Cultural Perspectives

Micronutrients - Molybdenum

Molybdenum (Mo) is the sixth of the micronutrients that we have discussed in this series. It has the lowest average concentration in plant tissue - only 100 parts per billion (Table 1). Except for chlorine, molybdenum was the most recently recognized of the essential plant nutrients. The breakthrough came when molybdenum was found to be associated with "whiptail" disease of cauliflower and "yellow-spot" of citrus crops. However, the greatest response to molybdenum fertilization has been with pasture crops because of its stimulating effect on nitrogen fixing microorganisms.

Table 1 - The seven essential micronutrients and their typical concentrations in seedling tissue

Element	Symbol	Average Concentration in Plant Tissue (%)	Adequate Range in Seedling Tissue (ppm)		Where and When Published
			Bareroot	Container	
Iron	Fe	0.01	50 to 100	40 to 200	Forest Nursery Notes: July, 1997
Manganese	Mn	0.005	100 to 5,000	100 to 250	Forest Nursery Notes: January, 1998
Zinc	Zn	0.002	10 to 125	30 to 150	Forest Nursery Notes: July, 1998
Copper	Cu	0.0006	4 to 12	4 to 20	Tree Planters' Notes: 49 (3)
Molybdenum	**Mo**	**0.0001**	**0.05 to 0.25**	**0.25 to 5.00**	**This Issue**
Boron	B	0.002	10 to 100	20 to 100	Forest Nursery Notes: Summer 2001
Chloride	Cl	0.01	10 to 3,000	NA	To Do: Summer, 2002

Role in Plant Nutrition

Molybdenum functions as a metal component of several enzyme systems, and its value is attributable to its ability to undergo valence ("electrical charge") changes. The two enzymes utilizing molybdenum in higher plants are nitrate reductase and nitrogenase, and both facilitate nitrogen uptake.

Fertilizers supply nitrogen as either nitrate (NO_3^-) or ammonium (NH_4^+) ions or a mixture of both. Plants are able to take up both forms but incorporation into organic molecules within plants requires that the nitrogen be part of an ammonium (NH_4^+) ion. The conversion process from nitrate to ammonium is accomplished by the enzyme nitrate reductase. Molybdenum is necessary for the chemical reaction reducing nitrate ions to ammonium ions prior to their incorporation into functional and structural components such as amino acids, amides, chlorophyll, and others. The actual molybdenum requirement depends in part on the nitrogen supply. Nursery plants, which receive high levels of nitrogen fertilizer, will therefore have a higher demand for molybdenum. In general, for plant metabolism to proceed, only one molybdenum atom is required for every million nitrogen atoms. For this reason, this essential micronutrient is sometimes overlooked since trace amounts contained in soil, growing media, and applied fertilizers can often take care of minimum plant requirements.

The other enzyme, nitrogenase, allows legumes and other plants to fix atmospheric nitrogen (N_2). Hence, the root nodules of legumes, and those of non-leguminous nitrogen fixers such as alder, have a relatively high requirement for molybdenum. This requirement is reduced if adequate nitrogen is present in the soil or supplied from fertilization. Conversely, on molybdenum deficient soils, nitrogen fertilization of legumes and other nodule forming plants can be reduced or replaced by the application of molybdenum fertilizer combined with inoculations of the appropriate microorganisms.

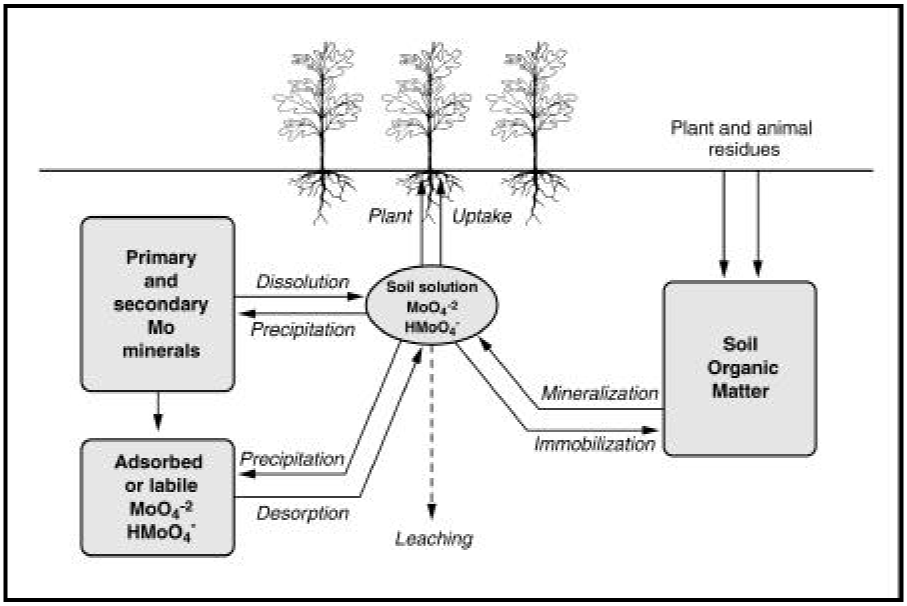

Figure 1

Although not as well documented as its role in nitrate reduction, molybdenum has other functions in higher plants. Molybdenum deficient plants typically have lower levels of sugars and ascorbic acid, and concentrations of some amino acids can be extremely low.

Availability and Uptake

The main sources of molybdenum to the soil solution include primary and secondary minerals, iron and aluminum oxides, and that held in soil organic matter (**Figure 1**). Because molybdenum ions are negatively charged, they are not tightly held in the cation exchange complex of soil particles. Therefore, molybdenum can be readily leached under high rainfall or irrigation conditions, similar to other anions such as phosphate and nitrate. Soils with low organic matter content are even more vulnerable to leaching because they possess fewer cation exchange sites.

Molybdenum is a non-ferrous metallic element, and is absorbed by plants as an anion (MoO_4^{2-}). In whole plant tissue, it is normally found in the range of 0.1 to 5.0 ppm on a dry weight basis (Table 1). Molybdenum is unique among the metallic trace elements in that its availability increases with increasing pH, unlike other nutrient elements such as iron and manganese. This would cause an impending molybdenum deficiency to materialize more quickly under acidic soil conditions, which is the case in most forest nursery soils and artificial growing media. Molybdenum is taken up by the roots in accordance with metabolic need. Since it moves readily in both the xylem and phloem, molybdenum is translocated within the plant.

There is an ongoing debate as to how much lower the requirement for molybdenum is when plants are supplied with nitrogen in the already reduced form of ammonium or urea. The fact remains that there will always be some requirement for molybdenum since nitrification (NH_4^+ >>> NO_3^-) occurs naturally in growing substrates, thus some nitrate will always be present.

Diagnosis of Deficiencies and Toxicities

Deficiency symptoms - Visible deficiency symptoms vary by plant species and the form of nitrogen fertilizer. Symptoms can develop in the foliage of nitrate fed plants below 1 ppm on a dry weight basis, but normally occurs within the range of 0.1 to 1.0 ppm. Because of molybdenum's importance to the uptake of nitrate fertilizers, the presence of elevated tissue nitrate levels can be used along with visual symptoms to help diagnose molybdenum deficiency. When deprived of molybdenum, legumes and other nitrogen fixing plants may display typical symptoms of nitrogen deficiency, including stunting and lack of vigor.

Plants supplied with both forms of nitrogen but operating under molybdenum deficient conditions display local necrosis and chlorosis of leaf tissue. Many agricultural crops exhibit drastic irregularities in leaf formation - a symptom called "whiptail" (**Figure 2**). Local chlorosis along leaf veins ("yellow spot" in citrus)

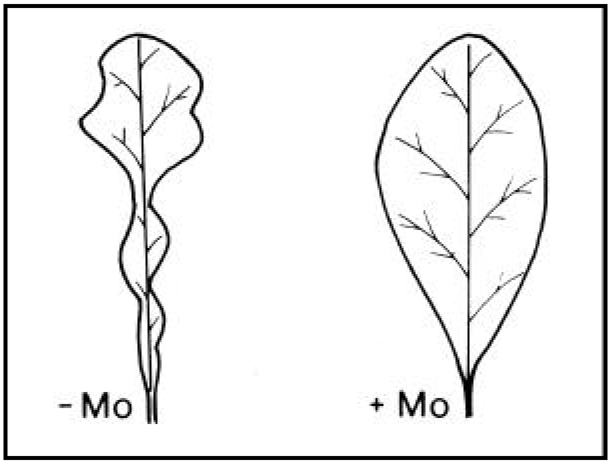

Figure 2

is another classic molybdenum deficiency symptom. This condition is not well known in forest and conservation crops. In some broadleaf tree seedlings, molybdenum deficiency causes scorching and burning of the leaf margins whereas in other species, the primary symptoms are interveinal chlorosis and necrosis. Nutrition trials with two conifer species showed no visual deficiency symptoms and only a slight stunting effect.

Toxicity symptoms - In agricultural species, toxicity symptoms take the form of leaf malformation and a golden yellow discoloration of shoot tissue. Instances of molybdenum toxicity have not been observed on forest and conservation plant species. Since there is a relatively large range between deficiency and toxicity levels, most plants are able to withstand tissue levels up to 1000 ppm of molybdenum.

Molydenum Management

Molybdenum deficiencies have never been reported in forests, and should not be a problem in forest and conservation nurseries. However, as always, prevention is the best management strategy.

Monitoring - Tissue testing is the best diagnostic tool since molybdenum deficiency can often go undetected or, in nitrogen fixing plants, be indistinguishable from nitrogen deficiency. The recommended foliar concentrations for molybdenum in forest and conservation species can vary from as little as 0.05 to 5 ppm (Table 1). Elevated tissue nitrate levels with visual symptoms can also help pinpoint molybdenum deficiency.

Soil Management - On acid soils, where a molybdenum deficiency could be expected, soil applications or seed

Table 2 - Some common fertilizers containing molydbenum (Mo)

Fertilizer	**Chemical Notation**	**Mo (%)**	**Use in Nurseries**
Single Nutrient Fertilizers			
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}$ $2H_2O$	54	Foliar application
Sodium molybdate	NH_4MoO_4 $2H_2O$	39	Seed treatment
Molybdenum trioxide	MoO_3	66	Foliar application
Multinutrient Fertilizers			
Soluble Trace Element Mix— STEM®	Mo as Sodium molybdate	0.4	Foliar or soil applications
Micromax®	Mo as Sodium molybdate	0.1	Incorporation in growing media
Frits	Mo as Sodium molybdate	0.005 to 0.07	Only for soil applications
Plant-Prod® Chelated Micronutrient Mix	Mo as Sodium molybdate	0.06	Foliar or soil applications
Compound 111®	Mo as Sodium molybdate	0.025	Incorporation in growing media
Osmocote Plus®	Mo as Sodium molybdate	0.02	Incorporation in growing media

treatments may be warranted. The recommended soil application rates are very low, ranging from 0.5 to 5 oz of fertilizer per acre (35 to 350 g/ha). On acid soils, liming can increase the availability of molybdenum.

Fertilization - To our knowledge, molybdenum fertilization has never been required in bareroot nurseries. However, nurseries growing alder, locust, acacia or other nitrogen fixing plants should be aware of their greater molybdenum requirement. Where molybdenum deficiency has been confirmed, the most effective treatment is the application of a foliar spray using ammonium or sodium molybdate (Table 2).

Artificial growing media do not contain any molybdenum and so it must be included in the fertilization program. Based on blended fertilizers available on the market, container forest seedlings are receiving application rates ranging from 0.003 to 0.05 ppm on a constant basis (based on a 100 ppm nitrogen regime). It should be noted that some micronutrient fertilizer mixes do not contain any molybdenum so always check the technical grade analysis on the bag or call the supplier if there is any question. Pelletizing lupine tree seed with molybdenum oxide has been an effective treatment for curing deficiencies in New Zealand.

Conclusions and Recommendations

Molybdenum deficiencies should not be a problem in forest and conservation nurseries, especially as long as good soil management is practiced. Maintenance of soil pH is particularly critical. Because of its importance of molybdenum to nitrogen fixation, nurseries growing leguminous plants should be especially watchful. A regular program of tissue analysis should detect any problems and deficiencies can be easily cured with fertilizers.

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