Limiting Factors --Mineral Nutrients

As we have been discussing in the last few issues of FNN, plants need six different "limiting" factors for good growth and development. Four are found in the ambient environment (light, temperature, humidity, and carbon dioxide) and two are supplied from the soil or growing medium (mineral nutrients and water). In this issue, we will take a look at the different mineral nutrients that seedlings need for normal growth and development.

Throughout history, humans have been adding "mineral" substances such as wood ash or lime to the soil to improve the growth of their crops. It was not until the 19th century, however, that Justus von Liebig proposed the mineral element theory which stated that elements such as nitrogen, phosphorus, and sulfur were essential for plant growth. But, it was only in the past 60 years that plant physiologists identified the 16 different chemical elements that were essential for plant growth and development (Table 1). Carbon, hydrogen, and oxygen are obtained from the air and water, and together comprise 96% of the oven-dry weight of an average plant. The remaining 13 mineral elements are absorbed through the root system from the soil or growing medium.

Chlorine is needed in such minute amounts, and is so ubiquitous, that scientists have to go to extreme measures to create a deficiency. That leaves an even dozen mineral nutrients that have to be supplied in nursery culture.

Biophysics of mineral nutrition

Tree seedlings obtain most mineral nutrients from the soil solution as ions, although some can also be taken up as molecules or organic complexes. Being electrically charged, nutrient ions become adsorbed on exchange sites in the soil or growing medium where they serve as a nutrient reserve (Figure A).

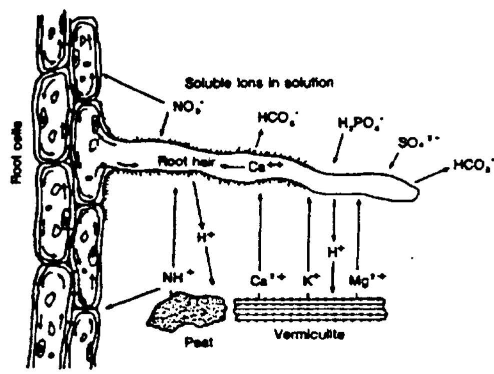

Figure A. Mineral nutrient ions are absorbed directly from the growing medium solution surrounding the root, which is replenished through ion exchange with growing medium particles (adapted from Donahue and others 1977).

Table 1 *- The 16 essential chemical elements required for plant growth, types of fertilizers, and fertilization methods*

Concentration in Plant Dry Matter					Type of Fertilizer and Fertilization Method	
Element	***Symbol***	***(%)***	***ppm***	***Source for Plants***	***Bareroot Nurseries***	***Container Nurseries***
Carbon	C	45	----	Carbon Dioxide	------	------
Oxygen	O	45	----	Carbon Dioxide/Water	------	------
Hydrogen	H	6	----	Water	------	------
Macronutrients						
Nitrogen	N	1.5	----	Soil/Growing Media	Granular Top-dressing	Liquid Fertigation or Slow-release Incorporation
Potassium	K	1.0	----	Soil/Growing Media	Granular Top-dressing	Liquid Fertigation or Slow-release Incorporation
Calcium	Ca	0.5	----	Soil/Growing Media	Granular Incorporation	Liquid Fertigation or Slow-release Incorporation
Magnesium	Mg	0.2	----	Soil/Growing Media	Granular Incorporation	Liquid Fertigation or Slow-release Incorporation
Phosphorus	P	0.2	----	Soil/Growing Media	Granular Incorporation	Liquid Fertigation or Slow-release Incorporation
Sulfur	S	0.1	----	Soil/Growing Media	Granular Incorporation	Liquid Fertigation or Slow-release Incorporation
Micronutrients						
Iron	Fe	----	100	Soil/Growing Media	Rarely Needed	Liquid Fertigation or Slow-release Incorporation
Chlorine	Cl	----	100	Soil/Growing Media	Never Needed	Never Needed
Manganese	Mn	----	50	Soil/Growing Media	Rarely Needed	Liquid Fertigation or Slow-release Incorporation
Zinc	Zn	----	20	Soil/Growing Media	Rarely Needed	Liquid Fertigation or Slow-release Incorporation
Boron	B	----	20	Soil/Growing Media	Rarely Needed	Liquid Fertigation or Slow-release Incorporation
Copper	Cu	----	6	Soil/Growing Media	Rarely Needed	Liquid Fertigation or Slow-release Incorporation
Molybdenum	Mo	----	0.1	Soil/Growing Media	Rarely Needed	Liquid Fertigation or Slow-release Incorporation

Nutrient uptake can be divided into active and passive absorption. Passive absorption means than ions are carried into the plant root along with the transpirational water stream. Factors controlling passive absorption include the volume of water being absorbed and the ion concentration in the growing medium solution surrounding the roots. Active absorption occurs when nutrient ions are selectively taken up against the osmotic gradient that normally exists between the root cells and the growing medium solution.

In the soil or growing medium, mineral nutrient availability is affected by the movement of ions with the soil solution, by diffusion, and by the growth of plant roots. Note that nutrient absorption and water uptake are closely linked, especially considering the large volumes of water that move towards the roots and into the plant during transpiration. Growers must keep soil water near optimum levels in order to realize the full benefits of fertilization. For example, the growth stimulation of N fertilizer decreases as soil moisture stress increases until it is completely negated (Figure B).

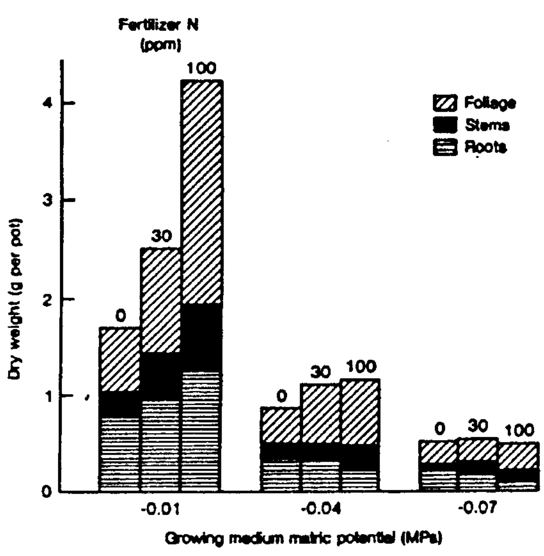

Figure B. The beneficial effect of nitrogen (N) fertilizer decreases with increasing moisture stress in the growing medium (from Squire and others 1987).

Effects of mineral nutrients on seedling growth

There is a characteristic relationship between the concentration of a nutrient ion in seedling tissue and its growth (Figure C). When a nutrient is present in low concentrations in seedling tissue and limiting to growth, it is said to be "deficient". At the lower end of the deficiency range,

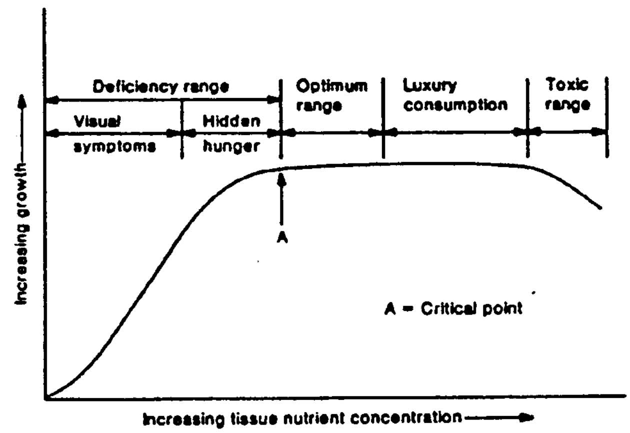

Figure C. The relationship between seedling growth and seedling tissue nutrient levels follows a characteristic pattern. Growth increases with increasing nutrient levels up to a critical point (A). Beyond this point, increasing nutrient levels do not result in more growth, but lead to luxury consumption or even toxicity.

plants often exhibit certain visible abnormalities called "deficiency symptoms", which include stunting and foliar discoloration. At slightly higher concentrations, the nutrient is still deficient enough to limit seedling growth and "hidden hunger" results. This condition is so named because there are no visible symptoms, so growers must diagnose it with chemical analysis. When the mineral nutrient supply is no longer limiting, seedling growth reaches a plateau termed the "optimum" range (Figure C). The limits of the optimum range are different for each of the 13 mineral nutrients, and growers must keep them all in balance to achieve maximum seedling performance. When they are present in surplus quantities, seedlings may continue to take up mineral nutrients with no measurable increase in growth (Figure C). This "luxury consumption" is common in forest and conservation nurseries where fertilizers are readily applied Many growers keep nutrient levels in the luxury consumption range because fertilizers are cheap, and there are no obvious drawbacks. However, if nutrient concentrations in seedling tissue reach extreme levels, nutrient toxicity will cause a decrease in growth. Fertilizer "bum" is a typical symptom of nutrient toxicity that occurs because fertilizer salts cause a physiological drought in plant tissue.

Monitoring mineral nutrient levels

Determining the proper nutrient levels for growing plants is not easy and is as much an art as a science. This art cannot be taught, but must be learned through many years of practical experience and patient observation.

Deficiency symptoms

Visual nutrient deficiency symptoms are often the first sign that something is wrong, but it is difficult to diagnose their exact cause. For example, foliar yellowing (chlorosis) can be caused by a deficiency of several nutrients including N, S, Fe, and Mn. Besides, growers should never wait until symptoms develop to begin treatment; by the time a nutrient deficiency is visible, a significant amount of growth will have already been lost (see hidden hunger—Figure C).

Soil or growing media

Because all nutrients are absorbed through the roots, it makes sense to try and monitor the levels in the soil or growing medium. Most nurseries do some soil testing. Bareroot nurseries usually have soil tests done prior to sowing so that they can amend any deficiencies before the crop is sown. For multiple year crops, additional samples are taken at the end of the growing season. Analysis of soil samples for "available" nutrients is difficult, however, because of the many chemical interactions that can occur. So, most nurseries have their samples analyzed by professional testing laboratories who also provide fertilizer recommendations. Sampling growing media in small containers is much more difficult, so container growers must analyze growing medium extracts that are obtained by vacuum or a pourthrough sampling.

Fertilizer solutions

Container nursery managers who fertilize through the irrigation system ("fertigation") have another option for monitoring mineral nutrient levels. Collecting samples of the applied fertilizer solution as it comes out of the irrigation nozzle is an excellent way to directly keep track of the nutrients being applied to the crop. Sampling the leachate from the bottom of the container can also indicate mineral nutrient problems.

Seedling nutrient analysis

One of the best ways to monitor mineral nutrient levels in nurseries is to chemically analyze seedling tissue and determine its nutrient status. Growers can sample the entire shoot of small seedlings or the green foliage of larger ones and have it analyzed by a testing laboratory. Because nutrient levels change so rapidly during periods of shoot growth, most nurseries only sample when seedlings are resting or dormant. General ranges for all mineral nutrients for both bareroot and container seedlings are available (Table 2). Foliar nutrient values are typically higher for container seedlings because they are given more frequent and complete fertilization (Table 1). However, because the response of each species will vary, growers should analyze tissue from healthy seedlings and make their own standards (Figure D). And, when suspected nutritional problems occur, samples of symptomatic and normal seedlings should be collected and analyzed for comparison.

Modifying mineral nutrition in nurseries: Fertilization

Nurseries apply fertilizers to keep mineral nutrients at their optimum level for seedling growth. In fact, fertilization is one of the primary reasons for the rapid seedling growth rates that can be achieved in nursery culture. Fertilizer use differs considerably between bareroot and container nurseries in type and amount, as well as in the application method. Bareroot nurseries supply only a few of the essential mineral nutrients as fertilizer, whereas container nurseries typically provide them all (Table 1).

Table 2 - ***Standard values for mineral nutrient concentrations in conifer needle tissue***

Adequate Range			
Mineral Nutrient	Units (% Dry Wt.)	Bareroot Seedlings	Container Seedlings
N	%	1.20 to 2.00	1.30 to 3.50
P	%	0.10 to 0.20	0.20 to 0.60
K	%	0.30 to 0.80	0.70 to 2.50
Ca	%	0.20 to 0.50	0.30 to 1.00
Mg	%	0.10 to 0.15	0.10 to 0.30
S	%	0.10 to 0.20	0.10 to 0.20
Fe	ppm	50 to 100	60 to 200
Mn	ppm	100 to 5000	100 to 250
Zn	ppm	10 to 125	30 to 150
Cu	ppm	4 to 12	4 to 20
Mo	ppm	0.05 to 0.25	0.25 to 5.00
B	ppm	10 to 100	20 to 100

Bareroot nurseries

Good agricultural soil contains a base level of all mineral nutrients, so growers usually fertilize based on pre-sowing soil tests. Depending on the type of soil and initial pH, nurseries add dolomitic lime (Ca, Mg) to raise the pH, or sulfur (S) to lower the pH, and incorporate it before the crop is sown (Table 1). Most forest and conservation nurseries normally supply only large amounts of the 3 major "fertilizer elements" - N, P, and K. N is by far the most important of the three, and is used on all soil types and in the largest quantities. Because it is very soluble in water, N is applied as a "top-dressing" in a series of small applications starting before, and continuing through, the active shoot growth period. In contrast, P is immobile in the soil, and is always incorporated into the seedbed before sowing. K is moderately soluble, and is applied either as a pre-sow incorporation or as a top-dressing during the growing season. Some nurseries also apply an additional application of N in the fall to recharge seedling nutrient reserves prior to harvesting.

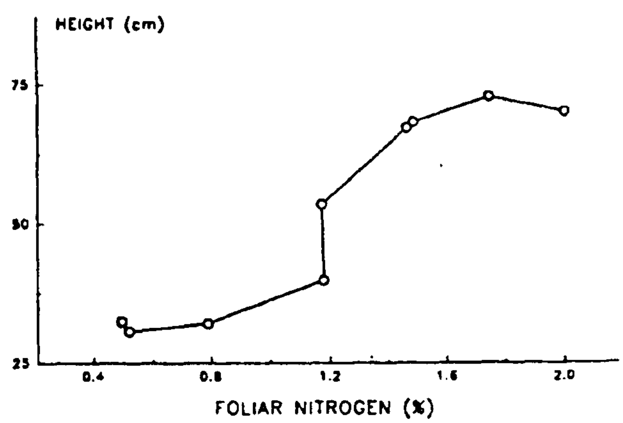

Figure D. Growers should develop their own tissue nutrient standards and growth response curves, such as this one for Juniperus virginiana (Henry and others 1992).

Container nurseries

The artificial growing medium that most container nurseries use is essentially infertile, so growers must add all 12 mineral nutrients through the irrigation system, or as a pre-sowing incorporation (Table 1). Because the growing medium is already slightly acidic, dolomite or sulfur is not needed to adjust the pH. Instead, most nurseries inject a mild acid to control the pH of the medium; many use phosphoric acid which also supplies P to the fertilizer mix. Some growers incorporate slow-release fertilizers into the growing medium to provide a starter charge of nutrients. Almost all nurseries have a fertigation program and fertilization frequency ranges from every day to once or twice a week. Different fertigation solutions are based on N concentration: starter solutions contain a moderate amount of N (75 ppm), rapid growth formulations have much higher levels (150 ppm), and hardening solutions have relatively low N levels (50 ppm). Some growers apply foliar fertigation solutions during the hardening period to maintain seedling color and nutrient reserves.

Problems with overfertilization

Most growers would rather overfertilize than risk a nutrient deficiency, with its resultant loss in growth rate. Although maintaining seedling nutrient levels at luxury consumption levels (see Figure C) is not generally considered harmful, overfertilization can cause other problems. In particular, high N fertilization has been shown to promote shoot growth at the expense of root development, and inhibit the formation of mycorrhizae. Perhaps the most worrisome effect is on outplanting performance (Figure E). In addition to their poor shoot: root ratio, seedlings with high foliar N levels are less cold hardy and suffer more animal browsing.

In recent years, concerns about agricultural pollution of surface and groundwater have made growers reevaluate their fertilization practices. High nitrates in drinking water can adversely

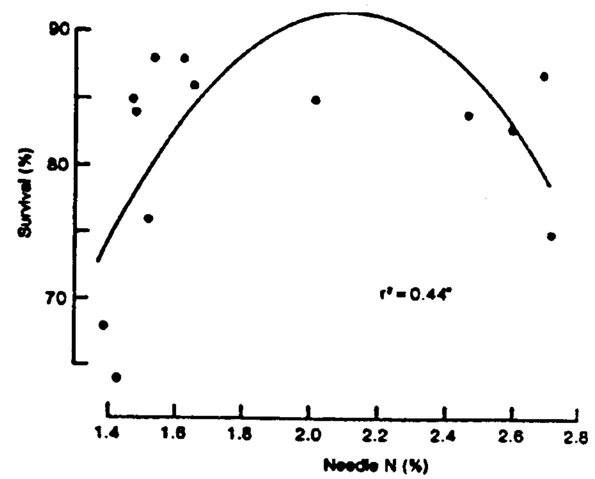

Figure E. Outplanting survival of 2 conifer seedlings decreased with higher foliar nitrogen (N) levels (van den Driessche 1988).

affect human health and all nutrients, and phosphates in particular, can lead to eutrophication of surface waters. Today, most nurseries are using less fertilizer, and are looking for more efficient types of fertilizers and fertilization methods. Slow-release fertilizers have obvious benefits, and incorporation of granular fertilizers can lessen the chance for surface runoff. Container nurseries are particularly suspect, so growers are converting to better fertigation systems, such as boom sprinklers, which significantly reduce runoff. Political concerns about agricultural pollution are so acute that fertilization may soon be regulated just like pesticide use.

Whew! That takes us through all of the limiting factors except water, and we will take a look at that most important factor in the next issue.

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