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MINERAL NUTRITION AS AN INDEX OF SEEDLING QUALITY

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ABSTRACT--Seedling quality, when defined as outplanting performance, is logically related to its mineral nutrient status. Nutrients such as nitrogen and phosphorus supply the building materials for new growth and newlyplanted seedlings must rely on a supply of stored nutrients until they are established in the field. Seedling nutrient status can be inferred indirectly by foliage color or nursery fertilization practices, but chemical tissue analysis is the only practical *way* of measuring nutrient levels in seedling tissue. Analytical techniques allow rapid and precise determination of plant nutrient levels, but interpretation of these tests can be difficult without good reference standards. The relationship between outplanting survival and seedling nutrient status is not clearcut because of variation due to storage, handling and outplanting site differences. .Relationships between foliar nitrogen levels and height growth after outplanting, however, are more positive. Although an adequate mineral nutrient level is no guarantee of vitality, the relationship between seedling nutrient status and growth after outplanting could be improved by including some measure of seedling size in the prediction equation. Combining seedling nutrient analysis and some measure of seedling vigor, such as a test of root growth capacity, could prove to be an excellent way to predict outplanting performance.

4.1 INTRODUCTION

Seedling quality can have many definitions but for reforestation purposes can be best defined in terms of outplanting performance-the ability of the seedling to survive and grow after outplanting. In reforestation, a seedling with a high survival and growth potential has a high intrinsic value; the problem consists of identifying and measuring the attributes that produce that desired result. A quality seedling represents an integration of many morphological and physiological factors in much the same way that human health represents a multitude of interacting facets of human physiology (Ritchie, 1984). Mineral nutrition is just one of a number of physiological characteristics that contribute to a healthy seedling (Wakeley, 1948), but the relative importance of nutrition to seedling survival and growth after outplanting is hard to quantify.

To those involved in reforestation, there is an intuitive relationship between mineral nutrients and seedling quality. Tree seedlings, like all plants, are autotrophs that utilize solar energy to produce organic compounds from the raw materials of water, carbon dioxide, and mineral elements. While some mineral nutrients may become limiting for the forest seedling, the nursery manager is able to supply nutrients through fertilization for optimal seedling growth. A tree nursery, therefore, should be able to produce high quality seedlings that are charged with optimum levels of mineral nutrients when delivered for outplanting.

Mineral nutrition can have both positive and negative effects on seedling quality, however. Large, well-balanced seedlings with healthy, green foliage should logically exhibit better outplanting performance compared to stunted, chlorotic seedlings. •Withholding nutrients such as nitrogen resulted in chlorotic seedlings that were half the size of fertilized ones (Timmis, 1974). Seedling size has been shown to be positively correlated with foliar nitrogen which was in turn directly related to nursery fertilization (van den Driessche, 1980a).

Negative effects of fertilization such as seedlings with reduced drought resistance or increased susceptibility to frost have also been discussed (Duryea and McClain, 1984). High levels of nitrogen fertilization have been shown to increase shoot growth relative to root growth, resulting in a poor shoot: root ratio; these unbalanced seedlings may be at a disadvantage on a dry outplanting site (Etter, 1969).

4.1.1 Objectives

The objectives of this chapter are twofold: first, to examine the relationship between mineral nutrition and seedling quality; and second, to determine if some mineral nutrition index can be used to predict outplanting performance.

4.2 PRINCIPLES OF MINERAL NUTRITION OF TREE SEEDLINGS

More than half the elements in the periodic table have been found in plant tissue (Kramer and Kozlowski, 1979) because most chemical ions in the soil solution are passively absorbed in the large volume of water that is absorbed during transpirational uptake. Only 16 elements have been proven to be required for plant growth. A mineral nutrient must meet two criteria if it is to be considered essential for plant growth. First, it must be required for the plant to complete its life cycle, and second, it must be part of some plant constituent or metabolite (Epstein, 1972). Of these 16 essential nutrients, carbon, hydrogen, and oxygen are obtained from water and carbon dioxide and together account for approximately 96% of the dry weight of plant tissue. The remaining 13 elements are of mineral origin, being

absorbed as ions from the soil. Based on relative concentration, these elements have been divided into six macronutrients and seven micronutrients although the actual distinction is somewhat arbitrary (Table 1).

TABLE 1. CONCENTRATIONS OF 16 ESSENTIAL ELEMENTS IN HEALTHY PLANT TISSUE (EPSTEIN, 1972)

	Proportion of O.D. Wt.	
Element	%	Cum. %
1. Carbon (C)	45	
2. Oxygen (O)	45	
3. Hydrogen (H)	6	
		96.0
Macronutrients		
4. Nitrogen (N)	1.5	
5. Potassium (K)	1.0	
6. Calcium (Ca)	0.5	
7. Magnesium (Mg)	0.2	
8. Phosphorus (P)	0.2	
9. Sulfur (S)	0.1	
		3.5
Micronutrients	ppm	
10. Iron (Fe)	100	
11. Chlorine (Cl)	100	
12. Manganese (Mn)	50	
13. Zinc (Zn)	20	
14. Boron (B)	20	
15. Copper (Cu)	6	
16. Molybdenum (Mo)	0.1	
		0.5
		100.0

The 13 mineral nutrients in Table 1 are listed in order of relative concentration for general plant tissue, nitrogen being most abundant (1.5%) being followed by potassium (1.0%) and calcium (0.5%) and these values closely agree with the concentration levels reported for loblolly pine (Pinus taeda L.) seedlings (Boyer and South, 1984).

The functions of mineral elements vary from the structural components of plant cells to the physiological actions of molecules such as enzymes. All the macronutrients, with the exception of potassium, are incorporated into cellular constituents (e.g., magnesium in the chlorophyll molecule) but may also serve physiological functions as coenzymes or enzyme activators. Micronutrients primarily serve in a variety of metabolic functions in cells but do not constitute a significant part of any structural component (Table 2).

4.2.1 Nutrient uptake patterns

The relationship between mineral nutrient uptake and plant growth follows a characteristic pattern (Figure 1). When a nutrient is present in relatively low concentrations in plant tissue, it is considered deficient and limiting to plant growth. At the lower ranges of this deficiency, the plant often exhibits certain observable characteristics and these deficiency symptoms can be helpful in diagnosis of the deficiency. At slightly higher concentrations, however, the deficient nutrient is still low enough to limit plant growth but not low enough to produce deficiency symptoms; this condition is called hidden hunger because it is difficult to visually diagnose. One interesting point in the nutrient uptake curve is called the Steenbjerg effect (A in Fig. 1) and occurs only when a nutrient is extremely deficient. When the limiting element is first supplied to the plant, a rapid increase in growth occurs which actually results in a temporary decrease in tissue nutrient concentration (Armson, 1973).

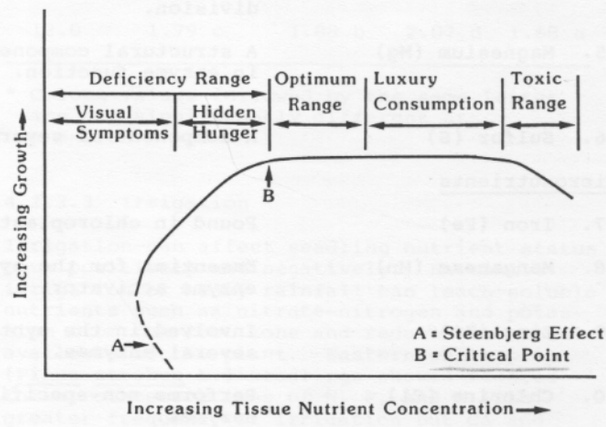

FIGURE 1. HYPOTHETICAL RELATIONSHIP BETWEEN MINERAL NUTRIENT CONCENTRATION IN SEEDLING TISSUE AND GROWTH (MODIFIED FROM CHAPMAN, 1967)

When the supply of the nutrient is no longer limiting to growth, the plant growth rate increases rapidly until the critical point is reached (B in Fig. 1). The critical point is the tissue nutrient concentration at which the growth rate declines significantly and is usually defined as 95% of the maximum growth or yield. The range of nutrient concentration at which maximum growth occurs has been defined as the optimum range. Plants may continue to take up mineral nutrients even though this additional uptake does not result in more growth (luxury consumption). When tissue nutrient concentrations reach extremely high levels, toxicity can occur with certain elements because plant growth begins to decrease with additional amounts of nutrient (Fig. 1) (Munson and Nelson, 1973).

4.2.2 Interactions between nutrients

Nutrients are not absorbed or utilized independently of each other and any change in the concentration of one element is usually accompanied by changes in the concentration of others. A dilution effect occurs

TABLE 2. STRUCTURAL AND PHYSIOLOGICAL FUNCTIONS OF MINERAL NUTRIENTS IN PLANT TISSUE. (ADAPTED FROM EPSTEIN, 1972 AND KRAMER AND KOZLOWSKI, 1979)

Mineral Nutrient	Functions
Macronutrients	
1. Nitrogen (N)	A constituent of amino acids and proteins but also found in a variety of other compounds such as chlorophyll, enzymes and cell membranes.
2. Phosphorus (P)	Found in nucleoproteins, phospholipids and high-energy phosphate bonds which serve as the major energy transfer mechanism in cells.
3. Potassium (K)	Specific functions are unclear but serves osmotic functions in cells and may also be involved in enzyme activity. Not a constituent of any known organic compound.
4. Calcium (Ca)	Occurs as a major constituent of cell walls and is also involved in N metabolism. Also an activator of enzymes and is required for cell division.
5. Magnesium (Mg)	A structural component of the chlorophyll molecule and is also involved in enzyme function.
6. Sulfur (S)	A component of several amino acids, proteins and coenzymes.
Micronutrients	
7. Iron (Fe)	Found in chloroplasts and several respiratory enzymes.
8. Manganese (Mn)	Essential for the synthesis of chlorophyll and also serves as an enzyme activator.
9. Zinc (Zn)	Involved in the synthesis of the hormone IAA and a constituent of several enzymes.
10. Chlorine (Cl)	Performs non-specific osmotic functions and acts in conjunction with enzymes.
11. Boron (B)	Plays a regulatory role in carbohydrate metabolism.
12. Copper (Cu)	A constituent of several enzymes.
13. Molybdenum (Mo)	Involved in several enzyme systems including nitrate reduction.

when an increase in the concentration of one limiting nutrient causes increased plant growth that results in a decrease in the tissue levels of other nutrients. Antagonisms between nutrients (e.g., excess ammonium nitrogen causing reduced uptake of potassium) can occur during absorption or within plant tissues (Armson, 1977). Nutrient interactions are particularly common among the micronutrients; a complex between levels of iron, manganese, zinc, and copper exists where the relative concentration of one element affects uptake and utilization of all the others (Tisdale and Nelson, 1975).

4.2.3 Nursery practices that affect seedling

Tree seedling nurseries utilize many cultural procedures to enhance plant growth and many of these practices have an influence on seedling nutrition. Duryea and McClain (1984) discussed four of the most significant practices in bareroot nurseries: fertilization, seedbed density, irrigation, and root culture. A fifth practice, lifting date, can be added.

4.2.3.1 Fertilization

The most obvious way to influence seedling nutrient status is through fertilization. Application of organic or inorganic fertilizers to the nursery bed or container media will usually affect the nutrient status of the seedling even if the applied nutrient is not limiting to growth and luxury consumption occurs. Fertilization with one nutrient may also affect the levels of other nutrients in plant tissue due to the dilution effect. In an experiment with nitrogen fertilizers on Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings, the N concentrations in the foliage increased but the P and K concentrations decreased (van den Driessche, 1980a). Different species may react differently to fertilization. Applications of N fertilizer

to four different conifer seedlings increased foliar N concentration in coastal and interior Douglas-fir and Sitka spruce (Picea sitchensis (Bong.) Carr.) but not in lodgepole pine (Pinus contorta var. latifolia Engelm.) (van den Driessche, 1984b) (Table 3). Different parts of the seedling may also react differently to fertilization. Switzer and Nelson (1963) reported that N fertilizer applications increased the N concentration of foliage, stem, and roots whereas P and K fertilizers only affected foliar concentration of the respective nutrients.

TABLE 3. EFFECT OF NITROGEN (N) FERTILIZER APPLICATIONS ON FOLIAR N CONCENTRATIONS OF FOUR SEEDLING SPECIES (FROM VAN DEN DRIESSCHE, 1984b)

	Foliar N Concentrations (% dry wt.)			
Fertilizer Treatment (Kg N/ha)	Coastal Douglas-fir	Interior Douglas-fir	Sitka spruce	Lodgepole pine
60	1.04 a*	1.30 a	1.07 a	1.71 a
140	1.46 b	1.51 b	1.53 b	1.67 a
235	1.64 c	1.59 b	1.75 c	1.69 a

* Column values followed by the same letter are not significantly different at p = 0.05

Timing of fertilizer applications is also important. Late season applications of N increased foliar N concentration to luxury consumption levels in five conifer species and this fertilizer effect was also reflected in foliage color. Applications of K fertilizer did not produce as dramatic results but still resulted in high K concentrations in the foliage (Benzian et al., 1974).

4.2.3.2 Seedbed density

'Control of seedbed density is probably the second easiest way to affect seedling nutrient status because decreasing the number of trees per unit area should increase the amount of soil nutrients that are available to each seedling. Reducing seedbed densities from 1200 to 300 seedlings per m^2 resulted in up to a 3X increase in N, Ca, and Mg content; a 5X increase in P; and a 4X increase in K content (Richards et al., 1973). In a experiment that studied both seedbed density and fertilization effects, both foliar N concentrations and color were significantly enhanced by decreasing density (Bell, 1968). Tree species are affected differently by changes in seedbed density. van den Driessche (1984b) found that coastal and interior Douglas-fir and Sitka spruce had greater foliar N concentration with increased space between seedlings whereas lodgepole pine showed no effect (Table 4).

TABLE 4. EFFECT OF SEEDBED SPACING ON FOLIAR NITROGEN CONCENTRATIONS OF FOUR SEEDLING SPECIES (FROM VAN DEN DRIESSCHE, 1984b)

	Foliar N Concentrations (% dry wt.)			
Seedbed Spacing Treatment (cm)	Coastal Douglas-fir	Interior Douglas-fir	Sitka spruce	Lodgepole pine
0.6	1.08 a*	1.35 a	1.11 a	1.63 a
1.0	1.08 a	1.29 a	1.12 a	1.71 a
2.0	1.21 ab	1.23 a	1.20 ab	1.74 a
4.0	1.37 b	1.34 a	1.33 b	1.73 a
8.0	1.75 c	1.73 b	1.89 c	1.66 a
12.0	1.79 c	1.88 b	2.07 d	1.68 a

* Column values followed by the same letter are not significantly different at p = 0.05

4.2.3.3 Irrigation

Irrigation can affect seedling nutrient status both positively and negatively. Excessive irrigation or heavy rainfall can leach soluble nutrients such as nitrate-nitrogen and potassium from the root zone and reduce the amount available to the plant. Eastern white pine (Pinus strobus L.) seedlings showed reduced foliar concentrations of N, P, and K with greater frequency of irrigation but Ca and Mg levels were unaffected (Schomaker, 1969). On the other hand, moisture stress caused by reduced irrigation can limit seedling growth and change foliar nutrient levels. Drought-stressed loblolly pine seedlings had significantly higher N levels than seedlings receiving ample irrigation (Pharis and Kramer, 1964).
Decreased irrigation also resulted in higher foliar N levels in white spruce (Picea glauca (Moench) Voss) (McClain and Armson, 1976).

4.2.3.4 Root wrenching

Wrenching bareroot seedlings by undercutting the root system with a horizontally-drawn, angled blade temporarily stresses seedlings by severing roots and disturbing the soil. Wrenching could have either a positive or negative effect on seedling nutrient status. Water and nutrient uptake may be initially reduced until the root system becomes reestablished however nutrient and water uptake should eventually increase due to e denser, more fibrous root system after a single wrenching. Three research studies have discussed the effect of repeated wrenching on seedling nutrient status. Wrenching Douglas-fir seedlings at intervals during

the growing season reduced foliar nutrient levels with P and K more affected than N (van den Driesache, 1983). Menzies (1980) reported that wrenched Douglas-fir seedlings had significantly lower foliar levels of N, P, K, and Ca when lifted in December and that the levels of these nutrients declined significantly when March lifted. Repeated wrenching of radiata pine (Pinus radiata D. Don) seedlings resulted in critically low N and P levels in the foliage (Benson and Shepherd, 1977). All authors agreed that supplemental fertilization may be required to compensate for the possibility of reduced nutrient uptake due to repeated wrenching.

4.2.3.5 Lifting date

The time of lifting will also affect seedling nutrient status through foliar leaching losses, reduced uptake due to cold soils, and the dilution effect of additional growth without a corresponding increase in nutrient uptake. The concentration of N, P, and K in slash pine (Pinus elliottii Engelm.) decreased when sampled during November, January, or March liftings whereas Ca and Mg levels increased slightly although levels in loblolly pine were unaffected (Munson and Stone, In Press). In a study of two fall lifting dates for Norway spruce (Picea abies (L.) Karst.) foliar concentratio [illegible]of all macronutrients were lower for the second lifting date except Mg which remained relatively constant and S which was not measured (Sandvik, 1976). Menzies (1980) found that foliar levels of N, P, K, Ca, and Mg of 2+0 Douglas-fir seedlings decreased significantly between December and March liftings. van den Driessche (1983) monitored seedling dry weight and foliar nutrient levels over 3 lifting dates from October to March and found that mineral nutrient concentration decreased in all cases whereas dry weight increased (Table 5).

TABLE 5. RELATIONSHIP BETWEEN LIFTING DATE AND MINERAL NUTRIENT LEVELS IN 2+0 DOUGLAS-FIR SEEDLING FOLIAGE. (AFTER VAN DEN DRIESSCHE, 1983)

Mineral Nutrient Concentration	Lifting Date October 16	December 18	March 3
N (%)	1.93 A*	1.80 B	1.54 C
P (%)	0.15 A	0.14 B	0.13 C
K (%)	1.00 A	0.76 B	0.60 C
Ca (%)	0.41 A	0.41 A	0.38 B
Seedling Dry Weight	6.4 A	7.8 B	7.9 B

* Row values followed by the same letter are not significantly different at P = 0.05

4.2.4 Ways of characterizing seedling nutrient status

A practical method of measuring and rating seedling nutrient status is needed before it would be possible to correlate mineral nutrition with seedling quality. Based on the literature there are three possibilities: foliar symptoms, nursery fertilization, and chemical analysis of plant tissue.

4.2.4.1 Foliar symptoms

The color of seedling foliage is affected by a number of biotic and abiotic factors. Foliar symptoms have been useful in diagnosing nutrient deficiencies, and specific symptoms may be correlated with individual nutrients (Aldhous, 1975, Armson and Sadreika, 1979). Many nutrient deficiency symptoms such as chlorosis, however, are not specific for an individual nutrient. Although chlorophyll concentration has been shown to be positively related to nitrogen status of seedlings (Linder, 1980) and foliage color has been classified according to Munsell color charts (Bell, 1968), color was not considered to be a reliable indicator of seedling grade in a review of grading criteria (Sutton, 1979). Because of this lack of specificity, foliar symptoms would not be useful for predicting outplanting performance of tree seedlings except in extreme cases.

4.2.4.2 Nursery fertilization

As already discussed, the practice of fertilization has a definite effect on seedling nutrient status. Although at one time it was possible to find nurseries that did not use fertilizers, it is now an accepted and widespread cultural practice in bareroot and container nurseries. Fertilizer application is indirectly related to seedling nutrient status because the mere application of fertilizer does not insure that the nutrients will be taken up by the seedling. Many research studies have related fertilization to outplanting performance, however, and have inferred seedling nutrient status by quantifying nursery fertilization.

4.2.4.3 Chemical analysis of plant tissue

The best way to characterize the mineral nutrient status of seedlings is to chemically analyze plant tissue and measure the levels of the various nutrients. Analytical chemistry techniques have been developed that allow accurate and precise determination of each of the 13 mineral nutrients in a small sample of seedling tissue.

Seedling nutrient analysis can be used for two purposes: first, to diagnose nutrient deficiencies at the nursery and improve fertilization practices and second, to predict growth response either at the nursery or after outplanting (van den Driessche, 1974).

4.3 MEASURING THE CHEMICAL COMPOSITION OF PLANT TISSUE

Seedling nutrient analysis can be performed by chemical testing laboratories which are either private or are located at state landgrant universities. Most of these facilities work primarily with agricultural or horticultural crops and have little experience with tree seedlings. Although the actual chemical testing methods are basically the same for any crop, it is recommended that testing be done by a lab that has experience dealing with tree nursery stock.

Before any actual sampling or testing is begun, it would be wise to discuss sampling, handling, storage, and shipping with the laboratory so that potential problems are avoided.

4.3.1 Selection of sample material

As with any scientific test, sample selection is extremely important because the characteristics of this limited sample must be representative of the population at large. The chance for serious error is much greater during the sampling phase than during the laboratory phase due to the large amount of inherent variability between seedlings and nursery location (Leaf, 1973). A sound sampling procedure for seedling tissue analysis is provided by Solan (1980).

4.3.1.1 Type of tissue

Either whole plants or parts of plants can be used for chemical nutrient analysis and the type of tissue depends on the objective of the test. To determine total nutrient uptake for fertilizer studies, whole plants should be tested; Leaf (1965) stated that no good evidence exists for analyzing only one plant component for determining nutrient status of the entire plant. In New Zealand, however, the common practice is to analyze only the shoot of 1+0 radiata pine seedlings (Knight, 1978) and in Great Britain, the Forestry Commission recommends needle samples for nutrient analyses (Aldhous, 1975). The common practice in agriculture is to sample leaves or petioles at a certain physiological age and there is good evidence that foliar samples are most appropriate in forestry (Lavender, 1970). The foliage is the site of photosynthetic activity and is therefore a sensitive indicator of mineral nutrient status (van den Driessche, 1974), and therefore van den Driessche recommends sampling whole seedlings or shoots for 1+0 seedlings but only foliage in older stock (van den Driessche, 1981). This also agrees with the recommendation of Youngberg (1984) in the Forest Nursery Manual.

The best tissue for nutrient analysis is dependent on whether you want to measure nutrient concentration or content (see Section 4.4.1). Because nutrient concentration is a proportional measure, either foliage or whole plants may be used. For total nutrient content, however, the entire seedling should be analyzed or dry weights and tissue samples of each seedling part taken so that the total content can be calculated. Both nutrient concentration and content have been used for seedling quality testing (see Section 4.5.4.2) but, on a practical basis, concentration is most useful.

4.3.1.2 Time of collection

Seedling nutrient level varies during the year due to differences in nutrient uptake and utilization and because of the dilution effect caused by new growth. Sampling date is therefore more of concern to those involved with testing for fertility analysis during the growing season because samples for seedling quality testing would normally be collected at the time of lifting or during storage. Seedling nutrient status has been shown to vary during the lifting season, however, and so therefore samples should be collected at a standard time each season (see Section 4.2.3.5). Nutrient levels should not change appreciably during refrigerated storage because seedling respiration losses would be inconsequential and so acceptable samples could be obtained any time during this period.

4.3.1.3 Number of samples

The number of samples to collect depends on the variation in the population (e.g. species, seed source, cultural treatment differences) and is usually limited by cost. A complete nutrient analysis of plant tissue generally costs from $10-50 per sample depending on the specific tests requested and so the total number of tests can be established by dividing the funds available by the testing fee.

Tissue samples are generally submitted as composites of individual seedlings from the population of interest. A composite sample should consist of a minimum of 20 (Aldhous, 1975) to 50 seedlings (So1an, 1980) although only lOg of dry or 60g of fresh plant tissue are required for the actual analysis. Composite samples, however, tend to "averageout" extreme values that may have biological significance and so there are advantages to analyzing individual seedlings if they are large enough to meet the minimum tissue requirement. The best procedure is to discuss the objective of the test with the analytical lab and base your sample size on their recommendations.

4.3.2 Handling, storing, and shipping samples

Seedling samples should be clean and free from soil contamination which can affect nutrient levels, especially of micronutrients like iron. Brushing or wiping the foliage clean with a wet cloth may help remove surface dirt

but the best recommendation is to obtain clean samples in the first place. Excessive washing of seedling foliage should be avoided at the nursery because of the possibility of leaching out soluble nutrients like potassium (Auchmoody and Greweling, 1979).

The seedlings should be placed in plastic or paper bags and legibly labeled. The bays should be kept out of direct sunlight and placed into an ice chest to minimize metabolic activity which can affect nutrient status if the sampling period exceeds 4 hours or the weather is warm (Figure 2a).

Once all samples have been collected, the needles can be removed from the stem of larger seedlings either manually or clipped with scissors. Although some sources recommend oven-drying at 65-80°C to stop metabolic activity (Auchmoody and Greweling, 1979), some N may be lost at temperatures as low as 70°C (Wilde et al. 1979). The best procedure is to freeze the tissue samples immediately which achieves the desired result without danger of volatilization losses.

To prepare the tissue for shipping, the frozen samples should be packed into Styrofoam ice chests or insulated cardboard cartons along with dry ice or packets of "blue ice". The shipping parcel should be sealed well and shipped by air freight or other reliable method of transportation so that they will arrive within 4-5 days (Solan, 1980). Again, the best recommendation is to check with your analytical laboratory to determine the best handling procedures.

4.3.3 Preparing samples for analysis

Once the samples are received at the laboratory, they are processed through a series of steps to prepare them for chemical analysis including washing, drying, grinding, and screening (Jones and Steyn, 1973). A series of photos showing some of the steps in seedling nutrient analysis are presented in Figure 2.

4.3.3.1 Washing

Fresh plant samples are usually washed at the lab to reduce soil contamination but dried samples should never be washed. Washing the foliage in a dilute (0.1-0.3%) detergent solution followed by a distilled water rinse is satisfactory if done quickly to avoid leaching out nutrients (Jones and Steyn, 1973). Samples can also be cleaned with an ultrasonic cleaner (Bickelhaupt, 1980).

4.3.3.2 Drying

After the samples have been washed, they are oven-dryed to minimize metabolic activity and prepare the tissue for grinding.

4.3.3.3 Grinding and Screening

The purpose of this step is to produce a uniform particle size for ease of handling and to ensure a homogeneous mixture. A mechanical grinder such as a Wiley mill is customarily used (Figure 2b); to eliminate metal contamination that may influence micronutrient levels, all the grinding surfaces should be stainless steel (Jones and Steyn, 1973). Plant tissues are ground until they are fine enough to pass through a screen with 0.5 to 1.0 mm size holes (Bickelhaupt, 1980).

4.3.4 Determination of chemical composition

4.3.4.1 Destruction of organic matter

The first step in the chemical analysis of plant tissue is the destruction of the organic matter component by removing the carbon, hydrogen, and oxygen through volatilization to produce a solution of inorganic mineral ions. There are two methods for the destruction of organic matter: dry oxidation (ashing) and wet oxidation (digestion) and both methods have advantages and disadvantages. Dry ashing consists of oxidizing the plant tissue at temperatures from 450 to 550°C for about 16 hours (Figure 2c) but has two disadvantages: possible volatilization losses, and the chemical tie-up of certain micronutrients such as zinc, manganese, and copper which can form insoluble complexes with silica (Bickelhaupt, 1980). Wet oxidation involves the use of several dangerous acids such as perchloric acid, which can cause explosions, sulfuric and nitric acid but is rapid and less prone to volatilization or retention losses. Boron can be determined only by dry ashing because this nutrient is volatilized during wet ashing (Jones and Steyn, 1973).

4.3.4.2 Wet chemistry analysis

Wet chemistry consists of traditional laboratory procedures such as gravimetric or titrimetric analysis (Table 6). The Kjeldahl method (Figure 2d) is a long standing technique that is still the most common way to measure total N in plant tissue and consists of two steps. First, the tissue sample is acid digested to convert the nitrogen to ammonium, and second, the ammonium is distilled and recovered as ammonia which is measured by sulfuric acid titration (Bickelhaupt, 1980). Sulphur analysis is particularly difficult because of the problems of converting all organic forms of S to a single inorganic form and because of possible volatilization losses during ashing. In a comparison of three methods of sulfur analysis, an autoanalyzer method involving titration was found to be best for tree foliage (Guthrie and Lowe, 1984).

FIGURE 2. STEPS IN COLLECTING AND ANALYZING TISSUE DURING SEEDLING NUTRIENT ANALYSIS: A) SEEDLINGS SHOULD BE STORED IN AN ICE CHEST DURING SAMPLING, B) DRY SEEDLING TISSUE IS GROUND TO A UNIFORM SIZE IN A WILEY MILL, C) DRY ASHING PROCEDURE, D) KJELDAHL PROCEDURE FOR MEASURING TOTAL NITROGEN, E) COLORIMETERS MEASURE VISIBLE LIGHT ABSORPTION, F) ATOMIC ABSORPTION SPECTROPHOTOMETRY MEASURES ELECTROMAGNETIC WAVE ABSORPTION AT SPECIFIC CHARACTERISTIC WAVELENGTHS.

TABLE 6. COMMON ANALYTICAL METHODS FOR MEASURING MINERAL NUTRIENT ELEMENTS IN TREE SEEDLING TISSUE

	Spectrophotometry		
Macronutrients	AAS/FES[1]	Colorimetry	Wet Chemistry
Nitrogen (N)		X	Kjeldahl
Phosphorus (P)		X	
Potassium (K)	X		
Calcium (Ca)	X		
Magnesium (Mg)	X		
Sulfur (S)		X	Gravimetric or Titrimetric
Micronutrients			
Iron (Fe)	X		
Manganese (Mn)	X		
Copper (Cu)	X		
Zinc (Zn)	X		
Boron (B)		X	
Molybdenum (Mo)	X		
Chloride (Cl)			Titrimetric

[1] AAS = Atomic absorption spectrometry
FES = Flame emission spectrometry

4.3.4.3 Spectrophotometry

As the name implies, spectrophotometry (or spectrometry) includes several chemical analysis techniques which use specific wavelengths of electromagnetic radiation, including visible light, to quantify nutrient element concentrations in solutions prepared from plant tissue samples.

Colorimetry - Also known as visible light spectrophotometry, several plant nutrients are measured colorimetrically, especially P and B (Table 6). As an example of this technique, orthophosphate forms a yellowcolored complex when mixed with certain reagents and shows optimal absorption at a wavelength of 440 nm (yellow). The color is allowed to develop for 30 minutes and the intensity of the color is measured with a spectrophotometer (Figure 2e). The P concentration is determined by comparison with a series of standard solutions of known P concentrations (Bickelhaupt, 1980).

Flame photometry - The most common types of spectrophotometry used in plant analysis labs are flame emission spectrophotometry (FES) and atomic absorption spectrophotometry (AAS).

FES is the older of the two techniques, having been used as an analytical tool for over 100 years. The basic procedure consists of vaporizing the sample by spraying it into a flame where the intense heat energy excites the atoms in the solution, causing them to emit light. The emitted light of each element is composed of certain wavelengths which are characteristic for that element. Light of the wavelength of interest (eg., Ca at 422.7 run) is separated from the rest of the emission by a selective filter called a monochromator. A photomultiplier measures the intensity of the light which corresponds to the concentration of the element in the sample solution (Isaac and Kerber, 1971) (Figure 3).

AAS (Figure 2f) is a more recent technique that was developed in the 1950's and the principle is essentially the inverse of FES. Atoms are capable of absorbing light at characteristic wavelengths (e.g., Fe at 248.3 nm) and so the AAS technique consists of quantifying the light absorbed by the nutrient atoms in a solution prepared from plant tissue. The sample solution is sprayed into a flame of relatively low temperature that dissociates the elements into a gaseous vapor. This atomic vapor lies directly between a light source that emits only the spectrum of the element of interest (248.3 nm for Fe) and a photomultiplier. The atoms in the vapor absorb a portion of the light of the specific wavelength and the degree of light absorption is measured by the photomultiplier (Fig. 3). The concentration of the nutrient element is calculated by comparison with a set of standard solutions (Isaac and Kerber, 1971). Any element can be measured by AAS if its light is in the spectral range of the instrument, most of which are sensitive down to 190 run. For that reason, the plant nutrients C, H, 0, N, S, and P cannot be measured by AAS since their characteristic wavelengths are below 200 nm (Slavin, 1968).

Other newer spectrophotometric techniques include the ICAP (inductively coupled argon plasma) spectrometer which is used by a few testing laboratories. This machine is computer-equipped and can measure up to 61 different elements at one time (Auchmoody and Greweling, 1979) but is also relatively expensive.

4.4 INTERPRETATION OF SEEDLING NUTRIENT ANALYSES

While most nursery managers do not need to be overly concerned about laboratory methodology, the interpretation of lab results is an entirely different matter. Most of us have struggled over lab reports of seedling nutrient analyses and attempted to make some sense out of them by comparing the reported nutrient values to ranges of values published in some nursery manual. The interpretation of seedling nutrient analyses requires an overall comprehension of the variation that can be expected and an understanding of how to compare the results to published standards. Skill in interpretation is only acquired through practice and experience and so professional help should be sought when considering nutrient analysis for the first time.

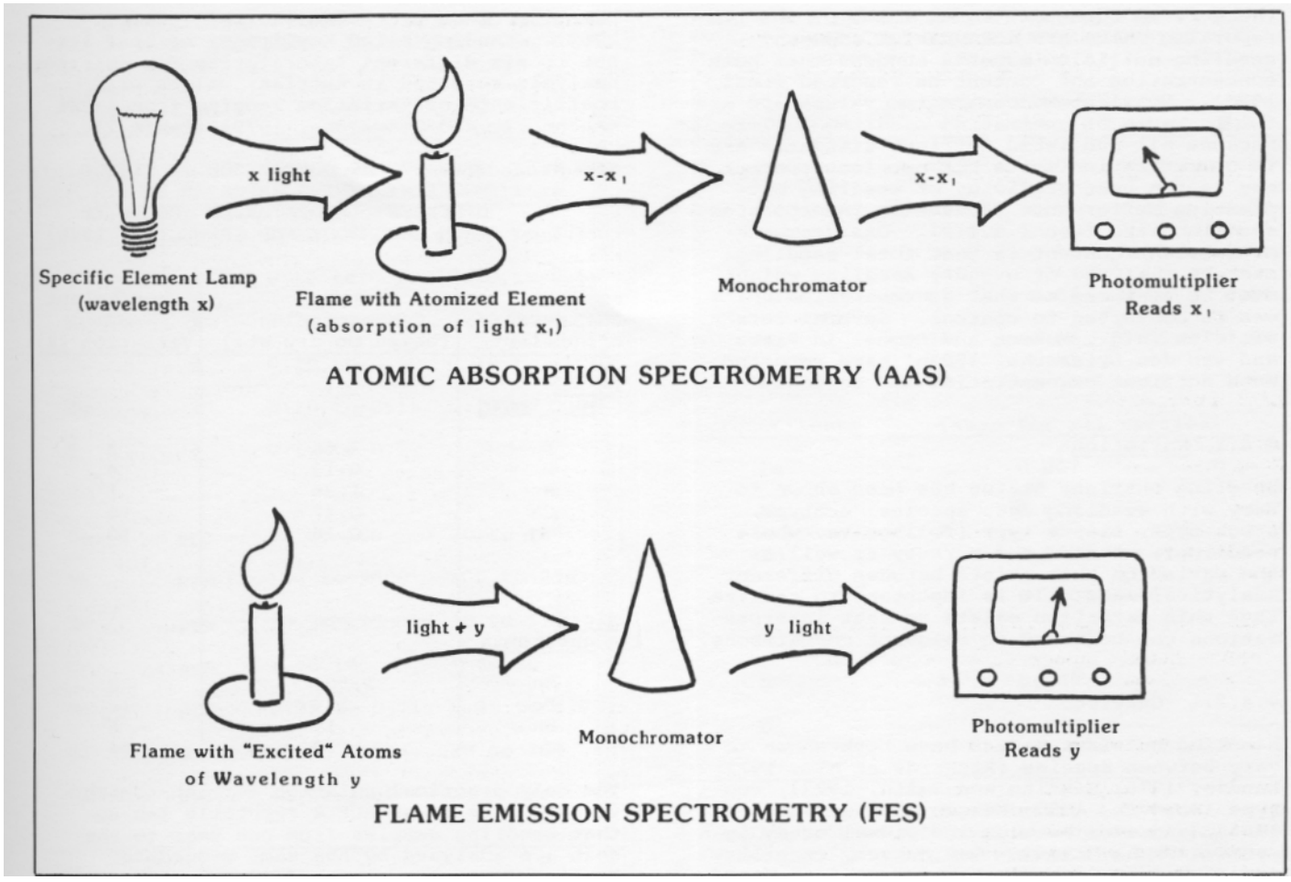

FIGURE 3. COMPARISON OF SPECTROPHOTOMETRIC METHODS FOR SEEDLING NUTRIENT ANALYSIS.

4.4.1 Units

The first thing to check when receiving a lab report is to look at the reporting units. The majority of analytical labs report their results in concentration units although nutrient content is sometimes reported in research studies.

4.4.1.1 Concentration

Plant nutrient levels are traditionally reported in proportional units of tissue dry weight: macronutrients in percent (%) and micronutrients in parts per million (ppm). Proportional units describe how concentrated the nutrients are in the tissue. Another unit of nutrient concentration is micrograms per gram (ug/g) which is the same as ppm.

Conversion between % and ppm is sometimes necessary and is very simple:

To convert % to ppm - multiply by 10,000 To convert ppm to % - divide by 10,000

4.4.1.2 Content

Another unit that is sometimes seen in the research literature is related to the total amount of nutrient that a seedling or seedling component contains and is usually expressed in weight per plant (mg/seedling) or, when converted to a seedbed basis, weight per area (kg/ha). Conversion between nutrient concentration and nutrient content is possible only if the oven-dry weight of the seedling is known. To determine nutrient content per seedbed it is necessary to know the seedbed density.

It is important to carefully distinguish between nutrient concentration and nutrient content during data interpretation. The terms are often confused in the literature which has confounded interpretation (Leaf, 1973). Both concentration and content units have limitations: data reported in concentration units are subject to the dilution effect resulting from new growth, and data reported in content units do not specify the size of the plant (Krueger, 1967).

There is no consensus as to which of the two reporting units are most useful and many seedling nutrition experts suggest that both concentration and content be reported (Leaf, 1965). Nutrient concentration values are useful in terms of estimating seedling quality because all published nutrient standards are in concentration units but nutrient content may be the best predictor of seedling outplanting performance because it incorporates seedling size (see 4.5.4.2). One drawback of nutrient content is that total seedlings must be analyzed or ovendry seedling weight must be measured so that concentration units can be converted to content. Several recent articles (e.g., Munson and Stone, In Press and van den Driessche, 1984b) have reported both nutrient concentration and content.

4.4.2 Variation

Seedling nutrient status has been shown to vary with seedling age, species, ecotype, stock type, tissue type (foliage vs. whole seedling), weather and nursery as well as the variation that exists between different analytical labs. It is important to realize that this variation exists so that interpretations can be based on relevant comparisons.

4.4.2.1 Genetic

Seedling nutrient values have been shown to vary between species (Richards et al., 1973; Landis, 1976; Benzian and Smith, 1973), ecotype (Sandvik, 1980; Mergen and Worrall, 1965), and even between individual trees (van den Driessche, 1969). One nursery fertility expert has published separate nutrient standards for different ecotypes of the same species - interior and coastal Douglas-fir (van den Driessche, 1984a).

4.4.2.2 Nursery

Nursery environment may also affect the nutrient status of tree seedlings because of differences in soil fertility, cultural practices, and climate. Nutrient values of conifer seedlings were found to vary between three British nurseries although manganese was the only nutrient showing large differences (Benzian and Smith, 1973). In a study of Douglas-fir seedlings, both macro- and micronutrients were shown to vary not only between nurseries but between sections in the same nursery (Krueger, 1967).

4.4.2.3 Laboratory

The problem of variation between analytical laboratories has been extensively debated (e.g., Jones and Steyn, 1973). Variation in reported values may be caused by different lab procedures or equipment. Two analytical procedures for measuring total N in seedling tissue were compared and the Kjeldahl method was found to produce consistently lower values than the Dumas procedure (Fornes et al., 1968). Sending blind replicates of leaf tissue to six different laboratories for nutrient analysis resulted in nutrient values with coefficients of variation ranging from 1-24% (Auchmoody and Greweling, 1979) (Table 7).

TABLE 7. STATISTICAL COMPARISON OF TISSUE NUTRIENT LEVELS REPORTED BY SIX DIFFERENT LABORATORIES (MODIFIED FROM AUCHMOODY AND GREWELING, 1979)

Mineral Nutrient	Average Concentration (based on dry wt.)	Coefficient of Variation (%)
Macro-nutrients	------- % -------	
N	2.66	2
P	0.13	4
K	1.36	1
Ca	0.47	14
Mg	0.16	10
Micro-nutrients	------ ppm ------	
Mn	1,500	3
Fe	139	14
Zn	15	6
Cu	7	24

The only practical solution for lab-to-lab variation is to select a reputable lab so that seedling samples from one year to the next are analyzed by the same procedure. Published results or standards should specify the analytical procedures used so that the interpreter of the data is aware of the possible implications (Leaf, 1965).

4.4.3 Comparing analytical results to standard values

In order for seedling nutrient values to be meaningful, they must be compared to some standard values. As just discussed, these standard values should be as specific as possible and take into account seedling species, stock type, type of tissue and analytical procedure if possible. Most sources present standard nutrient values as ranges instead of discrete values to accommodate natural variation. Nutrient ratios may be as useful as absolute values and may point out nutrient imbalances within the seedling (Ingestad, 1979; Hallet, 1982).

Nutrient standards for conifer foliage tissue are presented in Table 8 and nutrient ratios for several conifer seedlings are presented in Table 9. The problem with these "generic" nutrient standards is that they may not be sensitive enough to reveal significant differences. Due to luxury consumption of manganese by some conifer species, the guidelines in Table 8 are quite broad (100-5000 ppm) whereas

TABLE 8 - STANDARD VALUES FOR MINERAL NUTRIENT CONCENTRATIONS IN CONIFER NEEDLE TISSUE

Mineral Nutrient	Units (% dry wt)	Adequate Range: Bareroot [1] Seedlings	Adequate Range: Container [2] 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	---
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 5.0
B	ppm	10 to 100	20 to 100
Cl	ppm	10 to 3000	---

1/ Macronutrient values are from Youngberg (1984) and micronutrient values from Powers (1974)

2/ Both macronutrient and micronutrient values are from W. R. Grace Co.

the specific guidelines for Douglas-fir seedlings are more restrictive (390-1294) (van den Driessche, 1984a). Until more specific data can be accumulated, however, these general nutrient standards are the best that we have (Leaf, 1975).

Some nurseries are beginning to gather specific mineral nutrient values for their species and environments. Loblolly pine seedlings were collected from 33 southeastern U. S. nurseries by the Auburn Nursery Co-op and analyzed at the same laboratory for seedling nutrients to provide base data for soil management decisions (Boyer and South, 1984). Foliar nutrient levels for three conifer species were reported as tentative guidelines for one western U. S. nursery (Landis, 1976).

TABLE 9 - MINERAL NUTRIENT RATIOS FOR SEEDLING TISSUE (FROM INGESTAD, 1979)[1/]

Macronutrients	Douglas-fir	Sitka spruce	Western hemlock	Scots pine
N	1.00	1.00	1.00	1.00
P	0.30	0.16	0.16	0.14
K	0.50	0.55	0.70	0.45
Ca	0.04	0.04	0.08	0.06
Mg	0.05	0.04	0.05	0.06
S	0.09	0.09	0.09	0.09
Micronutrients	**(same for all species)**			
Fe	---	0.007	---	---
Mn	---	0.004	---	---
Zn	---	0.0003	---	---
Cu	---	0.0003	---	---
Mo	---	0.00007	---	---
B	---	0.002	---	---
Cl	---	0.0003	---	---

1/ To compute individual nutrient levels, multiply the N level by the decimal fraction (e.g. to determine the P level for Douglas-fir when the N level is 2.0 %, multiply 2.0 by 0.30 which gives 0.6 %)

4.5 RELATIONSHIPS BETWEEN SEEDLING NUTRIENT STATUS AND OUTPLANTING PERFORMANCE

4.5.1 Physiological factors affecting outplanting performance

Outplanting performance, defined as survival and growth, is related to certain seedling physiological factors which are all affected by nutrient status.

4.5.1.1 Dormancy

Ideally, seedlings are lifted and stored while dormant but break bud rapidly after outplanting in the field. Two studies have shown that late-season fertilization generally increased the speed of bud break after outplanting. Benzian et al. (1974) found a positive relationship between amount of N applied and speed of bud burst in Sitka spruce, Norway spruce, and western hemlock (Tsuga heterophylla (Raf.) Sarg.) but reported that nitrogen retarded bud break in grand fir (Abies grandis (Dougl.) Lindl.). In a study with Douglas-fir seedlings, both nitrogen and phosphorus had a significant effect

on percent bud break after field planting (Thompson, 1982).

4.5.1.2 Frost hardiness

Seedlings must not only be dormant, but also frost hardy when lifted so that they are not injured by cold temperatures during refrigerator or freezer storage or after outplanting. Research studies are contradictory on the effect of seedling nutrient status on frost hardiness. Aldhous (1975) stated that heavy late-season N applications may cause seedlings to flush prematurely and could lead to spring frost damage. High fertilization levels consistently reduced frost hardiness of Douglas-fir seedlings when frost hardiness was measured by electrical impedance (van den Driessche, 1983). Thompson (1982) found that fall N fertilization increased frost hardiness of Douglas-fir seedlings while P fertilizer had a variable effect. Timmis (1974) also studied Douglas-fir seedlings and found that nutrition had a definite effect on frost hardiness and recommended a K:N ratio of 0.6 in fertilizer programs for container seedlings.

Larsen (1978 as reported in Aronsson, 1980) reported that frost hardiness in Douglas fir was decreased at both high and low N concentrations and that maximum hardiness occurred in tissues with 1.3 to 1.4% N. Aronsson (1980) observed that frost damage to Scots pine (Pinus sylvestris L.) increased at N concentrations above 1.8 to 2.0%; laboratory freezing tests over a range of N levels gave lowest injury at tissue N concentrations between 1.3 and 1.8%. Although there is not enough information to prescribe specific levels of all mineral nutrients for maximum frost hardiness, the best recommendation at present would be to strive for adequate but not excessive levels of all nutrients, especially nitrogen.

4.5.1.3 Root growth capacity

The ability of a seedling to rapidly produce new roots after outplanting is an obvious asset, especially with bareroot seedlings that need to quickly reestablish soil-root contact. Ritchie and Dunlap (1980) stated that root growth capacity (RGC) should be related to seedling nutrient status and concluded that more studies are needed. In a factorial experiment with N and P fertilizer, there were no clear relationships between the treatments and new root growth of Douglas-fir seedlings (Thompson, 1982). A positive relationship between RGC and fertilization, however, was demonstrated in another study with 2+0 Douglas-fir seedlings (van den Driessche, 1983).

4.5.1.4 Drought resistance

Outplanted seedlings must be able to tolerate moisture stress until their roots can extend out and contact new sources of soil moisture. Ritchie (1984) stated that seedling nutrient status can affect internal water relations: N and K can reduce transpiration rates, perhaps through osmotic adjustments, whereas P may increase water loss. High nitrogen levels have been shown to reduce drought resistance of loblolly pine seedlings (Pharis and Kramer, 1964) and lower field survival of lodgepole pine seedlings (Etter, 1969). In a review of the relationship of fertilization to physiological quality of seedlings, van den Driessche (1980b) concluded that drought resistance of conifer seedlings can be increased by providing an adequate, but balanced,
supply of N, P, and K.

4.5.2 Predicting outplanting survival

4.5.2.1 Fertilization

Based on the available literature, the effect of nursery fertilization on outplanting survival is mixed--about half the sources reporting a positive effect and half a neutral or negative effect. Field trials with Douglas-fir seedlings showed a positive effect of fertilization in four cases (Smith et al., 1966; Anderson and Gessel, 1966; and van den Driessche, 1980b). White spruce seedlings showed increased survival after two growing seasons for both N and P fertilization (Bell, 1968). Wilde et al. (1940) reported a positive but statistically nonsignificant effect of nursery fertilization on outplanting survival of jack pine (Pinus banksiana Lamb.).

On the other hand, two studies reported little or no positive effect of fertilization on outplanting survival for either white spruce (Mullin and Bowdery, 1977) or loblolly pine (Switzer and Nelson, 1963) although outplanting site differences were noted. A neutral or negative effect was reported for red pine (Pinus resinosa Ait.) (Mullin and Bowdery, 1978), Douglas-fir (van den Driessche, 1983), and for several conifers in Britain (Benzian et al., 1974).

Considering the variable results reported here, it appears that nursery fertilization per se should not be considered as a predictor of outplanting survival.

4.5.2.2 Foliar nutrients

Only two studies have tried to correlate foliar nutrient levels and outplanting survival. van den Driessche (1980a) attempted to form regressions between foliar N and outplanting survival of Douglas-fir seedlings. Although a positive relationship was established, only 14% of the variation in survival could be explained by foliar N level. Working with four different species of conifer seedlings, van den Driessche (1984b) formulated regressions between percent survival and foliar nutrients (N, P, K) and found only three significant relationships for coastal Douglas-fir and Sitka spruce and the most

precise regression explained only 35% of the variation (Table 10).

TABLE 10. COEFFICIENTS OF DETERMINATION (R^2) FOR REGRESSIONS BETWEEN FOLIAR NUTRIENT LEVELS AND PERCENT OUTPLANTING SURVIVAL (MODIFIED FROM VAN DEN DRIESSCHE, 1984b)

	Nutrient Concentrations (% dry wt.)		
Species	N	P	K
Coastal Douglas-fir	0.24**	0.07	0.02
Interior Douglas-fir	0.02	0.00	0.04
Sitka spruce	0.35**	0.19**	0.00
Lodgepole pine	0.01	0.00	0.03

** = significant at p = 0.01

These results lead to the conclusion that, although foliar nutrient levels are related to outplanting survival, the regressions are not precise enough to yield accurate predictions. Other factors such as timing and rate of fertilizer applications, nursery cultural treatments and outplanting site conditions probably explain this lack of a useful relationship.

4.5.3 Predicting growth after outplanting

4.5.3.1 Fertilization

In contrast to field survival, nursery fertilization appears to be a good predictor of seedling growth after outplanting. A definite, positive relationship between nursery fertilization and seedling growth after outplanting is apparent from the literature with eight out of nine authors reporting positive results up to 5 years after planting Positive results were reported for a variety of species: Douglas-fir (Anderson and Gessel, 1966; Smith et al., 1966; van den Driessche, 1983); white spruce (Mullin and Bowdery, 1977; Bell, 1968); Sitka spruce, Norway spruce and western hemlock (Benzian et al., 1974); and jack pine (Wilde et al., 1940). The majority of the fertilizer treatments involved nitrogen but one micronutrient (Cu) increased shoot growth of radiata pine when outplanted on a copper-deficient podzol (Turvey, 1984). The only study that did not show a positve increased in field growth involved red pine and reported slight but nonsignificant effects (Mullin and Bowdery, 1978).

4.5.3.2 Foliar nutrients

Several studies have attempted to use foliar nutrient levels to predict growth after outplanting. The most successful of these endeavors resulted in a precise linear regression (R^2=0.84) between foliar N content and third-year field height of loblolly pine (Switzer and Nelson, 1963) (Figure 4). van den Driessche (1984b) computed a series of linear regressions between foliar nutrient concentrations of current height growth of four northwestern U. S. conifer seedlings (Table 11). The most precise of these regressions was for Sitka spruce and had a coefficient of determination (R^2) of 0.51 (Figure 5). The same author (van den Driessche, 1980a) reported a regression between foliar N concentration and secondyear height of Douglas-fir seedlings that had rather poor precision (R^2=0.18). Height increment of Norway spruce was reported to be "closely correlated" to foliar nitrogen concentration although no regression statistics were given (Sandvik, 1968, 1978 as reported in Sandvik, 1980). Larsen, et al. (1984) constructed a series of linear regressions between seedling attributes and outplanting performance of loblolly pine; foliar N content was most closely related to height growth after outplanting with an R^2=0.38.

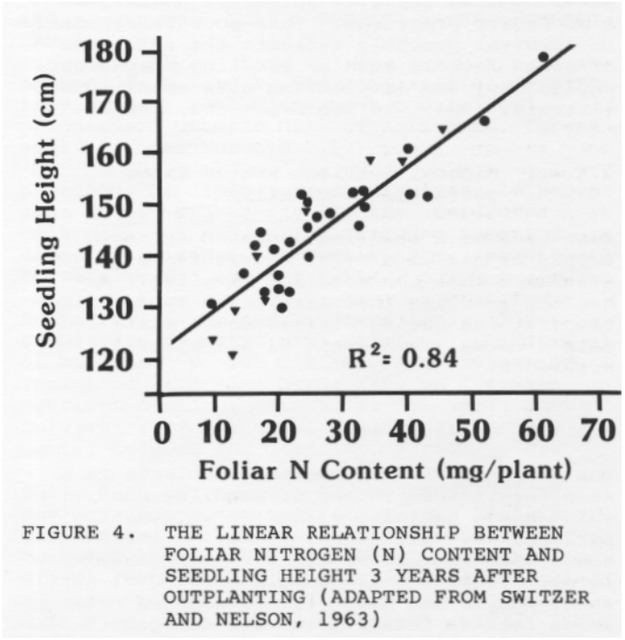

FIGURE 4. THE LINEAR RELATIONSHIP BETWEEN FOLIAR NITROGEN (N) CONTENT AND SEEDLING HEIGHT 3 YEARS AFTER OUTPLANTING (ADAPTED FROM SWITZER AND NELSON, 1963)

Foliar nutrogen appears to be a reasonable predictor of growth after outplanting and nutrient content may be a better independent variable than nutrient concentration.

4.5.4 Limitations of nutrient status as a predictor of outplanting performance.

It is obvious from the previous discussion that no single nutrition index could be used as an accurate predictor of outplanting performance when considering both initial survival and subsequent growth. Even though

TABLE 11. COEFFICIENTS OF DETERMINATION (R^2) FOR REGRESSIONS BETWEEN FOLIAR NUTRIENT LEVELS AND HEIGHT GROWTH AFTER OUTPLANTING (FROM VAN DEN DRIESSCHE, 1984b)

Species	Nutrient Concentrations (% dry wt.) N	P	K
Coastal Douglas-fir	0.31**	0.11**	0.15**
Interior Douglas-fir	0.00	0.08*	0.01
Sitka spruce	0.51**	0.22**	0.00
Lodgepole pine	0.02	0.02	0.23**

** = significant at p = 0.01
* = significant at p = 0.05

the relationship between foliar N levels and shoot growth are of acceptable precision, there appears to be no way to predict if the seedling will survive, which, of course, is a necessary precedent. This poor relationship to survival probably reflects the influence of other factors such as seedling morphology, physiology, and outplanting site conditions (Ritchie, 1984; van den Driessche, 1984b).

4.5.4.1 Mineral nutrient status is no guarantee of vitality

Just because a seedling contains an ample supply of all 13 mineral nutrients is no assurance that the seedling is alive. A healthy seedling that was killed by freezing temperatures during storage would still contain a normal complement of all mineral nutrients.

4.5.4.2 Seedling size

The concentration of mineral nutrients in a seedling is independent of seedling size, which has a definite effect on outplanting performance. Nutrient content, on the other hand, does reflect seedling size because a larger seedling will contain more total nutrients. Hoyle and Mader (1964) studied relationships between foliar nutrients and growth of red pine and found that higher correlation coefficients were almost always related to nutrient content rather than nutrient concentration. As reported in Section 4.5.3.2, the Best regression between foliar N levels and growth after outplanting used N content as the independent variable (Switzer and Nelson, 1963). van den Driessche (1980a, 1984b) also discussed the importance of using some measure of seedling mass when attempting to improve correlations using nutrient concentration.

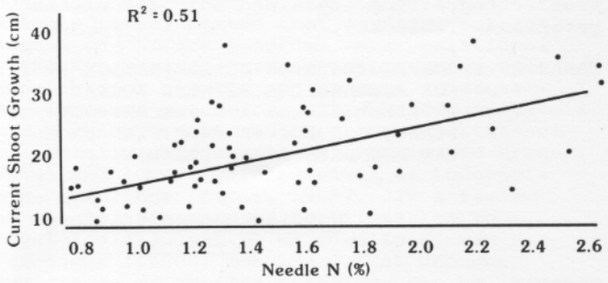

FIGURE 5. LINEAR REGRESSION BETWEEN FOLIAR NITROGEN (N) CONCENTRATION AND SHOOT GROWTH OF SITKA SPRUCE DURING THIRD YEAR AFTER OUTPLANTING (FROM VAN DEN DRIESSCHE, 1984b)

4.5.4.3 Seedling storage

The effect of cold storage on seedling nutrient status has not been widely studied and, because seedlings would normally be stored after nutrition samples were taken, could affect the value of nutrient levels as a predictor. Intuitively, proper storage should have no effect on seedling nutrient content since no mineral nutrients are being lost or gained. Nutrient concentration, on the other hand, could change during the storage period if temperatures were high enough to allow dry weight losses through respiration. van den Driessche (1983) found that higher nursery fertilizer levels reduced outplanting survival of Douglas-fir seedlings which were fall or winter lifted and suggested that high seedling nutrient levels could increase storage damage.

4.5.4.4 Outplanting site

Another complicating factor that could influence the precision of correlations between seedling nutrient status and outplanting performance involves environmental conditions on the planting site. The need to "custom-grow" tree seedlings to match outplanting site conditions has been much discussed (e.g., Iverson, 1984) but rarely practiced. While most of this work has centered on seedling morphology and stock types, Mullin and Bowdery (1977) suggested that "it may be necessary to grow nursery stock with a nutrient status to match the specific planting site". Obviously, much additional research is needed in this area.

4.6 CONCLUSIONS AND RECOMMENDATIONS

4.6.1 Relationships between mineral nutrition and seedling quality

The mineral nutrient status of forest nursery seedlings is related to many factors in the nursery environment and can be manipulated by cultural practices such as fertilization, seedbed density, root culture, irrigation and

lifting date. Although seedling nutrient status can be described by foliage color or fertilization practices, it is best characterized by chemical analysis of the foliage. Tissue samples should be analyzed both during the growing season so that cultural adjustments can be made and at lifting time to determine the levels of stored nutrients prior to outplanting.

4.6.2 Mineral nutrition as a predictor of outplanting performance

Seedling nutrient status is more closely related to growth after outplanting than to initial survival because an ample mineral nutrient supply is no guarantee of seedling vitality. An adequate and balanced nutrient status, however, provides a reserve of mineral elements for new tissue growth until the seedling root system can become established in the field.

Foliar nitrogen level appears to be a very good predictor of growth after outplanting but is not as well correlated with initial survival. Because seedling survival is so strongly affected by handling, field storage, planting techniques and outplanting site characteristics, no "material attribute" can be expected to be a sole predictor of outplanting performance.

Considering that foliar N level is one of the best predictors of field growth that is presently available, seedling nutrient analysis could be tested in concert with some measure of seedling vigor such as root growth capacity. The combination of these two seedling quality tests should provide an excellent estimate of total outplanting performance.

4.6.3 Research Needs

The precision of prediction equations between foliar nutrient concentration and outplanting performance could be improved by including a seedling size variable as a second independent variable. These research data could then be used to "fine tune" general mineral nutrient standards to reflect differences due to seedling species and individual nursery culture.

4.6.4 Implications for nursery management

Both container and bareroot nurseries should perform seedling nutrient analyses on a regular basis during the growing season and at the end of the rotation. Both nutrient concentration and nutrient ratios should be compared to standard values until more specific guidelines can be developed for particular species and nursery locations.

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