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Chemical soil properties under coastal Oregon stands of alder and conifers

Abstract

Chemical soil properties were compared under (1) adjacent 40-year-old red alder (Alnus rubra), conifer (mainly Douglas-fir (Pseudotsuga menziesii)), and mixed stands and (2) adjacent 30-year-old alder and conifer stands growing on the Oregon coast. Soils on all sites were Astoria-like Sols Bruns Acides developed primarily from Eocene siltstone. Organic matter, total nitrogen, and acidity were significantly greater in A horizons under alder and mixed stands. In A11 horizons of the older stands, organic content under alder averaged one-third greater than conifer (39 vs. 29 percent), nitrogen one-third greater (0.8 vs. 0.6 percent), and pH one unit lower (4.3 vs. 5.3). A horizons under conifer stands averaged three times richer in bases than those under alder stands. Similar differences, but of a much smaller magnitude, were observed in the B horizons. Observed effects of alder on acidity and base content disagree with the generally held concept of hardwoods as base conservers. These effects may indicate greater production of acid decomposition products in the organic- and nitrogen-richer alder soils.

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Red alder (*Alnus rubra*) is the most abundant hardwood in the Douglas-fir region of western Oregon and Washington. It is an aggressive pioneer on burned and logged-over lands, particularly in coastal areas. The abundance of red alder, together with its nitrogen-fixing habit, makes it a species of great interest in effective management of Pacific Northwestern forest lands.

The soil-improving properties of alder are generally well known. Studies have shown that red alder can make a significant contribution to fertility of forested sites in the Cascade Range (Tarrant, 1961; Tarrant and Miller, 1963). However, data are not available on its influence on some of the more fertile coastal soils. A preliminary study suggested red alder not only affects the nitrogen status of such soils but has a significant influence on acidity and base content as well.

Findings of the exploratory study prompted the detailed comparison, reported here, of chemical soil properties under adjacent stands of red alder and conifer. Some results were expected; e.g., an increase in nitrogen in soils influenced by alder litter and root sloughing. Others were surprising, such as the lower base content and increased acidity of soils under alder stands as compared with those under conifer.

The Study Area

The study sites are located in Cascade Head Experimental Forest just north of the Salmon River in Lincoln and Tillamook Counties, Oregon. The area lies within the "fog belt" forest zone of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii*). Red alder is common on cutover land in this zone. A marine climate provides equable temperatures, much cloudiness, frequent rain, and summer fog (Madison, 1957). Normal annual precipitation is 90 to 100 inches. Mean annual temperature is approximately 50° F, but days below freezing or in excess of 80° F are infrequent.

Soil properties were compared under adjacent contrasting cover types at two locations. The first (alder-conifer plots) utilized adjacent 40-year-old red alder (1-acre plot), conifer (½-acre plot, primarily Douglas-fir), and mixed (1-acre plot, alder and conifer) stands. These plots were created between 1935 and 1937 from mixed alder-conifer regeneration which developed on agricultural land abandoned about 1925 (Berntsen, 1961).¹ They occupy gently sloping topography, generally southwest in aspect, at an elevation of 700 feet and about 4 miles from the ocean. The alder stand has an open crown canopy and a dense shrubby understory of salmonberry (*Rubus spectabilis*) and blackbead elder (*Sambucus melanocarpa*). Relatively few shrubs or herbs occur under the very dense crown canopy on the conifer plot. The mixed plot is intermediate in quantity of understory vegetation. Complete vegetational descriptions have been provided by Franklin and Pechanec (1968).

The second study site (Widow Creek), utilized adjacent 30-year-old stands of red alder and of conifer (also dominantly Douglas-fir). They are growing on a gentle south slope at an elevation of about 900 feet, 5 miles from the ocean. As at the other site, vegetation is sparse under the conifer stand but consists of a dense cover of herbs and shrubs under the alder.

The Soil

Soils in the study area have not been classified. However, they are best characterized as Astoria-like Sols Bruns Acides, developed from deeply weathered siltstone. Parent material is a tuffaceous siltstone which is included within the Nestucca formation of Eocene age. Throughout the area, there are occasional intrusions of Tertiary basalt which result in some modification of the soil profile. The basalt in these areas is relatively fresh and unweathered, and the soil parent material was obviously siltstone.

Soils on the plots are moderately fine textured and moderately well drained. Soils exhibited no consistent differences among stands and were very similar with respect to horizon sequence and morphology. Largest variations in profile characteristics are found in depth to weathered parent material (C horizon) and degree of stoniness. Depth of solum varies from 22 inches to over 60 inches. Except in localized areas of basalt, the soils tend to

¹These plots are referred to as plots 1 (alder-conifer mixture unthinned), 2 (pure conifer, thinned), and 3 (pure alder, thinned) by Berntsen (1961).

be relatively stone free. Of 21 profiles examined two had stone contents ranging up to 70 percent – conifer plot pit 3 and mixed plot pit 2. Most profiles examined would be included in the Haplumbrept great soil group, according to the new system of classification (U. S. Soil Conservation Service, 1960). However, several profiles were classified as Dystrochrepts because of their thinner or light-colored A horizons.

The O1 horizon (Aoo) is relatively thin, averaging approximately 1 inch in thickness. It is made up of freshly fallen and partially decomposed leaves, needles, and twigs. A thin O2 horizon (Ao) was occasionally observed, but always in a discontinuous pattern.

Beneath the forest floor lies an A11 horizon, 2 to 4 inches in thickness. Color of this layer is consistently very dark brown (10YR 2/2),² and texture is generally a silt loam. Soil structure is weak fine, weak medium, or fine granular. This soil material is very friable when moist and slightly sticky and nonplastic when wet. Roots are abundant in all A11 horizons.

The A12 horizon averages 6 inches in thickness with a range from 3 to 9 inches. Color of this layer is a very dark brown (10YR 2/3) or dark brown (10YR 3/3). Texture is most often a silt loam; however, several profiles had A12 horizons with a silty clay loam texture. Structure is weak to moderate, fine and medium subangular blocky. The soil in this horizon is generally friable when moist and slightly sticky and slightly plastic when wet. Abundant roots are well distributed throughout the entire horizon.

An A3 or B1 horizon is usually found between the A12 and B2 horizons. This layer varies from 6 to 15 inches in thickness, with an average of approximately 10 inches. Color of this layer is most often dark yellowish brown (10YR 3/4); however, at several locations the color was dark brown (10YR 3/3). Soil texture is generally silty clay loam, although loam, silt loam, and clay loam were each encountered once. Structure is subangular blocky of varying classes and grades. The most commonly encountered structure in these layers, however, was moderate fine subangular blocky. Soil consistence is most often slightly firm when moist and slightly sticky and slightly plastic when wet. Roots are common in the A3 or B1 horizon.

The B2 horizon has the most variable thickness of all the layers – ranging from 6 to 35 inches and averaging about 14 inches. Color of the B2 horizon is generally dark yellowish brown (10YR 3/4) or brown (10YR 4/3). The most common soil texture is silty clay loam, followed by clay loam. Soil structure is generally weak to moderate, medium and fine subangular blocky. B2 horizon material tends to be friable to slightly firm when moist and sticky and plastic or slightly sticky and slightly plastic when wet. Roots are common in this layer.

Most often there is a transitional B3 horizon which in turn grades into the weathered siltstone parent material that comprises the C horizon. Generally the B3 horizon possesses many of the same characteristics as the B2 and is differentiated on the basis of gradually increasing amounts of weathered siltstone. Several profiles showed evidence of a lithologic discontinuity at the

²Munsell Soil Color notation, always referring to moist soil.

top of the B3 or C horizon. These discontinuities probably mark changes within the stratified parent material.

Methods

In May 1966, soil pits were dug to about 60 inches at three locations in each alder-conifer plot and at one central location in each of the two Widow Creek stands. Soil profiles were described according to current U. S. Soil Survey (U. S. Soil Conservation Service, 1951, 1962) practices. Two shallower pits (24 to 36 inches deep) were also dug in each stand and sketchily described to provide more sites for sampling the surface soil. Finally, thickness of highly variable A11 and A12 horizons was measured at nine additional systematically located points in each stand.

A bulk sample of each horizon was taken from each pit, air-dried, and divided into two subsamples – one for textural and the other for chemical analysis. Bulk density samples were obtained from at least one pit in each stand using two types of volumetric core samplers, and were oven-dried, and weighed. Resulting data were used to convert analytical data to a pounds-per-acre basis.

Chemical analysis was done in the Oregon State University Soil Testing Laboratory by the procedures outlined by Alban and Kellogg (1959): pH – 1:1 soil-water paste and glass electrode; available phosphorus – sodium bicarbonate method; cation exchange capacity – ammonium acetate technique; exchangeable potassium, calcium, magnesium, and sodium-flame photometer; organic matter – a modified Walkley-Black method; and total nitrogen – a Kjeldahl method.

Textural analysis of each horizon was carried out by a hydrometer method.

In calculation of pounds per acre of the various nutrients, values were calculated separately for each horizon and included adjustments for stone content. Resulting horizon figures were then added for each profile to obtain data for the desired 12- or 36-inch depths.

Results

Chemistry of Individual Soil Horizons

A horizons of soils under conifer and under red alder stands differ markedly in acidity, organic matter content, total nitrogen percent, C:N ratio, calcium and magnesium content, cation exchange capacity, and percent base saturation (Table 1). These differences are usually much smaller or nonexistent in B2 horizons, however.

Acidity. – Acidity of soils from alder stands is about one pH unit lower than in soils from conifer stands (Table 1). For example, A11 horizons under alder had average pH values of 4.3 and 4.4 at the two study sites in contrast with average values of 5.3 under both of the respective adjacent conifer stands. Differences are still significant in the B2 horizon, although of much smaller magnitude; pH values in the B2 horizons appear to be converging; i.e., the alder soil becoming less acid with depth, the conifer soil more acid.

TABLE 1. – Chemical properties of A11, A12, and B2 or B21 horizons in soils under 40-year-old (alder-conifer study plots) or 30-year-old (Widow Creek) stands of pure alder, pure conifer, or mixed alder-conifer¹

Location and Stand	Horizon	Thickness ²	pH	Organic Matter	Total Nitrogen	C/N Ratio	Phosphorus	Potassium	Sodium	Calcium	Magnesium	Sum of Bases	Cation Exchange Capacity	Base Saturation
		<i>Inches</i>		<i>Percent</i>	<i>Percent</i>		<i>Ppm</i>	<i>Meq / 100 g ----- Percent</i>						
Alder-Conifer Study Plots														
Alder	A11	2.5 (1.0 - 4.0)	4.3 (4.0 - 4.5)	37.5 (24.8 - 56.3)	1.00 (0.73 - 1.19)	21 (16 - 28)	5.0 (2.0 - 8.5)	0.94 (0.72 - 1.52)	1.05 (0.83 - 1.25)	1.30 (0.4 - 2.0)	0.98 (0.2 - 1.3)	4.27 (2.40 - 5.35)	85.0 (70.0 - 102.0)	5.0 (2.6 - 6.3)
	A12	3.4 (0 - 7.0)	4.7 (4.4 - 4.9)	23.1 (18.1 - 32.9)	0.47 (0.26 - 0.59)	21 (18 - 25)	4.1 (1.5 - 8.5)	0.72 (0.47 - 1.18)	0.82 (0.68 - 0.95)	0.66 (0.2 - 1.4)	0.30 (T - 0.7)	2.50 (1.47 - 4.03)	60.3 (57.5 - 81.6)	4.2 (1.9 - 4.9)
	B2 or B21	4.9 (4.7 - 5.0)	4.9 (4.7 - 5.0)	9.7 (5.4 - 16.8)	0.28 (0.17 - 0.40)	20 (17 - 24)	0.6 (0.2 - 1.0)	0.41 (0.26 - 0.62)	0.79 (0.65 - 0.98)	0.15 (T - 0.4)	0.04 (T - 0.1)	1.39 (1.04 - 1.70)	54.3 (43.5 - 57.1)	2.6 (1.8 - 3.3)
Mixed	A11	2.39 (1.0 - 4.0)	4.6 (4.4 - 4.8)	31.8 (26.2 - 37.4)	0.79 (0.73 - 0.82)	23 (21 - 26)	4.5 (2.5 - 6.0)	0.79 (0.58 - 1.00)	0.95 (0.77 - 1.13)	0.93 (0.30 - 1.55)	0.96 (0.50 - 1.60)	3.63 (2.35 - 4.86)	72.4 (70.0 - 80.0)	5.0 (3.6 - 6.9)
	A12	4.64 (0 - 16.0)	5.0 (4.8 - 5.1)	20.4 (13.8 - 26.4)	0.50 (0.38 - 0.62)	22 (19 - 26)	2.0 (0.5 - 5.0)	0.61 (0.26 - 0.83)	0.99 (0.72 - 1.30)	0.77 (0.20 - 1.25)	0.60 (0.20 - 1.30)	2.97 (1.88 - 3.95)	61.0 (53.5 - 65.3)	4.9 (3.5 - 6.6)
	B2 or B21	4.9 (4.7 - 5.2)	4.9 (4.7 - 5.2)	5.3 (2.8 - 9.8)	0.19 (0.14 - 0.31)	15 (12 - 18)	0.7 (0.5 - 1.0)	0.44 (0.27 - 0.79)	0.75 (0.56 - 1.13)	0.34 (T - 1.30)	0.36 (T - 1.30)	1.89 (0.87 - 4.52)	40.7 (25.3 - 48.5)	4.6 (1.9 - 9.3)
Conifer	A11	1.61 (0 - 4.0)	5.3 (5.1 - 5.5)	28.9 (21.7 - 37.8)	0.60 (0.46 - 0.66)	28 (21 - 36)	4.3 (3.0 - 6.5)	0.85 (0.49 - 1.30)	1.00 (0.72 - 1.25)	3.41 (0.40 - 7.20)	2.88 (0.1 - 5.7)	8.14 (1.71 - 15.20)	66.1 (55.0 - 77.5)	12.3 (2.6 - 20.2)
	A12	4.34 (1.5 - 9.0)	5.3 (5.2 - 5.4)	21.8 (15.3 - 32.7)	0.34 (0.04 - 0.49)	28 (25 - 35)	1.6 (1.0 - 3.0)	0.93 (0.58 - 1.79)	0.93 (0.87 - 1.05)	2.78 (0.8 - 4.0)	2.74 (1.0 - 5.2)	7.38 (3.25 - 13.84)	65.1 (61.2 - 70.0)	11.3 (5.3 - 21.4)
	B2 or B21	5.2 (5.1 - 5.3)	5.2 (5.1 - 5.3)	6.5 (2.8 - 14.5)	0.19 (0.11 - 0.37)	18 (16 - 23)	0.6 (0.2 - 1.0)	0.34 (0.12 - 0.45)	0.83 (0.65 - 1.20)	0.34 (0.2 - 0.5)	0.60 (T - 0.4)	2.11 (1.20 - 2.02)	48.6 (41.5 - 52.5)	4.3 (2.2 - 4.6)
Widow Creek														
Alder	A11	3.67 (3.0 - 5.0)	4.4 (4.2 - 4.5)	24.9 (22.2 - 27.3)	0.74 (0.69 - 0.77)	20 (18 - 21)	3.3 (3.0 - 4.0)	0.55 (0.41 - 0.66)	1.04 (0.92 - 1.25)	0.83 (0.5 - 1.2)	0.63 (0.2 - 1.5)	3.05 (2.20 - 4.61)	53.3 (47.8 - 57.6)	5.7 (4.0 - 8.0)
	A12	9.67 (8.0 - 12.0)	4.9 (4.7 - 4.9)	18.4 (14.4 - 21.0)	0.54 (0.51 - 0.58)	20 (16 - 23)	2.2 (1.5 - 3.0)	0.45 (0.37 - 0.56)	0.84 (0.78 - 0.87)	0.40 (0.2 - 0.5)	0.27 (T - 0.8)	1.96 (1.63 - 2.45)	49.3 (46.7 - 53.3)	4.0 (3.1 - 5.1)
	B2 or B21	5.0 (4.9 - 5.0)	5.0 (4.9 - 5.0)	12.3 (10.6 - 13.1)	0.39 (0.34 - 0.44)	18 (17 - 19)	1.7 (1.0 - 2.5)	0.31 (0.29 - 0.33)	0.79 (0.78 - 0.80)	0.30 (T - 0.6)	0.50 (0.1 - 0.8)	1.90 (1.71 - 2.07)	37.3 (33.2 - 43.5)	5.1 (3.9 - 5.5)
Conifer	A11	3.33 (2.0 - 6.0)	5.3 (5.1 - 5.4)	23.5 (20.8 - 26.0)	0.53 (0.46 - 0.65)	26 (23 - 29)	3.7 (2.5 - 4.5)	1.07 (0.76 - 1.31)	1.09 (1.02 - 1.20)	2.77 (1.7 - 4.0)	3.50 (2.4 - 4.2)	8.43 (5.88 - 10.53)	52.6 (47.8 - 55.5)	16.0 (12.3 - 19.4)
	A12	7.83 (6.0 - 11.0)	5.2 (5.0 - 5.4)	16.2 (12.8 - 23.0)	0.46 (0.37 - 0.57)	20 (17 - 23)	2.2 (1.0 - 3.0)	0.84 (0.41 - 1.08)	0.93 (0.78 - 1.05)	1.00 (0.2 - 1.6)	1.83 (0.5 - 3.0)	4.60 (1.89 - 6.63)	46.6 (41.3 - 51.8)	9.9 (4.6 - 12.8)
	B2 or B21	5.0 (4.9 - 5.2)	5.0 (4.9 - 5.2)	7.2 (5.4 - 8.3)	0.20 (0.15 - 0.24)	21 (20 - 23)	1.0 (1.0 - 1.0)	0.31 (0.26 - 0.33)	0.72 (0.65 - 0.78)	0.30 (0.2 - 0.5)	0.70 (0.5 - 1.0)	2.03 (1.68 - 2.25)	37.0 (34.8 - 41.3)	5.5 (4.8 - 5.9)

¹All averages except for thickness based on five values in the alder-conifer study plots or on three values in the Widow Creek stands.
²Average of 14 measurements in alder-conifer study plots and five in the Widow Creek stands.

In all cases, pH values for soil under the mixed stand are intermediate between pure alder and pure conifer, although tending to be closer to the alder soil. pH values recorded in this study are similar to those obtained in the same stands by Franklin³ and by Bollen and Lu (1968).

Organic matter content. — A horizons have very high organic matter contents (Table 1), particularly in A11 horizons which in the field appear as distinctive, very dark brown horizons dominated by mineral particles. Differences in organic matter content between the A11 horizons under different stands are large at the alder-conifer study site — contents average 37.5 percent under pure alder and 28.9 percent under pure conifer. Data from lower horizons are inconsistent; organic matter contents are slightly higher in B2 horizons under alder than under conifer, but contents in the B2 horizons sampled in the mixed plot are lower than either. Also, greater differences in organic matter content occur in B2 horizons at Widow Creek than in A horizons.

Total nitrogen and C:N ratio. — Nitrogen contents of surface soils under alder consistently average higher than those under conifer — 0.4 percent on the alder-conifer plots (Table 1). Greatest differences are again found in A horizons, but differences are still distinct in B2 horizons.

On the alder-conifer study site, C:N ratios in A horizons under alder average 21 whereas those under conifer average about 28. Similar differences are encountered on A11 horizons at Widow Creek, but alder and conifer soils average the same in A12 horizons. The C:N ratios of the B2 horizons do not differ significantly.

On the mixed plot, nitrogen percent and C:N ratio of the A horizons are intermediate between the alder and conifer plots. Data from the B2 horizon of the mixed plot are not consistent in their ranking relative to the alder and conifer soils; however, total nitrogen percentage of the mixed soil is the same as that in B2 horizons of the conifer soil, whereas the C:N ratio is lower than that in the B horizon of either the conifer or alder soil.

Bollen and Lu's (1968) values for total nitrogen in a given horizon are considerably higher than ours, and conversely, their C:N ratios are generally lower. Except for the relative nitrogen contents of B horizons under alder and conifer, the stands have the same relative ranking, however.

Available phosphorus. — There are no significant differences between soils developed under different vegetative covers in amount of available phosphorus (Table 1). All profiles have greater amounts of available phosphorus in A horizons and lesser amounts in B horizons.

Exchangeable bases. — Quantities of exchangeable bases were low in all soils examined, but they were distinctly lower in soils under alder stands than in soils under conifer stands (Table 1). Base content (sum of exchangeable K^+ , Na^+ , Ca^{++} and Mg^{++}) of A horizons under alder was half or less of those under conifer. If anything, differences were more pronounced in A12 than in A11 horizons. Data from B2 horizons indicated the same relative

³Franklin, Jerry F. *A fertility analysis of the soil under alder, alder-conifer, and conifer cover.* 1962. (Office report on file at Pacific Northwest Forest & Range Exp. Sta., U. S. Forest Serv., Portland, Oregon.)

ranking of stands, but all B horizons were so poor in bases that differences were very small.

Practically all of the difference in base content of soil is due to differing amounts of exchangeable calcium and magnesium. Exchangeable calcium is two to three times more abundant in A horizons under conifer compared with alder, and differences in exchangeable magnesium are even greater. There are no significant differences between stands in amount of exchangeable potassium and sodium.

These data on exchangeable bases agree with the data obtained by Franklin.⁴ Bollen and Lu (1968) reported greater total quantities of exchangeable calcium and magnesium in all stands, but there was still three to five times as much calcium and about twice as much magnesium in the conifer soil as in the pure alder or mixed stand soils. Bollen also recorded greater amounts of exchangeable potassium, but found soil under alder and mixed stands superior to that under conifer in this nutrient.

Cation exchange capacity. – Cation exchange capacities are high and follow trends in organic matter content very closely (Table 1). Average cation exchange capacity of A horizons is greatest under alder and least under conifer, with the mixed stand intermediate. Differences are greater between alder and conifer at the alder-conifer study plots than at Widow Creek, probably reflecting the relative organic matter percentages at the two sites. Cation exchange capacities of the B horizons are lower than those of A horizons. However, except for the mixed plot (for which B horizon data on organic matter content and nitrogen percentage are also inconsistent), B horizons under alder still have higher average cation exchange capacities than those under conifer.

Base saturation. – Base saturation percentages are extremely low, around 4 to 5 percent in A horizons under alder and 10 to 16 percent under conifer. Base saturation in B2 horizons is about 4.5 to 5.5 percent except in soils under the 40-year-old alder stand. These low values reflect the high cation exchange capacities of the soils and very low quantities of exchangeable bases (Table 1).

Total extractable bases were not determined directly in this study. Base saturation percent was calculated by summing exchangeable K^+ , Na^+ , Ca^{++} , and Mg^{++} . Base saturation percentage was 40 to 70 percent higher when total exchangeable bases were determined directly.⁵ Bollen and Lu (1968) found higher base saturation values than we did, even though they did not determine exchangeable sodium.

Total Quantities of Nutrients

When the values previously discussed are placed on a pounds-per-acre basis – adjusted for horizon thickness, stone content, and bulk density – the magnitude and importance of some differences are more apparent. Pounds per acre of total nitrogen, available phosphorus, and exchangeable potassium, calcium, and magnesium to 12- and 36-inch depths are shown in Tables

⁴See footnote 3.

⁵See footnote 3.

2 and 3. Data for the surface 12 inches are more meaningful since each average is based on a larger sample and because the relative influence of different cover types is more easily seen in the surface soil.

Weight of nitrogen (lbs/acre) is much greater under alder or mixed stands than in soils under conifer stands. At the alder-conifer study site, there is 65 percent more nitrogen under the alder stand than under conifer in the upper 12 inches (8,095 vs. 5,308 pounds per acre), and 70 percent more in the upper 36 inches (16,682 vs. 11,721 pounds per acre). Differences are not so great at Widow Creek, although the soil under alder is still significantly higher.

Differences in weight of available phosphorus and exchangeable potassium (lbs/acre) (Tables 2 and 3) are relatively small and inconsistent (e.g., compare relative pounds of phosphorus under alder and conifer at 12- and 36-inch depths). Typically, there are 2 to 4 pounds of phosphorus and 300 to 400 pounds of potassium per acre in the upper 12 inches of soil and 2 to 2½ times this amount to 36-inch depth. The only exception was at Widow Creek where weight of potassium was consistently less in the alder soil than in the conifer soil.

The greatest differences between soils under alder and conifer are in pounds per acre of calcium and magnesium (Tables 2 and 3). In either the upper 12 or 36 inches, there is over three times as much calcium in soils from conifer stands as in those under alder stands, and six or seven times as much magnesium. Soils from the alder and mixed plots were similar in quantity of calcium and magnesium (178 and 171 pounds per acre of calcium, 46 and 99 pounds of magnesium) relative to the amounts found in soil from the conifer plot (607 and 331 pounds per acre of calcium and magnesium, respectively).

Discussion

These data are typical for a coastal Oregon forest soil – high acidity, low base saturation, and high organic matter content. Values are generally within ranges reported by the Forest Soils Committee of the Douglas-fir Region (1957), although organic matter and total nitrogen percentages are somewhat higher. Three items require special consideration, however – the contrasting effects of alder and conifer on soil nitrogen, base content, and acidity.

The contribution alder and its nitrogen-fixing symbiont can make to the nitrogen status of soils is well known. Tarrant (1961) and Tarrant and Miller (1963) compared soil properties under adjacent stands of mixed red alder-Douglas-fir and pure Douglas-fir on an area which had been burned repeatedly in the southwestern Washington Cascade Range. Both studies showed higher levels of soil nitrogen in the 0- to 3-inch depth under the mixed stand – 0.25 vs. 0.14 percent – with significant differences extending to at least 21 inches in depth (Tarrant and Miller, 1963). Nitrogen had accumulated at an average annual rate of 36 pounds per acre more in the mixed than in the pure conifer stand. Similarly, Crocker and Major (1955) and Ugolini

TABLE 2. – Weight of various nutrients in the upper 12 inches of soil¹
(In pounds per acre)

Location and stand	Total nitrogen		Available phosphorus		Exchangeable potassium		Exchangeable calcium		Exchangeable magnesium	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Alder-conifer plots:										
Alder	8,095	6,560	4.0	2.1	386	304	178	85	46	9
		to		to		to		to		to
Conifer	5,310	3,810	2.3	1.7	389	142	607	163	331	104
		to		to		to		to		to
Mixed	6,680	6,090	2.7	1.4	297	173	171	54	99	45
		to		to		to		to		to
Widow Creek:	7,370	6,920	3.2	2.7	234	201	132	63	59	7
		to		to		to		to		to
Conifer	6,450	5,970	3.1	2.3	441	309	314	227	337	219
		to		to		to		to		to
		6,910		4.0		575		410		504

¹Averages for alder-conifer plots based on five profiles per plot; those for Widow Creek based on three.

TABLE 3. — Weight of various nutrients in upper 36 inches of soil¹
(In pounds per acre)

Location and stand	Total nitrogen		Available phosphorus		Exchangeable potassium		Exchangeable calcium		Exchangeable magnesium	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Alder-conifer plots:										
Alder	16,680	15,810 to 17,400	7.4	5.2 to 9.1	1,167	975 to 1,371	324	157 to 525	131	17 to 249
Conifer	11,720	8,210 to 14,610	8.3	4.8 to 14.9	920	515 to 1,172	1,123	476 to 1,602	508	134 to 736
Mixed	12,640	10,815 to 15,207	5.1	4.6 to 5.9	805	512 to 1,090	246	54 to 447	176	45 to 431
Widow Creek:										
Alder	15,160		6.7		668		193		252	
Conifer	14,530		7.3		1,095		564		1,048	

¹Averages in the alder-conifer plots are based on three profiles; there is only one value per plot at Widow Creek.

(1966) have shown *Alnus sinuata* is responsible for a rapid buildup of soil nitrogen on recently deglaciated moraines. Ovington (1956a) found the nitrogen content of litter and mineral soil highest under an *Alnus incana* plantation out of five species present in one of his study areas.

Our study revealed that alder will fix significant quantities of nitrogen, even on sites already having high nitrogen levels. The soil under the conifer stands apparently contains about 12,000 pounds per acre of nitrogen. This nitrogen level is much higher than any previously reported for Northwest forest soils, although two or three other soils comparable or superior in nitrogen fertility have been reported from California's redwood region (Cooper, 1965).

Increased soil acidity and reduced base content in soils under alder had been suggested in an exploratory study.⁶ Generally, however, hardwoods are considered to reduce soil acidity and build up soil fertility through conservation of bases and accumulation of organic matter. This relationship is due to low acidity and high base content of most hardwood leaf litters (Lutz and Chandler, 1946). For example, Daubenmire (1953) found that litter of *Populus tremuloides* was superior in average nutrient content to that of any northern Idaho conifers studied. Average calcium, potassium, and nitrogen contents of the aspen leaf litter were all higher than for the conifers. Tarrant et al. (1951) found that red alder supplied large quantities of leaf litter annually and this litter had the highest nitrogen content of 10 conifers and two hardwoods studied. Contents of calcium and phosphorus were above average for the 12 species. Litter of *Alnus rugosa* ranked first in nitrogen percent and fourth in calcium content when compared with that of three associated conifers and two other hardwoods (Voigt, 1965). Tarrant (1961) found calcium, magnesium, and potassium contents of the soil higher under a mixed stand of red alder and Douglas-fir than under a pure stand of Douglas-fir, although not significantly so.

On the other hand, soils under alder cover are often more acid or lower in bases, or both, than comparable soils under conifer stands. For example, at one site where Ovington (1958) and Ovington and Madgwick (1957) were able to compare soils under a plantation of *Alnus incana*, Douglas-fir, *Pinus nigra*, *Larix leptolepis* and *Betula alba*, litter and soil under alder ranked third in calcium and magnesium content. Soil acidity was greater only under Douglas-fir. On another site, soil pH was lowest under *Alnus incana* when compared with soils under plantations of eight conifers and two other hardwoods. Yamaya (1968) found soil under a stand of *Alnus inokumae* had a much higher exchange acidity, a smaller quantity of exchangeable calcium, and a much lower pH than comparable soils under *Castanea crenata* or *Cryptomeria japonica*. Yet the calcium oxide content of fresh *Alnus inokumae* litter, when compared with three other hardwoods and three conifers (including the above), was exceeded only by that of *Thujaopsis dolabrata*. Crocker and Major (1955) and Ugolini (1966) have both pointed out the acidifying influence of *Alnus sinuata* on morainal soils.

⁶See footnote 3.

Karpachevskiy (1963) found the Ao horizon under Kamchatka alder was not only one of the most acid, but also ranked seventh out of eight species studied in CaO content. In his article, he also compares characteristics of A1 horizons under different plant communities – acidity and exchangeable $A1^{+++}$ was highest under the alder thicket formation. Tarrant et al. (1951) compared the pH of “Ao” horizons under 12 Northwestern species and found the litter was not particularly acid – alder was 10th in a ranking from the most to the least acid. However, the surface soil beneath this Ao layer was the most acid of soil from under all 12 species. A similar phenomenon is apparent in Voigt’s (1965) study – after 3 months of laboratory incubation or 15 months of greenhouse pot culture, litter of *Alnus rugosa* was the most acid of three hardwood and three conifer species studied.

Apparently, either acidity is sufficiently high or amount of exchangeable calcium is low enough under the alder stands we studied to be limiting for some biological processes. Bollen and Lu (1968) found addition of calcium carbonate greatly increased nitrification in soils under alder and mixed stands, but had no influence in the conifer soils.

What explanation can we offer for increased soil acidity and reduced base content in soils developing under alder cover? Our explanation is only conjectural until more research can be carried out, but considers the following points. First, an explanation apparently must be sought in the decomposition process and products and not in the chemical nature of fresh alder litter (with an exception noted below). Red alder litter is not particularly acid (Tarrant et al., 1951), and base content of alder litter is average or better than that of most associated forest species (Tarrant et al., 1951; Yamaya, 1968).

Second, in our study area an abundance of nitrogen-rich litter is deposited annually on the soil surface. Decomposition is rapid in the mild, wet coastal climate. Considerable acidity, i.e., carbonic acid and hydrogen ions, is a byproduct of decomposition processes and of the nitrification process, as ammonium-N is converted to nitrate-N.

These abundant acid byproducts, together with a rainfall of around 100 inches, could result in considerable leaching of already limited exchangeable bases from the surface soil under alder stands. Balci’s (1964) comparison of leachates from red alder and Douglas-fir forest floors in the Puget Sound area appears to substantiate this hypothesis. He found red alder leachates had higher concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, and tannin and lignin compounds than leachates from Douglas-fir forest floors. Furthermore, the magnitude of elemental leaching beyond 15-cm depth was $Ca > Mg > K > N > P$.

However, available data on mineral composition of forest stands suggest that at least a portion of the calcium absent from soil under the alder may be found in the standing crop of trees and understory vegetation. Hardwoods, including alder, typically contain a much greater amount of calcium than do conifers, when growing on comparable sites (Ovington, 1962). Although there is a greater cubic volume of wood in the conifer stand (Berntsen, 1961), more pounds of calcium are probably incorporated in the red alder

stand. Similarly, the calcium content of flora under a stand of *Alnus incana* was found to be much higher than that of flora under other forest stands (Ovington, 1956b). If a similar situation exists at Cascade Head, it would further increase the difference between alder and conifer stands in amount of calcium present in the biomass, particularly since the understory vegetation is much more abundant under alder (Franklin and Pechanec, 1968).

One final thought: Red alder leaf litter contains a phenolic compound not present in any associated conifers. Thus, there are possibilities that this substance, or one of its byproducts, or some other organic compound unique to this genus, effectively mobilizes bases and facilitates their removal from surface soils.

Results of this study suggest some important areas for future investigation. We now know alder will make a significant contribution to the nitrogen economy of almost any site on which it will grow. But how widespread is its effect on soil acidity and base status? These effects were found on the Oregon coast but not in a study in the Washington Cascade Range (Tarrant, 1961). What aspects of alder litter decomposition and what decomposition products are responsible for the phenomenon observed in our Oregon coast study? How much of the "missing" base can be accounted for in the standing crop? Once these questions have been answered, it will be possible to predict the extent and degree to which similar effects of alder on soil can be expected.

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