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# Managing Manganese Deficiency in Nursery Production of Red Maple

*J. Altland*

## Key points

- Plants require 13 mineral nutrients, all of which must be supplied in balanced quantities.
- Manganese (Mn) availability in soil depends primarily on soil pH.
- Mn is not mobile in soil; it must be incorporated into soil prior to planting.
- Mn moves from plant roots to foliage but is otherwise immobile in plants. It must be available to plant roots, where it can be absorbed and distributed throughout the plant.
- Mn deficiency must be prevented with management practices prior to planting.

  — Select soil with adequately low soil pH.

  — Avoid sites with poor drainage.

  — Adjust soil pH and nutrient levels prior to planting, when fertilizers can be incorporated.

  — Use $MnSO_4$ to increase Mn in soil. Do not use chelated Mn for soil applications.
- Foliar Mn applications are largely ineffective. Do not rely on them to solve a maple chlorosis problem.

Oregon State University Extension Service

*Manganese deficiency in red maple leaves is characterized by interveinal chlorosis; in severe cases, necrosis occurs.*

Field-grown red maple (*Acer rubrum*) trees often develop foliar chlorosis during mid- to late summer. Initially, the condition appears as mild interveinal chlorosis in newly developing foliage. As symptoms intensify, entire leaves turn chlorotic. Under severe conditions, interveinal necrosis occurs. Chlorotic plants often have reduced height and caliper.

The chlorosis is most often caused by manganese (Mn) deficiency. Mn is an essential nutrient for plant growth. Several soil properties affect Mn availability and the severity of chlorosis.

This publication discusses the importance of Mn in nutrition of red maples in nursery production and explains the combination of soil factors that can cause Mn deficiency and resulting chlorosis. Management guidelines for preventing red maple chlorosis are presented.

Chlorosis caused by Mn deficiency has also been documented in urban landscape trees throughout the United States. Concepts discussed in this publication are applicable to landscape situations. However, the management practices discussed here are intended primarily for nursery production on western Oregon soils. They may not be completely relevant in landscape situations or in other regions.

## Nutrient nomenclature

Plants require 13 mineral nutrients (Table 1, page 3). Three of the mineral nutrients are needed in relatively large quantity and are called *macronutrients*. Three more are needed in slightly lower levels and are called *secondary nutrients*. The other seven are needed in relatively small quantities and are called *micronutrients*.

*James Altland, Extension faculty (nursery crops), North Willamette Research and Extension Center (NWREC), Oregon State University.*

*Manganese deficiency occurs first on new growth, with stunted yellow foliage. (Plant at left is chlorotic; plant at right is healthy.)*

*Red maples grown in soil with sufficiently low pH grow vigorously without supplemental Mn sprays.*

Each nutrient is abbreviated by an elemental or atomic symbol. Manganese is the focus of this publication and is abbreviated Mn. Do not confuse this element with magnesium (Mg). Mn is a micronutrient, essential for plant growth but needed in very small quantities. Mg is a secondary nutrient needed in much larger quantities.

## Manganese (Mn) reactions in soil

Manganese is abundant in Oregon soils; however, most of it is unavailable for plant uptake. Plants can absorb Mn only when it occurs in solution as a divalent cation ($Mn^{2+}$). $Mn^{2+}$ is referred to as the *reduced* form. Mn also occurs in *oxidized* forms ($Mn^{3+}$ and $Mn^{4+}$), both of which are unavailable for plant uptake.

Soil microorganisms oxidize plant-available $Mn^{2+}$ to $Mn^{3+}$, which makes it unavailable to plants. This biological reaction occurs slowly when soil pH is between 5 and 6.5. However, it proceeds more rapidly as pH increases up to 7.5 (Russell, 1988). Thus, the form of Mn in a soil system depends largely on the functioning of soil microorganisms, and their activity depends on soil pH.

Conversely, Mn can be reduced (from $Mn^{3+}$ to $Mn^{2+}$), making it available to plants, either chemically or by other soil microorganisms that function more efficiently at low pH (Russell, 1988). Increased Mn reduction to $Mn^{2+}$ also can result from the action of materials secreted by plant roots. These *root exudates* are solutes that aid in nutrient acquisition, increase root tolerance to high concentrations of aluminum, and/or act as a lubricant as roots grow through soil. The organic acids contained in root exudates, particularly malic acid, increase the solubility of Mn in the soil, making it more available to plants. Attachment of $Mn^{2+}$ to organic compounds in root exudates (*chelation*) prevents the $Mn^{2+}$ from reoxidizing to the unavailable form.

Mn is relatively immobile in soil. Therefore, Mn applied to the soil *surface* will remain at the surface. To alter soil Mn levels and prevent Mn deficiency, Mn must be distributed throughout the root zone so that all roots can intercept and absorb it.

## Mn movement in plants

Plants have a vascular system for moving water, metabolites, and solutes from one part to another. The plant vascular system consists of two components, *xylem* and *phloem*. Xylem transports water and dissolved

*Table 1. Tissue nutrient values of high-quality 'Red Sunset' maple (*Acer rubrum*).*

| Nutrient | Units | Minimum | Maximum |
|---|---|---|---|
| **Macronutrients** | | | |
| Nitrogen | % | 2.8 | 3.1 |
| Phosphorus | % | 0.28 | 0.38 |
| Potassium | % | 0.9 | 1.1 |
| **Secondary nutrients** | | | |
| Calcium | % | 0.45 | 0.65 |
| Magnesium | % | 0.15 | 0.20 |
| Sulfur | % | 0.18 | 0.22 |
| **Micronutrients*** | | | |
| Iron | ppm | 120 | 250 |
| Manganese | ppm | 70 | 285 |
| Zinc | ppm | 45 | 56 |
| Copper | ppm | 6 | 8 |
| Boron | ppm | 13 | 19 |

*Molybdenum and chlorine are considered plant micronutrients, but were not analyzed in this experiment.

nutrients from roots upward to shoots, with virtually no downward movement. Phloem transports water, metabolites, and solutes in all directions throughout the plant.

Mn is absorbed by roots and moved *upward* to the leaves through the xylem; however, Mn cannot be transported through the phloem. Therefore, Mn accumulated in leaves cannot be remobilized in any significant quantity (Graham et al., 1988).

Similarly, Mn absorbed by foliage directly via foliar sprays will not move out of the foliage and back into stem or root tissue. While foliage can be made to look more green and healthy with supplemental foliar-applied Mn, root systems on those plants will still be deficient. Likewise, Mn absorbed by one root cannot be redistributed to another part of the root system (Nable and Loneragan, 1984).

## Mn function in plants

Mn plays four major roles in plant growth and development. It is involved in the plant's ability to capture light energy for use in photosynthesis. In nitrogen (N) metabolism, it plays a role in the conversion of nitrate to ammonium, probably through interaction with an enzyme known as nitrate reductase (Marschner, 1997).

Critical to production of nursery crops is the role of Mn as a precursor to the plant hormone auxin. Mn activates the auxin oxidase system (Russell, 1988). Mn deficiency reduces auxin levels and causes hormone imbalance. A decrease in the ratio of auxin to other plant hormones causes reduced lateral root development and root extension (Landis, 1998).

Finally, Mn plays a vital role in carbohydrate production. Carbohydrates are molecules containing carbon, hydrogen, and oxygen that are used by plants for energy storage. An abundant supply of carbohydrates is produced in leaves through photosynthesis. These carbohydrates can be used locally to fuel cellular processes within the leaf, or they can be shuttled to other parts of the plant to be used as an energy source. During the winter when plants are dormant, carbohydrates are stored in stem and root tissue.

Stored carbohydrates in the root system are important for root regeneration the following year. Mn deficiency reduces the plant's ability to produce carbohydrates, thus reducing a harvested plant's ability to regenerate roots and grow vigorously when replanted the following year.

## Mn in Oregon field nurseries

'Red Sunset' maples (*Acer rubrum*) in nursery production fields were sampled over a 2-year period to determine how soil nutrient levels affect Mn concentration in the plant and the occurrence of Mn chlorosis. Soil and foliar tissue samples were collected from 24 bare-root shade tree nurseries throughout the northern Willamette Valley in Oregon.

Soil and tissue samples were analyzed for parameters listed in Tables 1 and 2. Trees were measured for height, caliper, foliar chlorophyll content, and overall quality. Tree quality was measured on a subjective scale from 1 to 10, where 1 is a tree of poor quality with severe chlorosis, and 10 is a tree of high quality with no sign of chlorosis.

In both years, trees at every nursery appeared healthy when samples were collected in June. All plants were growing vigorously and had dark green foliar color. Almost all trees had quality ratings of 9 or higher. Despite uniformly excellent foliar color, however, trees differed greatly in levels of absorbed Mn. Foliar Mn levels ranged from 10 to 535 ppm. By late August, trees at some nurseries appeared healthy and vigorous, while others were chlorotic, stunted, and lacked vigor.

Data from both years clearly indicated that poor Mn absorption early in the year was the cause for late-season chlorosis. Table 1 indicates ranges of nutrients in analyzed tissue from high-quality red maple trees.

*OSU research studied the relationship between soil chemical factors and red maple health and identified a strong relationship between soil pH and foliar Mn concentration.*

*Table 2. Soil properties and soil nutrient values in fields with high-quality 'Red Sunset' maple (*Acer rubrum*).*

| Nutrient | Units | Minimum | Maximum |
|---|---|---|---|
| pH | | 5.0 | 5.6 |
| SMP pH | | 6.0 | 6.4 |
| Organic matter | % | 3.0 | 4.4 |
| Phosphorus | ppm | 50 | 100 |
| Potassium | ppm | 160 | 220 |
| Calcium | meq | 4 | 20 |
| Magnesium | meq | 1.0 | 1.6 |
| Sulfur | ppm | 9 | 18 |
| Iron | ppm | 50 | 120 |
| Manganese | ppm | 20 | 40 |
| Zinc | ppm | 1.8 | 2.7 |
| Boron | ppm | 0.2 | 0.3 |
| Copper | ppm | 1.0 | 2.1 |
| Soluble salts | mmhos | 0.2 | 0.9 |

Table 2 shows soil properties and levels of soil nutrients associated with high-quality red maple trees.

Soil and foliar Mn levels were highly correlated to soil pH. As soil pH decreased, available soil Mn levels increased, as did the concentration of foliar Mn. Soil pH between 5.0 and 5.6 consistently resulted in healthy red maple trees with no sign of chlorosis. As soil pH increased beyond 5.6, Mn levels in plant foliage decreased, and the associated chlorosis became more intense.

Soil pH lower than 5.0 did not cause any noticeable problems in the trees we observed. However, very low soil pH (lower than 4.5) can result in aluminum (Al) toxicity.

While this survey did not rigorously explore the role of topography in Mn deficiency, plants growing in low-lying or poorly drained areas were more prone to chlorosis. Plant-available Mn typically is low in poorly drained soils (Camberato, 2001).

## Management practices

Successful management of red maple chlorosis must be preventative. Site selection and soil preparation prior to planting are key to preventing this problem. Curative practices are largely ineffective.

### *Site selection for planting*

Using historical knowledge, narrow down the possible planting sites for red maples to those fields where you think pH is lowest. Collect soil samples from these fields, and avoid planting red maples where pH is greater than 5.6. As pH increases above 5.6, Mn availability in soil and absorption by plants decrease dramatically. Planting red maples in soil with pH less than 5.6 is the most critical step in preventing chlorosis.

Select sites that are well drained. Well-drained soils typically are necessary for growing any nursery crop; however, red maple may be more sensitive than most species. Avoid planting areas of a field that lie at the bottom of swales. For large areas that drain poorly, use drainage tile to improve drainage or plant a crop more tolerant of wet soils.

Red maple also is known as swamp maple, implying it is suited to wet soils. Nonetheless, most native

*Red maples growing in low or poorly drained areas often suffer from Mn deficiency.*

red maples are found in dry upland forests of the eastern U.S. rather than in wet, swampy areas (Teuscher, 1956). Red maple tolerance to environmental conditions often is genotype-specific. Cultivars common in Oregon nurseries perform better in noncompacted, well-drained soils.

## Adjusting soil nutrient levels

Soil test nutrient values should be within the range of values in Table 2. If any value is not within the range specified, consider some action to compensate.

Incorporate fertilizers into the soil before planting. Phosphorus, secondary nutrients, and micronutrients move slowly in the soil profile and are more readily available to plants if incorporated throughout the root zone of the future crop.

Sulfate often is limiting to plant growth. Sulfate influences Mn absorption, and sulfate levels required by red maple trees are greater than for most other crops. Sulfates are a component of many fertilizers, so they can be applied along with other nutrients that are shown to be deficient on the soil test. Ammonium sulfate is a common source of nitrogen, and it can be used throughout the growing season. Unlike most nutrients, sulfate and nitrogen are mobile through the soil profile and can be topdressed on the soil surface.

## Manipulating soil pH

Growers must manage soil pH in order to improve Mn availability for plants. For red maple, raise or lower the soil pH to the target level of 5.0 to 5.6.

Do not apply lime unless pH is well below 5.0. Lime does two things: it adds calcium to the soil and raises pH. (Dolomitic lime also adds magnesium.) Calcium (Ca) and magnesium (Mg) levels should be within ranges listed in Table 2. If pH is suitable but Ca or Mg is deficient, add gypsum ($CaSO_4$) to raise Ca levels and/or Epsom salt ($MgSO_4$) to raise Mg levels. These two products are readily available, inexpensive, and have no effect on soil pH.

If pH is below 5.0, lime applications may be necessary. If necessary, apply lime during field preparation (before planting) and incorporate it into the soil. For lime rates, consult the OSU Extension publication *Fertilizers and Lime Materials* (Hart, 1998).

If soil pH is greater than 5.6, apply granular elemental sulfur to lower soil pH. For the most thorough information on acidifying soil pH in Oregon nurseries, see the OSU Extension publication *Acidifying Soil for Crop Production West of the Cascade Mountains* (Horneck et al., 2004).

Elemental sulfur is oxidized to sulfate by soil bacteria (*Thiobacillus*), a process that results in lower soil pH. Soil temperatures need to be above 50 °F for this reaction to occur. Optimum reaction rates occur at temperatures between 70 and 80 °F. Applications can be made any time of the year, but changes to soil pH will not occur until soil temperatures have warmed. Elemental sulfur is not soluble in water, so it will not leach away with winter rains if applied in late fall.

It typically takes at least a year for all of the applied sulfur to be oxidized. Because of the long time needed for the resulting pH change to occur, it is best to incorporate sulfur 6 to 12 months before planting.

Because elemental sulfur is not soluble, it must be incorporated into the soil profile to be effective. Sulfur topdressed on the soil surface will not be accessible to soil bacteria, and thus will not lower soil pH.

## Promoting healthy root growth

Healthy, fibrous root systems release more root exudates, resulting in higher levels of Mn available for plant growth. Cultural or management factors that negatively affect root

*Most nutrients need to be incorporated into the soil profile so that they are available for root uptake.*

growth exacerbate Mn deficiency. In nursery field production, plant healthy liners with vigorous root systems. Provide plants with sufficient water and fertility so that other factors (aside from low Mn levels) do not impede root growth.

## Mn applications to soil

Mn absorption increases with increasing soil Mn levels; however, Mn availability usually can be regulated more effectively by adjusting soil pH than by Mn applications. If pH is lowered through sulfur applications, more Mn will become available.

If you apply Mn as a fertilizer, remember that Mn is not mobile in the plant or in soil. Plants cannot translocate Mn from a well-supplied part of the root system to a deficient part. If Mn fertilizers are topdressed after planting, only those roots near the soil surface will have sufficient Mn, while the remainder of the root system will remain deficient and of poor quality.

Even if surface-feeding roots can absorb sufficient Mn to supply the plant for excellent shoot growth, the part of the root system with limited access to Mn will be poorly developed. Therefore, topdressing Mn fertilizer is insufficient to "cure" the entire tree.

For soil applications of Mn, use $MnSO_4$ (Mills and Jones, 1996). When soil Mn levels are low, adjust pH to appropriate levels and add $MnSO_4$ as recommended by a soil test.

Mn also is available in a chelated form. Chelated fertilizers are nutrients that are enclosed by an organic molecule. In the chelated form, the micronutrient is soluble over a wider range of soil pH conditions, thus allowing fertilizer applications in high pH soils where the nutrient otherwise would be unavailable for plant uptake. In agricultural fertilizers, the organic molecule most often is EDTA (ethylenediaminetetraacetic acid).

Chelated Mn applied as a soil application is **not** effective at raising available Mn levels in soil. When MnEDTA was applied to a soil with pH of 5.7, less than 3 percent of the Mn remained in solution 20 hours after application (Norvell and Lindsay, 1969).

The chelated Mn ion is replaced by iron (Fe) in low pH soils and by Ca in high pH soils (Russell, 1988). Excess Fe in soil solution exacerbates Mn deficiency by outcompeting Mn for uptake. When chelated Mn is applied and Fe displaces it in the chelated molecule, Mn uptake is not improved, and the additional absorbed Fe further depresses Mn uptake. This effect was demonstrated in research on a loam soil, where chelated Mn application worsened Mn deficiency (Schulte and Kelling, 1999).

## Mn applications to foliage

Foliar Mn sprays are not effective remedies for Mn deficiency in red maple. Although foliar sprays can improve tree foliage color, they do not correct the deficiency in stems and roots. Mn is not mobile in plants, so applying Mn to foliage only temporarily affects those parts of the plants contacted by the spray. Repeated sprays can be made to continuously supply Mn to new growth. However, recall that Mn is critical for auxin production and carbohydrate storage in plant roots. Mn that is supplied only to plant foliage will not be translocated from the foliage; thus, plant roots will be Mn deficient despite sprays that "green up" foliage.

Production, digging, and shipping methods often dictate the size of the root system; roots that remain attached should have maximum stored energy (carbohydrates) for regenerating small feeder roots when trees are planted in customer fields or landscapes. Mn deficiency limits root vigor by reducing carbohydrate storage, and foliar Mn sprays will not remedy this critical problem.

## Conclusion

Mn deficiency occurs late in the growing season and often is ignored. By the time foliar chlorosis is visible, growth has already been adversely affected.

The first and most fundamental practice for preventing Mn deficiency is to test soil pH and plant red maples in fields with sufficiently low pH. Using Mn sprays and/or soil supplements after planting is ineffective for managing chlorosis. By planting maples in soil with low pH, you avoid the hopeless venture of trying to get Mn into a plant that cannot absorb it.

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