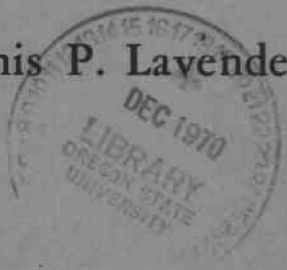
# FOLIAR ANALYSIS AND HOW IT IS USED

## A REVIEW

Denis P. Lavender

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## FOREWORD

Information reviewed here was adapted from a talk presented at the short course in *Forest Fertilization: Theory and Application* by the Institute of Forest Products, College of Forest Resources, University of Washington, at Shelton, Washington, January 22-23, 1968. It is presented as a guide for collection and preparation of coniferous foliage for submission to laboratories for chemical analysis, and for interpretation of the mineral analyses.

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The first reported chemical analysis of plants, by de Sausure in 1804, was concerned with their ash content (Ulrich, 1952). This worker demonstrated that the ash content varied with plant, age, organ, and soil upon which the analyzed plant grew, but it remained for Hall in 1905 to suggest that plant analysis might prove a useful guide to fertilization practices. Unfortunately, difficulty in establishing standards by which individual plant analyses might be judged discouraged further progress in this field for 20 years.

Renewed interest in plant analysis developed during the third decade of this century with two groups of investigators, those who preferred to analyze fresh plant material and workers who dried their samples to a constant weight before analysis. Among this latter group was Mitchell (1934), the first scientist to publish extensive data upon the mineral nutrition of North American forest species. Earlier investigation, during the last half of the nineteenth century and early twentieth century, had been conducted in Europe upon foliage, wood, and litter of species indigenous to that continent (Leyton, 1948). The last 40 years have seen a world-wide spread of forest nutrition studies, which have defined at least some of the variables that affect nutrient concentrations and have established "deficiency," "critical," and "luxury" levels of nutrition for several species.

One of the difficulties in employing plant analysis as a measure of the nutritional status of all save very deficient plants is the selection of plant tissue that will best reflect the physiological condition of the entire plant. Workers in agriculture have analyzed many tissues, from clearly defined plant parts, such as the petioles or blades of leaves, to entire plant tops. The usefulness of the first approach depends upon identifying accurately that portion of the plant which most closely reflects the current nutritional environment. Utilization of the entire plant accomplishes this objective, but suffers from lack of uniformity from plant to plant in the proportion of tissue types and ages. And, for other than greenhouse studies of tree seedlings, it has the further disadvantage of being impractical for investigations of forest tree nutrition.

Work reviewed by both Ulrich (1948) and Lundegardh (1951) for agricultural crops clearly indicates that the plant tissues yield the most meaningful data are those in which the mineral concentrations are most affected by fertilizer. Therefore, most analyses of agricultural crops are performed on leaf blades or petioles, and most workers concerned with forest tree nutrition have analyzed foliage almost exclusively.

If foliar analyses are to be most efficiently employed in the studies of the nutritional status of a tree or forest stand, standard sampling procedures that will result in a minimum of sample-to-sample variation as a consequence of the sampling program must be followed. Table 1 presents several of the variables inherent in foliar analysis and the procedures that will produce the most uniform sample. Figure 1 and Tables 2 and 3 illustrate the variation that may be expected in foliar analyses as a consequence of the variables of Table 1.

Table 1. Variables That May Affect Foliar Analyses.

| Variable | Recommended sample |
|---|---|
| Foliage age | Current foliage |
| Crown position | Upper three whorls |
| Season of year | September-December |
| Elevation | --- |
| Crown Class | Dominant or co-dominant |

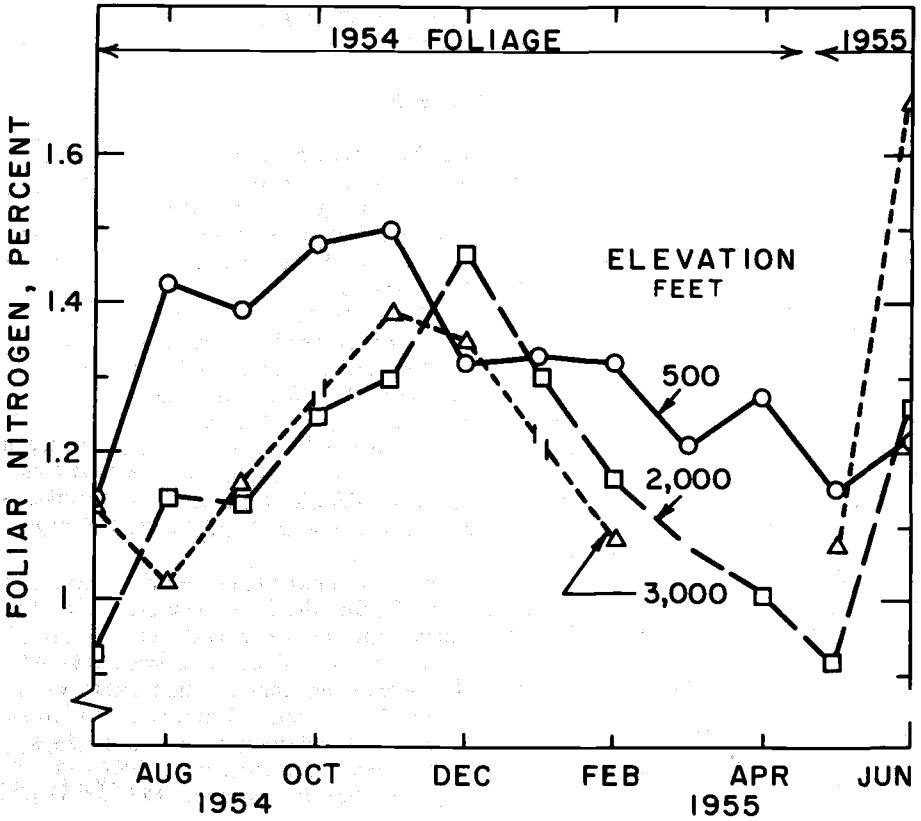


**Figure 1. Effect of elevation on foliar nitrogen content. (after C. T. Youngberg, Dept. of Soils, Ore. State Univ., unpublished).**

Equally important for meaningful foliar analyses is the collection technique. Gessel *et al.* (1960) illustrate the standard sampling procedure. We follow a slight modification of this procedure, in that we utilize the current year's needles from only the terminal and two first-year laterals and from the terminal of two second-year laterals, all from a third-whorl branch. These five tips (or ten when two branches are harvested) provide a basis for comparing production of foliage from study populations. If the foliage is collected near dusty roads or from small plants, it should be thoroughly rinsed (but not soaked) to remove dust or soil. As soon as practical after harvest, and preferably within 24 hours, the foliage should be kept for about 3 days in an oven at about 70 degrees C. (158 degrees F) until it is thoroughly dry. The needles should then be removed from the twigs and, if suitable equipment is available, ground to pass a 40-mesh screen.

Wehrmann (1959), working with Scots pine (*Pinus sylvestris* L.) in Europe, has published data that indicate at least 10 trees must be sampled to estimate the nitrogen and phosphorus status of a pine stand; 30 trees for the potassium and magnesium status; and 100 trees for the calcium. Unfortunately, I know of no similar guides for Douglas-fir. Figure 2 illustrates, however, the variation in foliar nitrogen content of about 100 trees sampled in one 10-acre area in the Oregon Coast Range. This stand is about 50 years old and has a site index of 85.

Table 2. Nitrogen in Douglas-Fir Foliage; Percent, Based on Ovendry Weight of Foliage.

| Foliar year | Lower crown | Middle crown | Upper crown | Top 3 whorls | Lower crown | Middle crown | Upper crown | Top 3 whorls |
|---|---|---|---|---|---|---|---|---|
| | | | SPRING | | | | FALL | |
| 1957 | 1.072[1] | 1.105 | 1.084 | 1.106 | 1.116 | 1.144 | 1.118 | --- |
| | 0.108[2] | 0.079 | 0.076 | 0.107 | 0.096 | 0.097 | 0.094 | --- |
| 1958 | 1.069 | 1.130 | 1.138 | 1.202 | 1.185 | 1.216 | 1.270 | 1.325 |
| | 0.106 | 0.079 | 0.102 | 0.121 | 0.140 | 0.181 | 0.149 | 0.180 |
| 1959 | --- | --- | --- | --- | 1.111 | 1.188 | 1.269 | 1.361 |
| | --- | --- | --- | --- | 0.107 | 0.112 | 0.161 | 0.174 |
| | | | SUMMER | | | | WINTER | |
| 1957 | --- | --- | --- | --- | 1.156 | 1.168 | 1.165 | --- |
| | --- | --- | --- | --- | 0.091 | 0.089 | 0.104 | --- |
| 1958 | 1.196 | 1.275 | 1.296 | 1.399 | 1.221 | 1.272 | 1.336 | 1.410 |
| | 0.116 | 0.116 | 0.149 | 0.220 | 0.113 | 0.141 | 0.177 | 0.199 |
| 1959 | 1.121 | 1.118 | 1.191 | 1.319 | 1.140 | 1.238 | 1.322 | 1.444 |
| | 0.142 | 0.126 | 0.125 | 0.166 | 0.098 | 0.122 | 0.179 | 0.199 |

[1]The upper of the paired values is the mean of eight observations.

[2]The lower of the paired values is the standard deviation.

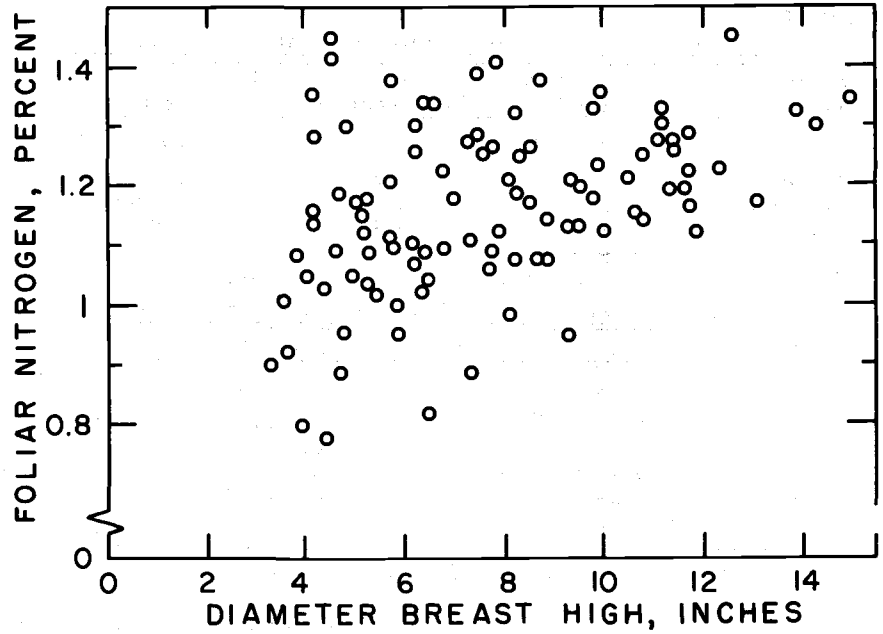


**Figure 2. Variation of foliar nitrogen in 50-year-old Douglas-fir on a 10-acre area of site index 85 in the Oregon Coast Range.**

This wide range in foliar nitrogen on a low site is perhaps not surprising, as Ulrich (1952) notes: "One of the important findings through tissue testing in the field is the great variability of individual plants growing under uniform conditions of soil and climate. This variability is particularly noted in plants in a field that is verging on a deficiency of one or more nutrients. For example, one plant will be found to have depleted its nitrate supply while another adjacent to it will still have an ample supply as shown by a high nitrate test, thus indicating that the latter plant was more favorably situated with respect to nitrogen availability in the soil, or that its early growth had been more advantageous and thereby had absorbed a larger proportion of the available nitrogen than its neighbor. In view of the great variability of plants and soils, it would be remarkable indeed if all plants became deficient in nutrients at the same time."

Although the data in Table 2 indicate that winter is a favorable season to sample for nitrogen, collecting after December is not recommended, because both phosphorus and potassium decline after late fall.

Table 3 presents both the mean foliar content of nitrogen for suppressed, co-dominant, and dominant trees sampled on the above area and the number of trees in this stand that should be sampled if one desired to estimate the foliar nitrogen content within 10 percent of the mean value. Four times the tabulated number of trees would be required to estimate foliar nitrogen within 5 percent of the mean value. Although the number of sample trees required to achieve similar accuracy for a stand growing on a better site would probably be substantially smaller than the above, the accuracy with which potential response to fertilizer is to be estimated will govern sample size.

Table 4 presents the range in concentration of the major elements in Douglas-fir foliage reported by Gessel *et al.* (1960). The low values generally represent deficiency levels for the given element.

Table 3. Variation in Foliar Nitrogen Content with Crown Class.

| Crown class | Nitrogen content | Trees required[1] | Range of means |
|---|---|---|---|
| | *Percent* | | *Percent N* |
| Dominant | 1.21 | 3.6 | 1.15-1.28 |
| Co-dominant | 1.18 | 6.1 | 1.12-1.24 |
| Suppressed | 1.07 | 9.8 | 0.96-1.17 |

[1]Number to estimate within 10 percent of the mean.

Table 4. Elemental Composition of Douglas-Fir Needles.[1]

| Element | Range |
|---|---|
| | *Percent* |
| Nitrogen | 0.6-2.3 |
| Phosphorus | 0.1-0.25 |
| Potassium | 0.3-1.00 |
| Calcium | 0.2-0.75 |
| Magnesium | 0.05-0.15 |

[1]After Gessel, Turnbull, and Tremblay (1960)

In his early review of mineral nutrition of plants, Macy (1936) concludes that: "The central concept of plant analysis is the *critical percentage* of each nutrient in each kind of plant, above which there is luxury consumption, and below which there is poverty adjustment

which is almost proportional to the deficiency until a minimum percentage is reached". And Leyton (1968) notes that plant growth and mineral concentration are linearly and positively related only within the deficiency range. He further concludes that if the mineral concentration of a given plant population can be shown to be positively correlated with the growth, this is evidence of a deficiency of the given element.

Figure 3 illustrates the terms "poverty adjustment" (foliar nitrogen concentrations below about 2.5 percent for greenhouse-grown seedlings), "critical concentrations" (foliar nitrogen concentrations between 2.5 percent and 3.0 percent for seedlings), and "luxury consumption" (Foliar concentrations greater than 3.0 percent). Toxicity response is shown at concentrations above 3.5 percent. The curves shown in this figure should not be extrapolated to other soils, as they reflect the growth responses of seedlings and mature trees upon only one soil from the Oregon Coast Range. Temperature, moisture, soil structure, and other environmental factors may modify the shape of the curves obtained from other growth trials. The critical concentration shown in this figure agrees closely, however, with similar data for other conifers published by Leyton (1957) and Ingestad (1963), so it may prove to be generally true for Douglas-fir.

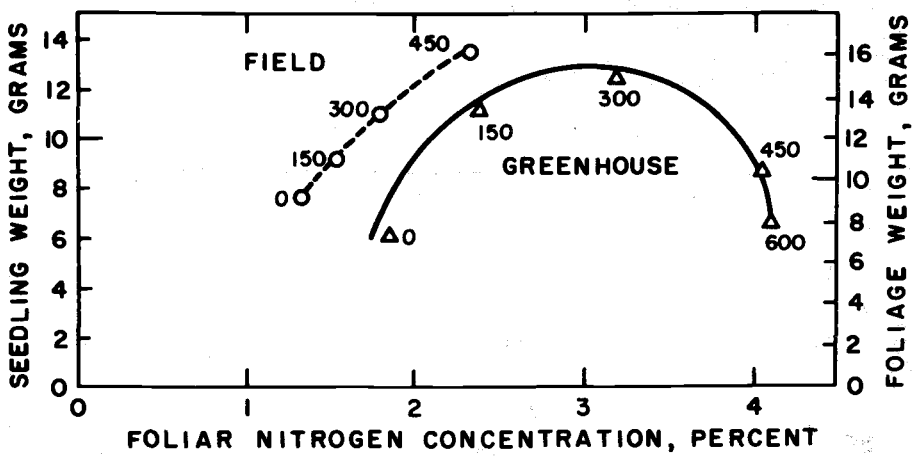


Figure 3. Relation between foliar nitrogen and growth of Douglas-fir seedlings in greenhouse and foliage of mature Douglas-fir trees in field. Numerals beside the plotted points indicate nitrogen applied in pounds per acre to a soil from the Oregon Coast Range.

Although most studies of mineral nutrition have limited significance, recent work by Ingestad (1966) offers a more general interpretation of foliar analysis. He has developed apparatus that automatically maintains the nutrient supply at selected levels and thus permits control of the internal nutrient concentrations of experimental populations. Under the growth conditions obtaining within his laboratory, he reports optimum growth for forest trees such as birch, pine, and spruce when the relative concentrations by weight of the major plant nutrients within the plants are within the ranges shown in the first line of Table 5. The remainder of the table presents the nitrogen concentrations determined for a range of Douglas-fir foliar analyses and the relative weights of the remaining elements.

Just as Table 5 illustrates the importance of considering nutrient balance rather than just one element in assessing the nutritional status of a forest stand, so the forest land manager should realize that foliar analysis, which thus far is based largely upon empirical trials rather than upon an understanding of the physiological significance of nutrient concentrations,

Table 5. Nutrient Balance of Elements in Foliage.

| Sample source | Nitrogen | Phosphorus | Potassium | Calcium | Magnesium |
|---|---|---|---|---|---|
| | %[1] | %[2] | %[2] | %[2] | %[2] |
| Ingestad (1966) | --- | 8-15 | 50-100 | 5-10 | 5-10 |
| Site II, Douglas-fir seedlings[3] | 1.91 | 16 | 46 | 17 | 7 |
| Site V, Douglas-fir trees[4] | 1.13 | 22 | 30 | 34 | 12 |
| Site V, Douglas-fir trees[4] | 1.94 | 9 | 43 | 13 | 7 |
| Springfield, Douglas-fir saplings[4,5] | 1.73 | 19 | 21 | 35 | 17 |
| Canby, Douglas-fir seedlings[4] | 1.49 | 3 | 58 | 9 | 7 |
| Greenhouse seedlings, ultra-basic soil[4] | 0.90 | 15 | 26 | 7 | 54 |

[1]Based on ovendry weight of the foliage.
[2]Based on relative weight of nitrogen in the foliage.
[3]Krueger, K. W. (1967).
[4]Unpublished data, For. Res. Lab.
[5]After fertilization with nitrogen.

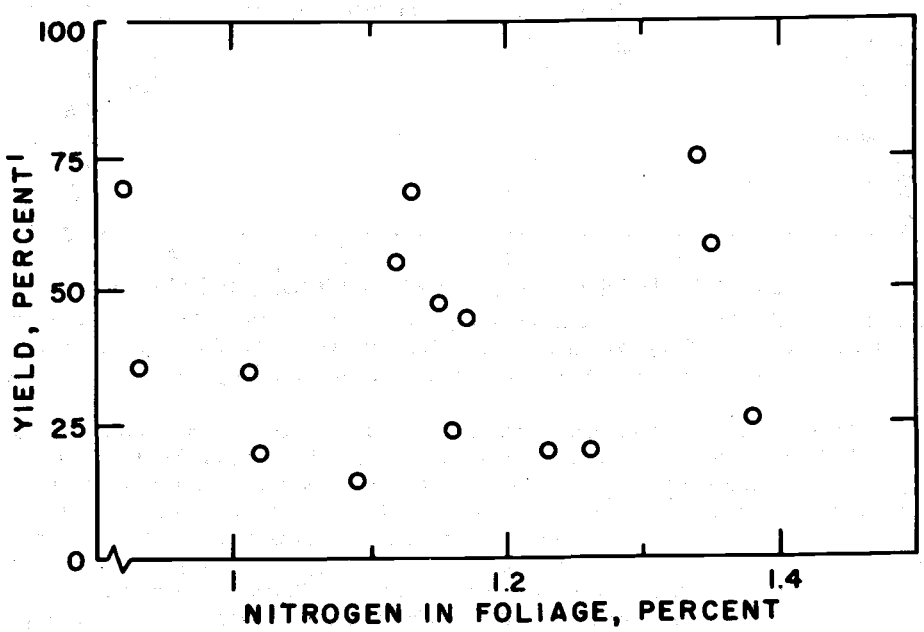


**Figure 4. Soil fertility in mountains of southern Oregon and foliar nitrogen in Douglas-fir 3-6 feet tall. (from R. H. Waring, Forest Research Laboratory, unpublished)**

[1]Based on maximum yield by dry weight of seedlings in controlled environments.

provides just one point in the total picture of tree growth. The data obtained from properly conducted foliar analyses can indicate which element or elements are deficient, but they cannot define the reasons for the deficiencies or show how to overcome them effectively. Figure 4 illustrates the very poor correlation between the foliar nitrogen content of saplings growing on a range of soils found in the mountains of southern Oregon and the relative growth of seedlings grown on these same soils in a controlled environment. Thorough knowledge of the physical and chemical nature of the soils, together with a good understanding of the ecology of each site, is clearly necessary to properly relate the foliar nitrogen concentrations to tree growth.

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