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TB63: Variation in Foliar Nutrient Concentrations in Red Spruce

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Variations in Foliar Nutrient Concentrations in Red Spruce

C. E. Schomaker[1]

INTRODUCTION

Fertilization is an accepted silvicultural practice in parts of North America. Experiments in Canada and the United States have shown that on certain sites, applications of one or more of the major fertilizer elements may increase tree growth rates by as much as 60 percent[2]. On the other hand, indiscriminate use of fertilizers on sites where responses are not likely to be obtained will result in financial losses and in extreme instances could be detrimental to the trees.

Determination of those forest sites which will benefit from fertilization is the initial problem in any fertilization program. While a completely reliable diagnostic technique to evaluate site fertility is still in the development stage, foliar analysis is apparently the most promising method to date. In order for foliar analysis to evaluate site fertility effectively, a standard technique of sampling and analyzing the foliage must be adhered to and the relationship of critical ranges in foliar nutrient concentration to the pattern of growth response for each tree species in question must be known.

A standard sampling technique is necessary because foliar nutrient concentration has been shown to vary by season of sampling, needle age, and the location of the needles within the crown of the tree (Tew, 1970; Lowry and Avard, 1965; White, 1954).

In the southeastern United States, a standard technique of foliage sampling has been adopted (Wells, 1968) and this technique is widely used elsewhere.

Critical ranges of foliar nutrient concentrations have been suggested for some tree species based on greenhouse experiments and field observations (Swan, 1971). Additional research is needed to strengthen these findings and to establish ranges for those forest tree species for which they have not been determined.

In establishing critical ranges of foliar nutrient concentrations for a particular tree species and in using such critical ranges to determine fertilizer needs, it is helpful to know the normal variation in foliar nutri-

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[1] Associate Professor, School of Forest Resources.

[2] From unpublished data of the author, personal communication with several Canadian Forest Scientists and other published sources in the United States and Canada.

ents that can be expected not only between different sites but also from year to year on the same site.

Red Spruce (*Picea rubens* Sarg.) is an important pulpwood species in northern New England and Canada. Management objectives favor this species and the closely related black spruce (*Picea mariana* Mill. BSP) on many sites. Foliar nutrient concentrations of unfertilized, economically mature, red spruce trees growing on four different sites and over two and three year periods are presented here and compared to foliar concentrations reported by other scientists.

EXPERIMENTAL BACKGROUND

In the falls of 1969 and 1970, a fertilization experiment was established as a cooperative venture involving twelve forest land owners in Maine and the School of Forest Resources, University of Maine at Orono. Plots were located near Princeton in Eastern Maine, near Telos Lake in north-central Maine and near Rangeley in western Maine. The fertilization plots were all established in stands with red spruce accounting for at least 50 percent of all tree species present.

In the autumns of 1969, 1970 and 1971 foliage samples were collected from three selected dominant or codominant red spruce on each plot of the study areas. The collections were made from two site locations in eastern Maine and from one site in north-central Maine. In the autumns of 1970 and 1971, foliage samples were also collected from a study site in western Maine (Figure 1). All needle samples were collected from the upper third of the live crown on the southerly side of the tree.

In each of the four study locations, three unfertilized plots out of the total treated were used as a check against the effect of the fertilizer treatments. Foliar nutrient concentrations of these unfertilized trees reflect the natural variation that occurs among the four study sites and from year to year on the same site.

Nutrient contents of the needle samples were determined by standard techniques using the micro-Kjeldahl method to determine total nitrogen and a Baird-Atomic spectrograph to determine phosporus, potassium, calcium, magnesium and the micro-nutrients iron, copper, zinc, boron, manganese and molybdenum.

LOCATION AND DESCRIPTION OF STANDS

Eastern Maine—Princeton F Area

This study area is located about two miles northeast of Princeton, Maine in Baileyville Township on land owned by the Georgia-Pacific

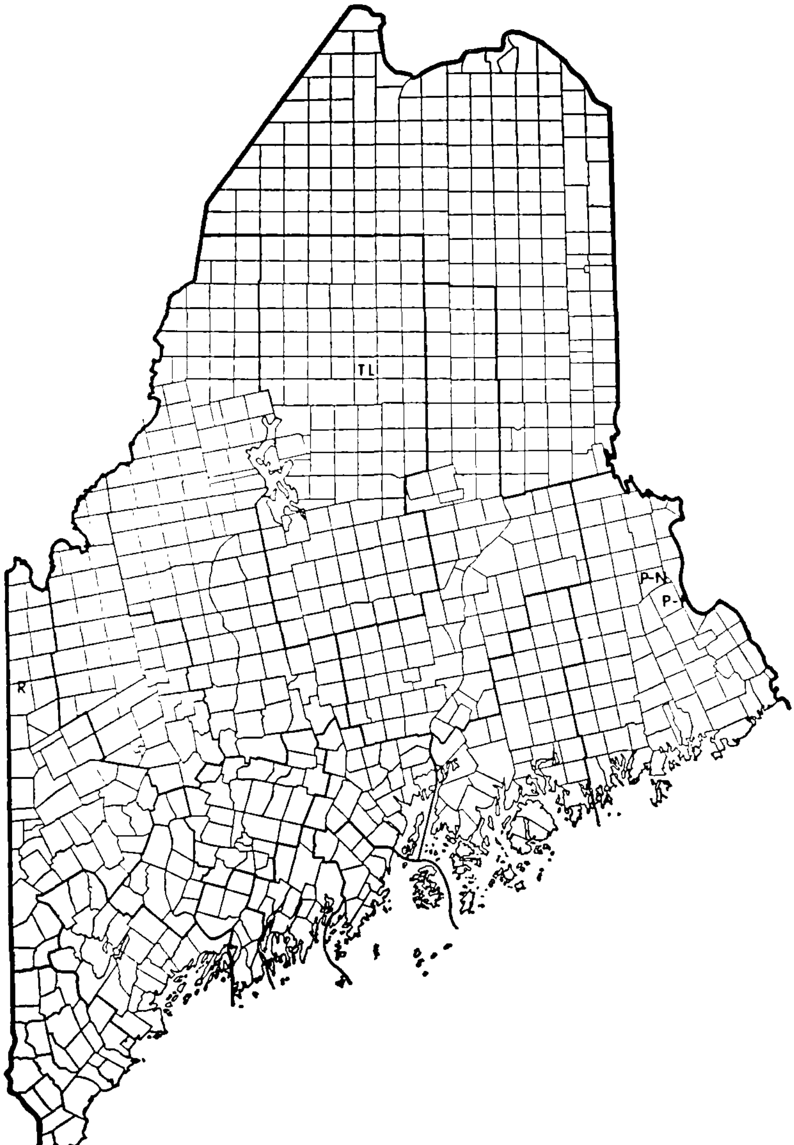

FIGURE 1. Locations of the four study areas.

Company. The stand had a basal area of about 130 square feet per acre with an essentially closed canopy (canopy coverage 95%). The dominant and codominant trees were approximately 55 years of age at breast-height (4½ feet above ground); the average dbh was 7.0 inches and the average total height was about 59 feet.

Eastern Maine—Princeton N Area

The study area is located close to the Demonstration Plot Road on Indian Township, Washington County. Basal area of the stand was about 191 square feet per acre with a canopy coverage that averaged 90 percent. The average age of the dominant and codominant trees at dbh was 87 years; the average dbh was 11.1 inches and the average total height was approximately 65 feet.

North-Central Maine—Telos Lake Area

The study plots are located along the "Golden Road" near Telos Lake (T5, R11, WELS) on land owned by the Great Northern Paper Company. This stand had a basal area of around 196 square feet per acre with an average canopy coverage of 95 percent. Ages of the dominant and codominant trees measured at breast height were quite variable, but averaged about 59 years; the dbh averaged 8.5 inches and average total height was about 60 feet.

Western Maine—Rangeley Area

The study plots are located two miles off of State Highway 16 near Beaver Pond T5 R1 Oquossic Quadrangle of U.S.G.S. on land managed by the Seven Islands Land Company. Basal area of the stand averaged 158 square feet per acre and the average crown closure was 94 percent. Average age of the dominant and codominant trees was about 110 years at dbh; the average dbh was 9.5 inches and average total tree height was about 60 feet.

RESULTS

Nitrogen

Nitrogen is generally believed to be limiting on many forest sites. The statistical analysis of variations in foliar nitrogen (Table 1) showed significant differences in the average needle concentrations between the sites sampled but none in regard to yearly differences. Actual variation was small with the average high of 1.09 percent nitrogen at the Telos Lake location and an average low of 0.98 percent at the Rangeley loca-

Table 1

The extent of the variation in foliar nutrient concentrations between three or four red spruce stands and over a three-or a two-year period as expressed by the calculated F-values.

Nutrient Element	Calculated F-Values			
	Between three stands and for a three-year period		Between four stands and for a two-year period	
	Variation by Stands	Variation by Year	Variation by Stands	Variation by Year
Nitrogen (N)	4.84*	0.79	5.46**	1.51
Phosphorus (P)	17.15**	0.22	17.32**	0.14
Potassium (K)	0.12	31.46**	1.40	4.35*
Calcium (Ca)	9.03**	17.07**	4.35**	33.40**
Magnesium (Mg)	1.94	7.00**	0.72	3.29
Iron (Fe)	7.53**	10.51**	5.60**	4.75*
Manganese (Mn)	2.72	0.03	6.03**	0.27
Zinc (Zn)	1.13	8.03**	0.65	11.89**
Boron (B)	13.52**	27.30**	6.07**	4.04*
Copper (Cu)	7.71**	19.64**	4.55**	5.14**
Molybdenum (M)	0.76	2.73	0.18	0.96

* Indicates the variation is significant at the 95 percent level.

** Indicates the variation is significant at the 99 percent level.

tion (Table 2). Within site variation in foliar nitrogen was greatest at the Princeton-F location where the standard deviation was ±0.11 percent. The highest level of nitrogen found for any tree was 1.28 percent in 1969 and the lowest was 0.82 percent in the same year. According to Swan's (1971) judgment of the critical ranges for foliar nitrogen, based on both greenhouse experiments and field studies, foliar nitrogen levels for all trees sampled in this study were within the deficient range and the majority were in the range of acute deficiency. This condition is not unusual; Young and Carpenter (1967) found an average 0.97 percent foliar nitrogen in red spruce and Safford and Young (1968) found average foliar nitrogen concentrations of 1.11, 1.14 and 1.14 percent from trees growing on three different soil types.

Lowry and Avard (1965) found foliar nitrogen levels in black spruce ranging from 0.93 percent to 1.09 percent in needles from eight trees located on the same site. In another study (Lowry and Avard, 1967), foliar nitrogen ranged from 0.59 to 0.86 percent in needles from dominant-codominant black spruce trees on one site to 0.79 to 1.10 percent foliar nitrogen at another site. During an eight-year period, Weetman (1970) measured foliar nitrogen levels that varied between 0.8 to 1.0 percent for unfertilized trees growing on a black spruce fertilization study site. Gagnon (1964) found foliar nitrogen concentrations in black spruce needles to range from 1.04 percent for trees on the poorest site to 1.29 percent for trees on the best site.

Table 2

Mean foliar nitrogen concentration in percent of oven-dry needle weight of unfertilized red spruce trees from four different stands and over a two-or three-year period.

Stand Location	1969			1970			1971			1969-1971		
	Mean.	Stan.[2]	Range	Mean.	Stan.[2]	Range	Mean.	Stan.[2]	Range	Mean.	Stan.[2]	Range
Telos Lake	1.08	.11	0.88-1.28	1.11	.03	1.07-1.15	1.07	.09	0.90-1.21	1.09	.08	0.88-1.28
Princeton-F	1.01	.13	0.82-1.20	1.02	.08	0.91-1.15	1.00	.12	0.86-1.20	1.01	.11	0.82-1.20
Princeton-N	1.01	.04	0.94-1.08	1.06	.08	0.91-1.16	1.04	.10	0.90-1.20	1.04	.08	0.90-1.20
Rangeley	—	—	—	0.99	.08	0.87-1.10	0.97	.08	0.83-1.05	0.98	('70-'71) .08	0.83-1.10
Average of 3 stands[1]	1.03	.10	0.82-1.28	1.06	.07	0.87-1.16	1.04	.10	0.83-1.21	1.04	('69-'71) .09	0.82-1.28
Average of all stands	—	—	—	1.06	.08	0.87-1.16	1.02	.10	0.83-1.21	1.03	('70 - '71) 0.9	0.82-1.21

[1]For Telos Lake, Princeton-F and Princeton-N stands.
[2]Standard deviation.

Phosphorous

Like nitrogen, phosphorous showed no significant variation between years but did show a highly significant variation among the four sites examined (Table 1). The lowest average foliar phosphorous concentration of 0.189 percent was found for trees at the western Maine location and the highest average foliar phosphorus, 0.250 percent, was found in trees from the Princeton—N site (Table 3). The greatest variation was also observed at Princeton—N; the standard deviation was ±0.045 compared to ±0.022, 0.026 or 0.029 percent at the other locations. The lowest level of phosphorous for a single tree occurred at the Rangeley location with 0.148 percent phosphorous and the highest was 0.361 percent on the Princeton—N site.

Unlike nitrogen, however, the averages of all the foliar phosphorus levels were within the 0.18 to 0.28 percent range which is apparently sufficient for good to very good growth (Swan, 1971). Young and Guinn's (1966) report of 0.230 percent foliar phosphorus and Safford and Young's (1968) report of 0.18, 0.19 and 0.23 percent foliar phosphorus were also all in the good to very good growth range.

Average foliar phosphorus of black spruce from four different locations in Canada ranged from 0.09 to 0.12 percent (Lowry and Avard, 1967). In another study conducted by the same individuals (Lowry and Avard, 1965), average foliar phosphorus of the current year's needles from the top one-third of the crown of eight black spruce trees trees was 0.25 percent.

Although present indications from foliar analysis indicate that phosphorus is not limiting, Canadian results with black spruce show that this cannot be taken wholly for granted.

Potassium

Foliar potassium showed no significant differences among the various study locations but did show a highly significant variation between years, in most cases increasing in concentration from year to year (Table 4). At the north-central and eastern Maine locations, average foliar potassium increased from 0.660 to 0.897 to 0.985 percent during the three-year period 1969 to 1971. From 1970 to 1971 the average foliar potassium for the four locations increased from 0.879 to 0.964 percent. Variation in the results between the individual trees within samples was high with a standard deviation of ±0.205 percent for three locations for three years and a standard deviation of ±0.174 percent for the four locations for two years. Foliar potassium concentrations are all in the range of sufficiency with the upper measurements on individual trees in the range of luxury to excess consumption (1.10 percent and up).

Table 3

Mean foliar phosphorus concentration in percent of oven-dry needle weight of unfertilized red spruce trees from four different stands and over a two-or three-year period.

Stand Location	1969 Mean.	1969 Stan.	1969 Range	1970 Mean.	1970 Stan.	1970 Range	1971 Mean.	1971 Stan.	1971 Range	1969-1971 Mean.	1969-1971 Stan.	1969-1971 Range
Telos Lake	.209	.020	.173-.234	.206	.016	.183-.230	.219	.029	.163-.257	.211	.022	.163-.257
Princeton-F	.210	.025	.170-.245	.215	.017	.181-.246	.174	.012	.158-.188	.200	.026	.158-.246
Princeton-N	.231	.040	.173-.301-	.245	.031	.198 .295	.273	.053	.217-.361	.250	.045	.173-.361
Rangeley	—	—	—	.194	.029	.153-.245	.183	.030	.148-.252	.189	('70-'71) .029	.148-.252
Average of 3 stands	.217	.030	.170-.301	.222	.028	.181-.295	.222	.054	.158-.361	.220	('69-'71) .039	.158-.361
Average of all stands	—	—	—	.215	.030	.153 .295	.212	.051	.148-.361	214	('70 '71) .042	.148-.361

Table 4

Mean foliar potassium concentration in percent of oven-dry needle weight of unfertilized red spruce trees from four different stands and over a two-or three-year period.

Stand Location	1969			1970			1971			1969-1971		
	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range
Telos Lake	.679	.069	.575-.775	.736	.084	.605-.885	1.110	.234	.690-1.375	.842	.241	.575-1.375
Princeton-F	.680	.092	.550-.850	.900	.109	.800-1.160	.942	.129	.710-1.100	.841	.159	.550-1.160
Princeton-N	.621	.078	.550-.790	1.055	.142	.800-1.190	.902	.115	.765-1.150	.859	.214	.550-1.190
Rangeley	—	—	—	.826	.107	.700-.963	.902	.146	.705-1.150	.864	.130	.700-1.150
Average of 3 stands	.660	.082	.550-850	.897	.172	.605-1.190	.985	.186	.690-1.375	.847	('69-'71) .205	.550-1.375
Average of all stands	—	—	—	.879	.160	.605-1.140	.964	.178	.690-1.375	.922	('70-'71) .174	.550-1.375

The results here are comparable to the foliar concentrations of 0.82, 0.88 and 0.77 percent found by Safford and Young (1968). However, they are substantially higher than the average foliar concentration of 0.407 percent potassium observed by Young and Guinn (1966) for red spruce in the United States and those found for black spruce in Canada. Lowry and Avard (1965) found an average foliar potassium concentration of 0.57 percent for eight trees on one site. On four other sites, they noted a range of 0.26 to 0.52 percent average foliar potassium (Lowry and Avard, 1967). The results of this study and those of Safford and Young (1968) were obtained with the same instrument and technique, while the results of Young and Guinn (1966) and those in Canada employed other techniques or instruments. Discrepancies of analyses of different origins may well be the result of analytical techniques rather than real differences between trees. To check this possibility, some samples of the current study were reanalyzed using an atomic absorption technique rather than the spectrograph originally used. The original results for three unfertilized trees using the Baird Spectrograph were 0.60, 0.69 and 1.01 percent foliar potassium, while the same sample indicated 0.18, 0.44 and 0.45 percent foliar potassium by the atomic absorption technique. All leaf samples are being reanalyzed using a Colman Flame Photometer.

Calcium

Highly significant variation in the concentration of calcium in the foliage of the check trees was found between sites and between years (Table 1). Variation in foliar calcium concentration for all sites and for the three-year period was great with a coefficient of variation of 33 percent. Foliar calcium ranged from 0.081 to 0.625 percent with the lowest average foliar calcium concentration of 0.307 percent occurring at the Princeton—F site and the highest concentration of 0.405 being observed at the Princeton—N site. All average calcium concentrations lay within the range of luxury consumption, indicating more calcium than that required for good to very good growth (Swan, 1971). Because of the wide range in values, the lower end of the range for individual trees dips into the transition zone between deficiency and sufficiency (Table 5).

Young and Carpenter (1967) found an average calcium concentration of 0.420 percent for red spruce with a range of 0.260 to 0.840 percent. Safford and Young (1968) found average calcium concentrations of 0.27, 0.27 and 0.26 percent of oven-dried red spruce foliage from trees growing on three different soil series in Maine. For black spruce in Canada, Lowry and Avard (1967) found average calcium concentrations of 0.40, 0.33 and 0.35 percent from trees from three

Table 5

Mean foliar calcium concentration in percent of oven dry needle weight of unfertilized red spruce trees from four different stands and over a two-or three-year period.

Stand Location	1969			1970			1971			1969-1971		
	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range
Telos Lake	.309	.029	.260-.345	.377	.055	.260-.439	.290	.064	.196-.410	.325	.062	.196-.439
Princeton-F	.350	.111	.118-.540	.394	.149	.230-.555	.117	.062	.081-.245	.307	.145	.081-.555
Princeton-N	.455	.100	.328-.605	.433	.093	.325-.625	.327	.046	.221-.380	.405	.098	.221-.625
Rangeley	—	—	—	.327	.076	.245-.481	.273	.051	.194-.340	.300	('70-'71) .069	.194-.481
Average of 3 stands	.371	.105	.118-.605	.401	.105	.230-.625	.265	.085	.081-.410	.346	('69-'71) .114	.081-.625
Average of all stands	—	—	—	.383	.103	.230-.625	.267	.078	.081-.410	.325	('70-'71) .108	.081-.625

different locations. Weetman (1964) reported an average calcium concentration of 0.36 percent for black spruce foliage.

Magnesium

Magnesium concentration in red spruce needles showed no significant variation among the sites. A highly significant difference between years of sampling did exist for the three-year period for the eastern and north-central Maine location but in the analysis of the two-year period for all locations there was no significant difference (Table 1). Average foliar magnesium concentrations for the eastern and north-central Maine study plots for the years 1969 to 1971 were 0.106, 0.129 and 0.112 percent. The average for the three-year period was 0.115 percent ±0.025 percent. For all locations over a two-year period, average foliar magnesium concentration was 0.118 percent ± 0.024 percent (Table 6).

These values are all in the range of sufficiency for good to very good growth and are higher than the 0.083 percent (Young and Carpenter, 1967) and 0.07 percent (Safford and Young, 1968) foliar magnesium reported for red spruce in Maine. In Canada, average foliar magnesium concentrations of 0.08, 0.09 and 0.09 percent were reported for black spruce from three separate locations (Lowry and Avard, 1967) and a concentration of 0.14 percent foliar magnesium was found in two other studies (Lowry and Avard, 1965; Weetman, 1964).

Micronutrients

Six micronutrients were measured by means of spectrographic analysis of the tree foliage: iron, manganese, zinc, boron, copper and molybdenum. Of these elements iron, boron and copper showed highly significant or significant variations in foliar concentrations for red spruce both between study locations and year of sampling (Table 1). Zinc foliar concentration did not vary among sites but showed a highly significant variation between years of sample. Manganese showed no variation in foliar concentration due to year of sampling and no variation between foliar concentration of the trees from eastern and north-central Maine locations but did show a highly significant variation in concentration between the Rangeley plots and those from the other locations. Molybdenum concentrations did not vary by either location or year.

Critical ranges for these elements have not been established for forest tree species. While all of these micronutrients are known to be essential for tree growth, the quantity needed is apparently very small—making it exceedingly difficult to determine requirements by routine techniques.

Table 6

Mean foliar magnesium concentration in percent of oven dry needle weight of unfertilized red spruce trees from four different stands and over a two-or three-year period.

Stand Location	1969			1970			1971			1969-1971		
	Mean	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range
Telos Lake	.093	.012	.075-.118	.126	.017	.104-.161	.115	.018	.086-.136	.111	.021	.075-.161
Princeton-F	.124	.025	.094-.161	.148	.033	.106-.196	.095	.010	.080-.108	.123	.032	.080-.196
Princeton-N	.101	.007	.040-.113	.111	.018	.076-.135	.125	.020	093-.159	.113	.018	.076-.159
Rangley	—	—	—	.106	.013	.085–.120	.116	.021	.093-.131	.111	('70-'71) .017	.085-.131
Average of 3 stands	.106	.021	.075-.161	.129	.028	.076-.196	.112	.021	.080-.159	.115	('69-'71) .025	.075-.196
Average of all stands	—	—	—	.123	.026	.076-.196-	.113	.020	.080-.159	.118	('70-'71) .024	.076-.196

Table 7

Mean foliar micro-nutrients concentration in percent of oven-dry needle weight of unfertilized red spruce trees from four different stands and over a two-or three-year period.

ZINC

Stand Location	1969			1970			1971			1969-1971		
	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range
Telos Lake	29	5	22-40	30	5	21-38	49	17	23-85	36	14	21-85
Princeton-F	31	13	20-63	34	9	22-51	38	19	19-72	35	14	19-72
Princeton-N	36	8	25-52	37	13	25-62	45	9	36-68	39	11	25-68
Rangeley	—	—	—	34	8	24-50	41	4	35-49	37	('70-'71) 7	24-50
Average of 3 stands	32	9	20-63	34	10	21-62	44	16	19-85	37	('69-'71) 13	19-85
Average of all stands	—	—	—	34	10	21-62	43	14	19-85	39	('70-'71) 13	19-85

IRON

Stand Location	1969			1970			1971			1969-1971		
	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range	Mean.	Stan.	Range
Telos Lake	29	2	25-35	54	7	45-69	49	24	18-83	44	17	18-83
Princeton-F	44	16	28-69	57	8	43-70	36	10	27-56	46	14	27-70
Prinecton-N	26	5	21-37	38	21	15-76	33	5	23-40	33	13	15-76
Rangeley	—	—	—	35	10	19-51	37	13	23-57	36	('70-'71) 11	19-57
Average of 3 stands	33	12	21-69	50	16	15-76	39	15	18-83	41	('69-'71) 16	15-83
Average of all stands	—	—	—	46	16	15-76	39	14	18-83	42	('70-'71) 15	15-83

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COPPER

Stand Location	1969 Mean.	1969 Stan.	1969 Range	1970 Mean.	1970 Stan.	1970 Range	1971 Mean.	1971 Stan.	1971 Range	1969-1971 Mean.	1969-1971 Stan.	1969-1971 Range
Telos Lake	5.8	1.1	4.5-7.5	10.5	3.6	5.0-16.5	5.9	2.3	2.7-9.6	7.4	3.6	2.7-16.5
Princeton-F	5.9	1.2	3.5-7.5	8.2	1.3	7.0-10.5	3.3	0.9	2.4-4.5	5.8	2.3	2.4-10.5
Princeton-N	5.6	1.7	4.0-9.5	11.6	4.7	6.3-22.5	9.3	4.0	3.6-14.8	8.8	4.4 ('70-'71)	3.6-22.5
Rangeley	—	—	—	7.1	4.3	3.0-14.0	10.7	4.8	5.7-16.3	8.9	4.8	3.0-16.3
Average of 3 stands	5.8	2.0	3.5-9.5-	10.1	3.7	5.0-22.5-	6.2	3.6	2.4-14.8	7.3	('69-'71) 3.7	2.4-22.5
Average of all stands	—	—	—	9.4	4.0	3.0-22.5	7.3	4.3	2.4-16.3	8.3	('70-'71) 4.3	2.4-22.5

MANGANESE

Stand Location	1969 Mean	1969 Stan.	1969 Range	1970 Mean.	1970 Stan.	1970 Range	1971 Mean.	1971 Stan.	1971 Range.	1969-1971 Mean.	1969-1971 Stan.	1969-1971 Range
Telos Lake	1458	181	1135-1700	1756	131	1599-2010	1796	617	1265-2940	1670	395	1135-2940
Princeton-F	1473	249	960-1790	1806	515	1320 2650	923	303	415-1300	1400	516	415-2650
Princeton-N	1912	126	1710-2040	1198	430	551-2003	2028	822	1270-3760	1713	640	551-3760
Rangeley	—	—	—	897	247	495-1300	1181	182	930-1460	1039	('70-'71) 376	495-1460
Average of 3 stands	1615	238	960-2040	1587	471	551-2650	1582	767	415-3760	1594	('69-'71) 538	415-5760
Average of all stands	—	—	—	1414	520	495-2650	1482	690	415-3760	1448	('70-'71) 607	415-3760

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Table 7. CONTINUED

MOLYBDENUM

Stand Location	1969 Mean	1969 Stan.	1969 Range	1970 Mean.	1970 Stan.	1970 Range	1971 Mean.	1971 Stan.	1971 Range.	1969-1971 Mean.	1969-1971 Stan.	1969-1971 Range
Telos Lake	1.9	0.4	1.5-2.6	2.5	0.4	1.8-3.1	3.2	0.9	1.4-4.1	2.5	0.8	1.4-4.1
Princeton-F	2.4	0.6	1.5-3.3	2.8	0.5	2.1-3.5	1.9	0.6	1.0-2.6	2.8	0.7	1.0-3.5
Princeton-N	2.7	0.5	1.8-3.4	3.5	0.4	3.0-4.2	2.2	0.4	1.7-2.9	2.8	0.7	1.7-4.2
Rangeley	—	—	—	3.1	0.8	1.9-4.6	2.4	0.8	1.1-3.8	2.7	('70-'71) 0.8	1.1-4.6
Average of 3 stands	2.3	0.6	1.5-3.4	2.9	0.6	1.8-4.2	2.8	0.8	1.0-4.1	2.7	('69-'71) 0.7	1.0-4.2
Average of all stands	—	—	—	3.0	0.7	1.8-4.6	2.7	0.8	1.0-4.1	2.8	('70-'71) 0.8	1.0-4.6

BORON

Stand Location	1969 Mean	1969 Stan.	1969 Range	1970 Mean.	1970 Stan.	1970 Range	1971 Mean.	1971 Stan.	1971 Range.	1970-1971 Mean.	1970-1971 Stan.	1970-1971 Range
Telos Lake	18	4	12-26	10	4	6-19	18	7	10-32	15	6	6-32
Princeton-F	31	13	11-57	15	3	11-18	13	4	7-19	20	12	7-57
Princeton-N	40	10	28-61	19	6	8-26	21	6	15-36	27	('70-'71) 12	8-61
Rangeley	—	—	—	16	4	10-22	19	5	10-25	18	4	10-25
Average of 3 stands	30	13	11-61	15	6	6-26	18	7	7-36	20	('69-'71) 11	6-61
Average of all stands	—	—	—	15	5	6-26	17	6	7-36	16	('70-'71) 6	6-61

DISCUSSION

These results of foliar analyses of unfertilized trees will be supplemented by at least two years of sampling. The data presented along with data from other published sources give a preliminary cross section of the natural levels of foliar nutrients that are present in red spruce needles in Maine and also indicate some of the year to year variation that can be expected.

While foliar analysis is probably the best means presently available to diagnose nutrient deficiencies on forest sites, the results from such analyses need careful evaluation and are far from fool proof. For example, the results of this study indicate that only nitrogen is in deficient supply based on the best information available on critical ranges of the elements. Yet, preliminary data from the fertilization study from which this information was extracted show that on one of the study sites, the greatest gain in diameter growth resulted from the combined application of nitrogen, phosphorus and potassium. This happened where foliar analysis indicated that both phosphorus and potassium levels in the needles were within the range believed to be adequate for good growth. Much more information is needed on critical ranges of foliar nutrient concentration under a variety of environmental conditions and on the various intricate tree-nutrient element-soil interrelationships, particularly in regard to nutrient-element balance in the soil and the effects of soil moisture on nutrient-element uptake.

Differences in the results of the foliar analysis for potassium among the various analytical techniques emphasize the urgent need for a standardized system of analyses for each of the nutrient elements, or at least a set of constants to bring each of the different values to a comparable standard. The almost universal use of a Kjeldahl analysis technique for determining total nitrogen gives comparable nitrogen values and is a good example of what should be done. Only by using acceptable standards can foliar analysis be acceptable for diagnosing nutrient problems.

Calcium deficiency evaluation using foliar analysis poses special problems. Any site condition or deficiency that results in poor leaf development will have a tendency to raise the concentration (percentage) of calcium in the leaves. Most of the calcium in a leaf is found in the cell wall. Poorly developed leaf cells are smaller and have a smaller proportion of cell "cavity" to cell wall material, thus increasing the proportion of calcium in the total weight of the leaf. Conversely, larger, well developed leaf cells have a large cell "cavity" which reduces the proportion of calcium. Fast growing trees with large leaves might have a percentage of calcium in the deficient range even when calcium as a nutrient is not limiting.

The use of calcium to alter the acidity of the soil affects the availability of other nutrient elements and must also be taken into consideration even when calcium is not limiting as a nutrient element in itself.

It is difficult to assess the results of micronutrient measurements and the variation of these elements among sites and from year to year because critical ranges are unknown. For instance, does the 11.6 ppm of copper found in the leaves in 1970 represent a real difference from the 5.6 ppm found in 1969 or does boron with an average 30 ppm foliar concentration in 1969 differ appreciably from the 18 ppm found in 1971? In the case of the lower values, does this represent a deficiency or does the higher value represent a toxic amount? Much more research is needed in order to answer these questions accurately.

Where nutrient element concentrations in the foliage of trees on a particular site are near the deficiency range, it is possible that uptake of an element may be limiting to growth one year but the following year under different environmental conditions may not be. Analysis in a deficient year would indicate a need for fertilization with that element, while foliar analysis in a different year might not, although fertilization in the long run might be beneficial. Research must continue so that each forest stand can be correctly evaluated for its deficiencies, whether chemical or physical, and efforts should then be made to correct such deficiencies in order to have the best forest management possible.

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