Micronutrients: Copper

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Copper is an essential element for plants; it plays a vital role in the efficiency of photosynthesis and the conversion of photosynthates to macromolecules, particularly lignin. The copper content of most agricultural soils is high, often because copper was added with the application of pesticides. Copper deficiency in bareroot nurseries is rare for the same reason. However, some peat moss–vermiculite growing media are completely devoid of copper, although some can be supplied from copper irrigation pipes. Toxicity generally produces iron deficiency and can also be a concern, especially for sensitive species when copper-coated containers are used for chemical root pruning. Because soil tests do not measure actual availability, copper status should he monitored through foliar analysis. Growers can ensure an adequate supply of copper by maintaining a slightly acid pH and, when needed, applying a foliar spray of copper sulfate or copper chelate. Tree Planters' Notes 49(3): 44 48; 2000.

Copper (Cu) deficiency in soil-grown plants is infrequent because the content in agricultural soils is relatively high (2 to 200 ppm) and plant requirements are relatively low (4 to 20 ppm, table 1) (Tisdale and others 1975). Copper has been used in agriculture for many centuries. Copper sulfate solution was one of the first herbicides, but it was subsequently found to be most useful as a fungicide. In 1882, a severe epidemic of downy mildew disease threatened the grape crop in the Bordeaux region of France. However, crops along the roadside were disease free, and it was determined that the grapes had been sprayed with a mixture of lime and copper sulfate to deter thieves. This "Bordeaux mixture" saved the crop and became one of the most widely used fungicides in the world (Walker 1969). Because of this widespread past use of copper sulfate, agricultural soils are rarely low in Cu.

Table 1—*Concentration of copper in plant tissue in relation to other essential micronutrients*[a]

			Adequate range in seedling tissue (ppm)	
Element	Symbol	Average (ppm)	Bareroot	Container
Iron	Fe	100	50-100	40-200
Chloride	CI	100	10-3,000	[b]
Manganese	Mn	50	100-5,000	100-250
Zinc	Zn	20	10-125	30-150
Boron	B	20	10-100	20-100
Copper	Cu	6	4-12	4-20
Molybdenum	Mo	0.1	0.05-0.25	0.25-5.00

[a] Source: Adapted from Epstein (1972).
[b] Not reported.

Use of Cu as a fertilizer is more recent. While working with the Bordeaux mixture, researchers noted a stimulating effect on plant vigor and yield that could not be explained by the fungicidal effect alone. Copper was confirmed as an essential plant nutrient in 1931. Since then, an abundance of information has verified that Cu is essential for all plants (Reuther and Labanauskas 1965).

Copper's Role in Plant Nutrition

One of the main roles of Cu in plants is as a constituent of proteins and enzymes in oxidation–reduction processes. For example, the Cu-containing protein plastocyanin accounts for about half of the Cu in chloroplasts and is necessary for electron transfer in Photosystem I. As part of the enzyme superoxide dismutase, Cu is involved in detoxifying oxygen radicals generated by photorespiration (Turvey and Grant 1990). Hence, Cu plays a vital role in the efficiency of photosynthesis in general.

Copper also aids in the metabolism of phenol, carbohydrate, and nitrogen, thus making it critical for lignin biosynthesis and the conversion of photosynthates to macromolecules. The most common visual symptom of Cu deficiency is permanent bending and twisting of stems and branches. These symptoms indicate reduced lignin synthesis (Turvey and Grant 1990). The relationship between Cu nutrition and lignification is curvilinear (figure 1), and the adequate range for bareroot and container seedlings is relatively narrow—between 4 and 20 ppm (table 1). In addition to the visible effect on growth form, reduced lignification of xylem vessels weakens them to the point where water movement is impaired. This, in turn, increases susceptibility to water and heat stress.

Lack of Cu can induce nitrogen deficiency in legumes and other nitrogen-fixing plants such as alder (*Alms* sp. Mill.). The process of nitrogen fixation requires a constant supply of Cu to maintain carbohydrate availability. A steady supply of carbohydrate is used by symbiotic microorganisms in the root nodules to fix atmospheric nitrogen used by the plant (Marschner 1986).

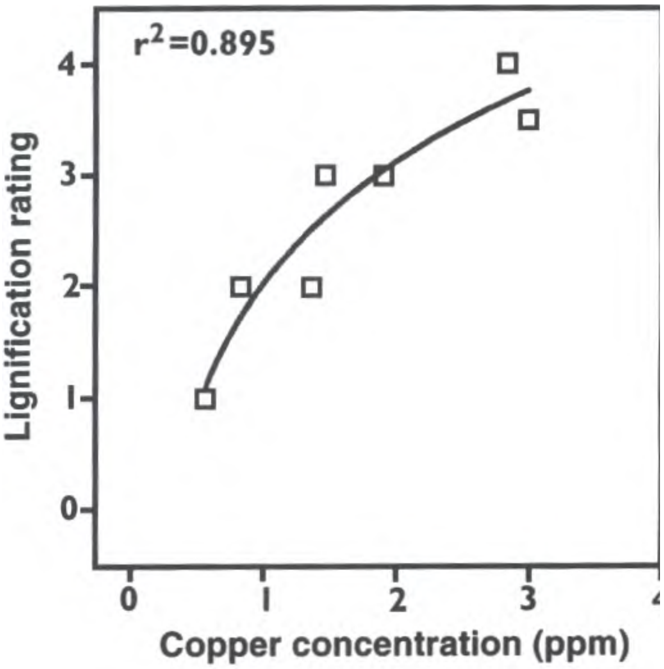

Figure 1—*Copper deficiency caused poor lignification of stem tissue of eucalyptus* (Eucalyptus maculata *Hook.) seedlings (Dell 1994).*

Availability and Uptake

Plants take up Cu as the cupric ion (Cu^{2+}), but because this ion is strongly adsorbed in most soils, it is not readily available. In bareroot nursery soils, Cu availability is affected by texture, pH, cation exchange capacity, and organic matter content. Highly leached sandy soils retain the least Cu, whereas fine-textured soils and those with high organic content retain the most. Soil pH affects Cu solubility and adsorption, and therefore its availability to plants. The Cu^{2+} ion becomes less available with increasing pH. On the other hand, low pH can depress Cu uptake by the plant due to competition with aluminum. The Cu^{2+} ion is subject to competition by other metallic ions including iron, manganese, and zinc. Heavy phosphorus fertilization has been shown to induce Cu deficiency in hybrid poplar *(Populus xeuramericana* Guinier clone DN17) (Teng and Timmer 1990). In the recommended pH range of 5.5 to 6.5, Cu availability should not be a problem for most bareroot nursery soils. In New Zealand and Australia, however, Cu deficiency has been observed in acidic nursery soils (Turvey and Grant 1990).

The situation is considerably different for container nurseries. Chemical analysis (Scarratt 1986) of a standard peat moss–vermiculite growing medium revealed that Cu was the only micronutrient to be completely absent (table 2). This has been confirmed in nursery practice; for example, Vlamis and Raabe (1985) reported Cu deficiency in manzanita *(Arctostaphylos densiflora* M.S. Baker) seedlings grown in a medium composed of tree bark and sand.

Table 2—*Chemical analysis of a commercial peat–vermiculite growing medium revealed no copper'*

Element	Concentration (ppm)
Iron	0.413
Manganese	0.046
Copper	0.000
Zinc	0.002
Boron	0.031
Molybdenum	0.010

'Source: Adapted from Scarratt (1986).

Diagnosis of Deficiencies and Toxicities

The most common visual symptom of Cu deficiency in commercial conifer plantations is a dramatic bending and twisting of stems and branches. Drooping, or "pendula" forms of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) in the Netherlands and radiata pine *(Pinus radiata* D. Don) in Chile, New Zealand, and Australia have been shown to be caused by a lack of Cu (Turvey and Grant 1990). Most of this published information deals with large trees, although a few instances of Cu deficiency and toxicity have been noted in nurseries.

Deficiency symptoms. Copper deficiency has been observed in forest and conservation nurseries in Canada and New Zealand. During an intensive survey of bareroot nurseries in British Columbia, Cu was one of the micronutrients found to be deficient (Maxwell 1988). At low levels of deficiency, reduced photosynthetic activity and turgor may go unnoticed but will still lower seedling quality and the ability to withstand moisture stress. Seedlings with severe Cu deficiency may exhibit chlorosis and tip dieback, looking as if they are potassium deficient. Deficiencies first appear in the youngest needles of conifer seedlings, which may be twisted, rolled inward, or curled, with needle tip burn (figure 2). There can be significant genetic variation in symptom expression, as has been demonstrated for Douglas-fir (van den Driessche 1989) and radiata pine (Pederick and others 1984). Foliar symptoms of Cu deficiency are more variable in broad-leaved species, but most leaves are smaller than normal, and some are blue-green or chlorotic (Hacskaylo and others 1969). The leaves of deficient eucalyptus *(Eucalyptus maculata* Hook.) seedlings showed necrosis and deformed margins (Dell 1994).

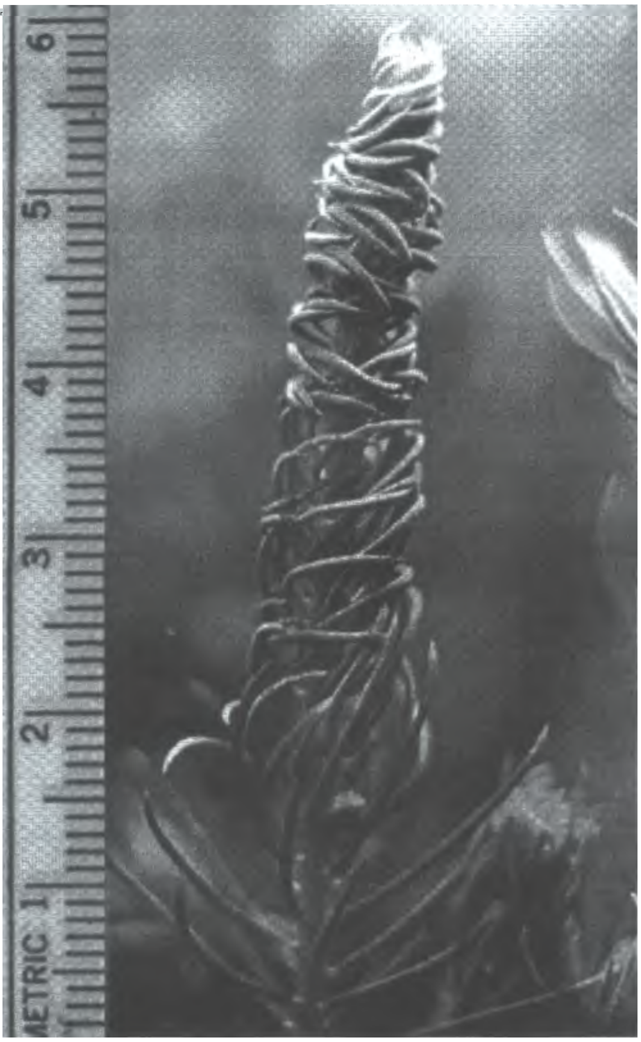

Figure 2—*Copper deficiency symptoms of white spruce* (Picea glauca *(Moench) Voss).*

Toxicity symptoms. In soil, excessive levels of Cu are rare except on sites treated with mine waste or sewage sludge and on agricultural fields subjected to repeated use of Cu-based fungicides (Turvey and Grant 1990). Toxic Cu levels generally produce iron deficiency and, in addition, shoot tips and roots may be stunted, needle and root tips may die, and roots generally turn dark brown to black (Reuther and Labanauskas 1965). In artificial growing media, Cu toxicity is more common where Cu-treated containers are used to prevent root binding and spiraling. Lodgepole pine *(P. contorta* Dougl. ex Loud.) and coastal sources of Douglas-fir are particularly sensitive in this regard (Van Steenis 1994, 1995a, 1995b). White spruce *(Picea glauca* (Moench) Voss) seedlings receiving 2 ppm Cu in a liquid fertilization experiment developed toxicity symptoms with extensive needle dieback (van den Driessche 1989).

Critical toxicity levels vary with species and individual plant parts. Above 20 to 30 ppm is considered toxic for leaves or needles. However, a foliar analysis may not indicate an impending toxicity because roots tend to preferentially accumulate Cu when supplied in excess. Root tissue levels can be up to an order of magnitude larger than foliar levels before transport to the shoot becomes evident. In roots, high Cu levels inhibit root elongation, often resulting in the enhancement of lateral root formation just ahead of the region where Cu is toxic.

Monitoring Copper in Nurseries

Foliar symptoms are of no practical usefulness because, by the time the symptoms are evident, the seedlings are stunted and slow to respond to fertilization. Instead, Cu availability must be monitored by chemical analysis of soils, growing media, or plant tissue.

Analysis of soil or growing media. Copper concentrations in the soil solution are usually less than 1 ppm because most of the ions are chemically bound to soil organic matter (Turvey and Grant 1990). So, from a practical standpoint, chemical testing of bareroot nursery soils has very little application because no method has been developed to assay the amount of Cu that is actually available to plants (Reuther and Labanauskas 1965). Chemical analysis of artificial growing media can be done, but the high affinity with which Cu becomes adsorbed on ion-exchange sites of peat may mask its true availability.

Tissue analysis. Foliar tissue analysis is the most recommended method of determining Cu nutrition in nurseries, and young foliage has been shown to be more diagnostic than older tissue. Sampling new foliage during the growing season is recommended for radiata pine because older tissue may accumulate Cu that is unavailable to the meristems (Pederick and others 1984). Although most standards for adequate Cu are general (table 1), more precise standards have been developed for a few species. For hybrid poplar, a midseason foliar Cu concentration of 3 ppm was a good predictor *of* the proper Cu level (figure 3). This value agrees with the critical range for white spruce and Douglas-fir seedlings of 3 to 4 ppm reported by van den Driessche (1989). Similar results were reported for radiata pine, with Cu deficiency occurring when foliar tests measured less than 2 to 5 ppm (Turvey and Grant 1990). However, in eucalyptus seedlings, Cu deficiency did not occur until foliar concentration dropped below 1.5 ppm (Dell 1994).

Root tissue may be a better indicator of Cu toxicity due to preferential accumulation in roots. However, sampling difficulty and desorption problems with roots

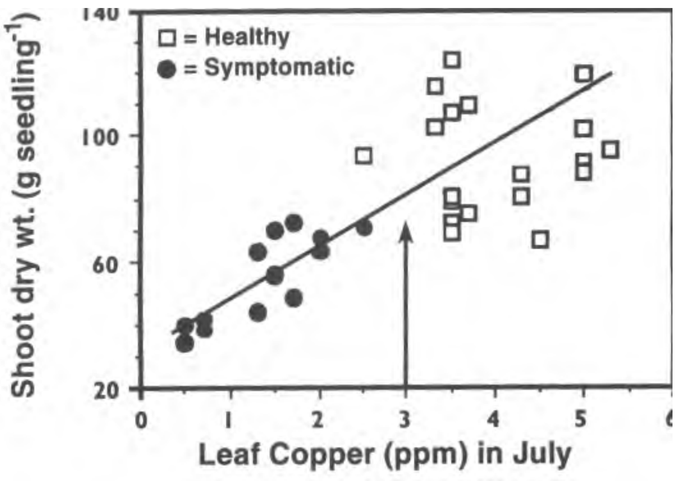

Figure *3—Sampling hybrid poplar* (Populus X euramericana *Guinier clone DN17) leaves during the growing season was found to be more diagnostic than sampling later in the season and .3 ppm was found to be the critical copper concentration (Teng and Timmer 1990).*

make analytical testing of foliage a better option (Turvey and Grant 1990).

Management of Copper Availability

Growers can ensure an adequate supply of Cu by maintaining a slightly acid pH and, when warranted, supplying Cu as fertilizer.

pH. Copper availability, like that of iron, zinc, and manganese, is largely pH dependent. Keeping soil and growing medium pH between 5.0 and 6.5 will prevent problems. Alkaline irrigation water can cause high pH in soils or growing media but can easily be treated by injecting a small quantity of mild acid into the irrigation water. In bareroot nurseries, however, soil amendments often are needed. The pH of naturally calcareous or over-limed soils can be lowered with sulfur applications, although this can take many years.

Fertilization. A wide range of compounds can be used to supply Cu to soil or as a foliar spray (table 3). The most common fertilizers in bareroot nurseries are copper sulfate or copper oxychloride, with the choice dependent on cost and availability. An application rate of 10 kg/ha (9 lb/a) was effective in treating Cu deficiency of a variety of species (Turvey and Grant 1990). Maxwell (1988) recommended a soil treatment of 25 kg/ha (23 lb/a) of copper sulfate. Other familiar formulations used are copper ammonium sulfate and various copper chelates. Because root growth is affected by Cu, it is important that Cu be accessible at all times. Once Cu becomes deficient, plant roots cannot be expected to "grow" in search of it. For this reason, applying small granules or droplets and ensuring good mixing if the fertilizer is incorporated into the medium before planting are imperative. Soil-applied Cu normally has a long residual effect.

Sprays of copper sulfate (table 4) or copper chelate are commonly used to quickly ameliorate symptoms. With hybrid poplar, a single foliar treatment of 0.5% copper sulfate raised the Cu concentration of the foliage better than a higher soil application (Teng and Timmer 1990). Although foliar sprays are easy and effective, follow-up applications are almost always needed (Turvey and Grant 1990).

Summary

Copper deficiency is not a common problem in forest and conservation nurseries and, if diagnosed early, is easily corrected with the addition of copper sulfate or chelate. Deficiency can be due to "starvation in the midst of plenty" because Cu needs to be not only present but also available. Ensuring proper mixing of fertil-

Table *3—Common fertilizers* containing *copper*

Fertilizer	Chemical notation	Copper (%)	Use in nurseries
Single nutrient fertilizers			
Copper sulfate	CuSO$_4$•5 F120	24	Foliar or soil applications
Copper oxychloride	CuC12•3Cu0•4H$_2$0	52	Foliar or soil applications
Copper ammonium phosphate	Cu(N1F14)PO4.H20	32	Foliar or soil applications
Copper chelate	CuEDTA	14	Foliar or soil applications
Multi-nutrient fertilizers			
Soluble Trace Element Mix · STEM ®	Copper as CuSO4	2.30	Foliar or soil applications
Micromax ®	Copper as CuSO4	0.50	Incorporation in growing medium
Plant-Prod °Chelated Micronutrient Mix	Copper as EDTA	0.10	Foliar or soil applications
Copper frits	Cu02	0.03-3.80	Only soil applications
Compound 111 ®	Copper as EDTA	0.11	Incorporation in growing medium
Osmocote Plus 0	Copper as CuSO4	0.05	Incorporation in growing medium

Table 4-Copper *sulfate was the only fertilizer treatment that cured symptomatic, copper deficient manzanita* (A. densiflora M.S. *Baker) seedlings grown in an organic growing mediums'*

Treatment	Nutrients supplied	Oven-dry weight of new growth [g (1b)]b	
Control	None	2.6 (0.0057)	b
Boric acid	Boron	1.9 (0.0042)	b
Copper sulfate	Copper. sulfate	24.8 (0.0547)	a
Calcium sulfate	Calcium, sulfate	2.0 (0.0044)	b
Hoagland's solution	All	2.3 (0.0051)	b

•Source: Adapted from Vlamis and Raabe (1985).
°Significant at the 5% level.

izer into soil and/or artificial growing medium, along with maintaining slightly acid pH levels and proper balance with other fertilizer elements, will help maintain availability. Maintaining an active and healthy root system is imperative.

Toxicities are rare in nature. They are usually self-inflicted through application of manures, sewage sludge, industrial waste, or the excessive application of Cu-based fungicides. Lately, Cu-treated containers for chemical root pruning are testing the fertilizer mixing and managing skills of seedling growers.

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References

Dell B. 1994. Copper nutrition of *Eucalyptus maculata* Hook. seedlings: requirements for growth, distribution of copper and the diagnosis of copper deficiency. Plant and Soil 167(2): 181-187.

Epstein E. 1972. Mineral nutrition of plants: principles and perspectives. New York: John Wiley and Sons. 412 p.

Hacskaylo J, Finn RF, Vimmerstedt JP. 1969. Deficiency symptoms of some forest trees. Wooster (OH): Ohio Agricultural Research and Development Center. Research Bulletin 1015. 68 p.

Marschner H. 1986. Mineral nutrition of higher plants. New York: Academic Press. 674 p.

Maxwell JW. 1988. Macro and micronutrient programmes in B.C. bareroot nurseries. In: Landis TD, editor. Proceedings, Combined Meeting of the Western Nursery Associations; 1988 Aug 8-11; Vernon, BC. Ft. Collins (CO): USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-167. p 11-14.

Pederick LA, Hopmans P, Flinn DW, Abbott IE. 1984. Variation in genotypic response to suspected copper deficiency in *Pinus radiata.* Australian Forest Research 14: 75-84.

Reuther W, Labanauskas CK. 1965. Copper. In: Chapman HD, editor. Diagnostic criteria for plants and soils. Riverside (CA): Homer D. Chapman. p 157-179.

Scarratt JB. 1986. An evaluation of some commercial soluble fertilizers for culture of jack pine container stock. Sault Ste. Marie (ON): Canadian Forestry Service, Great Lakes Forestry Service. Information Report O-X-377. 21 p.

Teng Y, Timmer VR. 1990. Phosphorus-induced micronutrient disorders in hybrid poplar: 3. Prevention and correction in nursery culture. Plant and Soil 126(1): 41-51.

Tisdale SL, Nelson WL, Beaton JD. 1975. Soil fertility and fertilizers. 4th ed. New York: Macmillan. 694 p.

Turvey ND, Grant BR. 1990. Copper deficiency in coniferous trees. Forest Ecology and Management 37: 95-122.

van den Driessche R. 1989. Nutrient deficiency symptoms in container-grown Douglas-fir and white spruce seedlings. Victoria (BC): Ministry of Forests. FRDA Report 100.29 p.

Van Steenis E. 1994. Growing in copper treated containers requires greater awareness. Victoria (BC): Ministry of Forests. Seed and Seedling Extension Topics 7(2): 4-5.

Van Steenis E. 1995a. Growing in copper treated containers...continued from page 4, vol. 7-#2. Victoria (BC): Ministry of Forests. Seed and Seedling Extension Topics 8(1): 3.

Van Steenis E. 1995b. Copper treated container culture...just a little bit more? Victoria (BC): Ministry of Forests. Seed and Seedling Extension Topics 8(2): 6.

Vlamis J, Raabe RD. 1985. Copper deficiency of manzanita growth in a bark-sand mixture. HortScience 20(1): 61-62.

Walker JC. 1969. Plant pathology. New York: McGraw-Hill. 1819 p.