Soil and Foliar Nutrient Relationships For Douglas-fir On Three Different Sites

B.D. Webber

Environment Canada Environnement Canada
Forestry Service Service des Forêts

SOIL AND FOLIAR NUTRIENT RELATIONSHIPS FOR DOUGLAS-FIR ON THREE DIFFERENT SITES

by

B. D. WEBBER

CANADIAN FORESTRY SERVICE

PACIFIC FOREST RESEARCH CENTRE

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ABSTRACT

The nutrient content of foliage and soil from three different 60-year-old Douglas-fir sites (site indices 125, 102, and 52) in the Cowichan Valley, Vancouver Island, were determined. Analysis of variance and simple correlation analysis showed that, except for nitrogen in the current year's foliage, there were no significant correlations to site index. Correlation analysis indicated significant relationships between soil and foliar phosphorus and calcium contents independent of site. Site differences in soil nutrient content were more obvious than those found for foliar analysis; however, statistical significance was not obtained, indicating that some factors determining site quality were not measured or that standard analytical methodology is not applicable to forested situations. Moisture conditions are possibly more influential than soil nutritional status for the sites studied.

Résumé

L'auteur détermina la teneur en principes nutritifs du feuillage et du sol en trois stations différentes de Sapin de Douglas (Pseudotsuga menziesii) âgés de 60 ans (index de station de 125, 102 et 52) dans Cowichan Valley, île de Vancouver. Selon l'analyse de variance et l'analyse de corrélation simple, les corrélations furent significatives avec l'index de station, sauf pour ce qui concerne l'azote dans le feuillage de l'année courante. Selon l'analyse de corrélation, des rapports significatifs furent établis entre le sol et la phospore foliaire et les teneurs en calcium indépendamment de la station. Les différences des stations, en ce qui concerne la teneur des principes nutritifs dans le sol, étaient plus accentuées que pour les principes nutritifs dans les feuilles; cependant l'auteur n'a pu obtenir de signifiance statistique, indiquant que certains facteurs déterminant la qualité de la station ne furent pas mesurés ou que la méthodologie analytique standards n'est pas applicable à des cas forestiers. Il se peut que l'humidité influe plus sur les stations étudiées que les éléments nutritifs du sol.

INTRODUCTION

To meet future fibre demands (13), increasing emphasis will be placed on management practices, such as fertilization, requiring detailed functional knowledge of nutritional relationships between trees and forest soils. Nutritional investigations in forest soils have produced a wide variety of results, due to differences in physical and chemical approaches and specific analytical techniques employed. The use of physical parameters, e.g. soil moisture and texture, as productivity indicators has been most successful (1, 2, 16, 22, 23). Soil moisture is particularly important because of soil moisture-fertility interactions and ionic movement in soils (2, 5, 18, 20).

By using a nutritional approach, site productivity evaluations have generally been less successful. The reasons for this range from a lack of actual relationships to inefficient or unreliable methodology (2, 3, 6, 8). The relationship between site quality and foliar nutrient level is further confounded by intra- and inter-tree variation (9, 10, 14, 15). Characterization of nutrient availability on a local basis has resulted in some successful analytical development. Voigt found phosphorous absorbed by young pitch pine was related to both water-soluble and extractable phosphorous in the tree rooting zone (19). White and Leaf correlated the level of acid extractable potassium to foliar content for red pine in New York (21). Despite partial success, a need still exists for the development of a functional relationship between site quality and tree nutrient status, particularly for the Douglas-fir region. In October 1967, a study was initiated to elucidate nutritional relationships for 60-year-old Douglas-fir (*Pseudotsuga menziesii*) on three sites of differing productivity.

METHODS

A. Field Sampling

Three sample plots were established on the British Columbia Forest Service Station at Mesachie Lake, Vancouver Island, in the C_2 Forest Region (17). *Pseudotsuga menziesii* was the dominant tree species, with a mixed understorey having increasing quantities of *Gaultheria shallon* with decreasing site quality.

Mini-humoferric podzolic soils (Appendix 1) are common to all three sample plots, visual site differences being soil depth and apparent moisture regime. The highest site (Ia) was on a moist to wet bottom slope; *Polystichum munitum* was the dominant understorey vegetation. The second best site (Ib) was on a moist mid-slope position with a mixed understorey vegetation having increasing quantities of *Gaultheria shallon* and decreasing *Polystichum munitum*. The poorest site (III) was on a dry upper slope; *Gaultheria shallon* was the dominant understorey vegetation.

Five sample trees were randomly selected from each plot; total height, diameter and age at breast height were recorded and site index was determined (Table 1). One branch sample from the northern aspect was obtained from the point of maximum crown width. Foliage was separated by age and dried to constant weight at 70°C.

B. Laboratory and Statistical Analysis

Foliar samples were analyzed for nitrogen (micro-Kjeldahl) and phosphorous (Phosphomolybdic blue) by digestion and wet ashing, respectively (11). Dry ashing and absorption spectrophotometry were used to determine potassium, calcium and magnesium (12).

Soil samples, using depth rather than a genetic horizon sampling plan, obtained from four positions around each sample tree, were aggregated by trees, air-dried, sieved to 5 mm and stored until required for physical and chemical analysis.

Three water soluble extraction techniques (Appendix 2) -- hot, warm and cold -- were used prior to determination of exchangeable cations. In the water samples, phosphorous (phosphomolybdic blue), nitrate (phenoldisulphonic acid) and potassium, calcium and magnesium (atomic absorption spectrometry) were determined. Cation exchange capacity (C.E.C.) was determined by using 1N NH_4Cl (pH 5.8) followed by acidified NaCl washes and back titration of distilled ammonium. Standard procedures for pH (soil:water paste), particle size analysis, total nitrogen (micro-Kjeldahl), available phosphorous, total carbon and organic matter were used (11). All samples values were corrected for moisture content.

Statistical analysis of the data included analysis of variance and simple correlation analysis.

RESULTS AND DISCUSSION

The three selected sites (Ia, Ib and III) were calculated to have site index values of 125, 102 and 51, respectively (Table 1).

A. Foliar Analysis

Foliar nutrient analysis was expressed in per cent dry weight and per cent ash weight basis (Table 2). Site differences in nitrogen content were significant at $p=.01$ for the current year's foliage and .05 for 1-year-old foliage, when expressed as per cent dry weight. For all other ages, elements and modes of expression, there were no statistically significant differences.

Soil profile characteristics (Appendix 1) and field evaluation indicated that the three plots were located on different moisture regimes of the same soil. Soil depth and associated rooting volume were the only other soil differences noted. Differences in nitrogen content for current and 1-year-old foliage are probably related to nitrogen mineralization rates, differences in moisture stress development and nutrient movement in the rooting zone. Understorey vegetation and its associated competitive properties were much greater on the lower sites. Foliar nitrogen content in

TABLE 1. Sample Tree Age and Height Values

	SITE Ia		SITE Ib		SITE III	
Tree	Total Age (Years)	Total Height (Feet)	Total Age (Years)	Total Height (Feet)	Total Age (Years)	Total Height (Feet)
1	56	139	60	99	66	63
2	58	144	61	108	64	58
3	59	129	61	127	59	51
4	57	135	60	127	61	58
5	60	144	59	114	63	66
Average	58	138	60	115	63	59
Site Index (BCFS 50 years)		125		102		51

all instances exceeded the 1% deficiency level for Douglas-fir (4). Except for site III, nitrogen content decreased with age, as has been found by others (9). Since site differences were discernible for foliar nitrogen in the current foliage, this sampling position might be useful for limited examination of site differences.

Phosphorous content was not maximum in 1-year-old foliage, as Lavender previously found in Douglas-fir (7); the pattern varied from an increasing concentration with age for the lowest site to decreasing concentration with age for the highest site (Table 2). A better relationship with site quality was indicated when all ages or 2 years and older foliage was considered.

Potassium, calcium and magnesium content (dry weight basis) all lie within Lavender's ranges (7) and were not related to site quality. Site differences were not reflected in foliar cation content when expressed on a dry weight basis because a larger plant biomass on a high site could dilute the effect of any additional nutrient uptake. By using percent age of ash weight, which eliminated this dilution problem, foliage from higher sites showed a higher cation content (Table 2).

The age patterns for potassium and calcium were well defined on a dry weight basis; potassium content decreased and calcium content increased with needle age. Magnesium however, showed little variation. By using per cent ash weight, the relationships between the former two elements and foliage age and site quality were heightened. The relationship for magnesium also

TABLE 2 - Mean Foliar Nutrient Content of Douglas-fir

Foliage Age Years	Site	ELEMENT % Dry Weight N	P	K	Ca	Mg	Ash	% Ash Weight K	Ca	Mg
Current	Ia	1.34 **	.16	.56	.40	.12	2.60	22.00	15.73	4.85
	Ib	1.25 **	.20	.57	.31	.14	3.05	20.04	13.29	4.93
	III	1.12 **	.17	.51	.31	.11	2.62	19.46	11.94	4.08
1 year	Ia	1.31 *	.13	.41	.65	.13	3.00	13.79	21.71	4.25
	Ib	1.22 *	.25	.45	.49	.14	3.56	12.69	17.09	3.86
	III	1.17 *	.24	.38	.50	.11	3.21	11.81	15.83	3.38
2	Ia	1.25	.13	.33	.71	.12	3.07	10.80	23.00	4.31
	Ib	1.17	.25	.39	.56	.13	3.96	9.80	17.83	3.22
	III	1.15	.29	.32	.68	.10	3.96	8.02	17.34	2.62
3	Ia	1.18	.11	.31	.81	.12	3.54	9.29	23.55	3.58
	Ib	1.09	.26	.34	.79	.13	4.39	7.65	17.94	3.04
	III	1.20	.32	.32	.78	.10	4.72	7.00	16.68	2.27
4+	Ia	1.10	.11	.29	.90	.12	3.96	7.72	22.58	3.00
	Ib	1.04	.25	.30	.97	.13	5.02	5.89	19.29	2.66
	III	1.03	.36	.33	.82	.11	4.89	6.72	17.15	2.31
All Years	Ia	1.20	.15	.36	.71	.12	3.15	10.86	22.27	4.03
	Ib	1.14	.25	.39	.71	.14	3.87	10.07	18.69	3.65
	III	1.08	.29	.38	.63	.10	3.86	9.96	16.12	2.83

Within foliage age, means followed by ** are significantly different @ p = .01

" " " " " " * " " " @ p = .05

became clearer. Similar results have been found in jack pine and black spruce for nitrogen, phosphorous, potassium and calcium (9, 10, 15).

B. Soil Analysis

Soil sampling depths used and the corresponding genetic horizon are given in Table 3, while the chemical analyses by extractive technique are shown in Table 4. Table 5 presents the results in a more classical manner, i.e., by site and sampling depth.

TABLE 3. Location and Depth of Soil Samples

Site	Sample Number	SAMPLING DEPTH IN CENTIMETERS		
		Genetic Horizon		
		L-H	Bf_1	BF_2
Ia	1	6-0		
	2		0-5	
	3		5-10	
	4			10-25
Ib	1	4-0		
	2		0-5	
	3		5-10	
	4			10-25
III	1	4-0		
	2		0-5	
	3		5-8	
	4			8-15

Nutrient content differences between extractive treatments were not statistically significant; however, some trends did develop (Table 4). Water soluble potassium, particularly in the upper profile, increased with extracting temperature. This could result from hydrolysis of exchange sites at the higher temperatures, accompanied by a shift from exchangeable to water soluble to fixation, leaching from the profile or plant utilization. The latter is supported by the higher foliar cation content (ash basis), as previously discussed. Both available and, especially, water-soluble phosphorous were lowest in the higher site. The C/N ratio in this site was more favorable for organic matter decomposition (Table 5); consequently, there may be phosphate fixation within microbial tissue. Total nitrogen was also

TABLE 4

Soil Chemical Properties for Each Site

By Each Extraction Techniques

Method 1: Hot Water

Site	Depth cm	C.E.C.	Water Soluble K (Meq/100g)	Water Soluble Ca (Meq/100g)	Water Soluble Mg (Meq/100g)	Exchangeable K	Exchangeable Ca	Exchangeable Mg	NO_3-N (Mg/100g)	PO_4-P (Mg/100g)
Ia	6-0	15.30	.17	.93	.28	.160	11.58	2.49	3.05	.09
	0-5	6.54	.03	.24	.09	.122	4.64	1.09	1.55	.00
	5-10	4.19	.02	.14	.05	.090	2.83	.65	1.44	.00
	10-25	2.91	.01	.10	.03	.068	1.57	.49	1.05	.00
Ib	4-0	38.62	1.59	1.03	.33	.276	20.98	2.87	10.77	4.62
	0-5	9.25	.05	.14	.05	.153	3.71	.66	1.34	.03
	5-10	6.15	.03	.11	.03	.123	1.80	.29	1.09	.01
	10-25	4.06	.02	.05	.02	.118	1.13	.19	1.02	.01
III	4-0	34.11	1.32	1.25	.56	.427	15.59	3.59	3.72	5.60
	0-5	8.40	.13	.15	.10	.234	2.10	.57	.44	.03
	8-15	3.89	.06	.04	.04	.120	.43	.23	.66	.00

Method 2: Warm Water

Site	Depth cm	C.E.C.	Water Soluble K (Meq/100g)	Water Soluble Ca (Meq/100g)	Water Soluble Mg (Meq/100g)	Exchangeable K	Exchangeable Ca	Exchangeable Mg	NO_3-N (Mg/100g)	PO_4-P (Mg/100g)
Ia	6-0	17.02	.20	1.45	.42	.15	10.58	2.17	2.50	.04
	0-5	7.11	.05	.49	.16	.12	4.51	1.07	1.19	.01
	5-10	4.88	.02	.21	.07	.08	2.36	.70	1.20	.01
	10-25	3.63	.01	.14	.04	.05	1.52	.32	.99	0.
Ib	4-0	33.10	.47	1.63	.49	.38	21.01	2.71	7.56	2.71
	0-5	8.11	.04	.16	.07	.22	4.05	.65	1.08	.06
	5-10	5.83	.03	.10	.05	.16	2.05	.31	.99	.06
	10-25	4.41	.02	.06	.03	.15	1.27	.19	.93	.04

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Table 4 - Con't . . .

III	4-0	35.64	1.37	2.20	.10	.47	16.06	3.38	2.94	5.57
	0-5	11.19	.12	.21	.13	.26	2.08	.57	.32	.02
	5-8	5.37	.07	.13	.08	.17	1.16	.33	.76	.03
	8-15	5.50	.05	.08	.07	.12	.41	.19	.30	.00

Method 3: Cold Water

Site	Depth cm	C.E.C.	Water Soluble Meq/100g			Exchangeable			NO_3-N	PO_4-P
			K	Ca	Mg	K	Ca	Mg	Mg/100g	
Ia	6-0	15.67	.12	.87	.26	.21	11.72	2.58	2.28	.08
	0-5	6.91	.02	.28	.11	.14	4.50	1.13	1.21	.00
	5-10	4.63	.01	.16	.07	.10	2.83	.66	1.22	.00
	10-25	3.15	.01	.11	.04	.05	1.55	.31	1.21	.00
Ib	4-0	32.88	.38	1.02	.32	.44	20.67	2.92	6.00	2.63
	0-5	8.25	.03	.12	.06	.21	3.83	.66	1.12	.07
	5-10	5.17	.02	.08	.04	.17	1.98	.33	.74	.06
	10-25	3.89	.02	.04	.03	.14	1.12	.21	.62	.02
III	4-0	35.03	1.23	1.06	.56	.79	19.31	4.31	2.80	6.71
	0-5	8.90	.08	.11	.09	.33	2.51	.60	.27	.02
	5-8	4.99	.05	.05	.06	.21	1.33	.27	.94	.02
	8-15	4.67	.05	.03	.06	.17	.50	.26	.32	.02

TABLE 5. Site Soil Chemical Properties

Site	Depth cm	C.E.C.	Water Soluble[1] K	Water Soluble[1] Ca	Water Soluble[1] Mg	Exchangeable[1] K	Exchangeable[1] Ca	Exchangeable[1] Mg	NO_3 [2]	PO_4 [3]	PO_4 [3]	N	C	C/N	pH
					-meq/100g-				--------mg/100g-------			%	%		
Ia	6-0	15.99	.16	1.08	.32	.17	11.29	2.41	2.61	.07	2.14	.54	4.1	26.1	5.3
	0-5	6.85	.03	.34	.13	.12	4.55	1.10	1.32	.00	1.24	.21	4.8	22.7	5.3
	5-10	4.57	.02	.17	.07	.09	2.67	.67	1.29	.00	1.01	.15	3.1	21.2	5.4
	10-25	3.23	.01	.12	.04	.06	1.55	.34	1.08	.00	1.01	.12	2.2	19.0	5.4
Ib	4-0	34.87	.81	1.23	.38	.36	20.89	2.85	8.08	3.32	9.77	.72	25.5	35.2	4.8
	0-5	8.54	.04	.14	.06	.20	3.86	.66	1.18	.05	7.03	.13	3.9	29.1	5.2
	5-10	5.72	.03	.10	.04	.15	1.94	.31	.94	.04	4.95	.10	2.6	27.1	5.4
	10-25	4.12	.03	.05	.03	.14	1.17	.20	.86	.02	2.60	.08	2.2	27.5	5.4
III	-0	34.92	1.31	1.50	.71	.56	16.99	3.70	3.15	5.96	7.73	.69	34.5	50.0	4.7
	0-5	9.50	.11	.13	.11	.28	2.23	.58	.38	.02	4.73	.21	6.5	30.7	4.7
	5-8	4.46	.07	.08	.07	.17	1.19	.28	1.01	.02	4.42	.13	3.3	26.4	5.2
	8-15	4.69	.05	.05	.06	.14	.45	.23	.34	.01	2.20	.14	3.0	21.7	5.0

1 Averaged over all extractive treatments

2 Water soluble

3 Olsen's phosphorous

somewhat lower on the higher site.

The greatest difference among the sites lies in cation exchange capacity; the value for site Ia is less than half that for the other two. Upper profile exchange capacity is largely influenced by organic matter, and in site Ia, as indicated by the C/N ratio, conditions are more favorable for organic matter decomposition, hence a lower C.E.C. This low C.E.C. should not adversely affect tree growth, since the soils are deeper on this site and more nutrients are being utilized and cycled. It is, therefore, not surprising that the water-soluble nutrients are minimal in site Ia. They are being continually drawn upon or leached from the profile, whereas in the other sites, especially III, moisture deficiency can develop, leading to lower nutrient movement and greater accumulation.

C. Correlations Between Soil and Foliage Nutrient Content

1. Nitrogen

Soil and foliar correlations (Table 7) are inconclusive, indicating that operative variables affecting nitrogen nutrition, e.g. moisture regime, ionic interaction, have not been accounted for or included in the analysis.

2. Phosphorous

There were more significant correlations between soil and foliar phosphorous contents than with nitrogen. The correlations between water-soluble phosphorous in the mineral soil and foliar phosphorous are of little value, due to the low quantities and minimal differences found in the water extracts (e.g. .02 mg/100g).

Olsen's easily soluble phosphorous, i.e., that fraction potentially available for plant uptake, shows definite correlations at every sampling depth, indicating the presence of a common phosphate source at each sample location.

Even though there is a strong relationship between soil and foliar phosphorous levels, there is no distinction between sites for either soil (Table 5) or foliar phosphorous (Table 2). As was the case with nitrogen, this indicates that another operative variable, e.g. moisture status, is more influential in determining site quality in this locality.

3. Potassium

The relationship between soil test values and foliar potassium levels is poor (Table 7). Luxury consumption of this element can confound any correlations between soil availability tests and actual physiological requirements.

4. Calcium

Correlations between water-soluble and exchangeable soil calcium and foliar calcium levels are similar on both a dry and ash weight basis (Table 7). More significant correlations are found when foliar analysis is

Table 6
Significant Correlations between Soil and Foliar Nitrogen and Phosphorous Content

FOLIAGE AGE

Extraction Treatment	Sample Number	Current	One Year	Two Year	Three Year	Four & Less	All Ages
				Water Soluble Soil Content			
1	1		bb	bb	bb	bb	bb
	2	aa	bb	b	a b	bb	bb
	3		b	b		b	b
	4						
2	1		bb	bb	bb	bb	bb
	2	aa	a				
	3		a b	b	b	b	b
	4	a	a b	aa	a b		
3	1		bb	bb	bb	bb	bb
	2			a	aa		a
	3		b	a b	a b	b	b
	4		bb	a bb	bb	b	bb
				Total Nitrogen Basis			
	1						
	2						
	3						
	4				aa	a	
				Olsen's Phosphorous Test			
	1		bb				b
	2		bb	b	b	b	bb
	3		bb	bb	bb	bb	bb
	4	bb	bb	bb	bb	bb	bb

a = Nitrogen significance .05 b = Phosphorous significance .05
aa = " " .01 bb = " " .01

expressed on an ash rather than on an oven-dry weight basis.

5. Magnesium

Correlations between foliar content and both water-soluble and exchangeable magnesium failed to develop any meaningful values (Table 8).

Inconclusive results occur for a multiplicity of reasons, including the following:

1. Extractive soil reagents, such as ammonium acetate, release a quantity of nutrients whose availability to trees is unknown.

2. Nutrient uptake by trees is poorly understood and is compounded by unknown contribution from nutrient diffusion, mass flow, contact exchange and the operative role of root mycorrhizae.

3. The interaction of roots and their environment, in terms of rooting volume and soil nutrients, was not elucidated.

4. Soil chemical tests have no relationship to seasonal stress situations in the field or adequacy of supply during such periods. The impact of stress situations such as moisture deficiency and its impact on ion movement and uptake cannot be estimated using conventional techniques.

5. Ionic composition of foliar material does not in any way indicate physiological necessity or partition out such phenomena as luxury consumption.

6. The function, role and adequacy of supply over a growing season, particularly during stress periods, is not even approached using ionic composition techniques.

7. The use of standardized techniques such as ammonium acetate extraction and cation exchange capacity allows for only a typic description of a soil, without enlightening on the operator role played by the soil. Similarly, per cent composition of foliage is a characteristic, not a functional description.

CONCLUSIONS

The same soil type was common to all three sample locations. Differences in site quality were likely a result of moisture influence and differences in nutrient availability. The effect of moisture is supported by foliar analysis results since there are very few significant nutritional differences among the three sites, the exception being nitrogen in the current year's foliage, which can probably be accounted for by a more rapid nitrogen mobilization in the higher site.

The use of per cent ash, instead of dry weight, allows for sharper resolution of site differences based on foliar cation contents. Even with the increased clarification when results were based on per cent ash weight

Table 7
Significant Soil-Foliar Correlations
for Calcium, Potassium and Magnesium

		Foliar Content											
		% Dry Weight Basis						% Ash Weight Basis					
		Foliar Age						Foliar Age					
Extraction Treatment	Sample Number	Current	1-year old	2-year old	3-year old	4 and older	All ages	Current	1-year old	2-year old	3-year old	4 and older	All ages
							Water Soluble						
1	1		b		a	c			b	b	b		
	2									a c			
	3		b	b	b		c			cc			c
	4							c		aa c	aa c	a	a
2	1					c				c			
	2									aa c	aa	aa	aa
	3			c	c		c			a cc	a		aa
	4							cc	c	a c	aa c	a	a
3	1									cc			
	2									aa c	aa	aa	aa
	3		b			c				a c	aa	a	aa
	4	b	b							c	a		

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Table 7 con't. . . . .

Exchangeable

	1				a	a			
1	2	aa		a		b c			a
	3				a	b	aa b		a c
	4						a		a
	1				a	a	a		
2	2	aa		a		c			a
	3					b	a		a
	4					b	a cc		a
	1		c		a	aa	aa	a	a
3	2	aa		a					aa
	3					b	a		a
	4					b	aa b		a c

aa = Calcium p = .01
a = " p = .05

b = Magnesium p = .05

cc = Potassium p = .01
c = " p = .05

basis, the usefulness of foliar analysis as a practical means of evaluating site quality, at least under the terms of reference for this study, is doubtful.

Site differences in soil nutrient content were more obvious than those found for foliar analysis. The better site had lower quantities of the water soluble and exchangeable or available constituents in mineral soil horizons (e.g. exchangeable potassium .17 compared to .56 meg/100g). Total nitrogen and cation exchange capacity were lower in the higher site (.54 versus .69% and 16.09 versus 34.9 meg/100g, respectively), but the C/N ratio was more favorable (26.1 versus 50.0), suggesting more rapid nutrient cycling. Although visual differences in tree growth and site characteristics were evident, statistically significant differences in soil nutrient status were not; thus, the usefulness of these particular techniques in predicting site quality is low.

Soil and foliar nutrient correlation to site was generally inconclusive and it was apparent that some variables affecting tree nutrition and nutrient uptake were not measured. A visual impression of the three sites lead to the conclusion that moisture stress, an unaccounted for operative variable, was possibly affecting such processes as nutrient movement and uptake. It is apparent that future investigations, particularly with regard to forest fertilization evaluations, are required to define both foliar and soil nutrient status within a more well-defined framework. This is a concept well aligned with Waring and Youngberg's (20) suggestions of evaluating nutrition within a framework of moisture regimes.

The need for soil-tree nutrition research is indisputable, particularly when the desirability of putting fertilization on a rational cause and effect basis exists. Future prospects and potential in this area are high only if one is not restrained through the use of present standardized techniques which have been developed for non-forestry situations. Present methodology is probably suitable for characterization of soils based on certain "fixed" properties; however, it is inadequate when either a cause-effect relationship needs elucidation or a predictive capability is desired. For future research along these lines, the necessity for the development of more adequate methodology cannot be understated.

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APPENDIX I

SOIL PROFILE DESCRIPTIONS

SITE Ia

Horizon	Depth cm	Descriptions
L-H	6-1	Black (7.5 Y/R 2/0 m) semi-decomposed organic matter; fine roots present; abrupt, wavy boundary; 3.8 to 5.1 cm thick.
Ah	1-0	Black (10 Y/R 2/0 m) well-decomposed organic matter; fine roots present; abrupt, smooth boundary; discontinuous to 1.3 cm thick.
Bf_1	0-20	Reddish brown (5 Y/R 4/4 m) loamy sand to sandy loam; structureless, single grain, loose; few stones; few fine and medium roots; gradual, smooth boundary; 20.3 cm thick.
Bf_2	20-51	Dark yellowish brown (8.75 Y/R 4/4 m) loamy sand; structureless, single grain, loose; abundant fine and medium roots; clear, smooth edge 25.4 to 30.5 cm thick.
C	51+	Light gray (10 Y/R 6.5 5/1 m) sandy; structureless, single grain, loose; large roots present in upper boundary; 10^+ cm thick.

SITE Ib

Horizon	Depth cm	Descriptions
L-H	4-0	Black (7.5 Y/R 2/0 m) semi-decomposed organic matter; fine roots present; abrupt, wavy boundary; 3.8 cm thick.
Bf_1	0-20	Reddish brown (5 Y/R 4/4 m) loamy sand to sandy loam; structureless, single grain, loose; few stones; fine and medium roots present; gradual, wavy boundary; 20.3 cm thick.

Bf_1	20-38	Dark yellowish brown (10 Y/R 4/4 m) loamy sand; structureless, single grain, loose; abundant fine and medium roots, few large roots; clear smooth edge; 17.8 cm thick.
C	38^+	Light gray (10 Y/R 6.5/1 m) sandy; structureless, single grain, loose.

SITE III

L-H	4-0	Black (7.5 Y/R 2/0 m) semi-decomposed organic matter; fine roots present; abrupt irregular boundary; 1.3 to 3.8 cm thick.
Bf	0-20	Dark reddish brown (5 Y/R 3/4 m) loamy sand to sandy loam; structureless, single grain, loose; few stones present; fine and medium roots; clear smooth boundary; 1.1-20.3 cm thick.
B-C	20-28	Light gray (10 Y/R 7/1 m) sandy; structureless, single grain, loose; occasional roots; abrupt smooth boundary; 3.8 to 7.5 cm thick.
Bedrock		

APPENDIX 2

WATER EXTRACTION TECHNIQUES

1. Hot water extraction

55 cc of mineral soil or 30 cc of organic surface material, weight 45-60 gm and 4-5 gm, respectively, was placed in a filter funnel containing a #4 filter. The sample was dampened with distilled water and left overnight. The next morning, hot water (90-95°C) was passed through the sample until 500 ml were collected.

2. Warm water extraction

The sample volumes, as in 1, were placed in a 250 ml erlenmyer flask and 200 (organic samples) or 100 ml (mineral soil samples) of cold distilled water was added. The flask was shaken by hand to mix the soil and water and then placed in a warm bath 60°C for 18 hours. The sample was filtered with warm water until 500 ml were collected.

3. Cold water extraction

Soil samples were placed in a 200 cc centrifuge tube to which 130-140 ml of cold (20°C) distilled water was added. The tube was shaken and left to stand overnight and then remixed, centrifuged and filtered until 500 ml of filtrate was collected.