are the major environmental factors affecting uptake of nutrients through foliar spray. High relative humidity improves the permeability because of cuticular hydration along with the late drying of the deposited soils on the surface of plant. Temperature affects solubility, viscosity and surface tension of spray solutions, as temperature increases the solubility of active ingredients and decreases the viscosity, surface tension as well as the point of deliquescence. Higher temperature also increases the evaporation rate of the solutions sprayed on the foliage, thus decreasing the surface wetness and leaf penetration. Further, the foliar nutrient spray may also be affected by other environmental factors including light intensity or precipitation.

Major sources of nutrients for foliar application

Water soluble fertilizers are preferred for foliar application in comparison to the insoluble or less soluble sources. Moreover, the efficiency of chelate sources of micronutrients is more as compared to the non-chelated ones. Selection of foliar sprays involving inorganic fertilizer is based upon the nutrient uptake efficiency as well as on the response to foliage burning. The foliar application of N solution to cereals resulted in leaf burning and tipping even at low N application rates (15 kg/ha). The foliar application of ammonium nitrate or ammonium sulfate is more sensitive to burning than urea due to low salt index which reduces the desiccation of leaf cells (Table 2).

Table 2. Principal soluble fertilizer carriers of plant nutrients for foliar application (Source: Fageria *et al.* 2009)

Fertilizer name	Formula	Element (%)
Urea	$\text{CO}(\text{NH}_2)_2$	46 (N)
Ammonium sulfate	$(\text{NH}_4)_2\text{SO}_4$	21 (N),
Ammonium nitrate	NH_4NO_3	35 (N)
Monoammonium phosphate	$\text{NH}_4\text{H}_2\text{PO}_4$	11 (N), 48–50 (P)
Phosphoric acid	H_3PO_4	55 (P)
Potassium chloride	KCl	60 (K)
Potassium sulfate	K_2SO_4	50 (K)
K-Mg Sulfate	$\text{K}_2\text{SO}_4 \cdot \text{MgSO}_4$	23 (K)
Potassium nitrate	KNO_3	44 (K)
Boric acid	$\text{H}_3\text{BO}_3[\text{B}(\text{OH})_3]$	17 (B)
Borax	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	11 (B)
Sodium borate	$\text{Na}_2\text{B}_4\text{O}_7$	20 (B)
Zinc sulfate (monohydrate)	$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$	36 (Zn)
Zinc oxide	ZnO	50–80 (Zn)
Zinc chelate	$\text{Na}_2\text{Zn} \cdot \text{EDTA}$	9–14 (Zn)
Copper sulfate (monohydrate)	$\text{CuSO}_4 \cdot \text{H}_2\text{O}$	35 (Cu)
Copper oxide	CuO	89 (Cu)
Copper chelate	$\text{Na}_2\text{Cu} \cdot \text{EDTA}$, $\text{NaCuH} \cdot \text{EDTA}$	9–13 (Cu)
Ferrous sulfate (monohydrate)	$\text{FeSO}_4 \cdot \text{H}_2\text{O}$	33 (Fe)
Iron chelate	$\text{NaFe} \cdot \text{EDTA}$, $\text{NaFeH} \cdot \text{EDTA}$, NaFeDTPA	5–14 (Fe)
Manganese sulfate (monohydrate)	MnSO_4	23–28 (Mn)
Manganese oxide	MnO	41–68 (Mn)
Manganese chelate	$\text{Na}_2\text{Mn} \cdot \text{EDTA}$	5–12 (Mn)
Sodium molybdate	$\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$	39 (Mo)
Ammonium molybdate	$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	54 (Mo)

Application of foliar spray

The foliar application timing of fertilizers also plays an important role for efficient absorption as well as to avoid any injury in leaf. Opening of leaf stomata and optimum temperature are essential for efficient absorption. High

temperature may cause the burning of plant foliage. In the early morning and late afternoon, the uptake of foliar-applied fertilizers is highest, whereas it is found to be lowest at midday. Late afternoon time is considered most efficient for foliar fertilization and the windy days should be avoided. At least 3–4 hours are required for the efficient utilization of nutrients. The most optimal timing for the application of foliar spray to the crop is under a given nutrient stress. Stress times occur mostly during the active growth of plant or during the changing stage of plant from a vegetative to a reproductive one. Latest techniques like electrostatic sprayers, which provide a definite charge to the particles of spray, allows them to bind more readily to plants and use of sound waves to increase the absorption of nutrients on leaves are also available.

Benefits of foliar nutrition in drought tolerance

Foliar fertilization to crop includes mixed responses, both positive and negative along with no response depending on the type of crop species and nutrient applied. Large scale research experiments were done under All India Coordinated Research project on Dryland Agriculture across different agro-climatic region of India to study the effect of foliar nutrition of N, K, Zn and Fe on various crops like wheat, maize, groundnut, chickpea, rice, pearl millet, soybean, pigeon pea and cotton. It was observed that there was a yield increase from 26–147% for various crops.

The normal physiology and growth of plants are majorly affected by drought stress in different ways. It leads to the increased solute concentration outside the roots as compared to the internal environment and results in reverse osmosis which leads to shrinkage of cell membrane eventually leading to cell death. On the other hand, water stress tends to shrink away from the interface with water-absorbing roots, which creates a gap in the soil-plant-air continuum. With the continuous loss of water from plant via transpiration, water is drawn from root cells due to which the cell membrane shrinks and loses its integrity and ultimately destroys the living cell. Deficiency of water results in higher quantity of cuticular wax and alters the composition to longer-chain hydrophobic waxes, and significantly decreases the absorption of foliar-applied nutrients. Additionally,



Effect of foliar spray in chickpea crop [A, with spray; B, without spray (farmer's practice)]

the turgor maintenance through osmo-protectants accumulation, decreased rate of transpiration and closed stomata further adds in minimizing the extreme effects of drought stress. Under limited conditions of water, the foliar application may be an alternative and efficient method for improving the availability of nutrients to plants. Foliar applied NPK fertilizers significantly contribute towards improved yield through an increase in biomass of the plants. The positive impact of foliar application of NPK to sustain proper nutrition in leaf and carbon balance along with the improvement in photosynthetic capacity is well established. The uptake of potassium in plants enhances the drought tolerance by mitigating harmful effects through enhanced translocation and maintenance of water balance. Various research studies have demonstrated that the negative impact of drought on wheat growth can be reduced by spraying K. Potassium foliar spray applied at 3% concentration is most beneficial and cover up the requirements of K in crop as compared to spray of 1% and 2% concentration.

Constraints of foliar nutrition

Higher concentration of nutrients causes toxicity. The toxicity levels vary depending upon the degree of localized deposited materials and could be influenced by the movement of the material applied inside and outside the leaf tissue. The normal toxicity symptom because of foliar application of fertilizers is burning or scorching. The cell wall may get ruptured due to the large differences in osmotic pressure across the cell wall with the application of highly concentrated fertilizer to the surface of leaf. The most easily observed toxicity

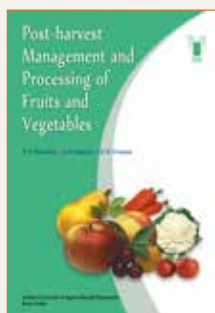
symptoms involve isolated necrotic spots and burned leaf margins and tips. Other constraints of foliar nutrition include high cost of application, the difficulty in foliar spray for tall crops or for crops at later growth stages, non-uniform application of spray, etc. But most of these constraints may be taken care by technical supervision and by making available suitable equipment for spray. Now, even precise application of foliar spray is possible using drones with sensors mounted on them.

SUMMARY

Foliar fertilization has great potential to give higher yields under intensive cropping system and in enhancing the crop tolerance to drought conditions. Conversely, it is disadvantageous due to the foliar burn, solubility issues, and application of minute quantities of the nutrients. Different responses of yield to foliar fertilization are probably associated with incorrect timing of application, use of inappropriate fertilizer and lack of concern of soil available nutrients and environmental conditions. The potential of foliar fertilization can be influenced through various factors such as the type of fertilizer, pH and concentration of the solution, the use of adjuvants, and compatibility with other agrochemicals. Soil application of nutrients cannot be replaced totally with foliar fertilization, but under various situations when soil applied nutrients are not available to plants, foliar nutrition can play very important role in enhancing crop yield and nutrient use efficiency particularly under dryland situation.

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TECHNICAL SPECIFICATIONS

Size	: Royal Octavo (16 cm x 24 cm)
No. of pages	: i-viii + 250
Price	: Rs 350
Postage	: Rs 50
Binding	: Paper Back
ISBN No.	: 978-81-7161-115-4

For obtaining copies:

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