Role of Molybdenum in Horticultural crops

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Molybdenum is a trace element found in the soil and is required for growth of most biological organism including plants (0.1-2.0 mg kg^{-1} plant dry matter) and animals. Specific plant enzymes participate in reduction and oxidative reaction have require molybdenum as a catalyst. Molybdenum itself is not biologically active but is rather predominantly found to be an integral part of an organic pterin complex called the molybdenum co-factor. The availability of molybdenum for plant growth is strongly dependent on the soil pH, concentration of adsorbing oxides (e.g. Fe-oxides), extent of water drainage and organic compounds found in the soil colloids. In alkaline soils, molybdenum becomes more soluble and is accessible to plants mainly as an anion in the form MoO_4^{--}. In contrast, in acidic soils (pH <5.5) molybdenum availability decreases as anion adsorption to soil oxides increase (Reddy et al. 1997). When plants are grown under molybdenum deficiency, a number of varied phenotypes develop which hinder plant growth. Most of these phenotypes are associated with reduced activity of molybdoenzymes. These enzymes include the primary nitrogen assimilation enzymes such as nitrate-reductase and the nitrogen-fixing enzyme nitrogen's found in bacteroids of legume nodules. Other molybdoenzymes have also been identified in plants including xanthine dehydrogenase oxidase involved in purine catabolism and ureide biosynthesis in legumes, aldehyde oxidase that is involved in ABA biosynthesis and sulfite oxidase that can convert sulfite to sulfate, an important step in the catabolism of sulfur-containing amino acids (Mendel and Haensch, 2002).

Source of Molybdenum:

Molybdenum is present in the lithosphere at average levels upto 2.3 mg kg^{-1} but can increase in concentration upto 300 mg kg^{-1} in Shales that contain significant organic matter (Reddy et al. 1997). Available molybdenum content in Indian soils varies 0.07- 7.67 mg kg^{-1}. In agricultural soil, molybdenum is present as many different complexes depending on the chemical speciation of the soil zone. It is absorbed by plants in the form of Molybdate (MoO_4^{--}) ions and it has some sort antagonism with high levels of Mn and NO_3^-. The availability of molybdenum depends on the following factors:

(1) Soil condition- The availability of molybdenum is low in coarse textured soil (i.e. sandy soil) due to leaching losses of nutrients.

(2) Soil pH- If the pH is 6 or above, its availability increase. At pH below 6.0, availability rapidly diminished because molybdenum is easily "fixed" in the soil by free Fe $(OH)_3$, AI $(OH)_3$ and Fe_2O_3.

(3) Mo:S Balance- Some researches show that sulfate applications can cause a reduction in Mo uptake by plants.

(4) Mo:P Balance – Application of phosphorus has increased the Mo content of plant in some research. It is thought that P reduces the adsorption of Mo compounds in the soil.

(5) NH_4: No_3 Balance- Plants can often grow well in low Mo soil when fertilized with NH_4 fertilizer, as against to No_3 fertilizers.

Function of Molybdenum:

Molybdenum is considered to be quite mobile as it moves readily in both the xylem and phloem conducting tissue of the plant. Still, its highest concentration is in mature leaves because it binds readily with sulfur-containing amino groups, sugars and poly-hydroxides that are usually in greater concentration in these leaves. It is found in the enzymes nitrate-reductase and nitrogenase, which are essential for nitrate reduction and symbiotic nitrogen fixation in plants.

1. It functions in converting nitrates (NO_3) into amino acids within the plant.

Some common fertilizers and organic material containing molybdenum include;

S. No.	Manure and fertilizers	Chemical formula	Typical Mo Content
1	Sodium Molybdate	$Na_2MoO_4.2H_2O$	39 %
2	Molybdenum Trioxide	MoO_3	66 %
3	Ammonium Molybdate	$(NH_4)_6\ Mo_7O_{24}.4H_2O$	52 %
4	Compost	-	0.10 PPM
5	FYM	-	0.13 PPM
6	Single Super Phosphate	-	3.3 PPM
7	Tripple Super Phosphate	-	9.1 PPM
8	Ammonium Phosphate	-	23 PPM

2. Molybdenum is essential to the symbiotic nitrogen-fixing bacteria in legumes and protein synthesis.

3. It is essential in conversion of inorganic phosphorus into organic forms in the plant.

4. Functions as a redox carriers

5. Molybdenum is a constituent part of the several enzymes and regulate enzymic activities

6. It also acts as an activator of some dehydrogenises and phosphates and as cofactors in synthesis of ascorbic acid.

7. Molybdo-enzymes are also involved in the synthesis of the phyto-hormones ABA and indole-3-acetic acid (IAA).

Deficiency Symptoms:

Molybdenum deficiency affects plant metabolism at many different levels. The responses are strongly linked to the requirement of molybdenum for the various types of molybdo-enzymes present in plants. The characteristic symptoms of molybdenum deficiency are mottling, leaf cupping and flaccid leaves in young plants. In older plants, symptoms appear in younger leaf tissues with the characteristic loss of proper lamina development, leathery leaves and meristem necrosis. Severe molybdenum deficiency creates different physiological disorder like whiptail in cauliflower, yellow leaf spot in citrus and scald in beans etc.

1. Molybdenum deficiency produces 'whiptail' in cauliflower, broccoli and other brassica crops, 'down ward cupping' in radish and scald in beans.

2. Flower formation is inhibited and if flowers do form, they abscise before setting of fruits.

3. Molybdenum deficiency imbalances various amino acids in the plant.

4. It reduces the activity of the symbiotic and non-symbiotic nitrogen-fixing organism.

5. Mo-deficient legumes vegetables (pea, cowpea, cluster bean) will not modulate well or fix the normal amount of nitrogen expected of them.

6. In acute deficiency case, destruction of embryonic tissue and necrosis of leaf tissue occurs.

7. Mottled pale appearance in young leaves of mo-deficient fruit plants and vegetables.

High response Horticultural crops: Since molybdenum is an essential element for all plants, some horticultural crops have been found to be especially responsive for molybdenum eg broccoli, Brussels sprouts, cabbage, cauliflower, clover, lettuce, pea, spinach, sugar beets, tomato and citrus.

Corrective measures of molybdenum deficiency: The deficiency of molybdenum can be corrected by application of molybdenum containing fertilizer and organic manure.

1. Apply 20-30 ton ha^{-1} well-decomposed FYM, 20 days before crop sowing / plantation.

2. The liming of acid soils (pH is raised to 6 or above) will usually increase the availability of molybdenum.

3. Quick and effective control of molybdenum deficiency in standing crop- apply 2 to 3 foliar spray @ 0.5 per cent of micronutrient mixture fertilizer foliar grade containing molybdenum.

4. If the soil pH is higher then 6.5, application of Sodium or Ammonium Molybdate at the rate of 0.7 to 2.3 kg per hectare at field preparation stage.

5. Molybdenum deficiency may be controlled by foliar spray of 0.01 to 0.02 per cent Sodium or Ammonium Molybdate at vegetative growth stage of the crop.

Physiological disorder in important horticultural crops:

1. Whiptail in cauliflower- The leaf-blades do not develop properly and may be strap like and severely savoyed. In severe cases only the midribs develop, which accounts for the name whiptail. Growing point is usually deformed and does not produce a marketable head.

Control measures:

1. Foliar spray of micronutrient mixture fertilizer foliar grade containing molybdenum at the rate 0.5 per cent on cauliflower seedling before transplanting and repeat it 2 to 3 weeks after transplanting. Third spray may be done at the same interval if needed.
2. Raise pH of soil above 6.5 by liming.
3. Proper nutritional management in cauliflower field with application of organic manure.

2. Cupping in radish- The general symptoms are the appearance of necrotic areas on the upper leaves, such areas turn yellow and white, the edges of the leaves turn downward with cupping shape.

Control measures:

1. Foliar application of 0.5 per cent

micronutrient mixture fertilizer foliar grade containing molybdenum at 2 to 4 leaf stage of crop and repeat it at 10 days interval.

2. Foliar spray of 0.01 to 0.02 per cent Sodium or Ammonium Molybdate. Spraying may be done at 2 to 4 leaf stage of crop.
3. Apply 20-25 ton ha^{-1} well-decomposed organic manure at 15-20 days before seed sowing.

3. Scald of beans- The leaf shows paleness, wilting, and marginal rolling or scorching of different legumes vegetables like pea, cowpea, cluster bean etc.

Control measures:

1. Two to three foliar sprays @ 0.5 per cent of micronutrient mixture fertiliser- foliar grade containing molybdenum- at 10 to 15 days interval on vegetative growth stage of the crop.
2. Two foliar sprays of Ammonium Molybdate at the rate of 0.02 per cent at vegetative growth and pre flowering stages of crop growth.
3. Apply dust lime at the rate 1.5 to 2.5 ton ha^{-1} at field preparation stage for soil reclamation.

4. Yellow leaf spot in citrus- Yellow spot in the leaves specially growing on acid soils. The spots are small in mandarins but large on grapefruit. The deficiency is more pronounced on trees grafted on rootstock of grape fruit.

Control measures:

1. Proper nutrient management of the fruit orchard by application of well decomposed organic matter with wood ash or basic slag.
2. At neutral pH condition, apply Sodium or Ammonium Molybdate at the rate of 7 - 10 g per plant mixed with 10 kg organic manure.
3. Two foliar sprays of Ammonium Molybdate at the rate of 0.02 per cent at new growth stage.
4. Foliar application of 0.5 per cent micronutrient mixture fertilizer-foliar grade, containing molybdenum at pre-flowering, fruit setting and fruit developing stage.

References

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Foliar Fertilization

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Foliar feeding is a technique of feeding the plants by applying soluble fertilizers directly on their leaves. Unlike roots, plant leaves are not adapted to assimilate large amounts of nutrients and meet the bulk of the nutrient requirement. Therefore, they are in a continuous dem and of plant nutrients. Hence, to give them a quick boost; foliar fertilization is the best short term solution.

The effectiveness of foliar feeding was first shown to the world by a renowned Plant Researcher and Head of the Department of Horticulture at Michigan State University (MSU), Dr. H. B. Tukey with his colleague, Mr. S. H. Wittwer. In 1953, the U. S. Atomic Energy Department provided a grant and radioisotopes of all essential nutrients to MSU to study the foliar absorption of nutrients and trace their movement in plants. Isotopes are the different forms of an atom of the samechemical element.Some is otopesare stable while some are regarded as unstable or radioactive isotopes, in short – radioisotopes. They used radioactive Phosphorus and Potassium to spray on the leaves to study their absorption, movement and utilization in the plant system. They found plant nutrients moved at the rate of about 1 foot per hour to all parts of the plant. They also proved as much amount of the fertilizer as possible finds itsway into the plants and that the minimum is lost in the environment.

The radioisotopes also showed that all foliar applied nutrients are absorbed not only by the leaves but a small amount is also absorbed through woody cambium tissue of the bark. The re search also proved that foliar fertilization is 8 - 20 times more effective compared to soil application, in terms of the amount of nutrients required and with which those nutrients were absorbed and utilized inthe plant's metabolism

Though we want to put a little more stress on FOLIAR FERTILIZATION, it does not mean that it completely replaces the SOIL APPLICATION. Therefore, foliar fertilization should never be taken as a SUBSTITUTE to soil application; instead it should be regarded as SUPPLEMENTATARY to soil application; as foliar feeding increases the uptake of nutrients present in the soil solution. Secondly, the nutrient demands are often high in the initial phase of vegetative growth when the plants are small and the leaf surface is insufficient for foliar absorption. Plant roots have evolved to be the major pathway for nutrient uptake and their health and function should be the primary goal of anyfarmer.In short,for sustainable yields, the Soil Fertility Management should never be compromised and nutrient replacements through soil are to be regularly followed.

A distinction needs to be made between foliar fertilization and the application of soluble nutrients in the root zone through drip irrigation, form where the majority of the nutrients taken up by plants are absorbed by the roots. When the same fertilizer is sprayed on foliage in dilute concentration, most of the nutrients are absorbed through the leaves. Thus Water Soluble NPK fertilizers, often supplied through drip irrigation, can be effectively and efficiently used for foliar feeding.

Advantages of Foliar Application:

1. **Increase in cellular based Chlorophyllsynthesis:**
   It can be visually diagnosed with in first few days of foliar application by closely observing plant leaves, which often exhibit a dark green colour. This can be measured by a Refractometer in as little as 4 hours. Increased chlorophyll synthesis results in increased rate of photosynthesis. By increasing photosynthesis, we increase efficiency of a plant to produce more food, which ultimately ends in increased yield of a crop.

2. **Increased Uptake of Nutrients form the Soil:**
   The increased cellular activity and respiration demands more amount of water by the vascular system in response to increased needs of water by the leaf, far in excess of that found in the plant for normal synthesis of new materials. This automatically brings more fertilizing elements into the plant via the vascular system. Excess carbohydrate produced by the plant, due to greater synthesis of sugars by increased chlorophyll, are excreted by the root hairs which stimulate microbial colonies on the roots by providing additional energy sources. The bacterial colonies in turn provide auxins and other root stimulation compounds (organic acids). More root tissue and root hair increase the plant's ability to uptake water and fertilizerions.

3. If the soil structure, texture and soil pH are not favourable, still nutrients can be supplied through foliar sprays. Foliar fertilizers are most effective when soil problems occur that restrict nutrient availability such as iron availability in high pH soils. Foliar fertilizers get readily absorbed right at the site of application.

4. Low application rate and uniform application of plant nutrients. Rapid absorption and movement leading to immediate availability. In terms of nutrient absorption, foliar fertilization can be from8to20 times as efficient as ground application. It is because of the fact that we are stimulating the entire 'Nutrient Pumping System' of the plant.

5. Researchers found that foliar feed nutrients have a high use efficiency than soil application. In case of foliar feeding the nutrient efficiency went up as high as 95 %, while in case of soil application it came down to as low as 10%, as most of the part of nutrients was subjected to leaching or volatilization losses and losses due to immobilization. By applying nutrients through foliar sprays we are minimizing or restricting the losses of nutrients. Therefore, a small amount of plant nutrients foliar applied; can replace a much greater amount applied through soil. Besides, their residual effect is negligible.

6. For all crops, foliar nutrition is the most economical and reliable method of providing some nutrients, especially micronutrients. Besides, foliar sprays of N on Wheat would result in increased Protein content in the grains. Foliar sprays with P at Transition Stage (a stage in between vegetative stage and reproductive stage) would result in increased number and more retention of

flowers on the plant. Foliar sprays of Katthepre-maturity stage would result in increased quality of fruits and vegetables.

7. Properly nourished crops with all essential nutrients will exhibit a natural resistance to insect - pests and disease organisms. While traditionally most practitioners try to achieve optimum nutrition through direct soil management, many consider foliar fertilization the final key to making some form of "induced resistance" a practical reality.

Fertilization strategies can influence the amount of vegetative growth, flowering, fruit set, fruit growth and development (fruit size), its nutritional content (fruit quality) and external parameters related to fruit quality, disease and pest resistance and other plant characteristics. By carefully choosing the components of a foliar or side-dress fertilizer, the grower can "nudge" a crop towards earlier, heavier fruit set, or discourage fruiting - an advantage when producing greens or a forage crop. This concept is fairly well recognized in the conventional agricultural community. Many citrus growers, for example, are known to foliar feed with fertilizer blends dominated by potassium and nitrate - vegetative growth enhancing nutrients - to increase fruit size after the crop is well set. Generally speaking, fertilizer blends dominated by potassium, nitrate nitrogen, calcium, and chlorine tend to promote vegetative growth and fruit size. Blends dominated by ammonium nitrogen, phosphorus, sulfur, and manganese encourage the setting of fruit and seed.

As said earlier, in case of foliar feeding the nutrient efficiency may go up as high as 95 %, but in practice we seldom get it. It is due to the negligence shown in any one of more factors associated with the efficiency of foliar fertilizers, as discussed below.

Effectiveness of Foliar Fertilizers:

1. Major part of the nutrients applied through foliar feeding gets absorbed through epidermal pores on the leaves, called stomata. They are spread on entire leaf surface either on upper or lower surface or both the surfaces of a leaf. But majority of the plant species possess stomata on their lower leaf surface, therefore, care should be taken to cover both the surfaces with spraying with the fertilizer solution. Under tropical conditions, the stomata are open from 7 to 10 a.m. and after 5 p.m. Therefore, the sprays are necessarily to be adjusted within the time frame. The stomata are usually closed at night.
2. Foliar fertilizers should necessarily be applied when the plant is not under water stress, when the soil is neither too wet nor too dry (i.e. under 'Field Capacity' condition) and are best applied when the plant is cool and filled with water (turgid).
3. Plants need 16 essential elements in balanced proportion throughout their life cycle. Most of the farmers wait for nutrient deficiency symptoms to appear on leaves. The plants are in the state of Hidden Hunger from the stage of requirement of a nutrient(s) to the stage of expression of nutrient deficiency symptoms. Spraying the plants after noticing the deficiency symptoms would not serve the purpose of Sufficiency Management or Luxury Consumption for getting higher yields, in turn; it would be Inadequacy or Poverty Management.
4. Growth stages of a crop are to be taken

into account while supplying the nutrients through foliar feeding. During Vegetative Stage, the plant's height, number of leaves and their size increases. It obviously needs large amounts of energies. Reproductive Stage is highly an energy consuming and energy demanding stage of a plant. While during Maturity Stage, the root activity is insufficient to provide a quick supply of nutrients to other plant parts in required amounts. All these stages need luxurious supply of required nutrients with their immediate availability. Therefore, foliar spray schedule should be such arranged to get maximum results.

5. The dilute solutions of nutrient formulations are suggested for easier and quicker absorption with their maximum amount. To get quicker and more results of foliar sprays, most of the farmers double up the recommended quantity of fertilizers. The suggested concentration needs to be strictly followed by a farmer.
6. Foliar sprays taken during heat hours of the day(11a.m.to5p.m.)or when the temperatures are high (more than 30 degree Celsius) or the sprays taken with higher concentrations than the recommended may lead to scorching of the leaves. The necrotic spots developed on the leaves by wrongly spraying of the fertilizers hinder their photosynthetic activity. However, the necrotic spots vanish from the leaves indue course of time; especially when the crop is watered and leaves attain turgidity.
7. Take note of possible chemical interactions among foliar fertilizers. Some materials are incompatible and should not be mixed together. They may create precipitates that tie up the nutrients and clog nozzles. To judge the compatibility of nutrients, mix relative quantities of the materials and water in a jar and shake it. If there is no precipitate, there should be no problem.
8. For convenience and cost savings, foliar fertilization can sometimes be combined with a pesticide application. However, timing conflicts and material incompatibilities can make combining sprays unwise and of no use.
9. Absorption of nutrients is enhanced when weather conditions are humid and moist. The presence of heavy dew on the leaves facilitates foliar feeding.
10. A fine mist spray is always to be preferred over large droplets as greater leaf contact and proper adherence of nutrients will be madewith the earlier one. It is a wrong practice of spraying the plants until the droplets start accumulating on the leaves and start dripping on the ground.

A law of thermodynamics states, “Energy can neither be created nor it will be destroyed; so that; total energy in the universe always remains constant.” But energy can be saved. By adopting foliar fertilization in a scientific manner, we are saving enormous energy of a plant which is often utilized in absorption of nutrients from the soil and supplying them to different parts of a plant. This saved energy can be diverted to wards higher production, qualitative enhancement of a product, to fight against environmental stresses, to fight against incidence of pests and diseases, etc. Foliar fertilization is particularly a useful technique, when we understand the principles behind it and rigorously follow them.