Nitrogen Content and Other Soil Properties Related to Age of Red Alder Stands

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ABSTRACT

The magnitude and pattern of nitrogen (N) accretion and other changes in soil properties were assessed for red alder stands (Alnus rubra Bong.) 5 to 41 years old growing on the same soil type in the same general area. Regression of soil nitrogen (N) content over stand age revealed that N has accumulated at a nearly constant rate of about 35 kg ha⁻¹ year⁻¹ in the mineral soil (0-20 cm depth) beneath alder stands. After an apparently rapid build-up in the first decade, forest floor N increased linearly from 10 to 40 years at a rate of 15 kg ha⁻¹ year⁻¹. Other mineral soil characteristics beneath alder stands differed markedly from those beneath adjacent Douglas-fir stands [Pseudotsuga menziesii (Mirb.) Franco]; organic matter content was 20% higher, and pH and bulk density were much lower. The rate of N accretion and improvement of other soil characteristics suggest opportunities for increasing yields of Douglas-fir grown in mixed or rotational culture with red alder.

Additional Index Words: Alnus rubra, N accretion, soil development, Douglas-fir.


RED ALDER (Alnus rubra Bong.) is the major hardwood in coastal forests of the Pacific Northwest. Its rapid occupation of disturbed forest land and fast early growth make it appear as an unwelcome competitor of the highly valued Douglas-fir (Pseudotsuga menziesii Mirb. 'Franco'). However, its effects on the site may enhance Douglas-fir yield. Tarrant (1961) found that the current diameter and height growth of 30-year-old Douglas-fir trees interplanted with alder was better than the diameter and height growth in an adjacent pure plantation of Douglas-fir of the same age. Fifteen years later, Miller and Murray (1978) evaluated the same two stands and found even greater differences; total average volume of the mixed stand was 159 m³/ha (Douglas-fir 88 m³/ha and alder 71 m³/ha). In contrast, total average volume of the pure stand of Douglas-fir was only 82 m³/ha. The mixed stand contained 98% more soil nitrogen (N) and 31% more soil organic matter than the pure stand (Tarrant and Miller, 1963). Substantial increases in soil N have also been observed in other red alder stands (Tarrant et al., 1969; Newton et al., 1968; Berg and Doerkson, 1975).

Because N is a major limiting factor to growth of Douglas-fir (Gessel et al., 1969; Miller and Fight, 1979), Tarrant and Trappe (1971) have proposed that the ability of red alder to fix atmospheric nitrogen (N₂) be exploited by growing the species in alternate rotation with Douglas-fir. Growth estimates for managed alder plantations indicate that pulp logs can be produced in 10 to 15 years and sawlogs in < 40 years (DeBell et al., 1978). But to begin to evaluate crop rotation options, we need information on the relation of N accumulation to the age of red alder stands.

The present study was designed to help meet this need and was conducted on sites that are highly productive for alder growth, thus on sites where opportunities for crop rotation are greatest. Also investigated were changes in soil pH, organic matter, and bulk density.

PROCEDURES

Description of the Study Area

The forest stands studied are within an area 4 km in radius in the Capitol Forest near Olympia, Wash. Elevation is 200 to 300 m above sea level, and climate is characterized by warm, dry summers and cool, wet weather during the rest of the year. Mean annual precipitation exceeds 1,500 mm. All plots were located on deep soils of the Boistfort series developed from Eocene basalt on level to moderately steep upland terraces. Douglas-fir productivity here is high, with site index values ranging from 165 feet (50 m) at 100 years (McMurphy and Anderson, 1968). Before 1875, the Capitol forest area was covered with old-growth conifer forests of Douglas-fir, western hemlock (Tsuga heterophylla (Raf.) Sarg.), and western redcedar (Thuja plicata Donn) and presumably only small amounts of red alder along streams. Most old growth had been logged by the early 1900's and much of the area was planted with Douglas-fir. Some Douglas-fir and other conifer and hardwood species have regen-

General Approach

The age-sequence method was used to assess patterns of N accretion and other changes in soils beneath alder, measuring soil characteristics in stands of different ages both of presumably similar origin (e.g., Newton et al., 1968; van Cleve et al., 1971; Silverstein, 1977). Because of concern about natural variability in soil N content, we also used the paired-plot method, comparing adjacent stands that presumably differ only in species composition (e.g., Tarrant and Miller, 1965; Berg and Doerkson, 1975; Cole et al. 1978).

Plot Selection

Candidate plots were those in pure red alder or Douglas-fir stands meeting the following criteria: (i) Boistfort soil series; (ii) sufficient size to eliminate edge effects on the sampling area; (iii) full, uniform stocking; (iv) slope < 20%; and (v) evidence (large stumps) that original vegetation was old-growth conifers. Thirteen red alder plots were selected for good age distribution and similarity in other characteristics such as aspect. Proximity to a Douglas-fir stand for paired-plot comparisons was also a selection factor. Six Douglas-fir stands were selected; some of those were paired with more than one alder stand to provide 10 paired-plot comparisons.

Field and Laboratory Methods

Two perpendicular 10-m transects, crossing in the center, were laid in north-south and east-west directions. Forest floor and mineral soil samples were collected along these transects. Average stand age was determined from increment cores extracted breast high from all trees located in a 50-m² (7.07 by
The soil characteristics of alder and Douglas-fir stands are provided in Table 1. Here we will examine the relationships between stand age and various soil characteristics individually.

**RESULTS AND DISCUSSION**

**Forest Floor Dry Weight and Nitrogen**

The forest floor weight was assumed to be negligible at age 0 because dense stands of alder rarely become established except on exposed mineral soil. Moreover, no conifer litter was observed in any of the sampled alder stands. Given this assumption, total dry weight of the forest floor beneath alder apparently increases rapidly for the first 5 years. It then accumulates more slowly to about age 25, when it may reach equilibrium (Fig. 1). Though we cannot firmly establish when equilibrium is reached with this data, it appears to be later than the 5 years predicted by Zavitkovski and Newton (1971). Their data include only alder litter, whereas ours include the contribution of all plant species, and field observations indicate that litterfall from understory species is appreciable in older stands.

![Fig. 1](image-url)
The accretion of N in the forest floor follows a pattern similar to that of total dry weight, but the tendency toward equilibrium appears less strong (Fig. 1). By age 10, the litter layer contained about 300 kg N/ha; accretion rate from age 10 to age 40, predicted by the slope of the least squares line, is about 15 kg N/ha annually.

Mineral Soil

Bulk Density

Average density of mineral soil (0-20 cm) under red alder stands was 0.69 g/cm³, 16% lower (p < 0.01, t-test) than in adjacent Douglas-fir stands (0.83 g/cm³). This parallels differences found by Tarrant and Miller (1963) between soil density beneath a mixed red alder and Douglas-fir plantation and an adjacent pure Douglas-fir plantation. Contrary to expectation, no significant relationship appeared between bulk density and stand age (Fig. 2).

Nitrogen

Nitrogen concentration in soil beneath alder stands averaged 0.30%, 41% higher (p < 0.01, t-test) than in soil beneath Douglas-fir (0.21%). When N content was expressed in kg/ha, differences were significant but not as pronounced, because soil bulk densities under alder were lower than under Douglas-fir. Nitrogen in mineral soil averaged 3,240 kg/ha for alder stands, 16% more than the 2,800 kg/ha for Douglas-fir stands. Similar findings of increased soil N in the presence of red alder have been reported by Tarrant and Miller (1963), Tarrant et al. (1969), and Berg and Doerksen (1975). Total amounts of soil N were significantly related (R = 0.802, p < 0.01) to stand age (Fig. 3A). Apparently N is accumulating in the 0- to 20-cm soil horizon of alder stands at a rate of about 34 kg ha⁻¹ year⁻¹; moreover, the rate appears to remain constant throughout the range of stand ages sampled (5-40 years). This finding conflicts with the hypothesis of Newton et al. (1968) that N₂ fixation in alder is rapid at first but insignificant after 20 years.

When differences in N content between adjacent alder and Douglas-fir plots were regressed against alder stand age, we obtained slope and correlation coefficients (Fig. 3B) similar to those we have described. Thus, estimates derived by the two approaches confirm each other. The two techniques show an average annual N accretion in the mineral soil of about 35 kg/ha.

The natural tendency for alder to become established on bare mineral soil and on subsoil (e.g., eroded areas) also supports the hypothesis that soil N contents at time of stand establishment were lower for alder than for Douglas-fir.

Estimated rates of annual N accumulation in the mineral soil for this study are somewhat lower than those reported by others. Berg and Doerksen (1975) estimated an annual accretion rate of 45 kg/ha for understory alder, and Tarrant and Miller (1963) estimated 40 kg/ha for a mixed alder-Douglas-fir plantation. Soils in these studies initially contained much less N than the Boistfort soils of our study.

The combined rate of N accretion for the forest floor and mineral soil is about 50 kg ha⁻¹ year⁻¹ from 10 to 40 years. A more rapid build-up probably occurs.
in the first decade (Fig. 4). Other data collected in our plots suggest that considerable amounts of N are accumulating in the lower horizons (20-50 cm) of these deep, well-drained soils—perhaps as much as 30 kg ha⁻¹ year⁻¹. This, in addition to accumulation of N in biomass, suggests an annual N accretion rate in the ecosystem of over 100 kg/ha.

Annual accretion rates suggested by Newton et al. (1968) for stands of 14 years or less were more than 300 kg N/ha. Our lower values may reflect the effect of higher N content of soils sampled in our study compared with those of Newton et al. (1968). Other investigations with legumes (Gibson, 1977) and alder (Zavitkovski and Newton, 1968) have shown that N₂ fixation can be reduced by high levels of N in the soil.

**SOIL ORGANIC MATTER**

Soil organic matter content was about 20% higher (p < 0.01, t-test) under alder stands than under Douglas-fir stands. Increased soil organic matter under alder was reported earlier by Tarrant and Miller (1963). Because the content is quite variable, especially in the younger stands sampled, no significant trends with age were evident (Fig. 5). Reasons for a high variability in organic matter than in soil N are unknown. Perhaps factors other than the presence of alder, such as microsite effects on decomposition and incorporation, degree of burning, or age of the previous conifer stand, are significantly related to present amounts of organic matter.

The accumulation of soil organic matter beneath alder aids long-term productivity. Organic matter is positively related to cation exchange capacity and moisture retention. Moreover, it can provide a stable storage mechanism for retaining N fixed by alder until it can be used by subsequent crops. In addition, Harvey et al. (1979) showed that increased soil organic matter leads to greater ectomycorrhizae development.

**SOIL ACIDITY**

The pH of mineral soil (0-20 cm) beneath red alder was significantly lower (p < 0.01, t-test) than pH of soil under adjacent Douglas-fir stands. This finding agrees with previous reports of increased acidity in red alder stands (Tarrant, 1961; Bollen et al., 1967; Franklin et al., 1968). Although there is a tendency for pH to decrease with increasing stand age (Fig. 2), this trend is not significant (p = 0.15). Increased decomposition rates, greater organic acid production, and higher nitrification rates under red alder may account for the difference in soil pH between alder and Douglas-fir stands and also for the tendency of pH to decrease with increasing stand age. Whether the lower pH of soil beneath alder stands will be detrimental to productivity over long periods is unknown, but it may contribute to the lower base status and decreased availability of other nutrients reported for alder soils (Bollen et al., 1967; Franklin et al., 1968).

Simple linear regressions among alder soil variables (Table 2) suggest that soil pH is strongly related to organic matter and moderately related to soil N weight. Soil N and soil organic matter, however, were only weakly correlated (R = 0.50); such variability in C/N ratio may be a further indication that some factors other than age of alder stands have importantly affected soil organic matter content.

Multiple regression analysis of soil variables indicates that together alder stand age and soil organic matter account for 81.4% of the variability in soil N content and constitute the best combination of variables for estimating soil N content by the Cₚ criterion (Neter and Wasserman, 1974). The least squares response surface is:

\[
Y = 1,258 + 31.6(X_1) + 11.9(X_2)
\]

where X₁ is stand age in years and X₂ is soil organic matter content in metric tons per hectare. Partial coefficients of determination suggest that stand age accounts for pH to decrease with increasing stand age (Fig. 2), this trend is not significant (p = 0.15). Increased decomposition rates, greater organic acid production, and higher nitrification rates under red alder may account for the difference in soil pH between alder and Douglas-fir stands and also for the tendency of pH to decrease with increasing stand age. Whether the lower pH of soil beneath alder stands will be detrimental to productivity over long periods is unknown, but it may contribute to the lower base status and decreased availability of other nutrients reported for alder soils (Bollen et al., 1967; Franklin et al., 1968).

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Table 2—Simple linear regressions among alder soil variables.

<table>
<thead>
<tr>
<th>Regression (Y vs. X)</th>
<th>R</th>
<th>P-value</th>
<th>Equation (Y = b₀ + bₓX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil organic matter (metric ton/ha) vs. stand age (year)</td>
<td>0.31</td>
<td>&gt;0.20</td>
<td>Y = 1,258 + X₁</td>
</tr>
<tr>
<td>Nitrogen weight (kg/ha) vs. stand age (year)</td>
<td>0.80</td>
<td>&lt;0.01</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Soil organic matter (metric ton/ha) vs. soil organic matter</td>
<td>0.50</td>
<td>0.08</td>
<td>Y = 3,132 + 11.4X₂</td>
</tr>
<tr>
<td>pH vs. stand age (years)</td>
<td>-0.43</td>
<td>0.15</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Soil organic matter (metric ton/ha) vs. pH</td>
<td>-0.82</td>
<td>&lt;0.01</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Nitrogen weight (kg/ha) vs. pH</td>
<td>-0.61</td>
<td>0.03</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Bulk density (g/cm³) vs. stand age (years)</td>
<td>0.44</td>
<td>0.14</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Bulk density (g/cm³) vs. soil organic matter (metric ton/ha)</td>
<td>-0.37</td>
<td>&gt;0.20</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Bulk density (g/cm³) vs. N weight (kg/ha)</td>
<td>0.46</td>
<td>0.12</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
<tr>
<td>Bulk density (g/cm³) vs. pH</td>
<td>0.13</td>
<td>&gt;0.20</td>
<td>Y = 2,450 + 33.5X₁</td>
</tr>
</tbody>
</table>

**Fig. 4**—Nitrogen accretion in the forest floor and < 2-mm fraction of the mineral soil (0-20 cm) beneath red alder.

**Fig. 5**—Organic matter content of the < 2-mm fraction of the mineral soil (0-20 cm) beneath red alder.

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counts for 64% and soil organic matter 17% of the variation in soil N content.

IMPLICATIONS

Our analyses indicate that N is accumulating at fairly rapid rates in the forest floor and upper mineral soil of the red alder stands. At the end of a 10-year pulpwood or 32-year sawlog rotation (DeBell et al., 1978), we would expect N addition to soil on this site to be 670 and 1,710 kg/ha, respectively. Most of this, and at least some of the N accumulated in biomass or transported to deeper soil layers, would eventually be available to a successive crop. Increased soil organic matter should improve soil tilth and stabilize soil N. Decreased bulk density should also be beneficial, but the effect of the trend toward lower pH is unknown.

Understanding the effects of alder-derived N and other changes in soil properties on site productivity will help determine the extent of future alder use. Preliminary assessments of economic feasibility of mixed and rotational cultures of alder in Douglas-fir managed forests have been made (Atkinson and Hamilton, 1978, Atkinson et al., 1979), but further work is needed in light of rapidly increasing energy costs and projected shortages of oil and natural gas. We believe that plantations of red alder or of admixtures of alder and other tree species will become, on some sites, an economically feasible alternative to N fertilizer derived from fossil fuels. Our optimism is based on the fact that alder can fix appreciable amounts of N on a wide range of sites varying from the poorly productive and low N soils studied by Tarrant and Milner (1963) and DeBell and Radwanc (1979) to the productive soils with high N content sampled in this study.

ACKNOWLEDGMENT

We would like to thank R. W. Walker for his guidance and insight, T. P. Bormann for her assistance in field sampling, and D. W. Cole for use of University of Washington, College of Forestry Resources analytical equipment. This research was sponsored by the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

LITERATURE CITED