Normal Foliar Nutrient Levels in North American Forest Trees

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Charles R. Blinn and Edward R. Buckner

Abstract

Numerous forest tree species native to the North America continent have been introduced into other regions of the woirld with varying degrees of success. In several instances, nutrition problems in these introductions have become apparent only in later stages of stand development, or in second generation stands, after large acreages have been planted. The economic implications of growth stagnation or plantation failure in these situations could become a threat to national resource development programs.

Monitoring the nutrient status of introduced trees should provide early warnings of nutrient problems, thereby enabling appropriate remedial action.

Foliar analysis has been widely used in North America to assess the nutrient status of forest trees. This publication briefly discusses foliar analysis principles.

This publication also provides a table summarizing much of the published literature, as of 1988, for the more common forest tree species native to North America. The "normal" foliar nutrient levels reported are for the essential elements that most commonly limit tree growth. These summarized values should provide forest researchers and managers with comparative data for healthy trees growing on their native sites, thereby enabling an assessment of the nutrient status of North American species introduced into other regions.

Introduction

Commercial forest plantations have been increasing in number and importance throughout the world. Numerous forest tree species native to North America have been introduced into other regions with varying degrees of success. In several instances, nutrition problems have become apparent only in the later stages of stand development, or in second generation stands, after large acreages have been planted (Belton and Davis, 1986; Boardman et al., 1979; Jorgensen and Wells, 1986; Stevens and Bond, 1957; Stone and Will, 1965b).

The economic implications of growth stagnation or plantation failure could threaten national resource development programs in many countries where exotic tree species have been widely introduced. Monitoring the nutrient status of introduced trees should provide an early warning signal that nutrition problems exist (Tamm, 1964), thereby enabling appropriate remedial action.

Plants must have 17 essential elements available in usable forms and in amounts adequate for plant growth (Brady, 1984). Two of these elements, C and O are obtained from air and one element, H, comes from water. Of the 14 essential elements obtained from the soil, six are macronutrients used in relatively large quantities (N, P, K, Ca, Mg, and S). Eight are micronutrients used in very small amounts (Fe, Mn, Cu, Zn, B, Mo, Cl, and Co).

Foliar analysis has been used widely in North America to determine the status of the essential elements in a wide variety of forest tree species. While there have been several attempts to summarize the dispersed literature on this subject (for example, Leaf, 1968; Morrison, 1974; Stone, 1968), most of those reviews reported on only a few elements in a limited number of trees.

This paper discusses the principles of foliar analysis and summarizes much of the published literature, as of 1988, for the forest trees commonly found in North America (Table 1). The summarizing table should provide the standards against which to judge the nutrient status of these species when they are introduced into exotic environments.

Foliar Analysis

Although authorities differ in their interpretation of the physiological meaning of specific foliar nutrient levels, foliar analysis provides a direct measure of the levels of specific nutrients in the tree foliage at a point in time. It is an indirect measure of soil nutrient availability.

Properly conducted and interpreted, foliar analysis also indicates which element or elements are deficient in a plant (Lavender, 1970). However, it does not define the reasons for the deficiencies.

Foliar analysis is especially valuable for determining nitrogen levels. Shortages of this element commonly limit tree growth and soil analysis of nitrogen is a poor indicator of its availability to plants.

While valuable diagnostic information can be gained by assessing the nutrient content of other tissues and tree sap solutions (i.e., tissue/sap from bark, buds, roots, phloem, etc.) most forest tree nutrition analyses are performed on tree foliage.

Investigators generally agree that whole leaves provide the best index for the status of each element in a tree (Howlett and Cahoon, 1964; Mead, 1984; Powers, 1984). They also provide the most meaningful indications of the need for fertilization (Lavender, 1970). Standardized foliage sample collection procedures (see Appendix) are essential, as most evaluations are based on comparisons with other studies (Bates, 1971; Lavender, 1970; Leaf, 1973; Mitchell, 1936; Turner et al., 1978; Wells and Allen, 1985; White, 1954).

Several researchers have found that nutrient element ratios provide a better indication of the nutrient status of forest trees than do individual nutrient levels (Goor, 1953; Heilman and Gessel, 1963; Ingestad, 1967; Leyton, 1957). This is especially true for the N/P ratio.

The relationship between plant growth and foliar nutrient levels is curvilinear (Dothie, 1969; Gessel and Walker, 1958; Melsted et al., 1969). A theoretical presentation of this relationship is diagrammed by Driessche (1974) (Figure 1).

Nutrient deficiencies occur when the available supply of any given element retards plant growth and development. Where a nutrient is deficient a tree will likely respond to a fertilizer application containing the deficient element (Goodall and Gregory, 1947). However, it is difficult to predict growth from element concentrations that are within the deficiency range, because large growth responses often occur with very small increases in the deficient element (Sucoff, 1962).

When the deficiency of an element is acute, visual deficiency symptoms generally develop (Baule and Fricker, 1970; Erdmann et al., 1979; Hackskaylo et al., 1970; Lyle, 1969). When more than one element is deficient, these relationships become much more complex (Wallace, 1951). Fertilizer applications based on foliar analysis should be monitored to assure that growth responses correlate positively with increased foliar nutrient levels of the deficient elements added.

Natural fertility levels of most forest soils in North America, along with rapid nutrient cycling, is generally sufficient to support stands and plantations that do not exhibit visual deficiency symptoms. However, unless factors other than nutrient shortages are limiting growth, these stands will show a positive response to fertilization.

In North America, N is almost universally in short supply for maximum growth and P and K are locally deficient (southeastern coastal plain and the glacial outwash plains of New York, respectively) (Armson et al., 1975; Heiberg and White, 1950; Pritchett and Fisher, 1987). Shortages of other elements that are so limiting that growth is severely restricted are rare.

The concept of "critical levels" has been used to identify a range of foliar nutrient levels below which growth drops rapidly (Richards and Bevege, 1972; Ulrich and Hills, 1967). It is conceived to be the range of nutrient concentrations above which only a small (10 percent) growth increase can be realized from additions of the deficient element and below which visual deficiency symptoms may become apparent. Implicit in this concept is the assumption that all environmental and genetic-physiological factors and essential nutrients, apart from the one in question, are not limiting growth (Leaf, 1969; Richards and Bevege, 1972; Timmer and Morrow, 1984). A weakness in most foliar analysis assessments is the inability to determine the degree to which this assumption is valid.

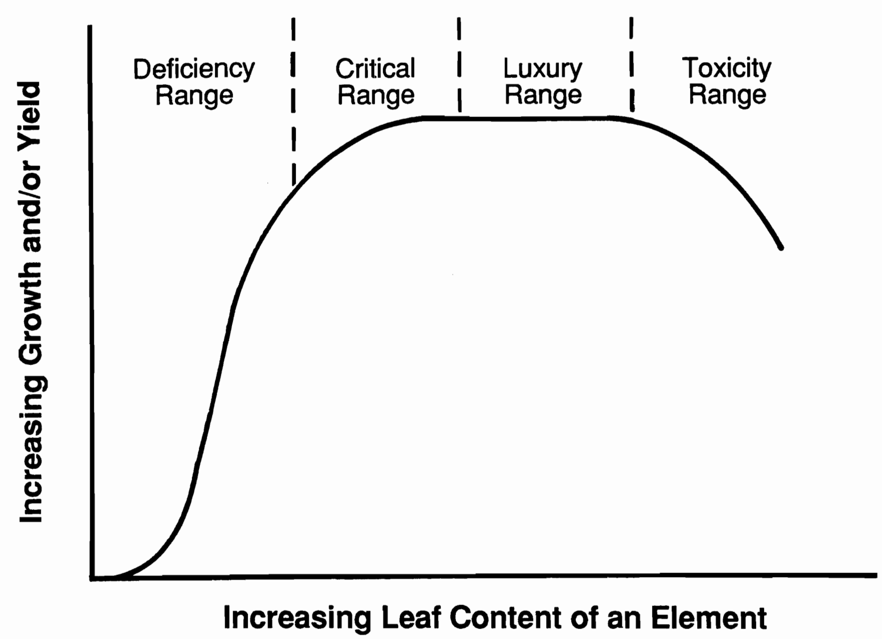
While the term "critical level" has been widely used in the literature to denote the nutrient level below which a response to fertilizer would be expected, several additional terms have also been used to denote these same levels. These terms include adequate (Morrison, 1974), intermediate (Leaf, 1968; Stone, 1968), optimum (Timmer and Morrow, 1984), and sufficiency (Swan, 1970).

These additional terms are both conflicting and contradictory and may not convey the intended meaning to many readers. Also, the term "critical", as defined in Webster's dictionary (Gove, 1967), has several different definitions, most of which are not compatible with the term as it is applied in foliar analysis.

Based on information presented in the literature the term "normal", as defined by Webster (Gove, 1967), best reflects the field conditions under which these measurements were made and best conveys the intended meaning of the reported values. Therefore, the term "normal" is used in this publication to denote nutrient levels found in healthy trees growing under natural conditions in their native habitat. As these normal values are within the critical range, as the term is applied in the literature, a response to fertilizer would be expected if nutrient levels dropped below the low end of the range.

Since the growth curve approaches a horizontal maximum at the upper end of the normal range (Figure 1), it has been argued that this foliar nutrient level is approaching the best possible

Figure 1. The different ranges in foliar nutrient content in relation to the corresponding portions of the growth response curve.



Source: Driessche (1974)

level for both tree growth and health (Sucoff, 1962). Above the normal range, there is a zone where there is little or no growth response associated with higher foliar nutrient concentrations; this is the zone of luxury consumption. Beyond this may come a toxicity zone in which there is a falling off of growth with increasing foliar nutrient levels (Armson, 1973; Barrows, 1959; Sucoff, 1962).

While alternatives to the critical nutrient level approach have been developed, such as the Diagnosis and Recommendation Integration System (DRIS) (Beaufils, 1973; Leech and Kim, 1981; Sumner, 1979) and a screening system using foliar analysis and short-term fertilizer plots (Timmer and Stone, 1978), further work is required before these procedures can be widely applied. At present, no method stands clearly superior to the critical nutrient level concept, provided that adequate standards exist.

Generally, the immediate effect of a fertilizer application is an increase in tissue concentration of the added nutrient(s). This may be the only first season effect. Growth increases may not occur until the second season, at which time plant nutrient uptake may not keep pace. The result may be a lowering in tissue nutrient concentrations of fertilized trees below that in unfertilized trees. This is termed the "Steenbjerg effect" (Steenbjerg, 1951; Tamm and Carbonnier, 1961). A similar effect has been observed when the supply of a nutrient is increased from extreme deficiency to the normal level (Steenbjerg and Jakobsen, 1963).

Changes in the supply of one nutrient may alter the concentration of other nutrients, either by direct interaction or by modifying plant growth (Tamm, 1956). Increasing the supply of a limiting element often results in a decrease in the concentration of other, previously non-limiting elements. This is termed a "dilution effect" (Cleve and Zasada, 1976; Ulrich and Hills, 1967; Wells et al., 1973). As dilution progresses, the levels of other nutrients may become low enough that they, in turn, become limiting. In this way, an increase in the supply of one nutrient may induce a deficiency of another element.

Plant macronutrient levels are generally expressed as concentration (percent) on an oven-dry-weight basis (dried to a constant weight at 70° C), whereas micronutrient levels are reported as parts per million (ppm). Values for S are generally expressed as ppm.

Various researchers have proposed other methods for expressing nutrient levels (Hoyle, 1965; Powers, 1984; Smalley, 1976; Woodwell, 1974). Although many of their arguments for using other methods are valid, it is unlikely that there will be a shift toward a new reporting convention.

While natural fertility levels of most North American forest soils may not be sufficient to support maximum growth, they are sufficient to support healthy forests that supply most of the forest products used on that continent as well as a sizeable export trade. The "normal" foliar nutrient levels reported in the following table were obtained from such "natural" average stands (e.g., stands/plantations that were not fertilized).

A Summary Table

The following table of "normal" foliar nutrient levels summarizes the work of a large number of researchers on North American forest tree species (Table 1). These normal values are in the "critical range", as defined in the previous discussion.

Unless otherwise indicated, values are not included for trees growing on sites where supplemental nutrients (fertilizers) have been added. However, some of the reported studies do contain values for trees growing on intensively prepared sites, provided supplemental nutrients were not added. Except as otherwise indicated, all values refer to mature, green, first season foliage from trees past the sapling stage growing under field conditions.

Foliar nutrient values for both macronutrients and micronutrients are presented as:

1) A range in which "normal" growth occurs, with the lower value likely reflecting a deficiency that limits growth while the higher value approaches the optimum for maximum plant growth.

2) A number preceded by a greater than (>) or less than (<) symbol, indicating that it is either at the lower (>) or upper (<) end of the normal range.

3) A single value reported as where normal growth was found to occur (somewhere in the normal range).

While a growth response to fertilizer applications would be expected for foliar nutrient levels at the lower end of the normal range, assuming that other factors are not limiting growth, the upper end borders on the range of luxury consumption where significant growth responses would be unlikely.

Some of the studies that reported only a single value (Method 3) were not conducted by tree nutrition researchers. These values may be less reliable than those reported under Methods 1 and 2. Data from forest fertilization studies are presented only for control plots that were not fertilized and growth was "normal" (e.g., no serious nutrient deficiencies were apparent).

The values presented in Table 1 should provide forest managers and tree nutrition workers with guidelines for evaluating the nutrient status of the reported tree species. It should be of particular value where these species are being introduced into exotic environments. Foliar nutrient levels that diverge markedly from the reported values likely indicate that nutrition problems are influencing tree growth.

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Table 1. Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
ANGIOSPERMS							
Acer negundo L. Boxelder	2.73	0.32	1.89	1.10	0.64	B 85;Cl 883;Cu 5.8;Fe 335;Mn 83; Mo 0.26;S 1600;Sr 36;Zn 25.3	74
			3.1			[c]	157
Acer rubrum L. Red maple	>1.65	>0.09	>0.46	>0.68	>0.16		12
				0.91			40
	1.67	0.16	0.53	0.62	0.20	Na 20	50
	2.00	0.17	0.69	1.15	0.20		63
	1.43	0.17	0.78	2.24	0.63	[c]S 2100 (Complete nutrient solution applied)	64
	0.90	0.07	0.35	0.94	0.33	B 57;Cl 2487;Cu 3.6;Fe 181;Mn 444; Mo 0.05;S 800;Sr 21;Zn 22.5	74
	1.70-2.61						78
	1.67	0.31	0.79	0.93	0.27	Al 25;B 37;Cu 7.2;Fe 67; Mn 608;Mo 8.4;Zn 50	99
	2.55-2.68						149
		>0.60					231
	1.40	0.275	0.65	0.705	0.103	Al 51;B 30;Cu 9;Fe 133; Mn 765;Mo 3.6;Zn 41	259
Acer saccharinum L. Silver maple			1.4			[c]	157
	2.3					[c]Complete nutrient solution applied	205
Acer saccharum Marsh. Sugar maple	1.37	0.12	1.42	1.09	0.17	Al 56;B 29;Cu 8;Fe 81; Mn 404;Mo 1.7;Zn 27	39
				1.75			40
	2.25	0.16	0.90	2.38	0.43	[c]S 1900 (Complete nutrient solution applied)	64
	0.73	0.12	0.39	1.01	0.45	B 62;Cl 299;Cu 9.8;Fe 157;Mn 80; Mo 0.05;S 500;Sr 58;Zn 42.3	74
	1.71-2.81						78
	1.84	0.29	0.86	1.45	0.20	Al 35;B 45;Cu 5.5;Fe 87;Mn 761; Mo 7.6;Zn 26	99
						Ba 245	117
	1.7-2.0	0.08-0.1					126
	>1.5						136
	1.78	0.30	0.95	2.42	0.28	Cu 12;Fe 220;Mn 100; Na 1400;S 100;Zn 54	141
	2.77-2.85						149
Aesculus glabra Willd. Ohio buckeye	1.60	0.29	0.92	4.37	0.31	Cu 7;Fe 340;Mn 120; Na 1100;S 1500;Zn 54	141
Alnus crispa (Ait.) Pursh Green alder		0.20	0.65			Cu 6.9;Fe 316	87
	2.28	0.16	0.56	1.07	0.24	Al 77;B 21;Cu 3.5;Fe 115; Mn 318;Mo 7.6;Zn 12	99
		0.12	<0.31	<0.04	0.13	[c]	162
Alnus glutinosa (L.) Gaertn. Black alder		0.138	0.20	0.29	0.10	[c]	162
	2.30	0.10	0.53	1.24	0.29	Co 7.25;Fe 404; Mn 1014;Mo 0.48	178

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
Alnus rubra Bong. Red alder	1.92	0.15	0.95	0.40	0.15	Al 34;Cu 10;Fe 48; Mn 130;S 1500;Zn 35	51
	>2.4	>0.16	>0.04	>0.08	>0.11	[c]	79
	>2.4	>0.16	>0.4	>0.08	>0.11	[c]	106
	2.69	0.17	0.86	0.87	0.23	[c] Cu 8;Fe 133;Mn 294;S 1800;Zn 47 (4 months after 300 kg P/ha)	167
Betula alleghaniensis Britton Yellow birch	1.82	0.16	1.88	1.37	0.36	Al 91;B 31;Cu 7;Fe 101; Mn 173;Mo 3.2;Zn 228	39
				1.21			40
	2.14	0.17	1.10	1.11	0.37	Na 20	50
			0.05-0.75				126
Betula nigra L. River birch	2.26	0.18	0.92	0.98	0.58	B 100;Cl 167;Cu 7.6;Fe 233;Mn 73; Mo 0.33;S 2000;Sr 24;Zn 212.4	74
Betula papyrifera Marsh. Paper or white birch	1.12	0.51	1.46	1.87	0.58	[c] S 2200 (Complete nutrient solution applied)	64
	2.07	0.28	0.84	1.01	0.32	Al 42;B 52;Cu 5;Fe 87; Mn 578;Mo 10.4;Zn 146	99
						B 41	176
	1.32	0.133	0.84	0.63	0.158	Al 35;B 31;Cu 6.8;Fe 72; Mn 315;Mo 4;Zn 77	259
Betula populifolia Marsh. Gray birch	2.44	0.22	1.37	0.61	0.22	Al 51;B 14;Cu 9;Fe 71; Mn 287;Mo 2.1;Zn 131	39
						B 21-42	197
			>1.00				231
Carya alba (L.) K. Koch Mockernut hickory				2.62			40
Carya cordiformis (Wang.) K. Koch Bitternut hickory				2.50			40
Carya glabra (Mill.) Sweet Pignut hickory	1.98	0.17	0.58	0.95	0.82		50
	1.75-2.40						78
	2.37-2.42						149
Carya illinoensis (Wangenh.) K. Koch Pecan						Cu 21	2
						Zn 40.3-93.3	53
	2.10	0.097	0.337	1.583	0.396		93
						B 61	94
	1.71	0.18	0.82	1.75	0.43	[c]	116
					0.18-0.43		186
Carya ovata (Mill.) K. Koch Shagbark hickory				1.94			40
	1.23	0.18	0.52	1.09	0.57	B 110;Cl 358;Cu 8.9;Fe 183;Mn 266; Mo 0.34;S 1500;Sr 40;Zn 62.5	74
						Mn 727	75
Catalpa speciosa Warder Northern catalpa	1.92	0.30	1.31	2.26	0.34	Cu 19;Fe 680;Mn 130; Na 1000;S 4800;Zn 50	141

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
Celtis occidentalis L. Hackberry	2.77	0.27	1.58	1.08	0.47	B 45;Cl 53;Cu 7.5; Fe 202;Mn 184; Mo 0.07;S 1200;Sr 80;Zn 18.5	74
	2.61	0.17	1.75	7.81	0.53	Cu 6;Fe 550;Mn 170; Na 1000;S 2900;Zn 32	141
			0.6			[c]	157
Cladrastis kentuckea (Dum.-Cours.) Rudd Yellowwood	2.24	0.78	1.88	3.68	0.29	Cu 12;Fe 250;Mn 70; Na 900;S 1100;Zn 36	141
Cornus florida L. Flowering dogwood	1.79	0.14	1.18	1.60	0.90		50
	1.37	0.18	0.37	4.21	0.51	Cu 7;Fe 240;Mn 50; Na 1200;S 7000;Zn 28	141
						B 22.5	142
Diospyros virginia L. Persimmon	2.28	0.14	1.98	1.63	0.36	Cu 5;Fe 210;Mn 220; Na 1700;S 2700;Zn 36	141
						Ba 920	177
Fagus grandifolia Ehrh. American beech	1.72	0.15	1.55	0.62	0.17	Al 69;B 20;Cu 10;Fe 84; Mn 435;Mo 1.5;Zn 25	39
				0.75			40
	1.95-2.81						78
	2.77-2.85						149
Fagus sylvatica L. European beech		0.06	0.61	0.94	0.36	Al 105;B 18.3;Ba 111;Co 0.17; Cr 0.35;Cu 4;Fe 58;Mn 931; Mo 0.03;Na 1400;Ni 15.6;Pb 2.6; Si 9100;Sr 36;Ti 2.6;V 0.11;Zn 18.1	89
Fraxinus americana L. White ash	1.73	0.16	2.01	0.98	0.26	Al 65;B 23;Cu 11;Fe 91;Mn 28; Mo 1.7;Zn 21	39
				2.19			40
	1.32	0.36	1.42	1.31	0.25	[c]S 1500 (Complete nutrient solution applied)	64
	0.72	0.27	1.23	0.94	0.40	B 38;Cl 344;Cu 19.2;Fe 173;Mn 38; Mo 0.11;S 2900;Sr 35;Zn 15.4	74
	2.01-2.83						78
	2.80-2.86						149
Fraxinus pennsylvanica Marsh. Green ash	2.13	0.37	1.64	1.46	0.36	Al 49;B 48;Cu 17;Fe 105; Mn 71;Mo 8;Zn 22	99
	1.93	0.30	0.95	1.15	0.22	[c]	116
						Cu 13.2	175
						B 59	176
Fraxinus nigra Marsh. Black ash	2.11	0.17	2.70	2.01	0.47	Al 216;B 29;Cu 20;Fe 288; Mn 96;Mo 2.7;Zn 25	39
						Cu 7.1	175
Fraxinus quadrangulata Michx. Blue ash	2.10	0.42	1.26	1.98	0.30	Cu 13;Fe 250;Mn 80; Na 2900;S 1100;Zn 34	141
Ilex opaca Ait. American holly	1.08	0.07	0.74	0.97	0.51	Cu 6;Fe 270;Mn 540; Na 900;S 3300;Zn 240	141

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight				— — —	ppm	
Juglans californica S. Wats.							
California walnut	>2.5	>0.11	>1.00		>0.30	B 35;Cu 4;Mn 30;Zn 20	185
Juglans cinerea L.	1.79	0.44	0.82	1.11	0.72	B 79;Cl 1348;Cu 9.2;Fe 196;Mn 149; Mo 0.50;S 2500;Sr 150;Zn 58	74
Butternut							
Juglans nigra L.	1.92	0.54	1.48	0.95	1.01	B 50;Cl 782;Cu 10.7;Fe 292;Mn83; Mo 0.27;S 1400;Sr 82;Zn 49.6	74
Black walnut							
	1.50-1.86	0.18-0.35	0.65-0.79	0.88-1.05	0.29-0.37		121
	1.74	0.46	1.98	3.23	0.50	Cu 11;Fe 400;Mn 190; Na 1500;S 100;Zn 42	141
	2.60	0.25	1.30	1.10	0.45	B 50;Cu 10;Fe 100;Mn 80; Mo 0.10;S 2500;Zn 50	159
						B 40-67	176
						Ba 2860	177
						B 50;Cu 10.8;Mn 136; Zn 50	217
Liquidambar styraciflua L.			0.60	0.95	0.33		12
Sweetgum	1.50	0.35	0.79	1.05	0.37	[c]	116
	1.51	0.29	0.60	1.97	0.43	Cu 9;Fe 200;Mn 700; Na 700;S 100;Zn 27	141
						B 19.2	142
Liriodendron tulipifera L.				3.24			40
Yellow-poplar	2.22	0.18	1.04	1.39	0.61		50
	2.07	0.15	1.05	1.64	0.59	Control	66
	4.28	0.34	2.0			[c]	68
	2.15-3.00						78
						Cu 5	88
	2.60	0.10				[c]Complete nutrient solution applied	108
	1.9-3.0	0.05-0.26	0.9-1.2				126
	2.81	0.22	0.86	3.52	0.21	Cu 5;Fe 280;Mn 90;Na 700; S 3700;Zn 28	141
	2.97-3.02						149
	1.75	0.20	0.89	3.18	0.32	Al 402;B 72;Cu 10;Fe 122; Mn 471;Mo 12;Zn 32	184
Magnolia macrophylla Michx.						Cu 6	88
Bigleaf magnolia	1.74	0.18	1.33	2.38	0.33	Cu 6;Fe 280;Mn 290; Na 900;S 2000;Zn 19	141
Nyssa sylvatica Marsh.	>1.65	>0.10	>0.41	>0.63	>0.31		12
Blackgum or black tupelo						Co 1.5-30.7;Cu 7.1-12.9; Mn 154-578;Zn 11.9-14.9	19
	1.74	0.17	1.04	0.96	0.51	Na 20	50
	1.83-2.80						78
						Co 1	118
						Co 6	119
	2.75-2.85						149
Ostrya virginiana (Mill.) K. Koch							
Eastern hophornbeam	1.89	0.16	1.30	2.34	0.31	Al 209;B 25;Cu 9;Fe 103; Mn 320;Mo 3.2;Zn 23	39
				2.27			40
	1.49	0.16	0.64	1.06	0.54	B 53;Cl 449;Cu 6;Fe 278; Mn 968;Mo 0.12;S 1300; Sr 24;Zn 17	74
	1.96	0.23	0.80	2.03	0.30	Al 92;B 36;Cu 6.8;Fe 126; Mn 866;Mo 11;Zn 22	99

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight				— — —	ppm	
<u>Oxydendrum arboreum</u> (L.) DC.	2.00	0.19	0.78	0.96	0.27	Na 40	50
Sourwood						B 66	142
<u>Platanus occidentalis</u> L.	1.81	0.12	0.71	0.96			91
American sycamore	1.62	0.18	0.81	1.24	0.25	[c]	116
	1.62-2.01	0.16-0.19	0.16-0.86	1.18-1.24	0.24-0.28		121
	2.07	0.16	1.25	2.19	0.30	Cu 4;Fe 260;Mn 150; Na 1000;S 800;Zn 42	141
<u>Populus deltoides</u> Bartr.	2.24					4 months after 150# N/A	30
Eastern cottonwood	1.36	0.28	0.92	1.11	0.72	B 70;Cl 737;Cu 8.8;Fe 104;Mn 106; Mo 0.13;S 3700;Sr 39;Zn 199	74
	1.75	0.17	1.01	2.15	0.37	[c]	116
						B 35	117
	1.6-2.4	0.18-0.22					126
	2.00	0.17	1.30	2.20	0.18	B 84;Cu 7	145
	2.00	0.17	1.30	2.30	0.18	[c]	250
<u>Populus grandidentata</u> Michx.						B 31-45;Cu 31-45	45
Bigtooth aspen	1.11	0.21	1.78	0.99	0.33	B 57;Cl 720;Cu 8.4;Fe 106;Mn 50; Mo 0.05;S 2000;Sr 42;Zn 108.2	74
	2.93	0.52	2.37	1.41	0.24	Al 33;B 77;Cu 14.1;Fe 91; Mn 229;Mo 7.2;Zn 213	99
<u>Populus tremuloides</u> Michx.				2.21			40
Quaking (trembling) aspen	2.00-2.70						78
	2.42	0.40	2.59	1.26	0.22	Al 28;B 89;Cu 11.6;Fe 62; Mn 89;Mo 5.2;Zn 192	99
	2.64-2.77						149
	2.01	0.145	0.155	1.15	0.143	Al 58;B 30;Cu 8;Fe 105; Mn 460;Mo 7;Zn >100	259
<u>Prunus serotina</u> Ehrh.						B 28;Cu 7.1	1
Black cherry				2.14			40
						Mn 585	75
	2.05	0.40	1.52	1.36	0.35	Al 32;B 50;Cu 3.6; Fe 75; Mn 321;Mo 9.1;Zn 16	99
			1.2-1.6				126
	2.24	0.35	1.09	2.20	0.53	Cu 8;Fe 290;Mn 230; Na 700;S 1200;Zn 27	141
			>0.8				231
<u>Quercus alba</u> L.	1.78	0.12	0.70	1.00	0.21		12
White oak				1.36			40
	1.95	0.14	0.66	0.72	0.17	Control	66
	1.92	0.17	1.42	0.58			67
	2.19	0.19	0.85	0.82	0.36	B 38;Cl 43;Cu 7.7;Fe 126;Mn 1374; Mo 0.06;S 1300;Sr 23;Zn 22.3	74
	2.22-2.76						78
	2.72-2.80						149
<u>Quercus bicolor</u> Willd.	2.02	0.26	1.20	1.07	0.31	B 52;Cl 130;Cu 9.7;Fe 149;Mn 323; Mo 0.05;S 1300;Sr 21;Zn 26.3	74
Swamp white oak							
<u>Quercus falcata</u> var. <u>pagodaefolia</u> Ell.							
Cherrybark oak	1.52-1.64	0.13-0.14	0.54-0.78	1.14-1.26	0.27-0.32		114
	1.55	0.13	0.78	1.22	0.32	[c]	116

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a, b] and comments	Reference [d]
	— — — % of Oven Dry Weight				— — —	ppm	
Quercus macrocarpa Michx.	1.22	0.16	0.70	1.10	0.45	B 64;Cl 74;Cu 5.6;Fe 180;Mn 100; Mo 0.09;S 800;Sr 6;Zn 18.5	74
Bur oak	2.63	0.33	1.12	1.06	0.25	Al 45;B 71;Cu 7.9;Fe 103; Mn 410;Mo 7.3;Zn 27	99
Quercus nuttallii Palmer	1.37-1.81	0.13-0.14	0.74-0.91	0.83-1.03	0.22-0.27		114
Nuttall oak	1.37	0.13	0.91	0.88	0.27	[c]	116
Quercus palustris Muenchh.	2.33	0.39	1.09	1.36	0.25	Cu 38;Fe 180;Mn 560; Na 7000;S 1600;Zn 88	141
Pin oak							
Quercus prinus L.				1.20			40
Chestnut oak	2.22	0.18	1.09	0.59	0.19	Na 10	50
	2.22-2.76						78
	2.72-2.80						149
Quercus rubra L.						B 55	1
Northern red oak	1.96	0.16	1.72	0.78	0.20	Al 81;B 36;Cu 9;Fe 63; Mn 464;Mo 1.5;Zn 27	39
	1.87-2.46						69
	1.97	0.14		0.75	0.40	B 57;Cl 69;Cu 5.1;Fe 125;Mn 1736; Mo 0.07;Sr 12;Zn 24.9	74
						Mn 849	75
	2.20	0.25	0.95	0.95	0.26	Al 32;B 70;Cu 7;Fe 79; Mn 525;Mo 7.9;Zn 30	99
	2.46-2.57						149
	2.20-2.70	>0.20				[c]	158
Quercus velutina Lam.						B 19	1
Black oak	1.92	0.14	0.77	0.70	0.42	B 38;Cl 25;Cu 5.6;Fe 206;Mn 1459; Mo 0.13;S 1000;Sr 15;Zn 31.9	74
	2.22	0.20	1.00	2.17	0.31	Cu 7;Fe 250;Mn 1870; Na 900;S 400;Zn 66	141
Robinia pseudoacacia L.						B 32;Cu 8.9;Mn 70;Mo 0.05	1
Black locust				2.65			40
						Ba 215	117
	3.12	0.20	1.21	4.54	0.41	Cu 7;Fe 330;Mn 50; Na 600;S 200;Zn 50	141
						B 41	176
						Cu 4;Mn 19	224
						Cu 7.9;Mn 58	225
Salix nigra Marsh.	2.03	0.25	1.58	0.90	0.35	B 36;Cl 1347;Cu 5.1;Fe 132;Mn 2278; Mo 0.20;S 3200;Sr 14;Zn 101.5	74
Black willow							
Tilia americana L.	2.84	0.30	3.56	1.54	0.41	Al 76;B 28;Cu 12;Fe 108; Mn 180;Mo 1.6;Zn 41	39
American basswood				2.81			40
	1.39	0.17	0.89	1.11	0.52	B 79;Cl 635;Cu 7.8;Fe 164;Mn 124; Mo 0.14;S 900;Sr 109;Zn 49	74
	2.32-3.14						78
	2.34	0.31	2.02	2.06	0.35	Al 63;B 71;Cu 8.3;Fe 110; Mn 184;Mo 7.9;Zn 19	99
	1.89	0.22	1.12	6.43	0.81	Cu 10;Fe 330;Mn 210; Na 2500;Zn 54	141
	3.12-3.15						149

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Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight				— — —	ppm	
Ulmus americana L.				1.81			40
American elm	1.16	0.18	0.62	0.95	0.58	B 98;Cl 1148;Cu 7.6;Fe 155;Mn 267; Mo 0.11;S 900;Sr 29;Zn 28.5	74
	2.11	0.39	1.69	1.79	0.34	Al 66;B 45;Cu 4.4;Fe 123; Mn 109;Mo 8.6;Zn 30	99
	1.50	0.20	1.50	1.75	0.26	B 80;Cu 25;Fe 500;Mn 80;Zn 50	140
	2.13	0.13	0.59	2.45	0.53	Cu 7;Fe 680;Mn 130; Na 1100;S 700;Zn 20	141
			1.2			[c]	157
GYMNOSPERMS							
Abies balsamea (L.) Mill.	0.91	0.10	0.69	0.30	0.09		36
Balsam fir				1.15			40
	1.31-1.50	0.16-0.18	0.46-0.51	0.50-0.54	0.12-0.14	Mn 800-1100	48
	0.95	0.19	0.61	0.51	0.08	Fe 35;Mn 1600;Na 174;Zn 48	49
	1.22	0.13	0.46	0.75	0.13	B 22;Cl 154;Cu 4.2;Fe 120;Mn 862; Mo 0.04;S 1100;Zn 46.5	74
	1.29	0.20	0.62	1.39	0.16	Al 223;B 35;Cu 2.3;Fe 102; Mn 740;Mo 9.2;Zn 48	99
	1.13	0.16	0.48	0.59	0.15		151
						Cu 4.9	174
	<2.1						223
	1.15	0.134	0.277	0.77	0.086	Al 230;B 15;Cu 7.5;Fe 111; Mn 1155;Mo 5.1;Zn 50	259
Abies concolor (Gord. and Glend.) Lindl.							
White fir	1.15	0.15	0.58	0.12	0.06		3
	0.66-2.22	0.07-0.24	0.62-1.84	0.29-1.03	0.05-0.26		108
Abies grandis (Dougl.) Lindl.							
Grand fir						B 29;Cu 5;Mn 2272;Mo 0.073	1
	>1.4	>0.20	>0.70				65
Abies magnifica A. Murr.	1.15	0.15	0.58	0.12	0.06		3
Red fir							
Juniperus communis L.	0.91	0.12	0.42	1.20	0.17	Al 119;B 15;Cu 3.3;Fe 142; Mn 253;Mo 7.2;Zn 17	99
Common juniper							
Juniperus virginiana L.				2.93			40
Red cedar							
Larix laricina (Du Roi) K. Koch							
Eastern larch or tamarack	1.50	0.18	1.16	0.25	0.11	Al 232;B 19;Cu 7;Fe 183; Mn 340;Mo 1.8;Zn 40	39
	>1.8	>0.35	>0.7				65
	1.69	0.10	0.46	0.26	0.15	B 27;Cl 683;Cu 5.8;Fe 340; Mn 310;Mo 0.07;S 1000;Zn 31.8	74

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
Picea abies (L.) Karst.						B 14;Mn 1670;Mo 0.03	1
Norway spruce	0.92	0.20	0.89	0.25			4
	<2.40		<1.00				23
	>1.5	>0.18	>0.7				28
						B 13;Fe >70;Mn 270	52
	>1.50	>0.24	>0.70				65
	>0.90	>0.06	>0.17				78
						Mn 300	101
						Mn 2300	102
						Mn 78-160	109
	2.00	0.20	0.90	0.08-0.19	0.11	Fe 60;S 2000	110
	1.8-2.4	0.10-0.3	0.7-1.1	0.09-0.6	0.09-0.16	[c]S 1300	112
						Mn 327	139
	1.32	0.27	0.61	0.40	0.21		210
	1.80-3.00	0.20-0.40	0.45-0.80	0.12-0.85	0.12-0.35	[c]	214
	>2.0						217
Picea glauca (Moench) Voss	1.50	0.14	0.45	0.15	0.10		3
White spruce		>0.25				[c]	5
			0.45-1.00			[c]	7
						B 16-30;Cu 4-4.7; Mn 672-1052;Zn 59-117	55
	0.95	0.17	0.54	0.87	0.23	B 30;Cl 600;Cu 4;Fe 89; Mn 672;Mo 0.03;S 800;Zn 59	74
		>0.17					78
	1.16					Trees 133 years old	85
	1.39					[c]	85
		>0.17					95
	0.98	0.15	0.49	0.53	0.08	Al 18;B 12;Cu 1.8;Fe 29; Mn 236;Mo 3.5;Zn 59	99
		0.42					120
	2.82	0.59	1.60		0.25	[c]Complete nutrient solution applied; Total seedling top	209
	1.41	0.27	0.57	0.45	0.13		210
	1.50-2.50	0.18-0.32	0.45-0.80	0.15-0.40	0.10-0.20	[c]	212
	1.32	0.22				[c]	233
	1.50-2.00	0.27	1.00	0.45	0.15	[c]	238
Picea mariana (Mill.) B.S.P.			0.50-1.00			[c]	7
Black spruce	1.29						70
	1.04	0.159	0.67	0.43	0.018	Fe 188;Mn 618 (Trees 7 years old)	71
	0.92	0.08	0.46	0.47	0.20	B 42;Cl 735;Cu 3.6;Fe 95; Mn 634;Mo 0.05;S 800;Zn 44.3	74
	1.02	0.25	0.57	0.30	0.14		132
	0.861	0.105	0.401	0.405	0.115		133
						Fe 72-125;Mn 610-760	152
	2.78	0.54	1.72		0.31	[c]Complete nutrient solution applied; Total seedling top	209
	1.50-2.50	0.18-0.30	0.40-0.80	0.15-0.40	0.12-0.25	[c]	211
	1.10	0.16	0.62	0.255-0.64	0.09-0.165	Al 56;B 40.4;Cu 5;Fe 36; Mo 3;Na 57;Zn 39	236
Picea pungens Engelm.	1.50-2.00	0.12	1.26	0.63		Fe 65;Mn 32	38
Colorado spruce							

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Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a, b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
Picea rubens Sarg.				0.62			40
Red spruce	0.82	0.16	0.49	0.31	0.07	Fe 42;Mn 1600;Na 282;Zn 56	49
		0.18-0.23					181
	1.03	0.21	0.92	0.32	0.12	B 16;Cu 8.3;Fe 42; Mn 1448;Mo 2.8;Zn 39	183
	1.60-2.80	0.18-0.28	0.40-1.10	0.12-0.30	0.08-0.17	[c]	212
	0.97	0.23	0.407	0.84	0.135	Al 59;B 31;Cu 7;Fe 100; Mn 1400;Mo 4.8;Zn 45	259
Picea sitchensis (Bong.) Carr						B 17;Cu 4.5;Mn 1598	1
Sitka spruce	1.50	0.18	0.75	0.20	0.10		3
	1.47	0.24	1.15	0.24	0.12		10
	1.50	0.20	1.23	0.34	0.17		11
						[c]Cu 7-10.8	22
	1.37	0.22	1.15	0.25	0.12		25
	1.42	0.20	1.33	0.29	0.13		26
	1.59	0.22	1.27	0.35	0.14		27
	>1.5	>0.18	>0.7				28
	>1.84	>0.097	>0.27	>0.054	>0.066	[c]	41
						B 17-28;Cu 7-10.8; Mn 1598-2043;Zn 42-57	55
	2.3	0.33	1.2			[c]	56
	>1.5	>0.18	>0.70				65
	1.4-1.6						130
Pinus banksiana Lamb.			0.60-1.20			[c]	7
Jack pine						[c]	21
	1.25	0.12	0.36	0.38	0.19	B 31;Cl 785;Cu 4.6;Fe 141; Mn 412;Mo 0.07;S 700;Zn 74.4	74
	1.24	0.15	0.39	0.33	0.12	Al 273;B 17;Cu 2.6;Fe 70; Mn 467;Mo 11.3; Zn 101	99
						Fe 166-262;Mn 170-220	110
	2.47	0.41	1.16		0.22	[c]Complete nutrient solution applied; Total seedling top	209
	1.58	0.20	0.54	0.11	0.31		210
	1.50-2.50	0.18-0.35	0.35-0.70	0.11-0.40	0.09-0.16	[c]	211
		0.38					231
	1.4-1.7						239
Pinus contorta Dougl.	1.50	0.15	0.50	0.08	0.09		3
Lodgepole pine	1.44	0.19	0.57	0.10	0.09		10
	1.43	0.18	0.60	0.13	0.10		11
						B 4.3;Cl 148;Co 0.05;Cu 2.7; Fe 58.3;Mn 293;Mo 0.09;Zn 52.3	16
	1.42	0.16	0.54	0.09	0.07		25
	1.36	0.15	0.50	0.12	0.09		26
	1.48	0.16	0.53	0.13	0.08		27
	>1.4	>0.14	>0.5				28
						Mn 293;Zn 52	55
	>1.5	>0.15	>0.50				65
	1.70-3.00	0.17-0.40	0.50-1.10	0.08-0.30	0.09-0.16		213
	1.60-2.50	0.10-0.30	0.60-1.50	0.10-0.70	0.09-0.16	[c]	216
	>1.55	>0.15	>0.55	>0.10	>0.10		240
Pinus echinata Mill.						Fe 83-149;Mn 121-977;Zn 25.4	53
Shortleaf pine	1.34			0.23	0.11	Al >1250;B 7.5-10; Cu >3.5;Fe >0.11;Mn 600	179

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Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
Pinus elliottii Engelm.	1.00	0.09	0.30	0.10	0.06		3
Slash pine		>0.08					24
		>0.085					34
		0.085					43
	0.8-1.0	0.08-0.09	0.25-0.30				44
						Fe 167-186;Mn 330-346;Zn 30.5-59.3	53
						B 10	83
		0.09-0.10					163
	>0.90	>0.085	>0.275				165
	>1.00						166
	1.00-1.20	0.08-0.09	0.25-0.30	0.13-0.16	0.04-0.08	[c]	213
Pinus palustris Mill.						Fe 96-129;Mn 170-334;Zn 33	53
Longleaf pine		0.08	0.60	0.33	0.39	Co 0.73;Cu 32.8;Fe 162;Mn 346; Mo 0.10;S 800;Zn 12.4	62
Pinus ponderosa Laws.	0.95	0.08	0.48	0.05	0.05		3
Ponderosa pine						B 14-135;Cu 2.5-7.9;Mn 38-102	156
Pinus radiata D. Don	1.01	0.27	0.93	0.77	0.22	Cl 1300;Fe 50;Mn 220; Na 700 (Trees 9 years old)	9
Monterey or radiate pine	1.26	0.27	0.92	0.83	0.28	Cl 1500;Fe 60;Mn 460; Na 200 (Trees 36 years old)	9
		0.131	0.729	0.234	0.241	Al 1086;Fe 267;Na 132 (Trees 23 years old, 15 years after 86# P/A)	73
	1.61	0.20	0.693			Trees 8 years old; 2 years after 112# KCl/A	92
	1.62	0.18	0.96			B 101.4 (Trees 2 years old; 30 weeks after 17 Kg B/Ha)	103
		0.09		0.20			107
	1.0-1.4	0.10-0.14					168
						Cu >1.5 (Trees 9 years old)	169
			>0.35			Trees 9 years old	170
						Cu >2.3;Mn >36 (Trees 9 years old)	171
	1.00-1.70	0.10-0.17					172
						Cu >3 (Trees 3 years old)	180
						Zn >19	194
						B 16-61	197
						B >8	199
						Co 2;Cu 46;Mn 1500;Mo 4; Ni 7.4;V 67;Zn 520	221
						S 200-400	227
						[c] Cu >3	228
					0.12-0.14	[c]	251
	>1.6	>0.10	0.7-1.1		0.08-0.11	[c] Fe 40;Mn 280;Na 300	252
		0.11					253
					0.06-0.08	Trees 5 years old	254
						B >8	255
	>1.5	>0.14	>0.5	>0.10	>0.10	B >12;Cu >4;Zn >20	256
						B >15	257
Pinus resinosa Ait.			0.55-0.90			[c]	7
Red pine	0.93	0.11	0.78	0.24	0.08	Al 343;B 10;Cu 5;Fe 107; Mn 201;Mo 1.9;Zn 24	39
				0.80			40
	0.95	0.11	0.14	0.23	0.17	B 21;Cl 174;Cu 4.9;Fe 206;Mn 260; Mo 0.12;S 600;Zn 41.3	74
			>0.34		>0.10		78

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Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a, b] and comments	Reference [d]
	— — — % of Oven Dry Weight				— — —	ppm	
			0.45-0.74				95
	0.89	0.10	0.61			9 years after 150# K/A	96
	1.13	0.15	0.31	0.37	0.15	Al 336;B 15;Cu 1.9;Fe 66; Mn 418;Mo 13.8;Zn 49	99
			0.32-0.45				127
		0.18					137
			>0.30				143
			0.37-0.46	0.26-0.33	0.14-0.17		195
			>0.33				196
						B 21-34	198
			>0.35		>0.04	On xeric soils	201
	1.45	0.20	0.56	0.28	0.14		210
	1.80-3.00	0.15-0.30	0.45-1.10	0.04-0.30	0.07-0.20	[c]	215
					>0.16		232
Pinus strobus L.						B 18;Cu 5.1;Mn 266;Mo 0.052	1
Eastern white pine			0.50-0.90			[c]	7
				1.20			40
	1.48	0.15	0.54	0.32	0.23	B 23;Cl 174;Cu 6.4;Fe 267; Mn 184;Mo 0.08;S 800;Zn 65.6	74
			>0.34				78
			0.45-0.74				95
	1.61	0.16	0.48	0.34	0.14	Al 142;B 21;Cu 3.6;Fe 75; Mn 443;Mo 8.2;Zn 70	99
	<3.2					[c]	146
	1.33-2.70	0.28-0.56	1.02-1.49	0.24-0.28		[c]	148
	1.16-1.86	0.12-0.25	0.33-0.79	0.17-0.57	0.05-0.16	B 19;Cu 2.3;Fe 42; Mn 457;Mo 2.4;Zn 82	182
						B 21-34	198
			>0.40				231
	1.64	0.167	0.315	0.294	0.137	Al 136;B 13;Cu 5.3;Fe 72; Mn 375;Mo 1.4;Zn 52	259
Pinus sylvestris L.						B 12;Cu 4.6;Mn 610; Mo 0.05	1
Scotch pine	>1.4	>0.14	>0.5				28
	2.5-3.0	0.20-0.30					29
	1.8-2.0					[c]	33
	1.29	0.165	0.45	0.24		Na 500 (Trees 7 years old)	37
				0.69			40
	>1.5	>0.17	>0.60				65
	1.26-1.76	0.14-0.21					69
	3.00					[c]	72
	>1.25	>0.08					80
	3.0	0.23	0.9	0.05-0.24	0.13	[c]Fe >70;S 2000	111
	2.4-3.0	0.15-0.4	0.9-1.6	0.04-0.3	0.12-0.18	[c]S 2000	112
						Mn 220	153
					0.115-0.176		154
	1.4	1.8-2.1	4.5-6.0				160
	2.00	0.22	0.53	0.40	0.07	Al 985;B 36;Cu 9.5;Fe 96;Mn 898; Na 63;Zn 63 (Trees 4 years old)	191
			>0.40			[c]Shoots	193
			0.33-0.83				202
			0.15-1.17				203
	1.45	0.20	0.57	0.31	0.09		210
	2.0-2.5	0.10-0.18	>0.30			Optimal N levels	217
						Cu 12;Mn 87	241

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Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — —	% of Oven Dry Weight			— — —	ppm	
Pinus taeda L.	1.10	0.10	0.35	0.12	0.07		3
Loblolly pine		0.095-0.105					24
		0.09				Trees > 5 years	34
		0.11				Trees 1-3 years	46
	>1.1	>0.10	>0.35	>0.30	>0.06		47
						Fe 95-115;Mn 306-392;Zn 50.5	53
	1.05	0.10	0.39	0.14	0.10	Control	66
	1.7-2.3	0.14-0.16				[c]	69
	1.09	0.10	0.40	0.11	0.08		100
	1.216	0.127	0.415	0.248	0.104		187
			>0.26	>0.033	>0.07	[c]	204
				>0.033	>0.08	[c]	206
	1.36	0.124	0.479	0.227	0.102		220
	1.7	0.15	0.75	0.29	0.09	B 15;Cu 5;Fe 43; Mn 187;S 1600	230
	>1.2	>0.10	>0.26	>0.03	>0.07		232
	1.26-2.00	0.09-0.14					237
	1.30	0.10	0.32	0.13	0.12	Al 119;Cu 3.4;Fe 62;Mn 137; Zn 30 (Trees 7 years old; 2 years after 200# N/A)	242
		0.10-0.12					243
		0.085				Trees > 5 years old	244
		0.11				Trees 1 year old	
		>0.11				Trees 3 years old	245
	1.50	0.11				5 years after 224 Kg N/Ha	247
		0.10				Trees 3 years old	248
Pinus virginiana Mill.	1.7-2.3	0.14-0.16				[c]	69
Virginia pine					>0.08	[c]	206
			0.28-0.75	<0.10	0.08-0.18	[c]	207
					>0.08		232
Pseudotsuga menziesii (Mirb.) Franco							
Douglas-fir						B 30;Cu 5.6;Mn 390;Mo 0.06	1
	1.40	0.15	0.50	0.20	0.10		3
						B 5-15.8;Cl 73-138;Co 0.12-0.32; Cu 3-4.9;Fe 38.6-50.7;Mn 687-758; Mo 0.05-0.10; Zn 17.3-34.8	16
	2.31	0.16	0.36	0.39	0.11	S 1800 (1 year after 12.8# N/tree, 8.7# P/tree, and 11.2# S/tree and 1/2 year after 6.4# N/tree, 4.4# P/tree, and 5.6# S/tree)	17
						B 9-39;Cu 5.1-7.7; Mn 390-1294;Zn 17-63	55
	2.0	0.40	1.2			[c]	56
			>0.85			[c]	59
					0.12		60
		0.16-0.20				[c]	61
	1.4	>0.20	>0.7				65
	0.7-1.4						69
		>1.1					76
	1.1-1.7						77
	1.2-2.25						78
	0.6-2.3	0.1-0.25	0.3-1.0	0.2-0.75	0.05-0.15		80
						B 16;Cu 5.1 (Trees 3 years old)	84
	>0.90	>0.269	>0.495				98
	>1.25	>0.16	>0.6	>0.25	>0.17	B 20	123
			0.5-1.0				126

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Table 1 (continued). Normal levels of essential foliar nutrients in forest trees.

Species	N	P	K	Ca	Mg	Other elements [a,b] and comments	Reference [d]
	— — — % of Oven Dry Weight — — —					ppm	
						B 12.9;Cu >4.5 (Trees 4 years old)	155
						S >80	227
	>0.6	>0.1	>0.5	>0.2	>0.05	S 700	97
Taxodium distichum (L.) Rich.							
Bald cypress			0.44	1.37	0.27		12
Thuja occidentalis L.				2.48			40
Northern white-cedar or eastern arborvitae	1.21	0.13	0.47	0.80	0.28	B 20;Cl 357;Cu 2.8;Fe 155; Mn 94;Mo 0.04;S 700;Zn 30	74
Thuja plicata Donn.	>1.5	0.4				[c]B 32-104	234
Western redcedar							
Tsuga canadensis (L.) Carr.				0.80			40
Eastern hemlock	1.21	0.16	0.60	0.64	0.26	B 53;Cl 105;Cu 4.2;Fe 184; Mn 419;Mo 0.06;S 1100;Zn 12.5	74
	1.37	0.27	0.50	0.66	0.155	Al 215;B 44;Cu 4.5;Fe 127; Mn 1500;Mo 3;Zn 10	259
Tsuga heterophylla (Raf.) Sarg.							
Western hemlock	1.40	0.35	0.75				3
						B 5-17;Cl 75-134;Co 0.05-0.17; Cu 3.9-4.2;Fe 39.4-58.6; Mn 1583-1876;Mo 0.05;Zn 3-9.8	16
		>0.24					32
						B 17;Cu 3.9-4.1;Mn 1583-1876;Zn 10	55
	2.2	0.33	1.4	0.20	0.14	[c]	58
	>1.4	>0.35	>0.7				65
			0.5-1.0		0.10-0.3		126
	1.98	0.50	1.71	0.28		[c]Complete nutrient solution applied; Total seedling top	209

[a]/ Concentrations for "other elements" given as ppm (parts per million) and represent levels where growth is good. [b]/ Values for Fe are generally derived from unwashed leaves and hence are subject to an unknown degree of contamination from soil dust (Stone, 1968). [c]/ Seedlings grown in soil, sand or pot culture. [d]/ Numbers correspond to literature citations in previous section.

Appendix: Recommended Foliage Sample Collection Procedures

Standardizing foliage sample collection procedures is essential as most evaluations are based on comparisons with other studies. Sample collection variables that must be standardized to enable valid comparison with other reported values include:

1) *Season of collection*--Samples should be collected during a period when foliar mineral concentration is relatively constant. For deciduous trees, foliage sampling is generally done three to four weeks prior to the development of fall leaf color. Later sampling is risky because as leaf senescence approaches, many elements are translocated back into the conducting tissues of the tree. For conifers, late fall or early winter is the most suitable sample time.

   Foliar nutrient levels at these sampling periods do not provide a measure of nutrient levels while trees are physiologically most active. There is general agreement, however, that measurements during these "stable" periods are more meaningful than the highly erratic results obtained during other sampling periods.

2) *Trees sampled*--Only dominant and co-dominant trees should be sampled as the nutrient status of trees in other crown classes show poor correlations with growth.

3) *Crown position*--The tree crown should be free of competition for light at the point of sample collection. To accomplish this, foliage should be collected from the top one-third of the live crown.

4) *Foliage age*--Foliage is generally collected from the current year's growth. The nutrient concentration of current foliage generally provides higher correlations with: a) shoot length (Leyton and Armson, 1955), b) site index (Lowry and Avard, 1969), and c) availability of soil nutrients (Lavender and Carmichael, 1966).

   However, Wells and Metz (1963) found that the most suitable needle age for sampling in loblolly pine depends upon the nutrient being studied. Current season needles were most diagnostic for N, P, and K while one-year-old needles were most diagnostic for Ca and Mg.

   Powers (1984) found that the ratio of N in current needles to that in one-year-old conifer needles was most diagnostic of the N status. This reflects the high mobility of this element which is maintained at relatively high levels in current foliage at the expense of older needles.

In addition to the above recommendations, care must be taken to sample according to the intent of the assessment being made. Microsite differences may be detected by compositing several samples from within a single tree, keeping individual tree samples separate.

For experimental plots (0.05 to 0.25 acres) a composite sample from 7 to 10 trees is usually adequate.

Where the assessment is for large areas and the sampling objective is to estimate a mean value within 10 percent of the true population mean at the 95 percent confidence level, composite samples from a minimum of 15 trees (of a single species) should provide a good representation (Erdmann et al., 1988; Marshall and Jahraus, 1987; Mead, 1984; Wells and Allen, 1985). Reducing the error level to within 5 percent of the true mean will greatly increase the sample size requirement. When sampling large areas, samples should be stratified according to factors known to influence tree growth (soil type, aspect, slope position, etc.).