Chapter 8
Soil and Tissue Analysis: Tools for Maintaining Soil Fertility

C. T. Youngberg

Abstract
8.1 Introduction
8.2 Available Laboratories
8.3 Soil Analysis
  8.3.1 Sampling and handling
  8.3.2 Testing
  8.3.3 Interpretation
  8.3.4 Monitoring soil fertility: an example
8.4 Tissue Analysis
  8.4.1 Sampling and handling
  8.4.2 Testing
  8.4.3 Interpretation
8.5 Combined Soil and Tissue Analysis
8.6 Conclusions and Recommendations
References

Abstract

Systematic monitoring through soil and plant analysis is essential for understanding and managing soil systems in forest nurseries. Analysis services are offered by Oregon State University, University of Idaho, and seven commercial laboratories)n the U.S. Northwest, as well as the British Columbia Ministry of Forests. Suggested target fertility levels for raising Douglas-fir in Northwest nurseries are: pH of 5.0 to 6.0, total nitrogen (N) of 0.18 to 0.23%, available phosphorus (P) of 25 to 50 ppm, available potassium (K) of 80 to 120 ppm, exchangeable calcium (Ca) of 2 to 4 meq1100 g, and exchangeable magnesium (Mg) of 1 to 2 meq1100 g. Suggested ranges in macronutrient concentrations in Douglas-fir needle tissue are: 1.2 to 2% N, 0.1 to 0.2% P, 0.3 to 0.8% K, 0.2 to 0.5% Ca, 0.10 to 0.15% Mg, and 0.1 to 0.2% sulfur (S). The lower levels indicate deficiencies and the higher levels adequacy. Success of the fertility monitoring program depends on careful sampling and handling, consistency in laboratory services used, and meticulous recordkeeping.

8.1 Introduction

In view of the trends in reforestation research and resulting reforestation programs, the goals and objectives of a forest nursery are closely related to, if not dictated by, the goals and objectives of a given reforestation program. The nursery manager is expected to produce seedlings "tailor made" for specific planting sites. This may result in very complex management systems of which soil-fertility management is only one.

Although certain basic principles of soil management may apply to all forest nurseries, a sound soil-management program must be based upon a thorough understanding of the soil system of each individual nursery so that a monitoring program can be established to fit existing soil conditions. Knowledge of both physical and chemical conditions of the soil is important because these influence interpretation of analysis data (see chapters 6 and 7, this volume). For example, poor physical conditions such as compaction may result in poor drainage and aeration, which in turn will impact nutrient uptake.

A systematic sampling program must be the base upon which a sound soil-management program is developed. Benefits will accrue only if the data generated are accurate, interpreted correctly, and put to use and if the results are then evaluated. However, data are only as good as the samples analyzed. Consistent quality control in the sampling program, analytical procedures, and recordkeeping is essential so that valid trends may be distinguished from anomalies.

In this chapter, soil analysis and tissue analysis are discussed as valuable tools for monitoring soil fertility. Suggested target nutrient levels for Douglas-fir *[Pseudotsuga menziesii* (Mirb.) Franco] and for species grown in intermountain nurseries are recommended; however, interpretation of those levels will be influenced by soil conditions at a given nursery. Examples are drawn from the Oregon State University Soil Testing Laboratory in the Department of Soil Science (OSU Lab) because it is the one with which I am most familiar, but other Northwest facilities are named which provide similar valuable services.

8.2 Available Laboratories

In addition to the services offered at the OSU Lab, one other state-owned laboratory, one Canadian laboratory, and seven private laboratories in the Northwest offer soil and plant analysis services:

Agri-Check, Inc., Umatilla, Oregon
British Columbia Ministry of Forests, Victoria
Century Testing Laboratories, Inc., Bend. Oregon
Chinook Research Laboratories, Inc., Corvallis, Oregon
HR Consulting Services, Umatilla, Oregon
Marr Wadoups and Associates, Kennewick, Washington
Soil and Plant Lab (office in Bellevue, Washington; lab in Santa Clara, California)
United States Testing Co., Inc., Richland, Washington
University of Idaho, Moscow

The OSU Nursery Survey (see chapter 1, this volume) indicates that three nurseries (under single management) use Agri-Check, two use Soil and Plant Lab, five use the B.C. Ministry of Forests Lab, and nine use the OSU Lab. In addition, 15 nurseries not included in the Survey use the OSU Lab.

The analytical methods used by the above-listed laboratories are generally the same as those of the OSU Lab. At present, however, the results of nursery soil analysis from

In Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

these labs cannot be compared with those of the OSU Lab because nurseries are not submitting the duplicate samples necessary for comparison.

The methods used by the OSU Lab for pH, exchangeable potassium (K), calcium (Ca), and magnesium (Mg), cation exchange capacity (CEC), organic matter, and total nitrogen (N) are essentially the same as those used by the State University of New York at Syracuse (SUNY Lab) and the labs servicing nurseries in the southern and southeastern U.S. At an ad hoc meeting in Detroit in 1980, persons involved in forest-nursery soil testing agreed to aim at standardizing analytical methods for all tests frequently used, except for phosphorus (P) extraction techniques, so that comparisons of nurseries from different regions could be more meaningful. Such comparisons have limitations, however. For example, data for soil samples from the same sample areas in the Wind River Nursery (Carson, Washington)—analyzed by Wilde and Associates (Madison, Wisconsin), the SUNY Lab, and the OSU Lab—were compared. Absolute values for individual samples varied, but trends among samples were similar.

8.3 Soil Analysis

8.3.1 Sampling and handling

Soils should be routinely sampled at the end of the seedling crop rotation so that changes in nutrient levels can be monitored and fertilizer and lime added before establishment of a cover crop or new seedling crop. This is especially important in the case of the macronutrients P, K, Ca, and Mg, which do not readily move into the soil when surface applied.

The first step in the sampling procedure is to stratify the area on the basis of obvious soil differences, e.g., wet areas, areas having striking textural differences, or areas where topsoil has been removed as a result of land leveling. Most nurseries already have sampling patterns (e.g., predetermined lines or zigzag patterns) established within compartments or seedling blocks. The usual technique is to obtain a composite soil sample of each area according to the sampling pattern by coring soil to a depth of 15 cm (6 in.). The most efficient tool is a sampling tube having a 2-cm (3/4-in.) diameter. A minimum of 30 cores per sample unit are placed in a clean (free of fertilizer or other chemicals) plastic pail and thoroughly mixed. A 225-g (V2-1b) subsample sufficient for routine analysis is placed in a container and labeled. If particle-size analyses are desired, the sample should be split and placed in two containers. Samples are shipped to the soil-testing laboratory with information regarding tests desired. Samples may be air dried to reduce shipping weight.

An alternative, but more costly, method is random sampling. Randomly distributed samples are collected within each sample area so that an estimated mean value for each parameter measured can be calculated. If 20 samples are required to estimate the mean value of each parameter, the cost becomes prohibitive. This particular sampling method is used primarily for research purposes.

8.3.2 Testing

The basic tests available at the OSU Lab[1] for assessing soil nutrient levels are given in Table 1. Tests for mineralizable N and calcium carbonate ($CaCO_3$) equivalent also are available. Mineralizable N is determined with an anaerobic incubation technique [11] to provide an estimate of N availability. The $CaCO_3$-equivalent test determines the amount of acid or sulfur (S) required to lower the pH of alkaline soils and is used primarily in intermountain nurseries. Soil test #15 is designed for sodic soils [pH 8.5 to 10, > 15% exchangeable sodium (Na)] but will generally not be needed because such soils are avoided in selecting nursery sites.

In P analysis, the dilute acid-fluoride method of Bray and Kurtz [2] is used for acid soils and the sodium bicarbonate method of Olsen et al. [5] for alkaline soils.

Ammonium N (NH_4-N) and nitrate N (NO_3-N) tests are not common in nursery soil analysis, but they might be used to determine the amount of available soil N at the beginning of the growing season or the time and rate of early-season N fertilization.

Soil tests are useful within limits. Perhaps the most serious limitation is the arbitrariness of extraction procedures. Chemical extracting solutions do not necessarily remove the same amount of a nutrient element that a plant can. CEC measurements, which indicate the buffer capacity of the soil and its resistance to rapid change in pH as cations are added or leached, are adjusted to a standard pH for convenience, whereas exchange capacities are strongly pH-dependent in many soils.

A related and serious limitation is the lack of data correlating seedling growth response, quality, and performance after outplanting with soil-test values and fertilizer additions. Comparisons must be made for each species produced at a given nursery. Thus, soil-test values are, at best, only a starting point and must be related to overall soil-management practices and seedling performance. Furthermore, it cannot be overemphasized that the benefits derived from a soil-testing program depend on meticulous recordkeeping for soil-test data, soil-management practices, and seedling performance.

Table 1. Soil tests available at the OSU Lab.

Test #	Item tested
1	pH, P. K, Ca, Mg
2	pH, P, K, Ca, Mg, and boron (B)
3	Cation exchange capacity (CEC)
4	Organic matter (OM)
5	Total nitrogen (TN)
6	Ammonium nitrogen (NH_4-N)
7	Nitrate nitrogen (NO_3-N)
8	Ammonium and nitrate nitrogen
9	Sulfate sulfur (SO_4-S)
10	pH
11	B
12	Zinc (Zn)
13	Manganese (Mn)
14	Zn and Mn
15	pH, P, K, Ca, Mg, and soluble salts (SS)—Na if pH > 7.4
16	$CaCO_3$ equivalent
17	SS

8.3.3 Interpretation

Before his death in 1981, S. A. Wilde had undoubtedly used soil-test data more often for making fertilizer recommendations for forest nurseries than any other person in North America. The basis for his recommendations was soil-fertility standards developed for northern conifers [12] and northern hardwoods [14], as well as many years of accumulated experience. Using a similar approach, Youngberg and Austin [17] developed fertility standards for Douglas-fir. With some modification, these are presented in Table 2. It should be emphasized that these standards are only targets and are subject to revision as experience is gained.

Similar values are presented by van den Driessche in chapter 7, this volume. The levels of soil-test P recommended in that chapter are higher than those presented in Table 2; the range in total N is slightly higher. Because the method of P analysis referred to in chapter 7 is the same as that used by the

[1]The methods used by the OSU Lab are summarized in Berg and Gardner [1]; this report is available on request from the Department of Soil Science. Oregon State University, Corvallis.

OSU Lab, the differences in recommended levels are probably due to soil differences. The British Columbia nurseries generally have acid, sandy soils [pers. commun., 9], whereas soil pH in nurseries in the U.S. Northwest and northern California ranges from 5.0 to over 6.0. In soils with a pH range below 5.0, added P is strongly fixed by aluminum (Al) and iron (Fe). Landis [pers. commun., 4] has developed soil-fertility targets for intermountain nurseries (Table 3.).

Table 2. Soil-fertility levels recommended for Douglas-fir.[1]

	Total	Available		Exchangeable	
pH	N	P	K	Ca	Mg
	%	~ ~ ~ ppm ~ ~ ~		~ ~ meq/100g ~ ~	
5.0-6.0	0.18-0.23	25-50	80-120	2.0-4.0	0.8-1.5

[1]Based on OSU Lab values.

Table 3. Soil-fertility targets recommended for intermountain nurseries [pers. commun., 4].

	Range
pH	
Most conifers	5.5-6.5
Hardwoods and junipers	6.5-7.5
Electrical conductivity, mmhos/cm	
Conifers	< 2.0
Hardwoods	< 4.0
Organic matter, %[1]	2.0-5.0
CEC, meq/100 g	7.0-12
$CaCO_3$ equivalent, %	0
Total N, %	0.10-0.20
P, ppm[2]	30-60
lb P_2O_5/acre	17 5-3 50
K, ppm	100-200
lb K_2O/acre	300-600
Ca, ppm	500-1,000
meq/ 100 g	2. 5-5.0
Mg, ppm	120-240
meq/100 g	1-2

[1]Determined by Walkley-Black [10] method.

[2]Determined by Olsen et al. [5] sodium bicarbonate method.

Fertilizer added to make up the difference between the soil-test level and the desired level may not necessarily be adequate to supply seedling needs. As mentioned, these values are only targets. The actual amounts needed to meet crop requirements may vary considerably among nurseries due to differences in soil properties such as texture, structure, drainage, aeration, acidity, and clay mineralogy. Amounts of fertilizer required to supply needed levels of nutrients will vary even among soils having similar soil-test values. For example, nursery A (sandy-textured soil) and nursery B (sandy loam soil strongly influenced by volcanic ash) may both have test values of 10 ppm P. To raise the level to 50 ppm, adding the phosphate fertilizer equivalent of 40 ppm might be sufficient for soil in nursery A, but the allophanic or amorphous colloids weathered from the volcanic ash impart phosphate-fixing properties to the soil in nursery B; therefore, more phosphate fertilizer would be required for nursery B than A to attain the desired level. In some soils, clay minerals impart K-fixing properties to the soil, influencing the availability of added potash fertilizers. Even within a given nursery, the amount of fertilizer needed to supply the desired level may vary over time due to changes in physical conditions caused by cultural practices. For example, poor aeration resulting from these practices can depress the uptake of K; increase the availability of Fe, causing P fixation; and increase the availability of manganese (Mn), causing Mn toxicity. Recommendations for, or decisions made concerning, fertilizer additions generally assume good soil physical condition (see chapter 6, this volume). If these conditions do not exist, soil-test values may not accurately indicate nutrient availability.

For most fertilizer recommendations, it is probably better to aim too high rather than too low. In the case of N, however, overfertilization will result in poor shoot:root ratio and will delay hardening off (see chapter 15). In the case of liming, only sufficient lime to raise the pH to the desired level should be added; overliming can increase the incidence of damping-off and root rot [13].

For alkaline soils, CEC can be used to determine the amount of S or acid needed to acidify the soil: for acidic soils, it can be used to determine the amount of lime needed to raise pH to the desired level. The data from Table 4 illustrate the use of CEC and other soil-test values for making a decision on liming as well as increasing Mg levels. Dolomitic limestone is often used for liming because it supplies Mg as well as Ca. In the example in Table 4, the Mg level should be increased in both nurseries. Nursery A (pH 6.0) has 7 milliequivalents (meq) of exchangeable acid [CEC - (K + Ca + Mg)]. One ton of dolomite/acre would add approximately 1 meq of Ca and 1 meq of Mg. In this case, the desired increase in Mg could be effected without causing an excess of bases. On the other hand, Nursery B (pH 6.7) has only 1.4 meq of exchangeable acid. Adding 1 ton of dolomite/acre would result in an excess of bases, making soil alkaline (pH > 7.0). Some other means of increasing Mg-such as the more costly addition of $MgSO_4$ (Epsom salts)—would be called for.

Table 4. Soil-test data used for liming and Mg fertilization recommendations.

	Exchangeable				
Nursery	K	Ca	Mg	CEC	pH
	~ ~ ~ ~ ~ ~ ~ meq/100 g ~ ~ ~ ~ ~ ~ ~ ~				
A	0.32	5.0	0.37	12.7	6.0
B	0.42	6.0	0.35	8.2	6.7

CEC, a function of the contents of clay and organic matter, is a fairly stable parameter. Therefore, it should not be necessary to redetermine CEC every time a soil from a given area is tested. If organic matter content decreases over time, so probably will CEC. This relationship could be used to determine the advisability of obtaining a CEC analysis.

Nitrogen tests are the most difficult to interpret. Total N data provide information on the total amount of N in the seedling root zone, but nothing about its availability. Ammonium and nitrate N tests show **how much** of these forms of N are present in the soil when sampled, although this is partly a function of time of sampling and stage of seedling growth. Levels are usually low during periods of rapid growth but tend to build during the dormant season. Even if levels are high in the fall and early winter, winter rainfall will leach nitrate N to depths below the seedling root zone. Because ammonium N is held on the exchange complex, it is less subject to leaching losses; therefore, testing for this form some time before seeding might be a good indicator of the need for N fertilization. However, the demand for N by newly germinating seedlings is so small that N fertilization before seeding is probably a waste of money. Total N and organic matter data are used primarily for monitoring levels from one rotation to the next and to indicate the need for building up organic levels.

8.3.4 Monitoring soil fertility: an example

The changes in soil fertility over time in three nurseries are shown in Table 5. Data are mean values for all blocks at the Bend and Humboldt Nurseries but only for a single block at the Lava Nursery. The 1961 data for the Humboldt Nursery and the 1975 data for the Lava Nursery are from samples analyzed before these nurseries were established. Baseline data are being determined for each block at the Lava Nursery.

Over 28 years, management practices at the Bend Nursery have resulted in a wider range in pH values, increases in P, K,

and Ca, and an increase in organic matter. The soil is a coarse pumice sand. The nursery is in a low rainfall area (high desert), and native soil organic matter is naturally low. Irrigation and organic amendments have increased organic matter levels.

Over 20 years, pH values and P levels have increased slightly at the Humboldt Nursery. The increase in P has probably resulted from residual buildup from phosphate fertilizer applications. Potassium levels decreased during the first 10 years but are now at or above initial levels. The increases in exchangeable Ca and Mg, as well as pH, are the result of adding dolomitic limestone. Organic matter and total N have decreased over the 20-year period as a result of frequent cultivation.

Over 6 years, pH has not changed significantly, P and Ca have decreased slightly, and K and Mg have increased at the Lava Nursery. Initially, the soils were low in Mg, so $MgSO_4$ and dolomitic limestone were added. Organic matter has also decreased, probably due to cultivation.

Remember, however, that the data in Table 5 are mean values. For careful monitoring, data for individual sample areas should be used for comparison. But this will require more detailed recordkeeping (see chapter 27, this volume). Computer printouts such as those from the OSU Lab (Figs. 1 and 2) give the kinds of specific breakdowns essential for thorough analysis. To facilitate more detailed interpretations of cultural practices, more frequent sampling and analysis would be required.

Table 5. Mean soil-test values at different times at three Northwest forest nurseries.

		Available		Exchangeable			Organic
Year	pH range	P	K	Ca	Mg	Total N	matter
		~ ~ ppm ~ ~		~ meq/100g ~		~ ~ ~ % ~ ~ ~	
Bend Nursery							
1954	6.4-6.7	21	337	4.3	…..	0.06	1.3
1968	6.3-6.4	12	449	5.9	2.8	…..	2.5
1982	5.8-7.4	41	466	5.5	2.7	0.09	2.2
Humboldt Nursery							
1961	5.1-5.3	5	100	1.5	0.65	0.31	8.0
1971	5.4-5.7	17	60	1.8	0.46	0.26	7.1
1982	5.4-6.2	13	120	3.2	1.4	0.22[1]	6.3
Lava Nursery[2]							
1975	6.4-6.8	12	147	6.5	0.43	0.17	5.2
1981	6.3-6.6	7	221	5.5	1.4	0.16	3.7

[1]1981 data.

[2]Means for one block only.

8.4 Tissue Analysis

The nutrient concentration of seedling tissue is a measure of the soil's ability to provide nutrients to a seedling crop. Because tissue analysis does not rely so heavily on arbitrary extraction procedures, it can be very useful for calibrating soil-test values.

Most tissue sampling is done in the fall (October-November), when seedlings are generally dormant and nutrient levels somewhat stabilized. However, if the objective is to evaluate the efficiency of fertilizer uptake, periodic sampling during the growing season should be scheduled. The use made of tissue analysis will determine the time of sampling and kinds of samples taken.

8.4.1 Sampling and handling

For analyzing 1 +0 seedlings, the whole seedling is sampled. For analyzing 2+0 seedlings or transplants, only the needles (usually the current year's needles) are sampled. If, however, fertilizer-uptake efficiency or total nutrient uptake is to be evaluated, the whole seedling should be sampled. Samples submitted to the lab should represent soil conditions that are not too diverse. For more details, see Solan [6].

Tissue samples should be washed to remove soil and dust, especially if Fe analysis is desired, and sent as quickly as possible to the laboratory. if a drying oven is available, samples can be dried at 65 to 70°C for 24 hours; 10 g of dry plant tissue is adequate for lab analysis. If fresh seedlings cannot be sent to the lab soon after sampling, they should be stored in a refrigerator until ready for shipping; upon receipt, they are dried, if necessary, and ground in a Wiley mill to pass a 20-mesh screen in preparation for analysis.

8.4.2 Testing

The OSU Lab can analyze N, P, K, Ca, Mg, and S as individual elements or as a combined package. Additional analyses are available for boron (B), copper (Cu), Fe, Mn, Na, and zinc (Zn).

PAGE 1 OF 1

Forest Nursery Soil Testing Service

OREGON STATE UNIVERSITY
SOIL TESTING LABORATORY
CORVALLIS, OREGON 97331

OSU Forest Nursery Technology Center

NAME: EVERGREEN FOREST NURSERY
JOHN DOE
Address: RT 2 BOX 257
GILCHRIST OR 97737

Date Sampled: 7/20
Date Received: 7/25
Date Completed: 8/ 2/82

Sample From: East of Cascades XX
West of Cascades

Comments: ACID SOILS - USE BRAY P TEST. SEND RESULTS TO DR. YOUNGBERG.

Sample No.	Lab No.	pH	Bray P ppm	K ppm	Ca m/100g	Mg m/100g	CEC m/100g	OM %	TN %
4-PP	66111	6.0	38	304	4.70	1.90	7.60	0.91	0.04
4-LP	66112	5.9	41	276	4.20	1.60	7.40	1.10	0.05
5-2	66113	6.8	52	319	7.50	2.30	10.2	1.80	0.05
5-5	66114	6.5	54	280	5.00	1.30	9.40	1.20	0.06
5-8	66115	6.4	63	401	7.30	2.00	10.1	1.90	0.07
5-11	66116	6.7	48	331	6.20	1.60	8.30	1.80	0.05
5-13	66117	6.8	45	319	6.00	1.60	8.90	1.60	0.05
6-2	66118	6.5	41	253	5.90	1.90	8.10	1.70	0.05
6-5	66119	9.0	39	245	5.70	1.90	9.30	1.40	0.05
6-8	66120	6.4	39	218	4.90	1.60	7.60	1.60	0.05
6-11	66121	6.3	43	222	5.20	1.70	8.50	1.30	0.06
6-14	66122	6.2	45	234	4.70	1.70	7.50	1.30	0.04
6-17	66123	6.4	45	273	5.70	1.80	10.1	1.30	0.05
7-2	66124	6.2	32	265	5.20	1.80	9.30	1.30	0.05
7–5	66125	5.9	40	280	.20	1.90	9.00	1.70	0.07
7-8	66126	6.2	33	335	5.90	2.40	10.2	1.90	0.05
7-11	66127	6.3	35	343	6.00	2.70	9.60	1.80	0.06
12	66128	5.9	27	187	4.09	2.09	8.80	1.50	0.05

Figure 1. Computer printout reporting results of soil analysis for a typical forest nursery In the Northwest.

Forest Nursery Sail Testing Service

OREGON STATE UNIVERSITY
SOIL TESTING LABORATORY
CORVALLIS, OREGON 97331

OSU Forest Nursery Technology Center

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NURSERY SOIL FERTILITY MONITORING FORM

****

NAME: EVERGREEN FOREST NURSERY
JOHN DOE
Address: RT 2 BOX 257
GILCHREST OR 97737

Sample No. 4PP

8/02/82

Date	pH	Bray P ppm	K ppm	Ca m/100g	Mg m/100g	CEC m/100g	OM %	TN %
09/80	6.2	50	400	4.85	2.10	8.00	0.82	0.03
07/81	5.9	44	325	4.68	1.50	7.10	1.02	0.05
08/82	6.0	38	304	4.70	1.90	7.60	0.91	0.04

Figure 2. Computer printout reporting monitored nutrient levels in a typical nursery sample over time.

The sample size (0.5 to 1.0 g) used for digestion and analysis depends on the number of elements to be determined and the approximate elemental concentration in the tissue. A Kjeldahl digest is used for N and P. All cations including K, Ca, Mg, Fe, Mn, Cu, molybdenum (Mo), and Zn are digested with a nitric-perchloric acid mix. S and B are dry ashed. Elemental determinations are made using standard methods.[2]

8.4.3 Interpretation

The range in concentration of macronutrients in 2+0 Douglas-fir needle tissue collected in the dormant season (fall-early winter) is given in Table 6 ([unpubl. data, 16]; see also chapter 7, this volume). Concentrations below the low values indicate probable deficiencies, and those above the high values suggest possible luxury consumption.

Table 6. Range in nutrient concentrations in needle tissue of 2+0 Douglas-fir seedlings.

Level	N	P	K	Ca	Mg	S
	~~%			~~~~~~~~~~~~~~~		
Low	1.2	0.1	0.3	0.2	0.1	0.1
High	2.0	0.2	0.8	0.5	0.15	0.2

Micronutrient data for nursery-grown seedlings are scarce; most of the data available are for larger trees [7]. Availability of micronutrients is strongly influenced by pH. For example, Fe deficiency (chlorosis) is often observed on seedlings in nurseries with strongly alkaline soils. Toxicity problems may be caused by strongly acid soils. In 1972, pronounced Mn toxicity symptoms were observed on 2+0 Douglas-fir seedlings in a poorly drained area with strongly acid soil (pH 4.5) at the Wind River Nursery.

Micronutrient problems often occur on old, strongly weathered soil material. Fortunately, however, most of the forest nurseries in the Northwest are sited on young, relatively nutrient-rich soils. The levels of available nutrients in Northwest nurseries, even those on sandy glacial soils, are considerably higher than those in nurseries on strongly weathered soils in the southeastern U.S. Because most Northwest soils are only slightly to moderately acid, micronutrient problems will likely be minimal. Sewage sludge and other "exotic" amendments, which may cause toxicity problems, should not be used without first analyzing them for micronutrients.

[2]All procedures and methods used by the plant analysis laboratory are on file with the Department of Soil Science, Oregon State University, and are available on request.

The tissue analysis done by the OSU Lab for forest nurseries thus far has shown that for all species analyzed, elemental concentrations are generally within the ranges given in Table 6. In a few instances, concentrations of P and Mg have been low, but not deficient; those for K and Ca have varied from midrange to above the high levels in Table 6; and those for total N have ranged from low to very high, with most in the high range. Data on N concentration in seedling tissue from four Northwest nurseries (Table 7) seem to indicate that more N is being added to soils than is needed; concentrations much over 2% suggest overfertilization. Concentrations of the other macronutrients in seedling tissue from these four nurseries (Table 8) indicate that the nutritional status of the seedlings is satisfactory.

Table 7. Foliar N concentration of 2+0 Douglas-fir seedlings from four Northwest nurseries.

Nursery	Percent N Mean	Percent N Range	Remarks
1	1.59	1.24-2.03	7 of 15 samples < 1.6
2[1]	1.95	1.78-2.03	7 samples
3	1.78	1.26-2.67	32 of 37 samples < 2.0
4	2.29	1.92-2.57	1 of 13 samples < 2.0

[1]Total soil N = 0.22%: similar data unavailable for the other three nurseries.

Turner and Lambert [8] and Knight [3] have emphasized the importance of S in conifer seedling nutrition; Knight recommends adding 1 part of S for every 15 parts of N added as fertilizer. Foliar analysis for total N and total S is a valuable way of assessing this aspect of fertility management; a ratio at or below 15 N: I S is suggested for adequate S nutrition and protein synthesis.

Foliar S data were available from three of the four nurseries discussed in Tables 7 and 8; their N:S ratios ranged from 7:1 to 23:1. Seedlings from nursery 2 had foliar S concentrations ranging from 0.19 (adequate) to 0.24% (high) and N:S ratios of

Table 8. Mean soft and follar levels of four macronutrients for 2+0 Douglas-fir seedlings in four Northwest nurseries.

Nursery	P		K		Ca		Mg	
	Soil	Foliar	Soil	Foliar	Soil	Foliar	Soil	Foliar
	ppm	%	ppm	%	ppm	%	ppm	%
1	79	0.17	93	0.70	1.5	0.33	0.61	0.19
2	13	0.21	120	0.60	3.2	0.46	1.4	0.30
3	....	0.23	....	0.78	.....	.....	.....	.....
4	18	0.15	79	0.50	7.3	0.55	1.8	0.19

8:1 to 9:1: those from nursery 3 had foliar S concentrations ranging from 0.12 (low) to 0. 19% (adequate) and N:S ratios of 7:1 to 15:1: and those from nursery 4 had foliar S concentrations ranging from 0.14 (midrange) to 2.24% (high) and N:S ratios of 9:1 to 23:1. Seedlings with N:S ratios greater than 15:1 had high foliar N concentrations and S levels in the midrange. Sulfur deficiencies are known to exist in some Northwest soils [15], and color in Christmas trees has been observed to improve after addition of S. The use of fertilizers containing S should adequately supply that element to Northwest soils.

8.5 Combined Soil and Tissue Analysis

Either soil analysis data **or** plant analysis data can form the basis for fertilizer recommendations. From time to time, however, it is advantageous to have **both** types of analysis to verify the validity of management recommendations.

Soil analysis data also were available for three of the four nurseries examined in Tables 7 and 8. As might be expected, the correlations between foliar and total soil N were not consistent. Furthermore, foliar N was more responsive to fertilizer N than were foliar P, K, Ca, and Mg to fertilizer additions containing those elements.

In nursery 1, soil-test levels for P were well above the minimum recommended value, and those for K were within the recommended range (Table 2). Foliar P was midrange to high, and K was adequate (Table 6). Exchangeable Ca and Mg were both low (Table 2): however, foliar Ca was midrange and Mg high.

Soil-test values for P in nursery 2 (Table 8) were below those suggested in Table 2 and well below those recommended in chapter 7, this volume. However, foliar P concentrations were above the high levels suggested in Table 6 and in chapter 7. Correlation was good between foliar and soil K, Ca, and Mg. Total soil N was adequate (Table 2): in this case, the correlation between foliar and soil N was good. Because information was not available on N fertilization regimes, its influence could not be evaluated.

Soil-test levels for P in nursery 4 (Table 8) were less than the low values recommended in Table 2 and in chapter 7. Foliar P concentrations were in the midrange. Foliar and soil K, Ca, and Mg correlated reasonably well.

It should be emphasized that this discussion concerning the use of combined soil and plant analysis is based on general comparisons of data from a limited number of nurseries. The values cited for both soil and foliar levels are means. Sufficient data were not available to detect any nutrient interactions or dilution effects, although a comparison of foliar N and P data for nurseries 2 and 4 (Tables 7 and 8) suggests that there may be a slight dilution effect from high N on foliar P in nursery 4. Some correlations were good and others poor. Only careful sampling can assure that both soil and tissue samples come from the same area. Moreover, information on fertilizers and their rates of application are necessary for adequate interpretation of any analysis. Careful recordkeeping is therefore essential. Obviously, the use of combined soil and tissue analysis is an area requiring concentrated research.

8.6 Conclusions and Recommendations

Soil fertility is only one important factor among the many necessary for producing high-quality nursery stock. Soil and plant analysis are readily available tools that enable forest-nursery managers to monitor the fertility status of their soils. The success of the monitoring program depends on careful sampling-which requires sampling the same area each time, careful handling of samples, and consistency in laboratory services.

Suggested target nutrient levels for Douglas-fir in Northwest nurseries are: pH of 5.0 to 6.0, total N of 0.18 to 0.23%, available P of 2 5 to 50 ppm, available K of 80 to 120 ppm, exchangeable Ca. of 2 to 4 meq/100 g, and exchangeable Mg of 0.8 to 1.5 meq/100 g. Suggested levels for conifers and hardwoods in intermountain nurseries are: pH of 5.5 to 6.5 for most conifers (6.5 to 7.5 for hardwoods and junipers), total N of 0.1 to 0.2%, available P of 30 to 60 ppm, available K of 100 to 200 ppm, exchangeable Ca of 2.5 to 4 meq/100 g, and exchangeable Mg of 1 to 2 meq/100 g. Because amounts of fertilizer added to achieve desired levels will vary with soil type, tissue analysis is a useful cross-check for assessing the success of fertilizer-management regimes. Suggested ranges in macronutrient concentrations in Douglas-fir needle tissue are: 1.2 to 2% N, 0. 1 to 0.2% P. 0.3 to 0.8% K, 0.2 to 0. 5% Ca, 0.10 to 0.15 % Mg, and 0.1 to 0.2 % S.

Seedling nutrient status is assumed to influence performance after planting. Researchers and nursery personnel should seek to uncover the relationships between nutrient status and outplanting, bearing in mind, however, that many factors in nursery culture other than seedling nutrient status profoundly affect survival and growth of outplanted trees.

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