Secondary Nutrients—Calcium

Conventional fertilization is mainly concerned with the "Big Three" macronutrients-Nitrogen (N), Phosphorus (P), and Potassium (K). This is because together these elements comprise over 75 % of the mineral nutrients found in typical plant tissue (Table 1). The three "secondary" nutrients (Calcium, Magnesium, and Sulfur) are also important to seedling health and vigor, however, since adequate amounts are usually provided by the soil, or incidentally in N-P-K fertilizers, they do not receive as much attention. Beginning with calcium in this issue, we are going to take a more detailed look at these secondary nutrients.

Calcium is seldom in the spotlight in conifer seedling culture because it is found in all but the most acidic soils, and also is commonly present in irrigation water. Another complicating factor is that seedlings of forest and conservation species typically do not display visible calcium deficiency symptoms. This is not the case in horticulture where crops exhibit classic symptoms: tomatoes and peppers develop "blossom end rot, lettuce displays "tipburn" of the leaves, and celery comes down with "blackheart". Although there is no such thing as a true calcium toxicity, excess levels in the soil and water can induce serious deficiencies of other mineral nutrients.

Role in plant nutrition.
The key to understanding calcium-related disorders is knowing its mode of uptake and function within plants. Calcium is primarily found in the cell wall and plasma membrane where it performs a variety of roles in the development and maintenance of overall plant structure and function:

- **Facilitates cell division and elongation.** Calcium forms stable intermolecular linkages needed to build cell walls, so a continuous supply is necessary for normal growth.
- **Strengthens cell walls.** Calcium combines with pectate to form a type of semi-permeable glue called calcium pectate.
- **Helps regulate cell membrane permeability.** Calcium pectate helps control which ions are able to enter and leave the cell.
- **Helps prevent fungal disease infections.** Calcium pectate acts as a physical barrier to fungal hyphae penetration but is degraded by an enzyme called polygalacturonase, which is inhibited by high calcium concentrations. Many fungi, such as *Fusarium* and *Pythium* spp., manufacture this enzyme as a means to invade plant tissue. We don't have any research on forest crops, but in a study on tomato, the severity of Fusarium wilt decreased as the concentration of Ca^{2+} in the nutrient solution increased. In another study, calcium soil amendments reduced Pythium damping-off of cucumber seedlings.

Table 1. The three "secondary nutrients": Calcium, Magnesium, and Sulfur

Element	Symbol	Average Concentration in Plant Tissue (%)	Adequate Range in Seedling Tissue (%) Container-	Bareroot
Nitrogen	N	1.5	1.20 to 2.00	1.30 to 3.50
Potassium	K	1.0	0.30 to 0.80	0.70 to 2.50
Calcium	Ca	0.5	0.20 to 0.50	0.30 to 1.00
Magnesium	Mg	0.2	0.10 to 0.15	0.10 to 0.30
Phosphorus	P	0.2	0.10 to 0.20	0.20 to 0.60
Sulfur	S	0.1	0.10 to 0.20	0.10 to 0.20

- **Inhibits potential toxins.** Because it is a divalent cation (Ca^{2+}) calcium is very effective in ameliorating the adverse effects of toxic ions such as sodium. In the absence of adequate calcium levels, sodium ions can disrupt the structure and function of plant membranes.

Availability and uptake.
Calcium uptake is a function of soil solution availability, root system integrity, and seedling transpiration rate. In the soil solution, the type and relative concentration of ions is critical. Being a relatively large divalent cation, calcium can be outcompeted by smaller monovalent cations such as potassium and ammonium-nitrogen or other divalent cations (e.g. Mg^{2+}). Maintaining favorable nutrient ratios in the soil solution is paramount-1:1 for Ca:K and 3:1 for Ca:Mg. Nitrate-nitrogen, because it is an anion, does not suppress calcium uptake, but may actually enhance it. For this reason, calcium nitrate fertilizer [$Ca(N0_3)_2$] is used to correct deficiencies or uptake-related problems, and provides extra calcium during critical times in the crop cycle, such as the Hardening Phase.

The root system needs to be actively growing with a good complement of young root tips which have the greatest absorptive capacity. Anything that compromises root system morphology or physiology reduces calcium uptake. Temperature extremes, excessive moisture or drought, poor aeration, and pathogens all take their toll. After they enter the roots, calcium ions are transported throughout the plant in the xylem. Presence and movement in the phloem is very limited, hence there is little calcium translocation from older to younger tissue if a local deficiency occurs. Xylem sap flows in response to transpirational demand and/or root pressure to its final destination or "sink". Because root pressure is a relatively minor factor, the strength of a particular sink is mainly a function of transpirational demand. Unfortunately, "sink strength" may not correspond to physiological need. Meristems, the very tissues that need calcium the most often lose out to young leaves which transpire water at high rates. Organs with low sink strength have to rely on root pressure, which is only functional at night, for their calcium supply. Therefore, during high transpirational demand, calcium is being carried to places where it is less needed while during periods of lower demand, general calcium uptake is reduced.

Diagnosis of deficiencies/toxicities.
The metabolic functions previously listed explain some typical symptoms of calcium deficiency: disintegration of cell walls, collapse of tissues, root tip mortality, and an increased susceptibility to fungal attack. Minor deficiencies cause membranes to become leaky without any obvious disintegration. This increases the seedling energy requirement to maintain membrane function and reduces the energy available for other metabolic functions, leading to lower growth rates. Since newly-forming cells require a steady supply of calcium, meristematic tissues are the most susceptible to deficiencies. Unfortunately,

calcium deficiencies usually reach severe levels before they are noticed because meristematic tissues are not readily visible-buds are hidden within other tissue, whereas other meristems, such as root tips, are buried in the soil. In the case of root tips, a problem with calcium supply results in a complete cessation of root extension within only a few hours (Figure 4).

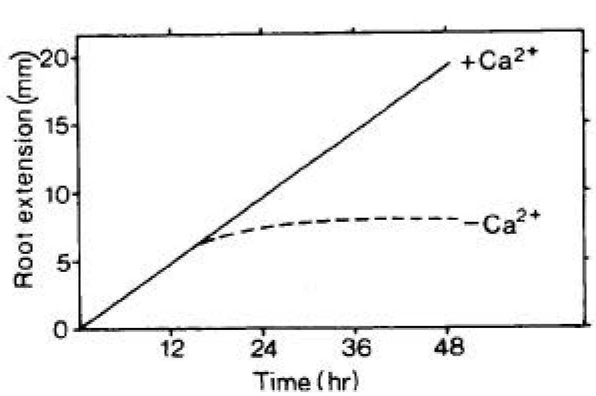

Figure 4. The first evidence of a calcium deficiency is often reduced root growth which is not immediately apparent to the grower. (Marschner and Richter, 1974.)

Monitoring.

Bareroot nursery managers can use annual soil tests to make sure that calcium levels are adequate, and should be particularly careful to maintain the proper pH level. If the pH is too acidic, calcium is leached out of the root zone, whereas at higher pH levels, calcium excesses can induce other nutrient deficiencies, especially iron and phosphorus. With container seedlings, monitoring the leachate will provide the best information about the availability of calcium to the roots.

Plant nutrient analysis only reflects the type of tissue analyzed, and may not give an accurate account of the current calcium status near the meristems. At best, tissue analysis tells us something about past uptake levels and whether or not calcium ions were available in the soil solution.

Calcium management.

So, what does all this mean to the grower? Let's summarize what it takes to insure adequate calcium availability to young, rapidly growing seedlings:

- Analyze your irrigation water, paying particular attention to the calcium, sodium, and total alkalinity levels. This is particularly important for container growers because artificial growing media have inherently low calcium levels unless limestone has been added. Moderately "hard" water (> 40 ppm Ca) provides a steady supply, reducing the need for additional calcium fertilizer. "Soft" water contains high sodium levels relative to calcium, so fertilization may be warranted.
- Monitor pH in the soil or growing medium, keeping it within the 5.5 to 6.5 range. Bareroot nurseries should use dolomitic limestone to raise soil pH, and sulfur amendments to lower it. Note the preference of dolomitic instead of calcic limestone—the former has the proper balance of Ca: Mg. Growing medium pH should not be a problem with most commercial mixes unless irrigation water is alkaline.
- Use fertilizers or amendments containing calcium if needed. Dolomitic limestone is all that is needed in bareroot nurseries, but container seedling growers need to insure a steady supply of soluble calcium. Simply adding dolomite amendments to the growing medium does not insure that young seedlings are getting a steady supply of calcium, hence liquid fertilization is recommended if the irrigation water does not contain enough. Most "complete" container seedling fertilizers do not contain any calcium because of solubility problems in the mixing tank but some newer formulations such as Peters Excel® now do (Figure 5). A concentration of 40 to 80 ppm Cain the "applied fertilizer solution" is a good target, but remember to watch mineral nutrient ratios as well as absolute levels.
- Balance irrigation and transpiration to maintain a moderate level of moisture stress, which keeps calcium moving into the plant and available to all tissues, especially the meristems.
- Maintain adequate calcium levels during all phases of seedling growth from germination though dormancy. During the Hardening Phase, stem meristems are particularly active and cells in foliar tissues are developing thicker

walls. Calcium nitrate is an excellent ingredient in a hardening fertilizer, not only because it is completely soluble, but also because it supplies nitrogen in the proper nitrate form. Be aware that some commercial hardening fertilizers do not contain calcium.

In conclusion, nurseries will benefit from paying more attention to secondary mineral nutrients such as calcium. Understanding the role of calcium in seedling growth and how it is taken up and utilized in plant tissue provides the key to proper management.

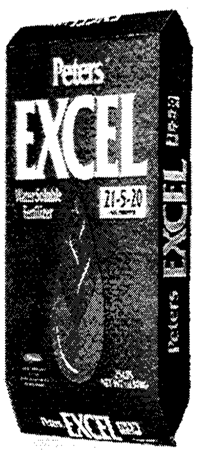

Figure 5. Peters® Excel is one of the few water soluble fertilizer mixes that contains calcium.

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