Foliar analysis and response of fertilized chlorotic western hemlock and western red cedar reproduction on salal-dominated cedar–hemlock cutovers on Vancouver Island

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Microplot and conventional plot trials were used to determine the nutritional status and required nutrient additions to bring young regenerations of western hemlock (Tsuga heterophylla (Raf.) Sarg.) and western red cedar (*Thuja plicata* Donn ex D. Don) out of "check." The trees were growing on deep mor-humus Podzols invaded by dense salal (*Gaultheria shallon*). Salal removal by grubbing and application of Garlon was also tested. Foliar vector analysis, used for hemlock, identified a response to N and P that was confirmed by subsequent 3-year height growth response. Salal removal resulted in increased N uptake only in cedar. Cedar also responded to N and P additions, but vector analysis was not feasible owing to indeterminate growth. Foliar analysis values are compared with published data. It is suggested that salal competition or allelopathy may be the primary cause of inadequate N and P nutrition.

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Une série d'expérimentations avec des microparcelles et des parcelles conventionnelles ont été effectuées afin de déterminer le statut nutritif et les ajouts d'éléments requis afin d'amener de jeunes peuplements chlorotiques de pruche de l'ouest (*Tsuga heterophylla* (Raf.) Sarg.) et de Cèdre rouge de l'ouest (*Thuja plicata* Donn ex D. Don) issus de régénération à un niveau de suffisance nutritionnelle. Les arbres croissaient sur des Podzols coiffés d'un humus mor épais, envahi par un couvert dense de *Gaultheria shallon*. L'enlèvement de la partie aérienne du *Gaultheria* et l'application de Garlon ont aussi été expérimentés. L'interprétation des résultats de l'analyse foliaire par la méthode des vecteurs a permis d'identifier des réponses à N et P chez la pruche; ces résultats ont subséquemment été confirmés par un accroissement en hauteur pendant 3 années suivant une fertilisation. L'enlèvement du *Gaultheria* s'est traduit par un accroissement du prélèvement de N seulement chez le cèdre. Ce dernier a aussi réagi aux ajouts de N et P mais l'interprétation par la méthode des vecteurs n'a pas été possible due à une croissance indéterminée. Les résultats de l'analyse foliaire sont comparés à ceux publiés dans la littérature. Il est suggéré que la compétition ou l'allélopathie peuvent être les causes premières d'une nutrition inadéquate en N et P.

[Traduit par la revue]

Introduction

In a study of 8- to 14-year-old chlorotic Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantations growing on so-called cedar–hemlock (CH) cutover sites in the Coastal Western Hemlock biogeoclimatic zone (CWHb) in Northern Vancouver Island (Pojar *et al.* 1987), it was noted that younger natural regeneration and plantations of western red cedar (*Thuja plicata* Donn ex D. Don) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were also chlorotic and slow growing and responded to fertilization (Weetman *et al.* 1989). On these cutovers, the dominant understory vegetation is salal (*Gaultheria shallon* Pursh), an ericaceous evergreen shrub which spreads vegetatively by means of rhizomes. The soils are classified as deep mor-humus Podzols, which have developed on well- to poorly drained deep till soils. These soils have developed under ancient cedar–hemlock forests that have not been disturbed for many centuries. This forest and soil condition is common in the CWHb biogeoclimatic zone of Coastal British Columbia (Pojar *et al.* 1987). The provincial site classification scheme defines these sites as CWHb1(3) (Green *et al.* 1984). Further details on the soil and site conditions are presented in Weetman *et al.* (1989).

This report describes attempts to elucidate the nutritional status of the chlorotic cedar and hemlock regeneration and to accelerate its growth using tree fertilizer screening trials and conventional plot fertilizer trials over a 4-year period 1984 to 1988.

Methods

The experimental methods used microplots screening trials and conventional plot (fixed area) fertilizer trials as described by Weetman *et al.* (1989). Foliar vector analysis of 1st-year needle response following fertilization was used to determine the stand nutritional status (Timmer and Ray 1988; Weetman and Fournier 1982). The technique assumes the number of needles is not influenced by treatment during the first growing season. Western hemlock is not determinate, i.e., needle number is not predetermined in the previous growing season's buds. Needle weight per 1000 needles was found to be more highly correlated with height increment than needle weight per unit of shoot length and was used as a measure of needle response in the hemlock foliar vector analysis. For western red cedar, also indeterminate, 1st-year foliar response was based on weight of the first lateral shoot as defined by Parker and Johnson (1987).

Cedar microplot screening trial

The screening trial in cedar used 0.008-ha fertilized temporary microplots. These plots actually contained up to nine trees natural or planted, two of which were selected for analysis in 1985. A 4 × 2 × 2 ((N0, N1, N2, N3) × (P0, P1) × (K0, K1)) factorial experiment in a completely randomized design was used with five replications of each treatment (where N0 = control, N1 = 75 kg $N \cdot ha^{-1}$, N2 = 150 kg $N \cdot ha^{-1}$, N3 = 225 kg $N \cdot ha^{-1}$, P1 = 75 kg $P \cdot ha^{-1}$, K1 = 75kg $K \cdot ha^{-1}$); N was added as ammonium

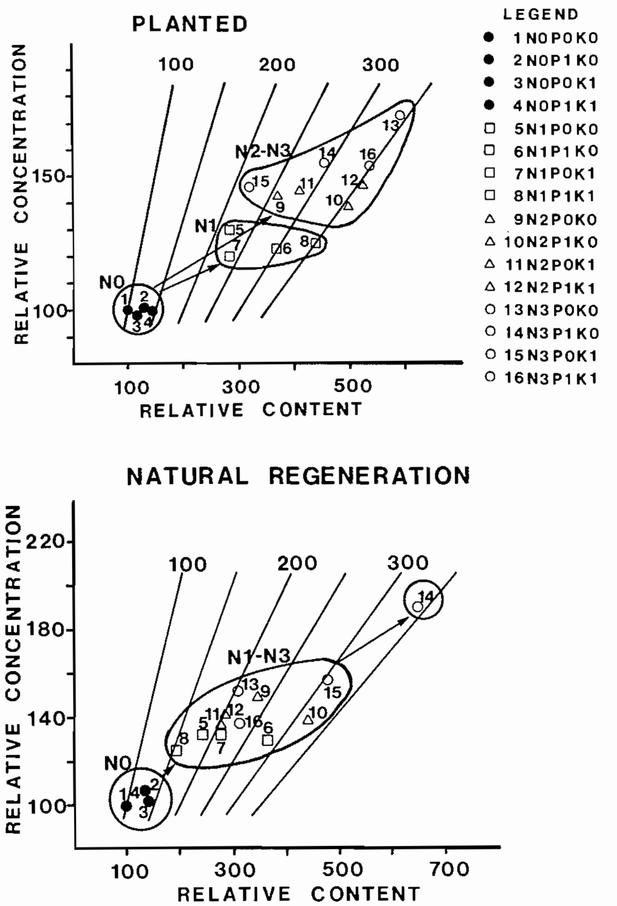

FIG. 1. Planted and naturally regenerated western red cedar: the directional relationships between relative nutrient concentration, relative nutrient content, and relative dry weight of shoots for nitrogen at the end of the first growing season. Values relative to control: %N = 1.15 for planted stands, 1.07 for natural stands; shoot weight = 0.52 g for planted stands, 0.40 g for natural stands. Values at the top end of the isobars represent relative shoot weight.

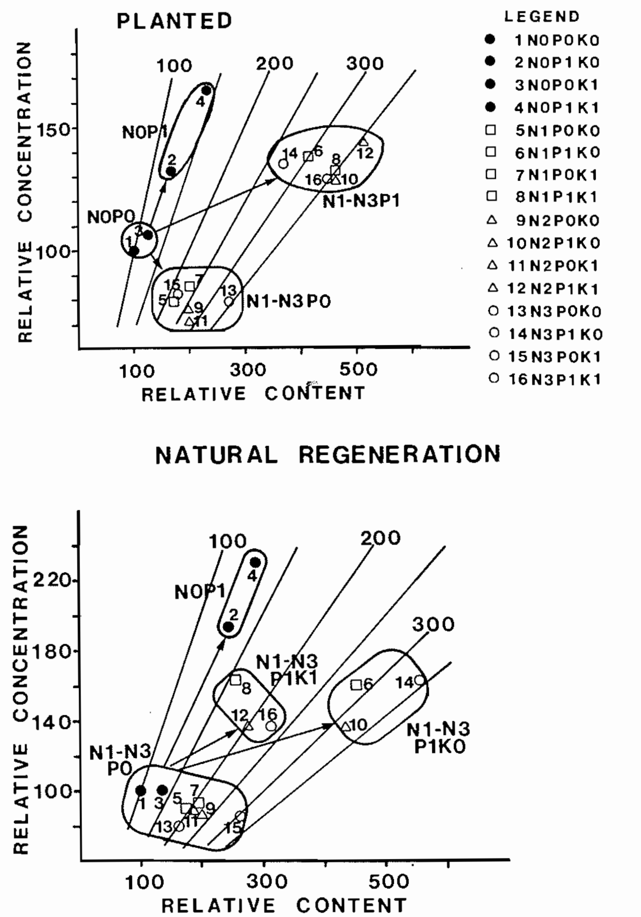

FIG. 2. Planted and naturally regenerated western red cedar: the directional relationships between relative nutrient concentration, relative nutrient content, and relative dry weight of shoots for phosphorus at the end of the first growing season. Values relative to control: %P = 0.17 for natural and planted stands; shoot weight = 0.52 and 0.40 g for planted and natural stands, respectively. Values at the top end of the isobars represent relative shoot weight.

nitrate, P as triple superphosphate, and K as muriate of potash in March 1985. Screening trials were established in five homogeneous sites logged 1978–1980, broadcast burned and planted (3), or left to regenerate naturally (2). The trees were 0.5 to 1.6 m tall and were "free growing" above the 100% cover of salal.

In November 1985, a first-lateral shoot was removed from each of two identified trees per microplot. Two sets of bulked samples, based on five replications, were assembled for each treatment.

Eight hundred cedar shoots were measured for shoot surface area, weight, weight per unit surface area, number of branchlets, shoot length, surface area per unit of shoot length, and specific leaf area; of these, shoot weight was found to be the most useful for vector analysis and is used in this report.

Current season first-lateral shoots were kept in cool storage until processing for shoot measurements. The samples were oven-dried at 70°C, individual shoot weight (g) was determined, and bulked samples were ground in a Wiley mill to pass through a 1-mm mesh screen. Samples were analyzed for N, P, K, Ca, and Mg. Total N and P were analyzed using the H_2SO_4–H_2O_2 digestion method with determination on a Technicon autoanalyzer. Potassium, Ca, and Mg were analyzed from the same digest with determination on an atomic absorption spectrophotometer (AAS).

Initial height (March 1985) and 3-year annual height growth (cm) were determined in November 1985, 1986, and 1987 using a height pole.

Initial diameter stump height (DSH; 30 cm from the ground) in March 1985 and 3rd-year DSH (November 1987) were measured to the nearest millimetre using vernier calipers. Three-year height growth (cm) and basal area growth (cm^2/tree) were fitted to polynomial regression functions using the BMDP statistical package. Tukey's multiple comparisons were used to compare treatments.

Sitka spruce conventional plot trial

The Sitka spruce plantation conventional plots experiment that was established in 1984 (Weetman *et al.* 1989) contained varying amounts of natural regeneration of cedar and hemlock. Ten to 20 of the available cedar and hemlock were selected for 4-year monitoring of annual height growth in each 0.09-ha plot. Four-year height growth (cm) was analyzed using two-way analysis of covariance, and Tukey's multiple comparisons were used to compare treatments.

Salal grubbing experiment

The salal grubbing experiment established in 1985 (Weetman *et al.* 1989) also contained natural cedar and hemlock; 20 to 30 trees of each species per plot were selected for 3-year monitoring of initial height, annual height growth, and annual foliar sampling. The grubbing treatment consisted of removal of aboveground salal with Pulaski axes and at the end of the second growing season by an application of Garlon 4E at 3.5 kg active ingredient/ha. Three-

TABLE 1

A. Three-year height growth (cm) response of the western red cedar regeneration to fertilization: mean of five experiments

	P + K regime				
	P0K0	P1K0	P0K1	P1K1	Mean
N regime					
N0	67	77	82	78	76*a*
N1	87	94	93	98	93*b*
N2	100	98	109	101	102*c*
N3	103	106	108	116	108*d*
Mean	89	98	94	99	
P0	92*a*				
P1	98*b*				

NOTE: Values followed by the same letters are not significantly different at $p = 0.05$. Values are covariance adjusted for initial 1985 basal area height as covariate.

B. Analysis of covariance

Source	df	F	p
Blocks (B)	4	7.71	0.003
N	3		
Linear (L)	1	99.12	<0.001
Quadratic (Q)	1	5.63	0.038
Cubic (C), lack of fit	1	0.31	0.841
P (L)	1	7.40	0.020
K (L)	1	1.01	0.481
N×P			
L	1	0.01	0.995
Q	1	0.22	0.887
C	1	0.08	0.959
N×K			
L	1	0.03	0.985
Q	1	0.70	0.640
C	1	2.86	
P×K	1	0.62	0.680
N×B	12	1.74	0.193
P×B	4	0.21	0.898
K×B	4	0.26	0.874
N×P×B	12	1.08	0.456
N×K×B	12	1.82	0.175
P×K×B	4	0.53	0.744
N×P×K×B*	12	—	—
Covariate	1	306.47	<0.001
Sampling error†	703	—	—

*Treatments × blocks (experimental error) was used as the error term for F determination (MS = 1108.2).
†MS = 1092.4.

year height growth (cm) was analyzed using three-way analyses of covariance with Tukey's multiple comparisons used to compare treatments.

Cedar and hemlock conventional plot trial

The experimental design for both experiments was a 4 × 3 completely randomized design (N0 (control), N100, N200, N300) × (P0M0, P100M0, P100M1); where N and P are the nutrients being supplied, and the number following them represents the concentration in which they were applied in $kg \cdot ha^{-1}$; M0 and M1 represent, respectively, the absence of and the addition of micronutrients) with three replicate plots per treatment. Nitrogen was added as urea and P and triple superphosphate. The micronutrient treatment, a revised commercial micronutrient mix designed by the British Columbia Ministry of Forests and Lands, was added at 1170 $kg \cdot ha^{-1}$ to deliver (in $kg \cdot ka^{-1}$) 99 P, 102 K, 129 Ca, 51 Mg, 50 S, 9 Fe, 3.5 Mn, 1.5 Cu, 1.5 B, and 1.0 Mo.

The fertilizer was spread in March 1987 on the 0.09-ha gross plot with an inner 0.0625-ha net plot containing 60 to 70 cedar or hemlock trees.

First season height growth (cm) was measured in November 1987. First growing season current foliage samples from 10 trees/plot were collected and bulked in November 1987. First lateral shoots were collected for cedar and the ovendry (70°C) weight for each shoot was determined (360 shoots). Five to 10 subsamples of 1000 hemlock needles were counted and weighed for each plot.

The foliar analysis techniques for N, P, K, Ca, and Mg were similar to those used for the cedar screening trial. Micronutrients were analyzed from the same macronutrient digest with determination on an atomic absorption spectrophotometer (AAS), except for B. The azomethene–hydrogen method (Page *et al.* 1982) was used for B determination. Statistical analyses followed the same methods used for the cedar screening trials.

Results

Cedar microplot screening trial

The determination of the nutritional status of the cedar was established by using microplot screening trials to test for response to N, P, and K additions in the planted and natural stands. Figures 1A and 1B show the foliar vector analysis for N on the planted and natural-regeneration cedars. Sets are separated for significant content (i.e., shoot weight × concentration). An increase in N concentration, shoot weight, and N content was observed. This is characteristic of an N deficiency situation. The 75 to 225 $kg \cdot ha^{-1}$ N dosages (N1–N3) resulted in concentrations and shoot weights that were significantly greater than the deficient control concentrations of 1.15 and 1.07% N (see Table 4) and shoot weights of 0.52 and 0.40 g for natural and planted stands, respectively. The highest treatment mean N concentration, based on 10 trees, was 2.07% N with the N3P0K0 treatment in the planted stand. A comparable N concentration of 2.03% was seen with N3P1K0 in the natural stands. Nitrogen content was significantly greater for this treatment. Large first-year shoot weight increases were found and N concentrations were in the 1.3 to 1.8% range.

Figures 2A and 2B present the equivalent vector analysis for P for both the planted and natural stands. The addition of P alone increased P concentration, but did not increase shoot weight, i.e., evidence for luxury consumption of P. The addition of N alone without P decreased P concentration while increasing shoot weight, indicating dilution of P. The addition of N and P together produced increases in P concentration, shoot weight, and uptake, suggesting that trees were deficient in both N and P. Their ability to respond required both nutrients. There was an indication that K addition reduced this effect. The circled data points were significantly different from each other. The deficient control concentration values were 0.17% P for both stands (see Table 4). The highest concentration observed was 0.38% P owing to luxury consumption when P was added alone. The range of foliar P concentrations associated with the greatest shoot growth was 0.21 to 0.27%.

The vector analysis of foliar K showed no significant data sets or shifts. There was no evidence for K response, deficiency, antagonism, or luxury consumption. Control K concentrations ranged from 0.55 to 0.58%. The highest K concentration observed was 0.80% owing to the addition of K alone.

TABLE 2

A. Three-year basal area growth (cm^2/tree) response of the western red cedar regeneration of fertilization: mean of five experiments

	P + K regime				
	P0K0	P1K0	P0K1	P1K1	Mean
N regime					
N0	4.7	7.8	4.7	6.6	6.4*a*
N1	8.3	8.9	9.5	9.6	8.9*b*
N2	9.8	8.2	8.7	7.7	19.2*c*
N3	9.3	9.4	10.0	13.9	10.2*c*
Mean	8.0	8.8	8.6	9.3	
P0	8.3*a*				
P1	9.0*b*				

NOTE: Values followed by the same letters are not significantly different at $p = 0.05$. Values are covariance adjusted for initial 1985 basal area per tree as covariate.

B. Analysis of covariance

Source	df	*F*	*p*
Blocks (B)	4	7.79	0.004
N	3		
Linear (L)	1	41.97	<0.001
Quadratic (Q)	1	3.48	0.090
Cubic (C), lack of fit	1	2.40	0.168
P (L)	1	3.08	0.109
K (L)	1	1.99	0.204
N×P			
L	1	1.06	0.455
Q	1	0.39	0.800
C	1	0.26	0.866
N×K			
L	1	1.19	0.389
Q	1	5.00	0.047
C	1	0.43	0.779
P×K	1	0.01	0.995
N×B	12	1.65	0.214
P×B	4	0.05	0.976
K×B	4	0.64	0.777
N×P×B	12	0.77	0.612
N×K×B	12	1.59	0.227
P×K×B	4	0.55	0.250
N×P×K×B*	12	—	—
Covariate	1	850.44	<0.001
Sampling error†	703	—	—

*Treatments × blocks (experimental error) was used as the error term for *F* determination (MS = 32.06).
†MS = 26.63

The 3-year height growth of the 800 sampled trees in the cedar screening trials showed a trend of increasing response with increasing N additions. A minor but significant response to P was evicent. No significant N and P interaction was found (Table 1). Three-year basal area growth (cm^2/tree) showed trends similar to height growth (Table 2).

Spruce conventional plot trial

The 4-year height growth response noted in the cedar and hemlock natural regeneration following fertilization of the Sitka spruce plantation is presented in Table 3. Both species responded significantly to the N and P applications. Hemlock responded more in height than cedar; the best response was noted with N300P50M1; for cedar, there was no significant difference between the dosages of N and P.

TABLE 3

A. Western red cedar and western hemlock 4-year height growth (cm) following fertilization

	Western red cedar		Western hemlock	
	Mean	SD	Mean	SD
Control	112 (100)*a*	35	36 (100)*a*	13
N100P50	166 (148)*b*	29	149 (414)*b*	50
N200P50	163 (146)*b*	27	178 (494)*b*	56
N300P50	172 (154)*b*	46	207 (575)*bc*	40
N300P150	165 (147)*b*	35	197 (547)*b*	46
N300P50M1	176 (157)*b*	36	244 (678)*c*	38

NOTE: Values are covariance adjusted for initial 1984 height as covariate. Values followed by the same letter(s) are not significantly different at $p = 0.05$. Values in parentheses are relative to control.

B. Analysis of covariance

Source	df	MS	*p*
Western red cedar			
Treatments (T)	5	13 430.0	0.013
Blocks (B)	2	3 753.1	0.240
B×T*	8	2 131.4	—
Covariate	1	12 559.0	0.044
Sampling error	106	940.3	—
Western hemlock			
T	5	54 543.0	<0.001
B	2	264.6	0.878
B×T	8	977.3	—
Covariate	1	8 510.3	0.020
Sampling error	49	1 920.4	—

*Block × treatments (experimental error) was used as error term to determine *p*-value.

Salal grubbing experiment

The results of grubbing out the salal followed by a Garlon treatment and the addition of urea and ammonium nitrate, with and without phosphorus, are presented in Figure 3. The western red cedar cumulative height over age curves show that, after 3 years, plots that had salal removed tended to produce more height growth. There were no significant differences in the height growth response due to urea or ammonium nitrate. The addition of P did not significantly improve the response due to N alone or grubbing alone.

The grubbing treatment alone significantly increased cedar foliage N concentrations in the 1st year from control 1.04% to 1.28% then up to 1.44% in the 2nd year and down to 1.14% by the third growing season. The single and combined effects of grubbing and N and P additions on the foliar N concentrations during the 3-year period following treatment are presented in Fig. 4.

The removal of aboveground salal and, also, some of the roots of salal by grubbing with Pulaski axes, resulted in more N uptake by the cedar trees; P uptake was not affected. It was also noted that the 3rd-year shoot weights were also significantly increased 77% with salal grubbing.

For western hemlock, the cumulative height over age curves show less sensitivity to salal grubbing than cedar (Fig. 5). Response was closely related to the fertilizer addition; with response to N plus P greater than N alone.

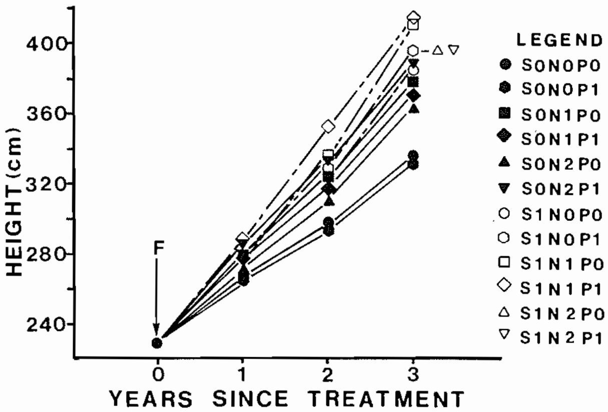

FIG. 3. Western red cedar: height development for the 3 years following salal removal (S1) by grubbing and fertilization with ammonium nitrate (N1) or urea (N2) and triple superphosphate (P1).

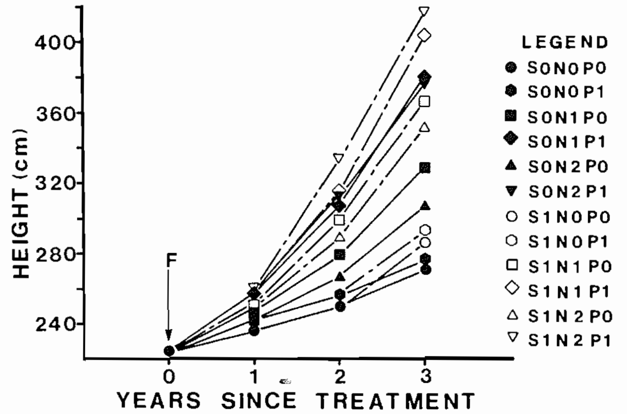

FIG. 5. Western hemlock: height development for the 3 years following salal removal (S1) by grubbing and fertilization with ammonium nitrate (N1) or urea (N2) and triple superphosphate (P1).

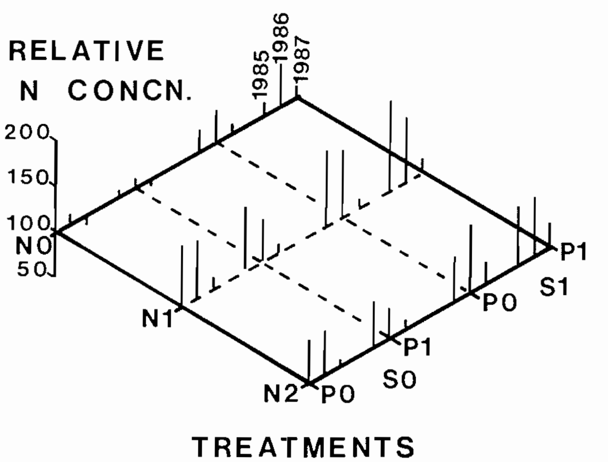

FIG. 4. Western red cedar: changes in foliar N concentration during the 3 years following salal removal (S1) by grubbing and fertilization with ammonium nitrate (N1) or urea (N2) and triple superphosphate (P1). Values relative to the 1985 control (1.04% N).

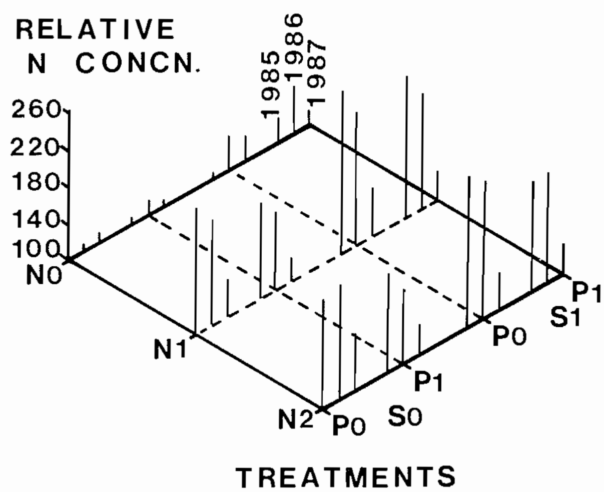

FIG. 6. Western hemlock: changes in foliar nitrogen concentration during the 3 years following salal removal (S1) by grubbing and fertilization with ammonium nitrate (N1) or urea (N2) and triple superphosphate (P1). Values relative to the 1985 control (0.76% N).

Figure 6 shows the relative changes in N concentration by hemlock due to fertilization, with and without salal grubbing. Salal grubbing followed by a Garlon application resulted in a significantly increased N uptake by hemlock at the end of the second growing season. There were no differences in N uptake due to the form of N applied. There was no evidence for an interaction between salal grubbing and fertilization.

Cedar–hemlock conventional plot trial

The conventional plot fertilizer trials in 7-year-old cedar and hemlock plantations used N and P additions and also a micronutrient mix. Table 4 provides the 1st-year macro- and micro-nutrient foliar analyses for cedar and hemlock for the control and the N300P100M1 treatments. Besides the changes in N and P concentrations, the only other significant increases in foliar nutrient concentration due to treatment were found in Zn and B in hemlock. For cedar, there were no significant changes in foliar micronutrient concentration following micronutrient additions.

Foliar vector analyses for N in cedar did not display the consistent relationship between treatment and foliage response found in the cedar screening trials.

Foliar N and P in hemlock (Figs. 7A and 7B) did show a consistent relation between treatment and foliar response. The circled values in Fig. 7 are significantly different from each other, i.e., significant contents. Both N and P additions showed shifts in relative needle weight, concentration, and content, suggesting a deficiency situation.

First season height growth for western red cedar is presented in Table 5. Of the three blocks, one established on transitional hemlock – *A. amabilis* (HA) – CH sites exhibited a minor but significantly greater height response. The trees treated with N alone, N with P, and N, P, with M showed a trend of increasing growth with increasing N doses. The slopes of the three treatments were similar and showed a scale effect of the order N < N + P < N + P + M.

First-season height growth for western hemlock is presented in Table 6. The lower slope (block 3) response to fertilization was greater than midslope (block 2) or upper slope (block 1) response. The elevation difference between the upper and lower blocks was 150 m.

The interactions are presented in Fig. 8. Response to N alone decreased with fertilization additions above 100 kg·ha^{-1}. When P was added and N was above 100 kg·ha^{-1}, the trend was reversed. Additions of M with

TABLE 4. Macro- and micro-nutrient foliar analyses for western red cedar and western hemlock regeneration, one growing season after fertilization, and comparative published values

Treatment	% ovendry weight					ppm				
	N	P	K	Mg	Ca	Mn	Fe	Cu	Zu	Bo
					Cedar					
Control	1.12	0.15	0.59	0.13	0.68	228	41	4	12	14
N300P100M1	1.64	0.22	0.64	0.11	0.74	273	39	5	15	16
Deficiency levels: sand culture	<1.5	0.4	0.39–0.78	0.06–0.18	0.10–0.20	—	—	—	—	15
Coastal stands[†]	1.06	0.16	0.48	0.13	0.66	160	54	6	20	18
Adequate range of values for forest trees[‡]	0.70–1.64	0.09–0.24	0.38–0.90	0.06–1.14	0.56–1.98	75–225	88–488	25–75	11–24	9–23
					Hemlock					
Control	0.93	0.08	0.76	0.14	0.25	1575	47	3	7	26
N300P100M1	1.82	0.20	0.74	0.14	0.42	2467	43	3	16	52
Adequate range of values for forest trees‡	0.86–2.10	0.11–0.33	0.30–0.09	0.08–0.30	0.09–0.39	434–1875	32–50	3.2–5.0	3.0–5.0	13–29

*Walker et al. 1955
†Radwan and Harrington 1986.
‡van den Burg 1985.

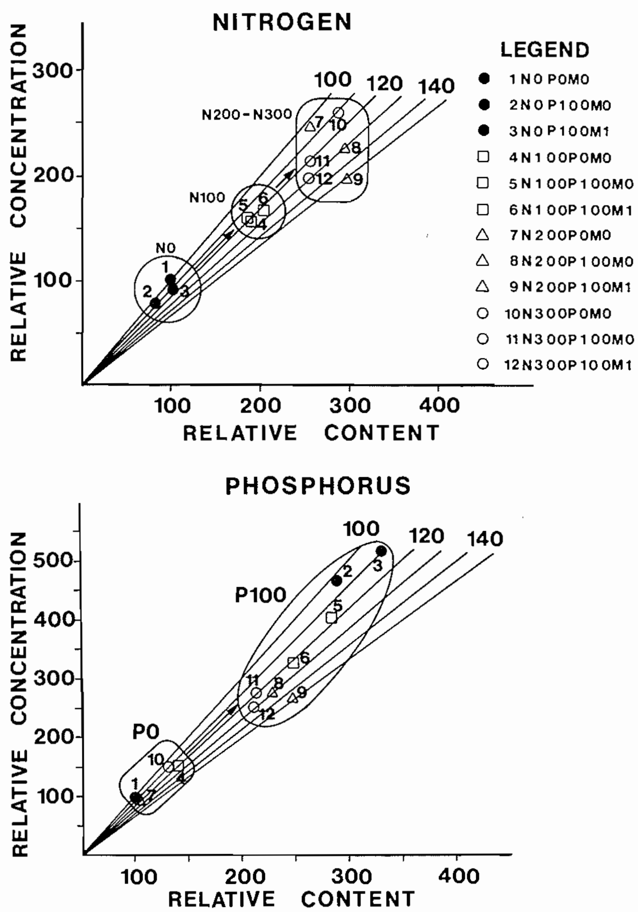

FIG. 7. Western hemlock: the directional relationships between relative nutrient concentration, relative nutrient content, and relative dry weight of needles for N and P at the end of the first growing season. Values relative to control: %N = 0.79, %P = 0.13, needle weight = 1.76 g/1000 needles.

N + P further increased response to the N200 level, with a decline beyond this N level.

Regression analyses

Table 7 provides the significant coefficients of determination (r^2) between the 1st-year foliage weight response and the annual height growth response. Cedar 1st-year foliar shoot weight was more strongly correlated with 1st-year height growth than 2nd- or 3rd-year height growth; N content was more weakly correlated than shoot weight.

For western hemlock, N content of the needles at the end of the first growing season was much more strongly correlated with subsequent height growth than was needle weight.

Discussion

The chlorotic and slow-growing cedar and hemlock regeneration has responded to fertilizer additions similarly to the Sitka spruce planted on the CH site. There appears to be a requirement for both N and P, as confirmed by foliar vector analyses and subsequent height growth response. The requirement of N and P to revitalize the regeneration on the cutovers was operationally tested by aerial fertilization at N225P75 and N300P100 dosages in 1986.

The values of 1.12% N and 0.15% P for control western red cedar are not low in comparison with published values (Table 4), but the stands were still responsive. Further work is needed on critical and adequate values for cedar. The ranges of values reviewed by van den Burg (1985) are based on few citations.

The response of hemlock to fertilization in the Pacific Northwest has been very erratic. Several authors have speculated on the reasons (Gill 1981; Radwan *et al.* 1984; Radwan and Shumway 1983; Radwan and DeBell 1989). In comparison to Douglas-fir, which responds consistently to urea and is largely rooted in mineral soil, hemlock growing

TABLE 5. Western red cedar demonstration trial, first season height growth (cm): analysis of covariance table, main effects, and interactions mean height growth

Analysis of covariance				Height growth*		
Source	df	F	p	Treatment	Mean	SD
Block (B)	2	1.95	0.203	N		
				N0	35	18
Nitrogen (N)	3			N100	42	21
Linear (L)	1	104.20	<0.001	N200	51	22
Quadratic (Q)	1	5.96	<0.033	N300	51	22
Cubic (C), lack of fit	1	0.33	0.830	P+M		
Phosphorus (P)				P0M0	39	20
– micro (M)	2	15.95	<0.001	P100M0	44	21
				P100M1	48	23
N×P+M						
L	2	2.77	<0.001	N×P+M		
Q	2	0.19	0.909	N0P0M0	33	24
C	2	0.01	0.995	N0P100M0	33	29
				N0P100M1	39	19
N×B				N100P0M0	39	20
L	2	0.24	0.885	N100P100M0	42	18
Q	2	0.09	0.957	N100P100M1	45	22
C	2	0.93	0.553	N200P0M0	45	21
				N200P100M0	50	20
P+M×B (L)	4	2.64	0.090	N200P100M1	54	23
				N300P0M0	43	19
				N300P100M0	53	19
N×P+M×B† (L)	12	—	—	N300P100M1	57	21
Covariate	1	235.9	<0.001	Block		
				1	43	21
Sampling error‡	2615	—	—	2	42	22
				3	48	24

*Values of covariance are adjusted with initial 1987 height as covariate.
†Treatments × blocks (experimental error) was used as the error term for p determination (MS = 877.3).
‡MS = 290.35.

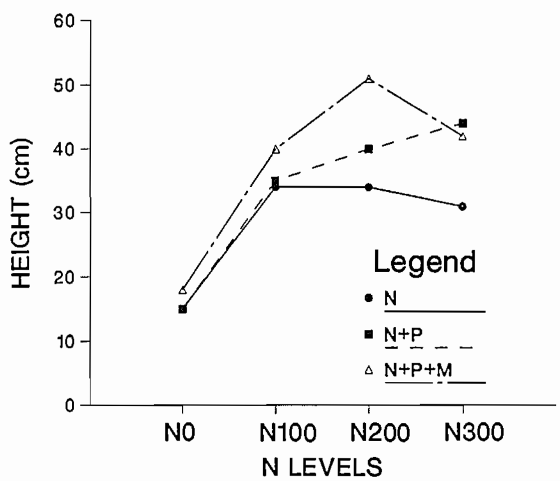

FIG. 8. Western hemlock conventional plot trial: first growing season following fertilization height growth (cm) for N levels without P + M, with P, and with P + M. M, micronutrients.

on the same sites does not respond consistently to urea and is characterized by many fine roots in the humus layer. Some form of "N shock" is suspected, with evidence (Gill and Lavender 1983; Radwan and DeBell 1989) that slow release N fertilizers may be beneficial. The control foliar analysis values were all in the adequate range, although percent N values were low.

It is interesting that in comparison to Sitka spruce, western red cedar and western hemlock seedlings have been found to be very tolerant of nutrient solutions of low pH which contained Al activities up to 0.88 mM (Ryan *et al.* 1986*a*, 1986*b*). On CH sites, the field evidence at Port McNeill, British Columbia, suggests that cedar and hemlock regeneration can better tolerate the low pH (3 to 4) raw humus Podzol conditions than can Sitka spruce. However, all three species display chlorosis and slow growth.

Under these conditions, the response of hemlock to N and P reported in this paper agrees with the study by Nuszdorfer (1987), which showed that on the same cutover condition planted western hemlock seedlings responded, in 2-year height and diameter growth to Osmocote (17-7-12; N:P:K) additions at time of planting. Improved growth was associated with improved N uptake (N supplied at 5 g/tree) and with P (1 g/tree).

It does appear possible with western hemlock to use foliar vector analysis shifts based on needle weight even though the species has indeterminate shoots where needles are not all preformed in a terminal bud. In comparison with fertilized Sitka spruce on the same site, there was more variation in hemlock needle weight response; hemlock needles are more variable in size than Sitka spruce needles.

Western red cedar, however, appears to lack a close relation between height increment and the weight of the first

TABLE 6. Western hemlock demonstration trial, first season height growth (cm): analysis of covariance table, main effects, and interactions mean height growth

Analysis of covariance				Height growth*		
Source	df	F	p	Treatment	Mean	SD
Block (B)	2	12.80	0.001	N		
				N0	16	16
Nitrogen (N)	3			N100	36	24
Linear (L)	1	146.05	<0.001	N200	42	25
Quadratic (Q)	1	74.02	<0.001	N300	39	25
Cubic (C), lack of fit	1	1.27	0.348	P+M		
Phosphorus (P)				P0M0	28	22
– micro (M)	2	26.87	<0.001	P100M0	33	25
				P100M1	37	26
N×P+M						
L	2	9.64	0.003			
Q	2	4.99	0.027	N×P+M		
C	2	3.39	0.073	N0P0M0	15	12
				N0P100M0	15	15
N×B				N0P100M1	18	18
L	2	5.22	0.024	N100P0M0	34	25
Q	2	0.63	0.697	N100P100M0	35	23
C	2	4.44	0.039	N100P100M1	40	23
				N200P0M0	34	22
P+M×B (L)	4	7.07	0.004	N200P100M0	40	22
				N200P100M1	51	26
				N300P0M0	31	17
N×P+M×B† (L)	12	—	—	N300P100M0	44	26
				N300P100M1	42	24
Covariate	1	108.05	<0.001	Block		
				1	33	25
Sampling error‡	2139	—	—	2	29	21
				3	37	30

*Values of covariance are adjusted with initial 1987 height as covariate.
†Treatments × blocks (experimental error) was used as error term for p determination (MS = 990.0).
‡MS = 422.2.

TABLE 7. The linear coefficients of determination (r^2) between first-season foliar parameters and 1st-, 2nd-, and 3rd-year height growth response for western red cedar and western hemlock regeneration: mean of five cutovers following spring fertilization (cedar N = 160, hemlock N = 60, p = <0.001 for all regressions)

	Western red cedar		Western hemlock	
Year	Log shoot wt.	Log N content	Log needle wt.	Log N content
1	0.84	0.62	0.06	0.34
2	0.28	0.30	0.12	0.54
3	0.32	0.35	0.08	0.55

lateral shoot. In this study, one trial showed a close relation between treatment and shoot weight response and another did not. It appears that a very large number of samples of lateral shoots may be required to overcome the natural variation. This makes the use of screening trials with foliar vector analyses difficult.

There has been little work done on cedar fertilization; the present state of knowledge has been reviewed by Weetman *et al.* (1988). It appears to be responsive to fertilizer addition, as noted in this study. C.A. Harrington and C.A. Wierman[1] also found cedar regeneration on a poor site in Washington to respond to fertilizer additions. Increases in foliar N and P associated with fertilization were still evident 5 years after treatment. The ability of cedar to grow and survive to great ages and sizes on these acid raw humus conditions on the Pacific coast high rainfall areas may be related to its reputation as a "calcium pump" (Minore 1983).

The relationship between the poor growth of hemlock and cedar regeneration on these sites and the competition from the dense salal cover is not understood. The salal grubbing and Garlon application did result in improved N uptake by cedar and hemlock, suggesting a strong competition for available N. The Garlon gave only a temporary reduction in salal growth. Whether or not allelopathy is involved is under investigation.

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