PONDEROSA PINE AND DOUGLAS-FIR FOLIAGE ANALYSES ARRAYED IN PROBABILITY DISTRIBUTIONS

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ABSTRACT

The data for fertility element content and weights of Douglas-fir and ponderosa pine foliage from sampling sites throughout Washington, Oregon, and California were aggregated to produce cumulative probability tables of the levels of each element to be expected in foliage analyses. These tables allow a ranking of an individual foliar analysis in order to assess possible deficiencies or excesses of an element.

INTRODUCTION

What does one do with the foliar analysis of a tree? Usually a question concerning a fertility problem has arisen and it is necessary to know how that particular foliage sample ranks in a population of possible foliar analyses for the species. Is it high or low for each element of concern? Which elements are high and low? What is the relative ranking for a given element, and how does this relate to the solution of a fertility problem? For an adequate interpretation of the foliar analysis, it is desirable to be able to rank the value in an array of possible values to be expected from the foliage of all the individuals of the species.

Thus, if the percent N content is obtained in an analysis of a sample it would be useful to be able to determine the rank of this value in terms of all possible values for that species. Distributions allowing such ranking are still unavailable in the forestry literature for common forest tree species.

This paper presents probability distribution for the analyses of nine elements in the foliage of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and ponderosa pine (*Pinus ponderosa* Laws.) trees sampled over a wide range of climatic, soil, and site conditions. The elemental analyses of these samples were arrayed as cumulative probability distributions expected for various values of each element. These distributions may be amended as more data become available to give closer approximations of the extremes of field variation of the species.

PROCEDURES

FOLIAGE SAMPLING

Douglas-fir and ponderosa pine foliage samples were collected at locations through much of Washington, Oregon, and California. These sites (78 for ponderosa pine and 82 for Douglas-fir) represented a wide range of soil and climatic conditions, avoiding areas that may have been fertilized. The collections were made during the growing season. At most sites collections were made from pole-size trees, but at some of the sites mature and pole-sized trees were sampled separately. Collection was made from the lower third of the south side of the crown of the tree. Several branch tips including foliage were collected from each tree.

The foliage was separated into age classes of current (designated first year) and older years up to the oldest, which in this study was 6 yr. This separation was made by cutting the twigs at bud scars just above the annual foliage group, and oven-drying each group separately. When dry the foliage was easily separated from the twigs. Weights were obtained of representative samples of leaves from 27 pine sample sites and 70 Douglas-fir sample sites. Leaves were weighed as leaf fascicles and sheaths for pine, and as single needles for Douglas-fir. Foliage was ground in a Wiley mill and analyses were made for each element.

FOLIAGE ANALYSES

The foliage samples were analyzed for N, P, Ca, mg, K, Na, Fe, Mn, and Zn content. Analyses for S, both as total and sulfate, were made on a selected subset of samples ($n = 24$) for ponderosa pine. Nitrogen was determined by the micro-Kjehldahl method, and determinations of the other elements were made on perchloric acid digestate of the foliage using methods of Johnson and Ulrich (1959). Phosphorus was determined on the digestate by molybdenum blue colorimetric method using stannous chloride oxidation. Sulfur was determined both as total and as sulfate by the methylene blue method reported by Johnson and Nishita (1952). The remaining elements were determined by atomic absorption spectrophotometry. The results of all analyses were expressed on the basis of ovendry weight. Phosphorus, Fe, Mn, Zn, and S were expressed as parts per million (ppm), and the remaining elements as percentage.

DATA AGGREGATION

A three-paremeter probability distribution proposed by Weibull (1949) was used to describe the distribution of the analytical data obtained for each element. Bailey and Dell (1973) have used this distribution to describe the diameter distributions of forest stands. The first parameter of this function is a *threshold value* (*A*) with a probability of zero that there will be a lower value. Thus, for foliage analyses it approximates a theoretical lower limit of the value for the foliage of that species. A *scale factor* (*B*) related to the magnitude of the values and a *shape factor* (*C*) related to the form of the distribution describe the distribution function above the threshold value. The shape factor may describe a probability function ranging from a normal distribution with a C of 3.25, to distributions skewed to the left with lower values, or to the right with values greater than 3.25. Thus, only the three values for threshold (A), scale (B), and shape (C) are needed to array all the data for each element in the Weibull distribution.

The following forms of the Weibull distribution were used in this study:

For the cumulative density function:

$$F(x) = 1 - e^{-\left(\frac{x-A}{B}\right)^{C}} \qquad (1)$$

For the probability density function:

$$\frac{dF(x)}{dx} = f(x) = \left(\frac{x-A}{B}\right)^{C-1} e^{-\left(\frac{x-A}{B}\right)^{C}} \qquad (2)$$

The forms used represent a transformation from the original distribution as used by Weibull. This transformation is described by Johnson and Kotz (1970).

A computer program for determining the three parameters describing the Weibull function was obtained from R. L. Bailey. This program was used to fit Weibull distributions to the analytical data obtained for each element for each age class of foliage for the two species studied. The functions derived from the sample population are presumed to fit the total field population of the foliage of the species.

RESULTS

NITROGEN CONTENT OF PONDEROSA PINE FOLIAGE AS AN EXAMPLE

The probability distribution of N in ponderosa pine foliage will be used as an example of the development of the function and the subsequent rating table.

In this example the N contents of ponderosa pine foliage from 78 widely diverse sampling sites were used. The data were arrayed and the cumulative probability function (equation 1) was fitted to them. The N values obtained for first-year foliage ranged from 0.660% to 1.715% for the 78 observations. The data array and the fitted curve are shown in Figure 1. The equation which describes the curve had the following parameter values: A (threshold) = 0.5881, B (scale) = 0.5596, C (shape) = 2.7144. This threshold value for the fitted curve is the presumed lowest value of N in first-year ponderosa pine needles, the calculated probability of a lower value being zero.

The shape value indicates a near-normal distribution about the mean. Using equation 2, Figure 2 was plotted to show the shape of this distribution. The most frequent value (mode) is 1.06% N, which is slightly lower than the arithmetic mean N content (1.09%) obtained from this sample population of 78. A chi-square test of the fit of this equation to the sample data gave a significance level of 0.0261 (X^2 = 4.95 with 1 degree of freedom).

Figure 1. Cumulative frequency of experimental data and fitted Weibull cumulative density function (equation 1) for first-year ponderosa pine foliage.

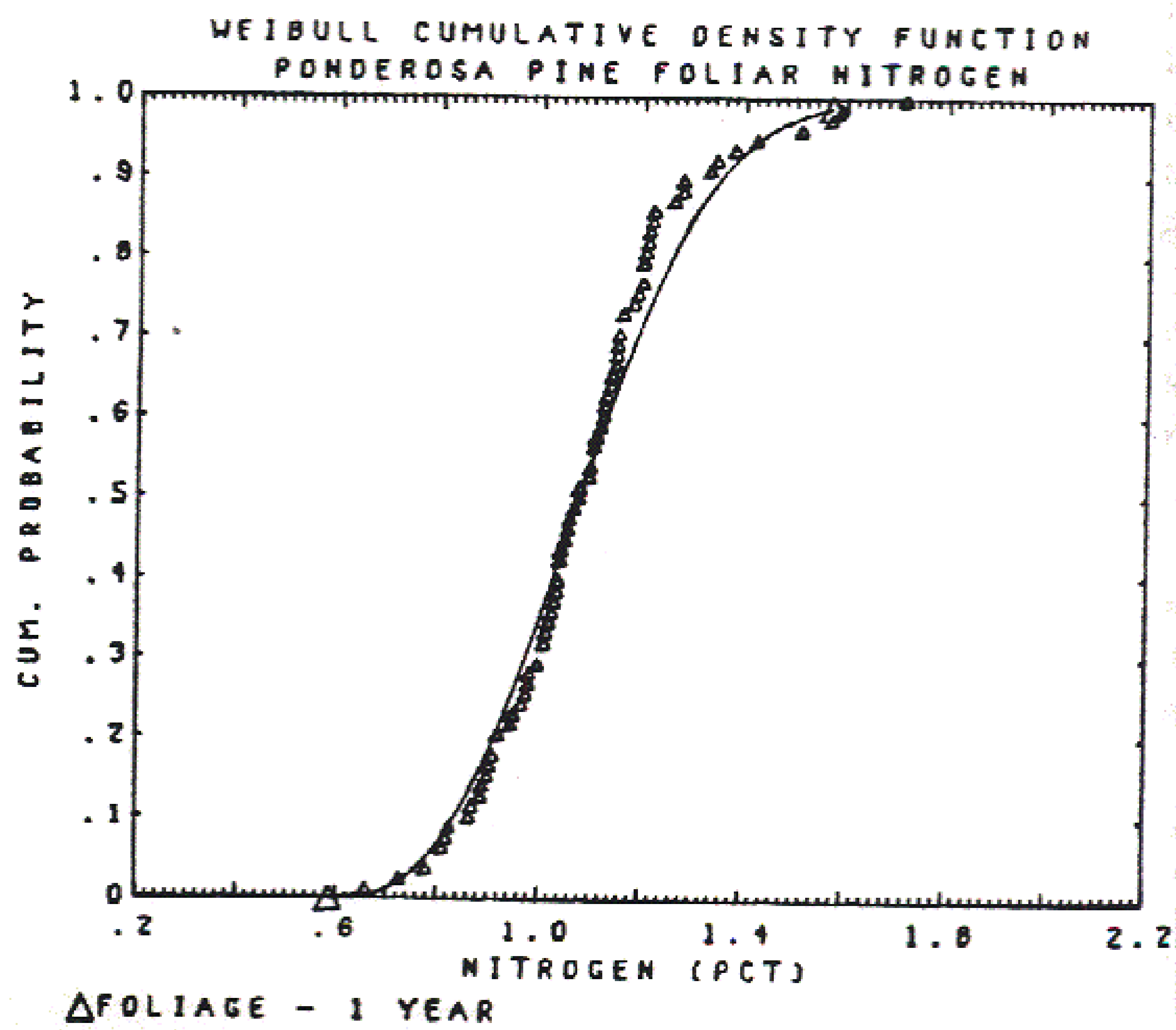
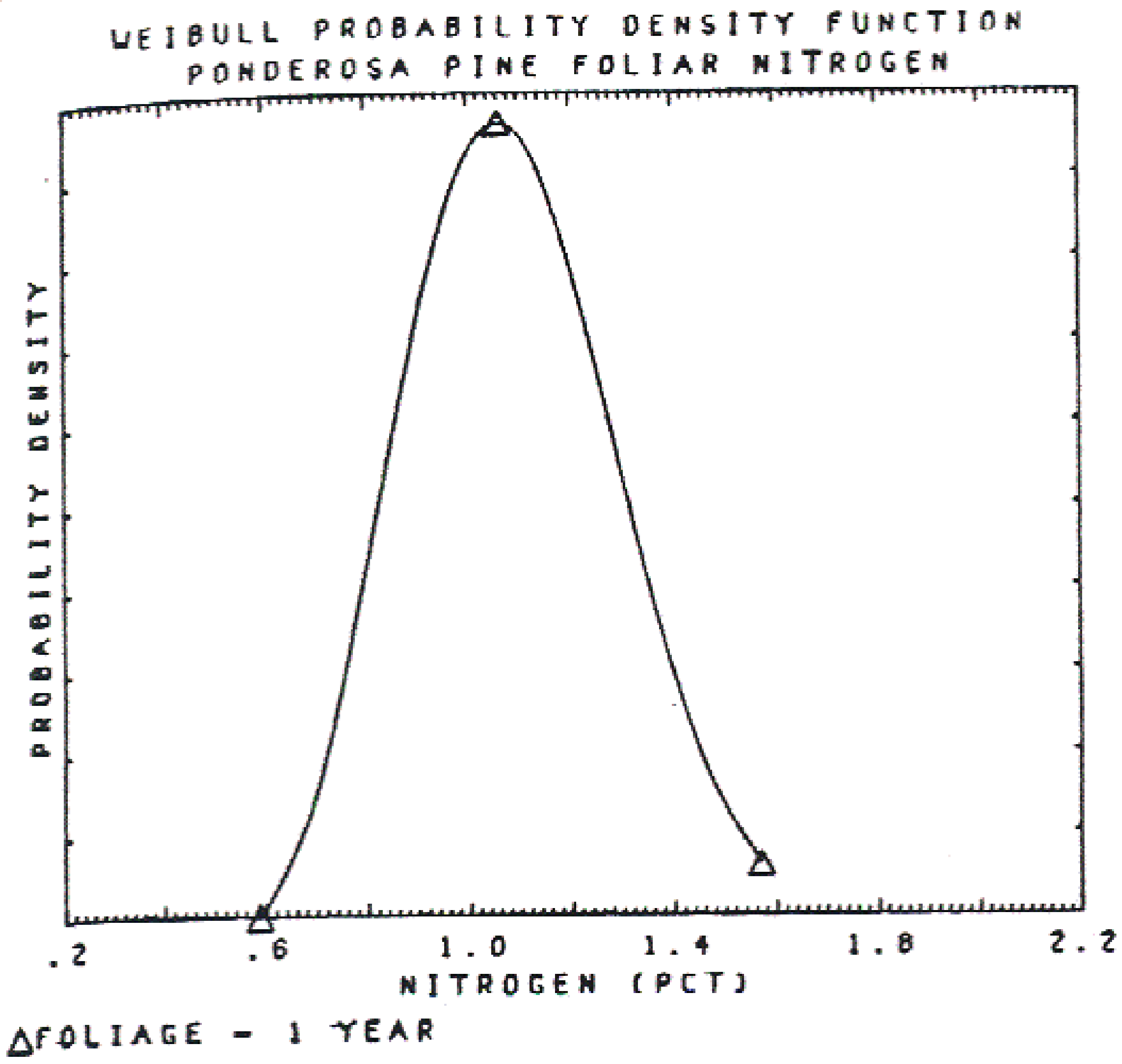


Figure 2. Fitted Weibull probability density function (equation 2) for first-year ponderosa pine foliage.



A cumulative probability table for N produced by the function described is shown in Table 1 in the column for N%. The lowest probable value at the zero percentile level is 0.588%; 50% of the foliage population will have N contents of 1.08% or less, and only 1% of the field population will exceed 1.57% N in the first-year foliage. Again, it is emphasized that sampling was of unfertilized trees.

SUMMARIZED PERCENTILE CLASS TABLES FOR PONDEROSA PINE AND DOUGLAS-FIR FOLIAGE ANALYSES

In a manner similar to the above example, cumulative probability functions were obtained for the weight of foliage (as grams per ten leaves), N, P, Ca, Mg, K, Na, Mn, Fe, Zn, total S, and S as sulfate for ponderosa pine needles of various age classes, and for Douglas-fir needles at a similar array of sampling sites.

Tables 1–4 present these values for current and second-year foliage of ponderosa pine and Douglas-fir. The values in the tables are weight in grams for ten-needle bundles (for ponderosa pine) or ten needles (for Douglas-fir), and the elemental content as percent of parts per million for each of the elements mentioned above. Sulfur has not yet been run on the Douglas-fir foliage and thus is absent. The foliage from the previous year was found to be less variable than that sampled during the current growing season and the second-year tables have been presented because they offer the utility of being more constant in relation to the site.

RATING FOLIAGE ANALYSES WITH PROBABILITY TABLES

Elements may be limiting, average, or excessive on a given site. Using the tables it is relatively easy to make a fertility profile of the data from analyses of foliage from a site, assessing the elements that are deficient and those that are in excess.

Table 1. Summary of percentile classes for ponderosa pine foliage--1-yr.

Percentile class	Wt[a] (g)	N (%)	P (ppm)	Ca (%)	Mg (%)	K (%)	Na (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)	S (tot.) (ppm)	S (SO_4) (ppm)
0	0.08	0.588	680	0.047	0.062	0.266	0.001	29	19	9	410	54
1	0.21	0.691	738	0.054	0.066	0.309	0.001	30	19	9	455	56
5	0.41	0.775	821	0.067	0.072	0.363	0.001	33	22	9	517	63
10	0.58	0.832	889	0.078	0.076	0.405	0.001	38	25	10	566	72
15	0.72	0.875	944	0.086	0.080	0.439	0.001	43	29	11	605	80
20	0.84	0.910	994	0.097	0.084	0.468	0.001	49	33	12	641	89
30	1.08	0.971	1085	0.113	0.090	0.522	0.001	62	43	15	706	106
40	1.31	1.025	1173	0.130	0.096	0.572	0.002	77	55	19	767	126
50	1.55	1.077	1263	0.147	0.102	0.623	0.004	96	70	23	829	148
60	1.81	1.130	1358	0.166	0.109	0.677	0.008	119	88	29	895	174
70	2.10	1.187	1467	0.188	0.117	0.737	0.017	149	113	37	970	206
80	2.47	1.255	1603	0.215	0.126	0.810	0.040	194	149	48	1063	251
90	3.01	1.349	1802	0.257	0.140	0.917	0.116	271	213	70	1198	323
95	3.49	1.426	1975	0.294	0.152	1.009	0.256	350	280	92	1315	392
99	4.45	1.570	2317	0.369	0.175	1.187	0.939	538	440	148	1544	547

[a]Per ten leaf fascicles and sheaths.

Thus, for example, current foliage on a Douglas-fir growing on a Cornutt soil (derived from peridotite rock) on Gasquet Mountain in Del Norte County, California, had the following values: weight, 0.0153 g; N, 1.485%; P, 1455 ppm; Ca, 0.128%; Mg, 0.139%; K, 0.617%; Na, 0.006%; Mn, 664 ppm; Fe, 157 ppm; Zn, 38 ppm. Using Table 3 for current Douglas-fir foliage the percentile rankings would be: weight, <1%; N, 85%; P, 57%; Ca, 1%; Mg, 65%; K, 47%; Na, 68%; Mn, >95%; Fe, 39%; Zn, 69%.

Thus the diagnosis would be that the foliage has very low

Table 2. Summary of percentile classes for ponderosa pine foliage--2-yr.

Percentile class	Wt[a] (g)	N (%)	P (ppm)	Ca (%)	Mg (%)	K (%)	Na (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)	S (tot.) (ppm)	S (SO_4) (ppm)
0	0.69	0.374	223	0.151	0.042	0.198	0.001	19	47	6	618	61
1	0.75	0.582	304	0.158	0.064	0.226	0.001	24	47	6	630	65
5	0.89	0.707	403	0.173	0.079	0.268	0.001	37	51	8	659	77
10	1.02	0.783	479	0.189	0.090	0.303	0.001	51	56	10	690	91
15	1.13	0.837	539	0.203	0.097	0.332	0.001	65	61	12	719	104
20	1.23	0.881	592	0.216	0.103	0.359	0.001	79	67	14	747	117
30	1.44	0.954	688	0.243	0.114	0.408	0.002	107	81	17	803	144
40	1.65	1.017	777	0.271	0.123	0.455	0.003	138	98	22	863	172
50	1.87	1.076	866	0.301	0.132	0.503	0.005	172	119	27	928	205
60	2.11	1.135	960	0.335	0.141	0.555	0.010	212	144	32	1002	242
70	2.40	1.197	1065	0.375	0.151	0.615	0.019	261	178	39	1092	288
80	2.78	1.268	1194	0.429	0.162	0.690	0.039	327	228	49	1211	349
90	3.35	1.365	1380	0.512	0.178	0.800	0.098	433	314	65	1400	448
95	3.87	1.443	1538	0.589	0.190	0.897	0.195	533	404	80	1576	542
99	4.95	1.584	1846	0.751	0.214	1.089	0.599	753	617	114	1952	747

[a]Per ten leaf fascicles and sheaths.

Table 3. Summary of percentile classes for Douglas-fir foliage--1-yr.

Percentile class	Wt[a] (g)	N (%)	P (ppm)	Ca (%)	Mg (%)	K (%)	Na (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)
0	0.01	0.446	475	0.101	0.048	0.073	0.001	11	54	4
1	0.02	0.602	568	0.125	0.051	0.209	0.001	21	58	4
5	0.02	0.727	695	0.160	0.057	0.307	0.001	44	69	5
10	0.02	0.810	796	0.189	0.063	0.372	0.001	67	81	7
15	0.03	0.872	878	0.213	0.069	0.418	0.001	87	94	8
20	0.03	0.924	952	0.235	0.075	0.457	0.001	107	106	10
30	0.03	1.012	1086	0.275	0.087	0.523	0.002	146	133	14
40	0.04	1.091	1213	0.313	0.100	0.581	0.002	187	161	18
50	0.04	1.166	1342	0.352	0.114	0.635	0.003	231	193	24
60	0.05	1.243	1479	0.394	0.130	0.691	0.004	281	231	31
70	0.05	1.325	1635	0.442	0.150	0.750	0.007	341	279	40
80	0.06	1.422	1826	0.502	0.176	0.820	0.011	419	342	52
90	0.07	1.557	2107	0.590	0.217	0.915	0.021	542	447	74
95	0.08	1.668	2350	0.667	0.256	0.993	0.034	654	547	96
99	0.09	1.874	2827	0.820	0.340	1.136	0.077	892	769	148

[a]Per ten leaves.

Table 4. Summary of percentile classes for Douglas-fir foliage--2-yr.

Percentile class	Wt[a] (g)	N (%)	P (ppm)	Ca (%)	Mg (%)	K (%)	Na (%)	Mn (ppm)	Fe (ppm)	Zn (ppm)
0	0.01	0.428	332	0.127	0.045	0.105	0.001	19	69	1
1	0.02	0.597	407	0.192	0.047	0.163	0.001	29	74	1
5	0.02	0.719	525	0.266	0.054	0.222	0.001	57	89	3
10	0.03	0.797	626	0.323	0.063	0.265	0.001	88	105	4
15	0.03	0.855	711	0.367	0.071	0.297	0.001	117	121	6
20	0.03	0.902	788	0.406	0.078	0.325	0.001	146	137	8
30	0.04	0.982	932	0.475	0.095	0.374	0.002	206	170	13
40	0.05	1.053	1072	0.539	0.112	0.419	0.003	270	206	19
50	0.05	1.120	1217	0.602	0.132	0.463	0.004	341	246	26
60	0.06	1.187	1374	0.669	0.155	0.509	0.007	424	293	34
70	0.06	1.260	1554	0.744	0.184	0.559	0.011	526	351	45
80	0.07	1.344	1781	0.834	0.222	0.619	0.020	661	430	61
90	0.08	1.460	2118	0.964	0.285	0.705	0.040	880	557	89
95	0.09	1.555	2416	1.075	0.344	0.777	0.068	1087	678	118
99	0.11	1.728	3012	1.287	0.475	0.913	0.162	1537	945	186

[a]Per ten leaves.

Ca, high amounts of N, approximately average values of P, K, Fe, and Zn, and excessive amounts of Mn. Predictably, if Ca deficiency were alleviated then leaf weight would increase and dilute the excess Mn with growth; however, this might induce a low K content if leaf weight were to increase to the 50th percentile value. Probably the high percentage was due to lack of needle growth.

As a rule of thumb it has been assumed that a 20th-percentile ranking or less is low, less than a 10th-percentile ranking is moderately low, and less than 5% is very low. On some very good sites, for example, the ranking of P is low because of high needle weight dilution obviously related to good growth. Thus the evidence from the tree on the field site should temper the diagnosis.

DISCUSSION

Many situations were sampled in gathering the foliage samples from which the probability tables were derived. Each of these was rated after the functions were derived and these subsequent ratings showed some general relationships between low foliage values and the soil situation. Thus: *Low N* values where not masked by dwarf growth of foliage occurred on soils derived from serpentine, on light-textured sandy soils, soils derived from rhyolitic tuff, and stony alluvial soils.

Low P values were obtained on soils derived from limestone, soils in high in pH, leached seepage areas, stony glacial alluvium soils, and soils derived from serpentine. *Low Ca* amounts were found on old red soils, stony alluvium, soils near timberline, and soils derived from serpentine and peridotite rock. *Low Mg* amounts were found at upper elevation extremes for a species (such as Douglas-fir on Mt. Spokane), and on stony alluvium. *Low K* values were associated with soils derived from serpentine, with stony alluvium, and with soils derived from limestone. *Excesses of Mn* were found at high rainfall limits of the species, where soil was acid and had high organic matter contents. These sites represented a "Mn curtain" for the distribution of the species beyond which frequent excesses of Mn content in the 99th percentile ranking occurred. They could be readily identified by very high Mn-Mn-to-Fe to r-Fe ratios in the foliar analyses.

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