Nitrogen accretion, soil fertility, and Douglas-fir nutrition in association with redstem ceanothus[1]

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Nutrient contents of soil and foliage of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) saplings were determined in areas without redstem ceanothus (*Ceanothus sanguineus* Pursh), at the edges of redstem ceanothus patches, and within patches. Tree growth was not examined. Total soil N (0–15 cm depth) was 50–75% greater at the edge of and within redstem patches than in areas without redstem. Assuming soil N was initially similar at all three positions, N accretion was 24–50 $kg \cdot ha^{-1} \cdot year^{-1}$ for 10 years. Total N accretion in the ecosystem was probably 45–80 $kg \cdot ha^{-1} \cdot year^{-1}$. Available N index and extractable Ca and Mg were 2–3 times greater at the edges of and within the redstem patches than outside them. Concentrations of N, Ca, and Mg in the Douglas-fir foliage were lowest outside the patches, intermediate at the edges, and highest within the patches. Because needle weight was lower for saplings within patches than for those at the edges, the latter had the greatest foliar nutrient content. Enhancement of site fertility by redstem ceanothus, as well as its benefits to wildlife and slope stability, make it an attractive candidate for mixed plantations with conifers.

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On a déterminé le contenu en éléments nutritifs du sol et du feuillage de Douglas taxifolié (*Pseudotsuga menziesii* (Mirb.) Franco) à l'état de gaulis croissant sur des terrains sans *Ceanothus sanguineus* Pursh., à la bordure, puis à l'intérieur de placettes où croissait cette plante. On ne s'est pas préoccupé de la croissance des arbres. L'azote total du sol (profondeur: 0–15 cm) était de 50 à 75% plus élevé dans la bordure et à l'intérieur des placettes que dans les terrains sans *C. sanguineus*. En prenant pour acquis qu'à l'origine l'azote du sol était de concentration uniforme dans les trois types de stations, l'accroissement de N était de 24 à 50 $kg \cdot ha^{-1} \cdot an^{-1}$ sur une période de 10 ans. L'accumulation totale de N dans l'écosystème était probablement 45–80 $kg \cdot ha^{-1} \cdot an^{-1}$. L'indice de N disponible et la quantité extractible de Ca et Mg étaient de 2 à 3 fois supérieures à la bordure et à l'intérieur qu'à l'extérieur des parcelles avec *C. sanguineus*. Les concentrations de N, Ca et Mg dans le feuillage des Douglas étaient les plus faibles dans les parcelles sans *C. sanguineus*, intermédiaires à la bordure et les plus hautes dans les parcelles avec cette plante. Le poids des aiguilles étant plus faible chez les gaulis à l'intérieur des parcelles que chez les tiges croissant en bordure, c'est dans les aiguilles de cette dernière position qu'on observe le plus fort contenu foliaire en éléments nutritifs. L'amélioration de la fertilité d'une station par *C. sanguineus* de même que les conséquences positives applicables à la faune et à la fixation des sols en pente, font de cette plante une candidate intéressante pour des plantations mixtes avec conifères.

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Introduction

Species of the genus *Ceanothus* are major components in the early stages of secondary succession in many parts of the Pacific Northwest. Although traditionally viewed as a brush problem, these nitrogen-fixing shrubs can have substantial silvicultural value (Youngberg 1966; Youngberg *et al.* 1979). Most research to date on the potential of *Ceanothus* in forest management has focused on snowbrush (*C. velutinus* Dougl.). This species has been estimated to fix up to 110 $kg\ N \cdot ha^{-1} \cdot year^{-1}$ (Youngberg and Wollum 1976), to cycle large quantities of N in easily decomposed litter (Zavitkovski and Newton 1968; Cromack *et al.* 1979), and to increase slope stability (Ziemer 1981). Redstem ceanothus (*C. sanguineus* Pursh), another common species in the region, has been documented as im-

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TABLE 1. Chemical properties of soil outside, at the edge of, and within redstem ceanothus patches (averages of 10 composite samples, 0–15 cm)

Property	Position relative to ceanothus			Significance[a]
	Outside	Edge	Within	
Bulk density,[b]				
$g \cdot L^{-1}$	530	540	480	O E W
Acidity, pH	5.3	5.4	5.3	O E W
N,				
%	0.079	0.138	0.120	O E W
$kg \cdot ha^{-1}$	630	1130	870	
Available N index,[c]				
$\mu g \cdot g^{-1}$	15.7	30.2	41.4	O E W
$\mu g \cdot cm^{-3}$	8.3	16.3	19.9	
Extractable[d] Ca,				
$mequiv. \cdot 100\ g^{-1} \cdot$	1.35	4.67	3.79	O E W
$kg \cdot ha^{-1}$	430	1510	1090	
Extractable[d] Mg,				
$mequiv. \cdot 100\ g^{-1} \cdot$	0.20	0.56	0.44	O E W
$kg \cdot ha^{-1}$	38	110	77	
Extractable[d] K,				
$mequiv. \cdot 100\ g^{-1} \cdot$	0.12	0.17	0.19	O E W
$kg \cdot ha^{-1}$	38	54	53	

[a]O = outside, E = edge, and W = within. Lines join means that do not differ significantly at the 0.10 probability level, as based on *t*-tests.
[b]Mass of <2 mm fraction per total soil volume.
[c]Ammonium N after a 7-day anaerobic incubation at 40°C.
[d]1 *N* NaCl extractable.

TABLE 2. Nutrient concentrations of Douglas-fir foliage from saplings growing outside, at the edge of, and within redstem ceanothus patches (averages of 10 composite samples of current needles in full sunlight)

Property	Position relative to ceanothus			Significance[a]
	Outside	Edge	Within	
Weight of 100 needles, mg	650	690	540	O E W
Nitrogen, %	1.05	1.23	1.41	O E W
Phosphorus, %	0.313	0.342	0.307	O W E
Potassium, %	0.673	0.644	0.664	O E W
Calcium, %	0.191	0.216	0.274	O E W
Magnesium, %	0.062	0.067	0.070	O E W

[a]O = outside, E = edge, and W = within. Lines join means that do not differ significantly at the 0.10 probability level, as based on *t*-tests.

portant wildlife forage (Trout and Leege 1971), but little information is available on its ability to fix N or on the silvicultural interactions between redstem ceanothus and conifers. Our objective in the present study was to assess the soil chemical properties and foliar nutrient concentrations in juvenile Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) inside, at the edge of, and outside patches of redstem ceanothus.

Site description

The study site is located at an elevation of 600 m on a southwest slope of Survey Mountain on southern Vancouver Island. The parent material is till, ca. 2 m deep, over shale bedrock. The soil, classified as a Duric Dystric Brunisol (Anonymous 1978) (= Typic Durochrept (Anonymous 1975)), has a discontinuous humus layer unrelated to redstem ceanothus cover and a very gravelly and cobbly B horizon of sandy loam, 50–60 cm deep, atop a cemented BC horizon. The site is in the Coastal Western Hemlock dry subzone, and productivity for Douglas-fir is good (Roemer and Korelus 1976).

The site was logged in 1969 and then burned and planted as well as aerially seeded in 1972. In 1980 when the study was

TABLE 3. Nitrogen fixation estimates for *Ceanothus* species

Species and rate of nitrogen fixation ($kg \cdot ha^{-1} \cdot year^{-1}$)	Component	Stand age (years)	Reference
Ceanothus sanguineus			
24–50	Soil 0–15 cm[a]	0–10	This study
45–80	Ecosystem[a]	0–12	This study
Ceanothus velutinus			
72–108	Ecosystem[a]	0–10	Youngberg and Wollum 1976
40	Ecosystem[a]	10–15	Youngberg *et al.* 1979
80	Ecosystem[b]	17	Cromack *et al.* 1979
32	Ecosystem[b]	11	McNabb *et al.* 1979
42–48	Soil to 30 cm[c]	0–12	Binkley *et al.* 1982
94–100	Ecosystem[c]	0–12	Binkley *et al.* 1982
0–20	Ecosystem[c]	0–15	Zavitkovski and Newton 1968;
0–20	Ecosystem[a]	15–32	D. Binkley, unpublished data

[a]Based on within-site accretion method.
[b]Based on acetylene reduction assays.
[c]Based on chronosequence method.

conducted, Douglas-fir stocking averaged 900 saplings · ha^{-1}; sapling height ranged from 1 to 2.5 m. Because of uneven stocking and heavy browsing by deer, it was not feasible to study the effects of redstem ceanothus on Douglas-fir growth. Redstem ceanothus patches covered approximately 50% of the site.

Methods

A 15-m transect was located perpendicular to the edge of each of 10 redstem ceanothus patches, with half its length inside and half outside the patch. Soil samples were taken at each end of the transect and at its midpoint (i.e., both inside and outside the patch and at its edge). Each sample was a composite of three cores 4 cm in diameter and 15 cm deep. Current-year foliage was collected in August 1980 from the third-whorl branches of nine Douglas-fir saplings on each transect, the three saplings nearest each of the three sampling points. All foliage from each point was bulked for chemical analyses. Prior to sampling, all foliage had been in full sunlight.

Soil samples were air dried and sieved; the <2 mm fraction was analyzed for acidity in a saturated water paste, for an index of N availability as ammonium N after a 7-day anaerobic incubation at 40°C (Keeney and Bremner 1966), for total N by colorimetry on semimicro-Kjeldahl digests (Allen *et al.* 1974), and for extractable cations by atomic absorption spectrophotometry on 1-*N* NaCl extracts (Lavkulich 1977). Coarse fragment-free bulk density was estimated for 45 (15 per canopy position) randomly selected soil samples (0–15 cm); sample volume was determined by filling a plastic bag placed in the sample hole with a measured volume of water.

Foliage samples were ovendried, ground, and analyzed as above for total N and P. Total foliar K, Ca, and Mg were determined on HCl extracts of dry-ashed samples (Allen *et al.* 1974).

Results and Discussion

We found that soil chemical properties differed significantly in relation to redstem ceanothus cover (Table 1), but no differences were found in bulk density. Total N concentration under redstem ceanothus was almost double that in the open, and differences in the available N index were even greater. Extractable cations were also greater beneath the ceanothus.

Improvements in soil fertility in the presence of redstem ceanothus were reflected in nutrient concentrations of the Douglas-fir foliage (Table 2). Nitrogen, Ca, and Mg concentrations were greater within and at the edge of the redstem ceanothus patches than outside them. Needle weight, however, was significantly lower for saplings within the patches than for those outside or at the edges; thus, nutrient content per 100 needles was generally highest in the edge position.

Total soil N contents to a depth of 15 cm were 630 $kg \cdot ha^{-1}$ outside the patches, 1130 $kg \cdot ha^{-1}$ at the edges, and 870 $kg \cdot ha^{-1}$ within the patches. Thus, an annual accretion rate of 24–50 $kg \cdot ha^{-1} \cdot year^{-1}$ for 10 years was indicated for the top 15 cm of soil.

Youngberg *et al.* (1979) reported that approximately two-thirds of the N accretion in a snowbrush ecosystem was in the top 23 cm of soil; the rest was apportioned in forest floor and snowbrush biomass. Inclusion of the probable N content of redstem biomass and deeper soil horizons in our study would conservatively increase the estimated N accretion for the total ecosystem to 45–80 $kg \cdot ha^{-1} \cdot year^{-1}$.

The observed N accretion was probably due to N fixation, although some redistribution of N within the ecosystem also may have occurred (e.g., redstem ceanothus roots may have taken up N from open areas). Nevertheless, the apparent rate of N fixation by redstem ceanothus in our study equaled that of snowbrush in Oregon (Table 3). The measured increases in total soil

N, in the available N index, and in Douglas-fir foliar N demonstrate the potential benefits of redstem ceanothus to the fertility of forest soils.

The usefulness of biologic nitrogen fixation in forest plantations will be affected by a variety of factors, including the rate of nitrogen fixation, the availability of the fixed nitrogen to crop trees, competitive interactions, and the costs associated with the establishment of the nitrogen fixer. We found a high rate of nitrogen accretion under redstem ceanothus at one location, but similar information is needed for other sites before the reliability of this species as a nitrogen fixer can be verified. Redstem ceanothus and snowbrush occur in similar habitats, and planting trials are needed to determine their relative performance as nitrogen fixers as well as competitive interactions with crop trees.

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ALLEN, S. E., H. M. GRIMSHAW, J. A. PARKINSON, and C. QUARMBY. 1974. Chemical analysis of ecological materials. J. Wiley & Sons, New York.

ANONYMOUS. 1975. Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. Soil Survey Staff, Washington, D.C. U.S. Dep. Agric. Agric. Handb. No. 435.

ANONYMOUS. 1978. The Canadian system of soil classification. Can. Dep. Agric. Publ. No. 1646.

BINKLEY, D., K. CROMACK, JR., and R. L. FREDRIKSEN. 1982. Nitrogen accretion and availability in some snowbrush ecosystems. For. Sci. **28**: 720–724.

CROMACK, K., JR., C. DELWICHE, and D. H. MCNABB. 1979. Prospects and problems of nitrogen management using symbiotic nitrogen fixers. *In* Symbiotic nitrogen fixation in the management of temperate forests. *Edited by* J. C. Gordon, C. T. Wheeler, and D. A. Perry. Oregon State University, Corvallis, OR. pp. 210–223.

KEENEY, D. R., and J. M. BREMNER. 1966. Comparisons and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agron. J. **58**: 498–503.

LAVKULICH, L. M. 1977. Pedology laboratory methods manual. Department of Soil Science, University of British Columbia, Vancouver, B.C.

MCNABB, D. H., J. M. GEIST, and C. T. YOUNGBERG. 1979. Nitrogen fixation by *Ceanothus velutinus* in northeastern Oregon. *In* Symbiotic nitrogen fixation in the management of temperate forests. *Edited by* J. C. Gordon, C. T. Wheeler, and D. A. Perry. Oregon State University, Corvallis, OR. p. 481.

ROEMER, H. L., and V. J. KORELUS. 1976. Biophysical mapping of Sooke Division. Pacific Forest Products Ltd., Victoria, B.C.

TROUT, L. C., and T. A. LEEGE. 1971. Are the northern Idaho elk herds doomed? Idaho Wildl. Rev. **24**: 3–6.

YOUNGBERG, C. T. 1966. Silvicultural benefits of brush. Soc. Am. For. Proc. **1965**: 55–59.

YOUNGBERG, C. T., and A. G. WOLLUM II. 1976. Nitrogen accretion in developing *Ceanothus velutinus* stands. Soil Sci. Soc. Am. J. **40**: 109–112.

YOUNGBERG, C. T., A. G. WOLLUM II, and W. SCOTT. 1979. *Ceanothus* in Douglas-fir clear-cuts: nitrogen accretion and impact on regeneration. *In* Symbiotic nitrogen fixation in the management of temperate forests. *Edited by* J. C. Gordon, C. T. Wheeler, and D. A. Perry. Oregon State University, Corvallis, OR. pp. 224–233.

ZAVITKOVSKI, J., and M. NEWTON. 1968. Ecological importance of snowbrush *Ceanothus velutinus* in the Oregon Cascades. Ecology, **49**: 1134–1145.

ZIEMER, R. R. 1981. Roots and the stability of forested slopes. *In* Proceedings of the International Symposium on Erosion and Sediment Transport in Pacific Rim Steeplands. *Edited by* T. R. H. Davies and A. J. Pearce. Int. Assoc. Hydrol. Sci. Publ. No. 132. pp. 343–361.