ci., Vol. 28, No. 4, 1982, pp. 720–724

ogen Accretion and Availability in Some Snowbrush Ecosystems

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ABSTRACT. We examined two chronosequences in the Oregon Cascade Mountains to assess nitrogen accretion and availability in relation to snowbrush (*Ceanothus velutinus* Dougl.). In two 12-year-old snowbrush ecosystems, total soil nitrogen to 30-cm depth exceeded levels in adjacent old-growth stands by 500 and 570 kg ha^{-1}. Inclusion of the approximate nitrogen content of aboveground snowbrush and forest floor biomass raised the estimate of nitrogen fixation to 94 to 100 kg ha^{-1} yr^{-1} over 12 years. Snowbrush also increased the availability index of soil nitrogen, but nitrogen availability appeared high in all ecosystems. We speculate that nitrogen fixation by snowbrush during early succession in these ecosystems has been sufficient to prevent nitrogen limitation throughout the entire successional sequence. The presence of snowbrush for 12 years also increased soil carbon 40 and 60 percent in the two chronosequences. FOREST SCI. 28:720–724.

ADDITIONAL KEY WORDS. *Ceanothus velutinus*, nitrogen fixation, forest soil fertility, carbon.

INTEREST IN BIOLOGICAL NITROGEN FIXATION in forest nutrition programs has recently increased (Haines 1978, Gordon and others 1979, Fortin and others 1980), with most attention in the Pacific Northwest focused on woody, actinorhizal nitrogen fixers.

Snowbrush (*Ceanothus velutinus* Dougl.), common in many early successional communities in the Cascade Mountains of Oregon, has the ability to fix substantial quantities of nitrogen, the rates ranging from 0 to 110 kg ha^{-1} yr^{-1} (Zavitkovski and Newton 1968, Youngberg and Wollum 1976, Cromack and others 1979, McNabb and others 1979). But, in addition to fixing nitrogen, snowbrush competes with regenerating conifers for water, light, and nutrients. Concern over potential competition between snowbrush and regenerating conifers often has induced managers to eradicate snowbrush in young plantations. However, the net effect of snowbrush in conifer plantations is the result of the competitive interaction with crop trees early in plantation development and the nutrient enhancement of the site for the entire rotation. Nutritional enhancement is composed of two factors: the rate at which nitrogen accrues and the rate at which it becomes available to conifers. To provide some understanding of the nutritional component of snowbrush and Douglas-fir interactions, our study examined the effect of snowbrush on these two factors in chronosequences at two sites. We also examined carbon accretion.

SITE DESCRIPTION

Our two study sites, in the Willamette National Forest of the central Cascade Mountains of Oregon, have a mild and constant climate compared to other temperate forests. Precipitation averages 250 cm yr^{-1}, about 10 percent falling as snow. Average temperatures for July and January are 18°C and 2°C.

The chronosequence of the first site, Watershed 6 in the H. J. Andrews Experimental Forest in the Blue River Ranger District (T15S R5E, Section 14), is classified a *Pseudotsuga menziesii/Acer circinatum-Berberis nervosa* habitat type after Franklin and Dyrness (1973). The site is near Reference Stand 11, which is described in detail by Hawk and

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others (1978). Average elevation is 1,000 m on southerly slopes that range from 20 to 40 percent. The Dystrandept soil is a deep, well-drained sandy loam. Three stages of succession are represented in Watershed 6, progressing from an old-growth base-line ecosystem through a 4-year-old ecosystem with a patchy, developing cover of snowbrush and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] to a 12-year-old ecosystem dominated by snowbrush and Douglas-fir. The youngest ecosystem developed after clearcutting and low-intensity broadcast burning, the 12-year-old ecosystem after clearcutting and moderate-intensity broadcast burning. The Douglas-fir seedlings were planted; the snowbrush seedlings germinated from buried seeds. Two- to four-year-old snowbrush seedlings were well nodulated, and nodulated roots commonly were found in soil pits in the 12-year-old ecosystem.

The second site is 10 km south of Watershed 6 in the Mill Creek drainage of the McKenzie Bridge Ranger District (T16S R5E, Section 8) at 760-m elevation. The Mill Creek site resembles Watershed 6 except for a finer textured, loamy soil. Again, three stages of succession are represented, progressing from an old-growth ecosystem through a 12-year-old snowbrush/Douglas-fir ecosystem to a 31-year-old Douglas-fir ecosystem that shaded out the formerly predominant snowbrush. The slash fire at Mill Creek was intense. Nodulated snowbrush roots were found in several soil pits in the 12-year-old ecosystem.

Methods

In May 1980, we sampled soils at 12 locations in each of five ecosystems and at 30 locations in the sixth to determine the differences in total nitrogen and carbon and in the available-nitrogen index within each chronosequence. We assumed that increases appearing through the sequences could be attributed to snowbrush. We chose a significance level of $P < 0.10$ for t test comparisons of means.

The 30 sampling points in the 4-year-old ecosystem were adjacent to systematically located, permanent vegetation plots. Snowbrush cover at each point was rated subjectively as absent, light, or moderate. The 12 sampling points in each of the other five ecosystems were located randomly along four parallel transects. Two soil samples were collected from the face of a pit at each sampling point, one at 0–15 cm and one at 15–30 cm. The soils were air-dried, sieved (2 mm screen) and analyzed by standard methods for total Kjeldahl nitrogen (Allen and others 1974), Walkley-Black total carbon (Allen and others 1974), and available-nitrogen index (ammonium-N after 7-day anaerobic incubation at 40°C; after Keeney and Bremner 1966). The mass per unit volume of the <2 mm fraction (coarse fragment-free bulk density) was determined from 10 random cores taken at 0–15 cm at each site. This value was also assumed to be representative of 15–30 cm soil. No significant differences were found for bulk density within either chronosequence.

Results

Snowbrush establishment in the 4-year-old ecosystem in Watershed 6 appeared independent of soil nitrogen content; percent total nitrogen in 0- to 15-cm soil samples was 0.19, 0.18, and 0.19 under snowbrush cover ratings of absent, light, or moderate. None of the values differed significantly from the other means for cover rating. The 4-year-old ecosystem also showed no significant difference in soil properties from the adjacent old-growth ecosystem (Table 1). However, the 12-year-old ecosystem had significantly more nitrogen; total soil nitrogen to 30-cm depth exceeded that of the old-growth ecosystem by 500 kg ha^{-1}.

At the Mill Creek site, the 12-year-old ecosystem also showed substantial nitrogen accretion, exceeding that of the old-growth ecosystem by 570 kg ha^{-1}. The 31-year-old ecosystem did not differ significantly in total soil nitrogen from the adjacent 12-year-old system, which suggests that fixation decreased rapidly as the conifers shaded out the snowbrush.

Index levels of available nitrogen were proportional to total nitrogen, and appeared to increase as a result of snowbrush; levels were high in all ecosystems. Carbon followed the pattern of nitrogen, with significant accretions in both 12-year-old ecosystems of 14,000 and 22,000 kg ha^{-1}. Carbon-to-nitrogen ratios were similar for soils of all stands.

TABLE 1. Mean soil nitrogen and carbon in two chronosequences at two sites.

Site and sequence	Depth, cm	C/N ratio	Nitrogen				Carbon	
			Total		Availability index			
			Percent	kg ha^{-1}	μg g^{-1}	μg cm^{-3}	Percent	t ha^{-1}
Watershed 6								
Old-growth	0–15	30	0.21 (0.01)[a]	780	71 (5)[a]	18	6.3 (0.5)[a]	23.6
	15–30	20	.16 (.01)	600	78 (5)	20	3.2 (.3)	12.0
4-year-old	0–15	26	.19 (.01)	710	85 (5)	21	5.0 (.5)	18.8
	15–30	19	.15 (.01)	540	66 (5)	17	2.9 (.3)	10.8
12-year-old	0–15	27	.28 (.03)	1,060	116 (13)	29	7.5 (.9)	28.1
	15–30	26	.22 (.03)	820	85 (14)	21	5.8 (.9)	21.8
Mill Creek								
Old-growth	0–15	26	.16 (.01)	790	70 (7)	23	4.2 (.9)	20.8
	15–30	20	.14 (.01)	700	64 (6)	21	2.8 (.5)	13.9
12-year-old	0–15	31	.25 (.02)	1,230	86 (11)	28	7.8 (1.2)	38.6
	15–30	21	.17 (.01)	830	53 (2)	17	3.6 (.3)	17.8
31-year-old	0–15	31	.27 (.02)	1,330	112 (10)	37	8.4 (1.6)	41.6
	15–30	24	.20 (.02)	990	70 (10)	23	4.7 (1.2)	23.3

[a] Value in parentheses represents standard error based on 12 samples per site (30 samples per site for the 4-year-old stand in Watershed 6).

Discussion

Nitrogen Accretion.—The mean annual accretion of soil nitrogen to 30-cm depth on the two sites was 42 and 48 kg ha^{-1}, if we assume a linear trend during the first 12 years after disturbance. The real soil nitrogen trend was probably curvilinear, the nitrogen fixation rates increasing with age. Youngberg and Wollum (1976) found a 10-year average accretion of 57 kg ha^{-1} yr^{-1} in the top 23 cm of soil at their site, and an additional 52 kg ha^{-1} yr^{-1} in the snowbrush biomass and forest floor. Assuming biomass nitrogen accretion in our stands was similar to theirs, an approximation of the ecosystem nitrogen accretion is 94 and 100 kg ha^{-1} yr^{-1} for 12 years. If nitrogen losses through leaching or denitrification occurred, the actual nitrogen fixation rate would exceed these nitrogen accretion estimates. Cromack and others (1979) estimated nitrogen fixation in a 17-year-old snowbrush ecosystem elsewhere in the H. J. Andrews Experimental Forest with the acetylene reduction technique; their estimate of 80 kg ha^{-1} yr^{-1} is also close to ours. To date, Zavitkovski and Newton (1968) report the only study finding minimal snowbrush fixation. A recent resampling of their study sites confirmed this conclusion (Binkley, Reassessment of nitrogen fixation in a snowbrush chronosequence in the Oregon Cascades, unpublished), but the factors responsible for the low incidence of nodulation and nitrogen fixation remain unexplained.

Coniferous forest ecosystems in the Pacific Northwest are extremely efficient at retaining nitrogen (Cole and Johnson 1979, Sollins and others 1980), with precipitation input generally exceeding leaching loss. Major nitrogen loss occurs primarily through logging or burning. A classic study on slash burning after logging mature Douglas-fir (Isaac and Hopkins 1937) showed a nitrogen loss of 490 kg ha^{-1}. Kimmins and Feller (1976) estimated nitrogen removal in logging of a forest of western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], Douglas-fir, and western redcedar (*Thuja plicata* Donn.) at 135 kg ha^{-1}, with slash burning raising the total to 680 kg ha^{-1}. Grier (1975) estimated a nitrogen loss of 900 kg ha^{-1} from wildfire in a Douglas-fir ecosystem. We believe nitrogen fixation by snowbrush during the early phases of secondary succession may be sufficient to compensate for such large losses and may be critical to the recovery and continued productivity of severely disturbed ecosystems.

Nitrogen Availability.—Keeney (1980) has reviewed the problems inherent in estimating nitrogen availability in forest ecosystems. We chose the anaerobic incubation procedure of Keeney and Bremner (1966) based on work by Shumway and Atkinson (1978), which calibrated this index with Douglas-fir growth response to nitrogen fertilization. Shumway and Atkinson reported that no growth response would be expected on sites with an anaerobic nitrogen index (0–15 cm) of 46 $\mu g\ g^{-1}$ or greater. Our soil nitrogen-availability indexes for 0–15 cm (given in Table 1 in $\mu g\ g^{-1}$ and also in $\mu g\ cm^{-3}$ to account for coarse fragment content) are all greater than 70 $\mu g\ g^{-1}$. If the pattern found by Shumway and Atkinson (1978) holds true at our sites, we conclude there would be no Douglas-fir growth response to added nitrogen in any of the ecosystems. This conclusion is supported in part by Scott (Effect of snowbrush on the establishment and growth of Douglas-fir seedlings, M.Sc. thesis, Oregon State Univ., 1970) in a study of Douglas-fir nutrition on a nearby site. He found greater nitrogen concentration in needles of Douglas-fir associated with snowbrush, but the 1.2 percent nitrogen in foliage without snowbrush influence is not commonly considered deficient (Morrison 1974).

Nitrogen-availability indexes based on anaerobic incubations are available only for a few forest soils in the Pacific Northwest. Our values appear to be uncommonly high but are similar to levels under red alder in the Coast Range (Cromack, unpublished data). Although we found that snowbrush only marginally increased soil nitrogen availability, we suggest that the high levels in our study reflect long-term patterns of succession for the sites. Snowbrush was probably a major component of early seral communities after each major fire, and an index of available nitrogen integrates both recent and long-term successional history of the ecosystem.

Nitrogen fixation by legumes generally is reduced when soil nitrogen availability is high (Sprent 1979), but our results are not the first to show substantial actinorhizal nitrogen fixation on highly fertile sites. Franklin and others (1968), assessing nitrogen accretion in a red alder (*Alnus rubra* Bong.) ecosystem in the Coast Range in Oregon, found that even in soil estimated to contain 13,000 kg ha^{-1} nitrogen, alder fixed more than 100 kg $ha^{-1}\ yr^{-1}$ for more than 30 years. Elucidating the interactions between actinorhizal nitrogen fixation and the availability of combined nitrogen in soil will be an important area for further research.

Carbon Accretion.—The presence of snowbrush for 12 years in our two sites increased soil carbon by 40 percent and 60 percent. Carbon accretion has been shown to occur under other N-fixing species such as red alder in the Pacific Northwest (Tarrant and Miller 1963). Soil organic matter contributes to water-holding capacity, soil structure, and ion exchange capacity (cf. Black 1968, Russell 1973), but we did not assess these properties in the present study. The importance of soil carbon accretion under nitrogen-fixing plants is a question which merits direct quantification in future studies.

Our results suggest that in the short term, absence of snowbrush in the plantations studied would not result in nitrogen limitation of young conifer growth. However, the present fertility of the sites probably developed from successions that included snowbrush communities. Long-term maintenance of site productivity may therefore be a function of the efficient retention and use of nitrogen fixed by snowbrush early in succession. Experiments of long-term design are needed to test this hypothesis. We believe an evaluation of long-term successional patterns should be made, in addition to short-term evaluations, in the design of forest management prescriptions.

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