Monitoring Seedling Nutrition in Bareroot and Container Nurseries

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Abstract

This paper discusses where, when, and how to monitor mineral nutrition in both bareroot and container nurseries. The focus will be on forest and conservation species whose culture differs significantly from woody ornamentals and other standard horticultural crops.

Introduction - Why Monitor Nutrition?

Application of fertilizers is a common part of nursery culture and is largely responsible for the rapid seedling growth rates that are possible in modern nurseries. Fertilizer cost is such a small portion of the nursery budget, usually less than 1%, and so some people might wonder why it is necessary to monitor fertilizer use. There are at least two good reasons:

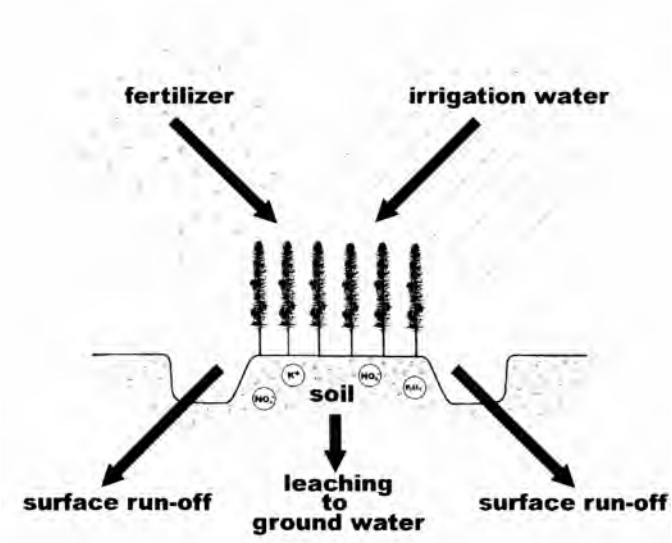

Figure 1. Monitoring mineral nutrients in forest and conservation nurseries should be managed as an input-output system. Fertilizers, and dissolved nutrients in irrigation water are the principal inputs, the soil or growing medium acts as a reservoir, and surface runoff and leaching are the outputs.

- Achieve maximum growth and seedling quality - The best quality seedlings result from applying the proper amount of fertilizer, in the proper balance, and at the proper time. Producing a high quality seedling crop involves more than forcing maximum growth. In fact, overfertilization can be a major cause of poor seedling quality in forest and conservation nurseries.
- Avoid possible pollution - All types of agriculture are under increasing scrutiny because of the possibility that fertilizer ions, notably nitrogen and phosphorus, will leave the nursery in surface runoff or contaminate groundwater (Figure 1). If they have not done so already, nursery managers would be well-advised to take a serious look at their fertilization and irrigation practices and initiate some tests to establish baseline levels in their surface runoff and groundwater (Landis et al. 1992).

Types of Nutrition Monitoring

Once they decide to begin a monitoring program, nursery managers can do so either indirectly or directly:

Indirect Monitoring

This consists of measuring mineral nutrient levels in the soil, growing media, or irrigation water (Table 1), and determining whether these nutrients are available to the seedlings. These techniques are indirect because the mere presence of a nutrient ion does not mean that it will be available to the crop. This is more of a problem in bareroot nurseries because native soils can chemically immobilize nutrients so that they are not available. Phosphorus is an excellent example, because it has maximum availability within the very narrow pH range of 5.0 to 7.0 (Bingham 1965). One of the attractions of container nursery culture is that all nutrients are more available in artificial growing media, such as the standard peat moss-vermiculite mixes.

Table 1 – Sources of mineral nutrients and need for fertilizers in forest and conservation nurseries

Mineral Nutrient	Chemical Symbol	Water	Soil	Growing Media	Fertilizer Requirement C Nursery	Fertilizer Requirement BR Nursery
Macronutrients						
Nitrogen	N	Negligible	Yes	Negligible	Yes	Yes
Phosphorus	P	Negligible	Yes	Negligible	Yes	Yes
Potassium	K	Negligible	Yes	Negligible	Yes	Yes
Calcium	Ca	Possibly	Yes	Negligible	Yes	Possibly
Magnesium	Mg	Possibly	Yes	Negligible	Yes	Possibly
Sulfur	S	Possibly	Yes	Negligible	Yes	Possibly
Micronutrients						
Iron	Fe	Negligible	Yes	Negligible	Possibly	No
Manganese	Mn	Negligible	Yes	Negligible	Possibly	No
Zinc	Zn	Negligible	Yes	Negligible	Possibly	No
Copper	Cu	Negligible	Yes	No	Possibly	No
Boron	B	Negligible	Yes	Negligible	Possibly	No
Molybdenum	Mo	Negligible	Yes	Negligible	Possibly	No
Chlorine	CI	Possibly	Yes	Negligible	No	No

Direct Monitoring

This involves directly measuring the nutrients that have been taken up by seedlings or observing their physiological and morphological condition. Descriptions and color photographs of mineral nutrient deficiency symptoms traditionally have been used to determine if fertilization is needed but, as will be discussed later, this procedure has serious limitations. A better direct monitoring technique involves collecting samples of seedling tissue and chemically analyzing them to determine their nutritional content.

Where Monitoring Can Be Done

Nurseries can either collect samples and have them analyzed by commercial testing laboratories or try to do the analyses themselves. Nursery testing is quicker and cheaper on a per-test basis but most of the sampling kits cannot match the accuracy and precision of a commercial lab test. Some bareroot nurseries use Hach Kits to monitor mineral nutrients in their soils, and although these tests cannot be directly correlated to laboratory tests results, they are useful for determining general trends and making fine tuning decisions about fertilization during the growing season. Container nursery managers have more options for monitoring mineral nutrition and these tests are discussed later.

Monitoring Fertility in Irrigation Water

Nursery fertilization should be viewed as an input-output system in which the inherent fertility of the soil or growing media is amended by the inputs of chemical fertilizers and those carried in the irrigation water (Figure 1). Although the addition by fertilizers is by far the major input, some irrigation waters can carry enough dissolved ions to have a considerable influence on nursery soil fertility.

Concept

Most people don't consider water a source of nutrients and, if they are talking about animal nutrition, then they are correct. For plants, however, irrigation water can be a valuable source of secondary mineral nutrients. In fact, certain waters can contain all or a substantial portion of the calcium (Ca), magnesium (Mg), sulfur (S), and some of the micronutrients needed for normal growth (Table 1). The concentrations of soluble mineral nutrients in irrigation water vary considerably from nursery to nursery, however, depending on the source of the water and the mineral content of the soils. Because it has had less time to dissolve soluble minerals in the soil, irrigation water that is obtained from surface sources such as streams and ponds will usually have lower soluble salt levels than water from underground sources.

Application

Nursery managers should analyze their irrigation water to determine nutritive content and factor that information into their fertilization schedules.

Sampling

Irrigation water quality should have been tested before the nursery was developed, but if it has been several years since that initial analysis, it would

be a good idea to have it tested again. Water quality can change during the year, especially if it is from surface sources or if different irrigation wells are used. Collecting water samples is easy - just let the water run long enough to flush out the pipes. There is almost no variability at a given collection time and so one sample is enough. The cost of the test will vary with the number of ions that are requested but is usually in the range of $25 to $100. A complete irrigation water analysis is recommended which, in addition to the 13 mineral nutrients, will include water quality ions (sodium, carbonate, and bicarbonate) and indices (pH, and electrical conductivity) (Landis et al. 1989).

"Hard" Water

The water at many places in the semi-arid Western US is called "hard" because it contains high levels of calcium and magnesium which cause scale to deposit on pipes and also leaves deposits on other surfaces. Nurseries with moderately hard water are fortunate because it often supplies all or most of the calcium and magnesium requirement (Table 2). However, very hard water can cause availability problems with other nutrients, notably P and Fe, in bareroot nursery soils.

Sulfur

Small amounts of sulfur dioxide are found in the atmosphere due to the burning of fossil fuels and decomposition of organic matter. Because sulfur dioxide is very soluble, it can be deposited in rainfall and therefore supplied to crops in ground water. In industrialized areas, this source is often sufficient to meet crop needs (Table 2). The amount of sulfur in irrigation water varies widely, however: a recent survey from across the US found that 4% of the water samples contained no S, and another 65% contained less than 10 parts per million (ppm). Compared to a target level of around 60 ppm, this is too low to supply the needs of rapidly growing seedlings but in Texas, however, the S content of irrigation water varied from 0 to 510 ppm. So, the only way to know how much sulfur your water contains is to have it chemically analyzed (Reddy 1996).

Micronutrients

Depending on its source, irrigation water can contain adequate levels of several micronutrients but the concentrations will vary considerably (Table 2). Because of the buffering capacity of soil, micronutrients from irrigation water are not high enough to be of consideration in bareroot nurseries, but they can be important in container nurseries using artificial growing media.

Standards and Interpretation

There are no nutritional standards for irrigation water but the target levels given in Table 2 will provide a guideline. Note that some micronutrients also can be toxic, and that the adequate nutrient range can be quite narrow, *e.g.* 0.50 to 0.75 ppm for boron.

Table 2 - Chemical analysis of irrigation water from forest and conservation nurseries compared to recommended mineral nutrient target concentrations

Essential Mineral Nutrients	Target Levels	Irrigation Water Analysis				
		Hawaii	Colorado	Idaho	New Mexico Well #1	New Mexico Well #2
Macronutrients	Parts per million					
Nitrate-nitrogen (NO_3)	156	NT*	3	2	1	0
Ammonium-nitrogen (NH_4)	66	NT*	0	0	0.6	0.3
Phosphorus (P)	60	0	0.07	0	0.01	0.05
Potassium (K)	155	0	2	2	3	4
Calcium (Ca)	60	1	82	26	17	31
Magnesium (Mg)	40	1	14	10	5	7
Sulfate-sulfur ($S0_4$)	63	NT*	43	14	31	57
Micronutrients	Parts per million					
Iron (Fe)	4.00	0.20	0.00	0.24	0.05	0.00
Manganese (Mn)	0.50	0.00	0.00	0.07	0.00	0.06
Zinc (Zn)	0.05	0.00	0.00	0.04	0.04	0.00
Copper (Cu)	0.02	0.00	0.00	0.01	0.00	0.00
Chloride (Cl)	4.00	NT*	3.00	2.00	13.00	24.00
Toxicity Threshold	70.00					
Molybdenum (Mo)	0.01	NT*	0.00	0.00	0.00	0.00
Boron (B)	0.50	0.00	0.06	0.00	0.30	0.40
Toxicity Threshold	0.75					

* = Not Tested

Monitoring Fertility in Soils and Growing Media

Concept

The theory behind nutritional analysis of soils or growing media is that "available" mineral nutrients can be chemically extracted and their concentrations accurately measured. Then, after comparing these available nutrient levels to crop requirements, the nursery manager can calculate what type of fertilizer is needed and how much to add.

There are significant differences between the way that a grower would manage fertility between a bareroot and container nursery. Soil contains a variety of mineral nutrients and a good agricultural soil will contain at least a small amount of all the 13 essential mineral nutrients (Table 1). When seed is sown in a fertile soil, the seedlings will grow and develop normally although the growth rate will be slow. Nurseries add fertilizers to increase this growth rate and fortify their seedlings for outplanting.

Application in Bareroot Nurseries

Sampling

Because of the tremendous variation that occurs in field soils, sample collection is of critical importance. Samples are typically collected in the Fall prior to sowing so that amendments can be made while the soil is being prepared. This is particularly critical for phosphorus and other elements that are immobile in the soil and so cannot be applied as top dressings over the crop.

The first step in the sampling procedure is to define the management unit. Some soil specialists recommend stratifying the nursery into blocks of similar soil types based on texture, depth or some other management criterion. Realistically, though, it makes more sense to define the sampling block as the minimum area that can be managed as a single unit although it probably contains soils of different characteristics. Samples can be collected in either a grid or linear pattern. A regular sampling grid can be established in each block to insure that all soil variations are represented. The sampling points in the grid can be referenced to irrigation pipes or some other permanent landmark so that they can be relocated. A simpler procedure is to collect the samples in a zig-zag pattern that traverses the entire unit. The number of samples that should be collected will depend on soil variation, time, and economics.

There have been many statistical studies on the proper number of samples to collect per block, but on a practical level, the cost of analysis per sample will be the final determining factor. A circular soil core is typical used and approximately 30 soil cores are collected in a bucket from each block. Then, the cores for the sampling unit are mixed together and composite samples taken from the soil mixture. A 225 g (0.5 lb) sample is usually sufficient for typical soil analyses. The soil samples should be placed in paper bags and labeled with a moisture-proof marker. The bags can be air-dried to reduce weight before mailing (Youngberg 1984).

Although there are many agricultural soil testing laboratories, most do not have experience with forest and conservation crops. Therefore, the best procedure is to contact the analytical laboratory beforehand and make sure that they can help with interpretation of the test results. Another good idea is to check with other local nurseries to see which testing laboratories they are using.

Standards and Interpretation

Chemical analysis of nursery soils has a couple of limitations. First, these tests do not actually measure the amount of available mineral nutrient but rather provide an index of availability. These indices must then be conelated with observed growth and vigor of the seedling crop to determine if fertilization is needed. The interpretation of soil test results, therefore, will

require actual field performance, practical experience and good record keeping (White et al. 1980). Second, the standards used to interpret soil tests are dependent on the types of soil tests that are done, especially the extracting solutions used for each nutrient (Table 3).

Table 3 - Soil fertility targets for forest and conservation seedling crops can vary with the analytical method used at the testing laboratory

Mineral Nutrient	Pacific Northwest Area (van den Driessche 1984)		Intermountain Area (Landis, 1982)	
Total Nitrogen (N)	0.20 to 0.25 %	Macro-Kjeldahl	0.10 to 0.20 %	Macro-Kjeldahl
Phosphorus (P)	100 to 150 ppm	Bray #1 Acid	30 to 60 ppm 175 to 350 lbs P_2O_5/ac	Olsen's Sodium Bicarbonate
Potassium (K)	78 to 117 ppm 0.20 to 0.30 meq/100 g	Ammonium acetate	100 to 200 ppm 300 to 600 lbs K_2O/ac	Ammonium acetate
Calcium (Ca)	600 to 1,600 ppm 3.0 to 8.0 meq/100 g	Ammonium acetate	500 to 1,000 ppm 2.5 to 5.0 meq/l	Ammonium acetate
Magnesium (Mg)	170 to 486 ppm 0.7 to 2.0 meq/ 100 g	Ammonium acetate	120 to 240 ppm 1.0 to 2.0 meq/l	Ammonium acetate

Soil testing is more useful for monitoring some mineral nutrients than others. Because nitrogen occurs in so many organic and inorganic forms in the soil, there is no one test that will give a good picture of the nitrogen that actually is available for plant uptake. Most analytical laboratories will recommend the Kjeldahl method (Bickeihaupt 1980) although some soil nutrition experts feel that this test is an unnecessary expense. They recommend that nursery managers just add the amount of nitrogen fertilizer that the crop will require per year - approximately 100 to 200 lbs per acre (112 to 224 kg/ha) - and then adjust for crop response (Landis and Boyer 1989). On the other hand, soil tests for phosphorus are considered a valuable help in monitoring availability but interpretation of test results can be confusing. The chemistry of soil phosphorus is extremely complicated and so analytical procedures have developed for different soil conditions. In a survey of US laboratories, five different extraction procedures are currently being used. The Hydrochloric Acid-Ammonium Fluoride Soluble Phosphorus Method, also known as the Bray and Kurtz method, is popular for more acidic soils in the Pacific Northwest while Olsen's Sodium Bicarbonate Soluble Phosphorus Method is recommend for more neutral or alkaline soils in the Intermountain area (Bingham 1965). In general then, soil analysis can be useful for all the macronutrients as long as the proper analytical tests are used (Table 3).

Plants can usually absorb adequate amounts of micronutrients from agricultural soils unless they are excessively sandy or alkaline. Soil tests are of questionable value for micronutrients such as iron (Fe). Although it is one of the most common metallic elements on earth, the Fe content and availabil-

ity in soils is extremely variable. In good agricultural soils, adequate amounts of iron are released by the weathering of minerals and so supplemental fertilization is not needed. However, iron deficiency is common on alkaline or calcareous soils in semi-arid and arid climates. Soil nutrition experts conclude that there are no soil extraction procedures for Fe which provide a reliable index of availability to plants (Wallihan 1965). Cox and Kamprath (1972) conclude that efforts to quantify the availability of micronutrients through soil testing has been mildly successful in localized areas but the results are not applicable elsewhere. Therefore, soil tests for micronutrients cannot be recommended for forest and conservation nurseries at this time. Instead, nursery managers should contact other local growers and soil experts to determine if micronutrient fertilization is warranted.

Because of the bewildering differences in types of tests and reporting units, interpretation of soil analyses can be challenging even for the experienced nursery manager. A good analytical laboratory should also be able to interpret their test results and help the grower convert this information into a fertilization plan. There is considerable variation between soil types and testing laboratories, and so nurseries should use the same laboratory from year to year. While test results from a single year can help give a general picture of soil fertility, the ideal situation is to create a database of soil test information. This will allow comparisons and show trends over time which are the true value of soil testing.

Application in Container Nurseries

People growing forest and conservation plants in containers have several advantages when it comes to monitoring mineral nutrients. First, they are starting with an artificial growing medium that is essentially infertile which is beneficial because it allows the grower to start with a nutritionally "clean slate". Second, the standard peat moss-vermiculite media will not tie-up nutrients like many soils and also has a high cation exchange capacity which holds nutrients against leaching until seedlings can take them up. Lastly, most container nurseries inject soluble fertilizers into the irrigation system and so fertilizer application is much more uniform and controllable. Artificial media has a few nutritional drawbacks, however. The inherently low fertility of growing media means that there are no nutrient reserves like in field soils and so growers must fertilize more often. Peat moss and vermiculite do not contain the normal complement of micronutrients and, because they also lack the minerals which fix phosphorus in field soils, this essential nutrient leaches rapidly. Finally, the low pH and lack of normal microflora can slow bacterial conversion of ammonium to nitrate, which can lead to ammonium toxicity under proper conditions. Still, it is much easier to monitor the status of mineral nutrients in container nurseries than in bareroot facilities (Landis et al. 1989).

There are two basic fertilization methods used in container nurseries and these determine both the type and timing of nutrient monitoring:

- Incorporation into the growing media - Growers often mix dry chemicals into their media prior to sowing to adjust the pH or add a starter dose of fertilizers. Dolomitic limestone amendments raise the normally acid pH of peat-vermiculite media and also supply calcium and magnesium. Calcium is much more difficult to supply in liquid form. Slow-release fertilizers, such as Osmocote® or Nutricote®, are sometimes incorporated during the media mixing process to provide the young seedlings with a nutritional boost before liquid fertilization begins. Although incorporating fertilizers is common with ornamental crops, this practice is used in only about 5% of forest and conservation nurseries.

- Fertigation - Injection of soluble fertilizers into the irrigation system is the most popular method of supplying mineral nutrients in container nurseries. Growers use either premixed commercial brands or mix their own custom fertilizers which supply all the mineral nutrients that the crop needs.

Sampling

Both the sampling method and the time of sample collection depend on the fertilization method.

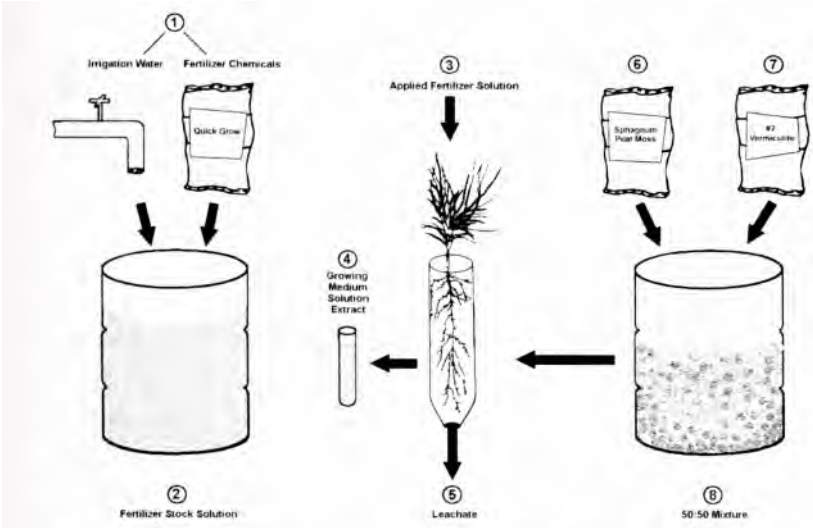

Figure 2. In container nurseries, mineral nutrients can be monitored at 8 different stages during the fertigation process or in the growing medium.

Nursery managers monitor the nutrient status of their growing media at two different times for different reasons (Figure 2). A preplant analysis reveals the basic nutritional status of the media and shows whether amendments are needed prior to filling the containers. Analysis during the growing season gives the grower a view of trends in pH and mineral nutrient accumulation over time, and is useful for making acid or fertilizer adjustments (Lang 1996). Preplant samples can be taken directly from the bags of media and so the major consideration is to make sure that enough small samples are collected. These are mixed together in a bucket and a composite sample is collected for analysis.

Once the containers are filled and the crop sown, all future samples are liquid and can be collected at several different locations (Figure 2). Samples of the irrigation water and the applied fertilizer solution can be collected directly, but liquid samples must be extracted from the growing medium. The amount of growing medium solution is relatively small and is strongly absorbed, and so

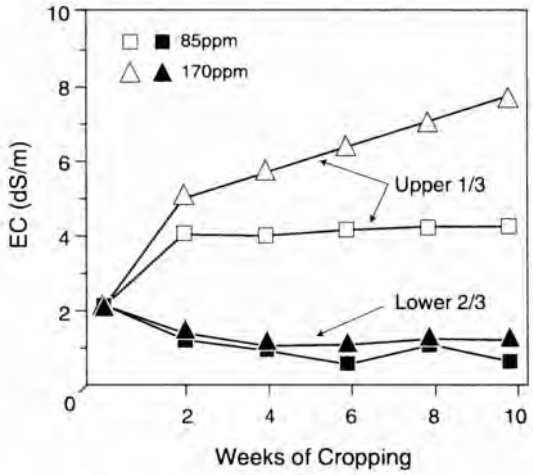

Figure 3. The electrical conductivity (EC) of growing media varied with vertical position in the container at two nitrogen fertigation rates (modified from Lang 1996)

special sampling techniques must be used to collect enough solution to measure. Both the standard dilutions and the saturated media extract (SME) techniques require destructive sampling. The dilutions are made by air drying a sample of media and mixing it in a beaker with either 2 parts (1:2) or 5 parts (1:5) of deionized water. The sample is mixed into a slurry, left to equilibrate for 15 to 30 minutes, and then poured through filter paper to obtain enough liquid to measure. In the SME technique, small amounts of deionized water are gradually mixed into the sample of growing medium until the paste begins to glisten - the saturation point. After 30 minutes of equilibration, a liquid sample is collected by vacuum (Lang 1996). Because of evapotranspirational losses from the top of the container and the presence of the perched water table at the bottom, considerable vertical stratification exists (Figure 3). To minimize variation, don't collect from the top where salts may accumulate and no roots grow anyway and collect a composite from the middle and lower layers. Full strength leachate or diluted "pour through" solutions are sampled from the drainage holes of the containers. This techniques is easiest with single cell container where test tubes can be taped over the bottom hole. Block containers must be removed and placed over trays and the liquid allowed to drain through.

Several commercial suppliers of horticultural products are offering chemical testing of irrigation water, fertilizer solutions, growing media, and seedling tissue at very attractive prices. These labs are equipped with the latest analytical equipment such as the ICAP (Inductively Coupled Argon Plasma) spectrometer and so the tests are done quickly and accurately. They will even telephone or FAX the result back to the nursery so that cultural corrections can be made within a matter of days.

Standards and Interpretation

Recommended standards for pH, soluble salts, and specific mineral nutrients vary with the method used to extract the solution from the growing media (Table 4). Therefore, growers should decide which extraction test they will use and then always use the same procedure so that the results will be comparable. Specific standards for forest and conservation crops can be found in Landis et al. (1989).

Table 4 - Standards for electrical conductivity (EC) of growing media vary by extraction technique

	Saturated Media Extract (SME)	1:2 Dilution	1:5 Dilution	Pour-through
EC in dS/m	2.0 to 3.0	0.8 to 1.2	0.3 to 0.6	3.0 to 5.0

Source: Lang (1996)

Deficiency Symptoms

Concept

Because mineral nutrients have specific functions, a deficiency of a specific nutrient will result in characteristic visual symptoms that can be used to diagnose the problem.

Application

Deficiency symptoms should never be used for monitoring mineral nutrition in forest and conservation nurseries for several reasons:

- Similar symptoms - Symptoms such as chlorosis can be caused by a deficiency of several different mineral nutrients including nitrogen, magnesium, sulfur, iron, and manganese and so are not diagnostic.
- Multiple deficiencies - Often, conditions in the soil or growing medium can cause several nutrients to be deficient at the same time.
- "Hidden hunger" - By the time that a deficiency is noted and diagnosed, the crop has already gone through a period of decreasing growth which can never be made up.

Seedling Nutrient Analysis

Concept

Mineral nutrient levels within seedling tissue are an index of overall nutritional health, and so monitoring the concentrations of nutrients will tell growers how much fertilizer to supply.

Application

Chemically analyzing the concentrations of mineral nutrients in the seedling foliage is a true measure of the effectiveness of a fertilization program because it integrates both availability and utilization. Testing laboratories are able to accurately measure the levels of all 13 essential mineral nutrients in a very small sample of plant tissue (Landis 1985). Although the analytical methods are basically the same for any crop, growers should use a laboratory that has experience with forest and conservation seedling crops so that they can also provide interpretation. Seedling nutrient analysis is relatively expensive and so growers must be careful so that samples reflect actual nursery conditions.

Sampling

Before starting to collect any samples, it is a good idea to contact the laboratory first to determine how much plant tissue they will require to perform the test, and ask about any other information that they might need. The type of sample will vary with the objective of the grower. If the purpose is to monitor the effectiveness of fertilization, then a random sample from the species and seed source should be collected. If the purpose, however, is to diagnose a specific problem then a sample of normal, healthy seedlings should be collected along with a sample of symptomatic seedlings so that comparisons can be made (Landis 1985).

The best tissue to sample is the entire shoot of young seedlings or the foliage of larger stock. Samples must be clean because even a small amount of soil can greatly affect the levels of micronutrients such as iron. Excessive washing is just as bad, however, because soluble nutrients such as potassium may be leached out. Around 20 to 50 seedlings are collected and then chopped and mixed together to produce a composite sample of approximately 60 g (2.1 oz) of fresh tissue. The samples should be packaged in a plastic bag, labeled with a water-proof marker, and stored under refrigeration until they can be shipped to the testing laboratory. If many samples are to be collected, it is a good idea to take a cooler with blue ice to the field or greenhouse to minimize overheating (Landis 1985).

Standards and Interpretation

The type of reporting units are the first thing to consider when analyzing the results of seedling nutrient analyses. The majority of commercial laboratories report test results in proportional concentration units: percent (%) for macronutrients and parts per million (ppm) for micronutrients. For research studies, however, nutrient content units are often used which reflect the total weight of mineral nutrient per weight of seedling tissue, *i.e.* milligrams (mg) per seedling or kilogram per hectare (kg/ha) on an area basis. Converting between concentration and content units is possible only if the oven-dry weight of the seedling is known and, for nutrient use per seedbed, the seedling growing density (Landis 1985).

Before they can be interpreted, seedling nutrient test results must be compared to some standard range of values. Very specific mineral nutrient values have been developed for common agronomic crops and cultivars (Chapman 1965) but these have minimal usefulness for forest and conservation nursery crops. Some general standards for commercial conifer seedlings are presented in Table 5. The problems with these

Table 5 - Standard range of values for mineral nutrient concentrations in conifer needle tissue

Nutrient	Symbol	Adequate Range	
		Container	Bareroot
Macronutrients - Units in			
Nitrogen	N	1.20 to 2.00	1.30 to 3.50
Phosphorus	P	0.10 to 0.20	0.20 to 0.60
Potassium	K	0.30 to 0.80	0.70 to 2.50
Calcium	Ca	0.20 to 0.50	0.30 to 1.00
Magnesium	Mg	0.10 to 0.15	0.10 to 0.30
Sulfur	S	0.10 to 0.20	0.10 to 0.20
Micronutrients - Units in ppm			
Iron	Fe	50 to 100	40 to 200
Manganese	Mn	100 to 5,000	100 to 250
Zinc	Zn	10 to 125	30 to 150
Copper	Cu	4 to 12	4 to 20
Boron	B	10 to 100	20 to 100
Molybdenum	Mo	0.05 to 0.25	0.25 to 5.00
Chloride	Cl	10 to 3,000	

Source: Landis (1985)

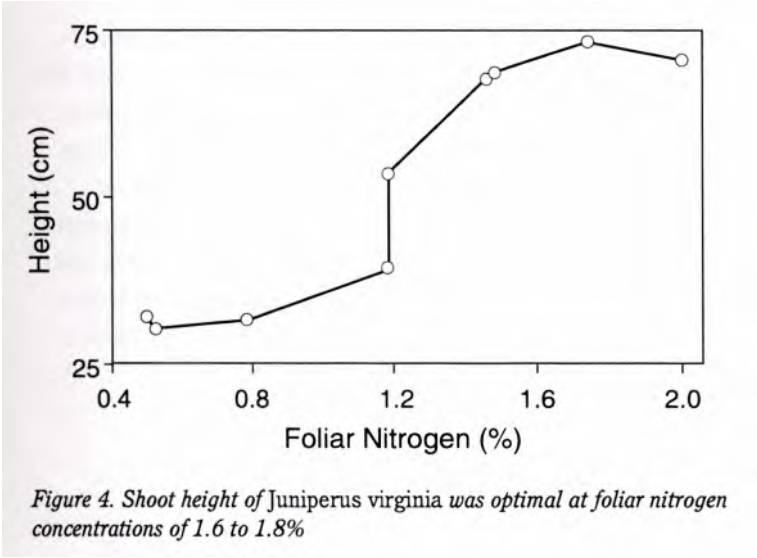

Figure 4. Shoot height of Juniperus virginia *was optimal at foliar nitrogen concentrations of 1.6 to 1.8%*

generic standards is that they are quite broad and so may not be sensitive enough to reveal subtle differences. In the highly fertile nursery conditions, seedlings will take up more nutrients than they actually need for growth. This "luxury consumption" is particularly noticeable in container nurseries and so these inflated ranges are much wider than they would be under more controlled conditions. Some nurseries or nursery cooperatives have developed their own standards for their own species. For example, the Southern Forest Nursery Cooperative at Auburn University collected and analyzed bareroot loblolly pine seedlings from 33 nurseries in the southeastern US and then developed nutrient standards for their members (Boyer and South 1985).

Because there is so much variability between species and growing conditions, the ideal situation is for nurseries to develop their own seedling nutrient standards and correlate them to seedling growth. For example, eastern redcedar *(Juniperus virginiana)* container seedlings were fertilized at nitrogen (N) levels of from 0 to 640 ppm. Shoot height, stem diameter, and shoot and root weights were recorded and plotted against foliar N levels. The results show that N is severely restricting height growth until foliar N levels reach 1.3% after which height growth increases rapidly (Figure 4). These trials confirmed that a fertilizer recommendation of 100 to 150 ppm N were optimal for producing well-balanced container redcedar seedlings (Henry et al. 1992).

Conclusions and Recommendations

Nursery managers should monitor seedling nutrition not only to increase seedling growth rate and quality but to determine if nutrients could be possibly polluting surface runoff or groundwater. The process of monitoring mineral nutrients in forest and conservation nurseries should be viewed as an input-output system. Fertilizers and dissolved nutrients in irrigation water are the principal inputs, the soil or growing medium acts as a reservoir, and surface runoff and leaching are the outputs. Monitoring can be either indirect with measuring nutrients in the soil, growing medium, or irrigation water and trying to determine if these nutrients are available to the crop. Direct monitoring consists of measuring the mineral nutrients that have been taken up by the seedlings. Growers should use both types of monitoring to get a true picture of mineral nutrition in their nurseries.

Irrigation water can contain significant amounts of several mineral nutrients and so should be analyzed if this has not been done already. Soils

and growing media serve as the nutrient reservoir for seedlings. Bareroot nursery soils should be tested annually in the fall of the year to determine the type and amount of soil amendments and fertilizers for the following season. Container nurseries can monitor the growing medium if fertilizers have been incorporated, and the nutrients can be tracked throughout the fertigation process. Only analytical laboratories with experience with forest and conservation crops should be used because they can also help with interpretation and application. Mineral nutrient standards are available for soil, growing media, and seedling tissue and can provide general guidelines but nurseries should develop their standards by accumulating test data over time.

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