NOTE

Soil carbon and nitrogen pools and processes in an old-growth conifer forest 13 years after trenching[1]

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Abstract : We measured surface soil (0–15 cm) C and N pools and processes inside and outside an area that had been trenched 13 years earlier in an old-growth conifer forest (>450 years) to assess the long-term impacts of reduced root inputs on C and N turnover. Trenching, combined with frequent clipping of understory plants, was originally conducted to prevent nutrient uptake by plants, as part of a study of the role of vegetation in ecosystem retention of N. Thirteen years following trenching, the median values of bulk density, pH, total C and N concentrations, annual rates of in situ net N mineralization and nitrification, microbial biomass C and N, microbial respiration, and anaerobically mineralizable N in the trenched plot were all within the 25–75% interquartile range of values found in the replicated, untrenched plots. The trenched plot had higher rates of net N mineralization (41% higher in October, 484% higher in June) and net nitrification (25% higher in October, and lower net NO_3^- immobilization in June) during laboratory incubation and a 22% higher water content in October. In June, soil water content in the trenched plot was about 8% lower than in the untrenched plots. Our results suggest that soil C and N dynamics in these old-growth forests are relatively resistant to perturbations resulting from major reductions in root input to the soil.

Résumé : Afin d'évaluer l'impact à long terme d'une réduction des apports par les racines sur le cycle de C et N, nous avons mesuré les pools et les processus de ces éléments dans la partie supérieure du sol (0–15 cm) à l'intérieur et à l'extérieur d'une aire qui avait été isolée 13 ans auparavant dans une vieille forêt de conifères (> 450 ans). L'isolement, combiné avec la taille fréquente des plantes du sous-bois, avait originalement été effectué afin de prévenir le prélèvement des nutriments par les plantes, comme partie d'une étude sur le rôle de la végétation dans la rétention de N dans l'écosystème. Treize ans après l'isolement, les valeurs médianes de la densité apparente, du pH, des concentrations totales en C et N, les taux annuels in situ de minéralisation nette et de nitrification de N, C et N de la biomasse microbienne, la respiration microbienne et N minéralisable anaérobique dans la parcelle isolée étaient tous dans le 25–75% de l'intervalle interquartile des valeurs trouvées dans les parcelles répliquées et non isolées. La parcelle isolée avait des taux plus élevés de minéralisation nette de N (41% de plus en octobre, 484% de plus en juin) et de nitrification nette (25% de plus en octobre et une plus faible immobilisation de NO_3^- en juin) lors d'incubations en laboratoire, et un contenu en eau de 22% plus élevé en octobre. En juin, le contenu en eau dans la parcelle isolée était d'environ 8% inférieur à celui des parcelles non isolées. Nos résultats suggèrent que les dynamiques de C et N du sol dans ces vieilles forêts sont relativement résistantes aux perturbations qui résultent de réductions majeures des apports par les racines au sol.

[Traduit par la Rédaction]

Introduction

Plant roots are a vital component of the soil flora (Brady and Weil 1996; Coleman and Crossley 1996). They alter soils directly by removing nutrients, water, and oxygen and by adding carbon dioxide and organic matter with varying chemical compositions. Indirect effects of roots also are substantial. Root proliferation affects soil structure and alters water and gas storage and movement. Roots comprise a major source of carbon (C) inputs to soils, and consequently, they are important suppliers of the energy that drives soil metabolism and associated nutrient transformations by the soil microflora.

Field experiments employing soil trenching have been used for over half a century to investigate the effects of plant roots on forest soil pools and processes (Romell 1938). Trenching prevents water and nutrient uptake from the treated area by surrounding plants and is usually combined with the installation of plastic or fiberglass barriers to

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prevent root ingrowth. Plant uptake of water and nutrients within the trenched area can be almost completely eliminated by frequent clipping of the vegetation within the plot. Prevention of root ingrowth also leads to reduced belowground inputs of organic matter.

Investigations using trenched plots include those assessing the role of plant roots in nitrogen (N) retention (Vitousek et al. 1982) and transformations (Fisher and Gosz 1986*b*), decomposition processes (Gadgil and Gadgil 1971, 1975; Fisher and Gosz 1986*b*), soil organism abundance (Romell 1938; Babel 1977), and soil respiration (Bowden et al. 1993). Despite these and many other studies that have used trenching to assess the effects of roots on soil pools and processes, few studies have determined the long-term impacts of root exclusion from soil. For instance, Fisher and Gosz (1986*b*) investigated the effects of trenching on soil C and N dynamics. They reported higher in-field rates of cellulose decomposition and laboratory estimates of soil CO_2 evolution and net N mineralization 2 years after trenching in a mixed-conifer forest in New Mexico. We might predict simply that long-term exclusion of the majority of plant roots from soil would have more dramatic effects than the results reported in this short-term exclusion study. Alternatively, long-term effects may be less apparent because the documented changes in soil attributes are short-term responses of the soil system to the recent disturbance of trenching or because other sources of organic detritus are large enough to mask any effects of root exclusion.

In 1990, we revisited an area of old-growth forest that had been trenched in the fall of 1977. This trenched plot was originally established to assess the role of plants in N retention (sensu Vitousek 1977; G. Spycher, unpublished data). We measured various C and N pools and transformation processes both inside and outside the plot to test for possible long-term changes in soil C and N turnover resulting from trenching.

Materials and methods

Study site

Our study site is an old-growth conifer forest stand (adjacent to Reference Stand 2; dominant trees >450 years old) located at an elevation of about 490 m within the H.J. Andrews Experimental Forest, in the central Oregon Cascades (44°14′N, 122°11′W). This stand is composed predominantly of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and scattered western red cedar (*Thuja plicata* Donn ex D. Don) also in the overstory. The stand is on a west-facing, 35% slope, and the soil is an unclassified fine-loamy, mixed, frigid Typic Dystrochrept (a Dystric Brunisol in the Canadian Soil Classification System). The climate in this region is quasi-Mediterranean, with mild, wet winters and warm, dry summers. Annual precipitation is about 2500 mm, and mean annual air temperature is about 9°C. During the sampling period (October 1990 – October 1991), approximately 1800 mm of precipitation fell on the stand, and the mean annual air and soil (10-cm mineral soil depth) temperatures were 8.3 and 8.8°C, respectively.

Experimental design, soil sampling procedures, and field incubations

In the fall of 1977, an area approximately 25 × 35 m that was devoid of large-diameter woody plants was trenched to a 1-m soil depth, well below the limit of most fine roots. To prevent regrowth of roots, the inner wall of the trench was lined with two layers of thick plastic film, and then the trench was backfilled. During the first 20 months after trenching, periodic clipping of understory vegetation further reduced root activity. Clipped vegetation was allowed to decompose on the plot. In the fall of 1990, at least 20 holes (about 20 cm in length by 50 cm in depth) were dug systematically around the trenched plot perimeter to check if the plastic was still excluding roots. No root regrowth into the plot was observed. Although we did not measure root biomass in trenched and untrenched plots, we rarely encountered roots in the trenched plots during soil sieving (see below), while roots were abundant in untrenched plots and were primarily from trees rather than understory vegetation (based on visual differences in root morphology). This result further suggests that the integrity of the root exclosure was maintained over the 13-year period and that the trenching treatment substantially reduced root biomass in the surface mineral soil.

Understory vegetation, composed primarily of blueberry (*Vaccinium* spp.), twinflower (*Linnea borealis* L.), and Oregon grape (*Berberis nervosa* Pursh), was sparse for both trenched and untrenched plots in this closed-canopy forest. Periodic clipping of the small amount of understory vegetation in the trenched plot was resumed in the fall of 1990, with the clipped vegetation again allowed to remain on the plot.

In 1990, eight 3 × 3 m untrenched plots were established systematically on both sides of the trenched plot, along the same topographic contour. On each of two sampling dates (October 18, 1990, and June 4, 1991), soil sampling locations within untrenched plots were determined at random. Soil sampling locations within the trenched plot also were selected at random after areas that had been disturbed from previous studies were removed from consideration (about 33% of the original area). After carefully peeling back the forest floor (O horizon), two adjacent intact mineral soil cores (0–15 cm; one pair within each untrenched plot and eight pairs within the one trenched plot) were removed using 5-cm inner diameter × 20-cm long, thin-walled polyvinyl chloride (PVC) pipe that had been sharpened at one end. One of these cores (the initial core) was placed in a polyethylene bag, kept cool (approximately 4°C), and returned to the laboratory for analysis within 72 h of sampling. These soil samples were used to estimate initial inorganic N concentrations, gravimetric water content, total C and N concentrations (October 1990 samples only), and microbial biomass and for conducting aerobic and anaerobic laboratory incubations (see below). The other core was used to assess net N mineralization and net nitrification rates under field conditions using the resin-core method (see Hart and Perry (1998) for methodological details). Soil cores sampled in October 1990 were incubated until the June 1991 sampling (hereafter called the “winter incubation”). Soil cores sampled in June 1991 were incubated until October 21, 1991 (hereafter called the “summer incubation”). Annual rates were calculated as the sum of the winter and summer incubation rates. Soil bulk densities (here defined as the oven-dry (105°C) mass of the <4-mm soil fraction per unit volume) were estimated using both initial and incubated cores. These values were used to convert field estimates of net N mineralization and nitrification rates from a milligrams N per kilogram to a kilograms N per hectare basis.

Laboratory incubations and analyses

Field-moist soils from initial and incubated soil cores were sieved through a 4-mm mesh screen. Soil water contents were not altered from their field values prior to laboratory incubation, because all soil samples had water contents near field capacity (approximately –33 kPa soil water potential based on a soil water retention curve) at the time of sampling, except for samples taken from the untrenched plot in October 1990, where soil water potential was about –150 kPa. From each initial soil sample on both

Table 1. Selected soil chemical and physical properties and in situ rates of net N transformations (0–15 cm mineral soil) in trenched and untrenched plots of an old-growth conifer forest.

Treatment	Quartile	Bulk density (Mg/m^3)[a]	pH(1:2 mass/mass soil:water)	Total C (g/kg)	Total N (g/kg)	Net N mineralization (kg·ha^{-1}·year^{-1})	Net nitrification (kg·ha^{-1}·year^{-1})
Trenched	75%	0.582	6.04	62.3	2.61	17.7	10.1
	Median	0.528	5.80	50.1	2.31	14.5	5.6
	25%	0.483	5.61	42.4	2.04	12.1	1.8
Untrenched	75%	0.562	5.92	63.9	2.75	26.2	8.3
	Median	0.537	5.75	51.1	2.15	16.8	2.0
	25%	0.468	5.56	39.8	1.85	11.4	0.1

Note: Source of variation in values denoted by the quartiles is within plot for the trenched treatment and among plots for the untrenched treatment; n = 8 for all values except bulk density where n = 32. For all variables, the median value for the trenched plot was within the 25–75% interquartile range of values for the untrenched plots. The trenched plot was established 13 years earlier prior to sampling.

[a] Oven-dry mass of the <4-mm fraction per unit volume.

sampling dates, subsamples were taken to conduct the following assays: net N mineralization, net nitrification, and CO_2 evolution (microbial respiration) during a 30-day aerobic incubation at 22°C; net N mineralization during a 7-day waterlogged incubation at 40°C (anaerobically mineralizable N); and microbial biomass C and N using the chloroform fumigation – incubation method. Details of these methods can be found in Hart et al. (1997).

Statistical analyses

We sampled only one trenched plot, and thus, we do not have any degrees of freedom to statistically test the effect of trenching on the measured soil variables; the eight samples taken from the trenched plot on a given sampling date are subsamples and not true replicates. As a qualitative measure of the relative likelihood that a soil value from the trenched plot came from the same population of values found in the replicated, untrenched plots, we compared the median values (50% quartile) from the trenched plot with the 25–75% interquartile range of values from the untrenched plots. Median values from the trenched plot lying outside this range were considered different from the untrenched values.

Results and discussion

Thirteen years of root exclusion from this old-growth soil appeared to have little effect on soil C and N pools and processes (Tables 1 and 2). Trenched and untrenched plots had similar values of bulk density, pH, total C and N concentrations, and annual rates of net N mineralization and nitrification measured in situ (Table 1). Seasonal patterns of in situ net N mineralization and nitrification (i.e., winter and summer incubations) also were similar (data not shown).

Higher soil water contents typically are found following trenching, presumably because of reduced transpirational water loss (Horn 1985; Fisher and Gosz 1986*b*; Hope and Li 1997). We also found a higher soil water content (about 22%) in the trenched plot in October 1990, but soil water content in the trenched plot in June was about 8% lower than in the untrenched plots (Table 2). The difference in soil water content between treatments in October may reflect the accumulated effects of transpiration throughout the warm summer months, with limited soil water recharge due to lack of summer precipitation. However, this difference in water content was still modest in absolute magnitude (about 0.09 kg/kg) and in terms of soil water potential (about 120 kPa lower in untrenched plots). With a monthly sampling intensity over a 2-year period, Hope and Li (1997) also found significant but relatively small absolute changes in mineral soil water content following trenching in a similar old-growth stand within the H.J. Andrews Experimental Forest.

If the rate of plant assimilation of N is the only potential fate of inorganic N altered by trenching (i.e., microbial N assimilation, denitrification, and leaching remain unchanged), we would expect higher soil inorganic N concentrations in trenched than untrenched plots. However, we found similar inorganic N concentrations on both sampling dates, and inorganic N pool sizes were consistently small (< 1 mg N/kg; Table 2). Similar values of microbial biomass C and N, microbial respiration, and anaerobically mineralizable N (another index of microbial biomass; cf. Myrold 1987) in trenched and untrenched plots on both sampling dates (Table 2) also suggest that rates of microbial N assimilation are similar between treatments. Higher denitrification rates following trenching are unlikely to offset any increase in inorganic N concentrations resulting from reduced plant N uptake, because ambient denitrification rates are low in these forests (Vermes and Myrold 1992), and NO_3^- comprised less than 5% of the inorganic N pool in trenched and untrenched plots (NO_3^- was not detected in untrenched plots; data not shown). Higher soil water contents in the trenched plot also might have led to higher N leaching rates, resulting in similar inorganic N concentrations in trenched and untrenched plots despite reduced plant N assimilation in the former. At a similar old-growth Douglas-fir site in Washington (≈300 years), Vitousek et al. (1982) reported higher NO_3^- leaching rates following trenching; however, leaching of NH_4^+ was low or nonexistent. Nevertheless, the small differences in inorganic N concentrations in the surface mineral soil that we found 13 years following trenching are consistent with the relatively short-term (<2 years) observations made by Vitousek et al. (1982) for these forest ecosystems.

The only measured C and N pools or processes that appeared to be altered by trenching were net N transformation rates measured during aerobic laboratory incubation (Table 2). Median rates of net N mineralization and nitrification in the trenched plot were higher than the 75% quartile values of the untrenched plots on both sampling dates. Fisher and Gosz (1986*b*) found higher rates of net N mineralization and microbial respiration during aerobic laboratory incubations of soils from recently trenched plots (about 2 years prior to

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sampling) within a mixed-conifer forest in New Mexico. Based on water addition studies, they attributed these differences to the reduction in microbial activity by plant water uptake in untrenched plots. Because soil water content differences between trenched and untrenched plots in our study were relatively small compared with changes in net N transformation rates, this mechanism does not explain completely our observed differences. Hence, we hypothesize that the exclusion of plant roots from this soil for 13 years has increased the quality of organic matter for net N mineralization, perhaps by reducing the ratio of available C to N (Hart et al. 1994) or by preventing mycorrhizal fungi from consuming labile organic-N pools (Allen 1991). Higher rates of net N mineralization should increase NH_4^+ availability to autotrophic nitrifiers (Hart et al. 1994) and ultimately lead to the greater net nitrification rates we observed during laboratory incubation. However, our other measures of C (microbial biomass C and respiration) and N (microbial biomass N and anaerobically mineralizable N) availability do not support this hypothesis (Table 2).

Organic matter quality may have improved if aboveground litter produced a more labile N source than root-derived soil organic matter. Reductions in root inputs should have increased the relative contribution of aboveground litter inputs to the soil organic matter pool. In a similar old-growth stand within the H.J. Andrews Experimental Forest, Sollins et al. (1980) estimated that net N mineralization rates from litterfall were higher than from root turnover, despite greater detrital C inputs from roots than leaves. However, we have no evidence that these initial differences in organic matter quality are preserved as these materials are transformed to humus in the mineral soil.

In general, our in situ and laboratory estimates of net N mineralization and nitrification provided conflicting evidence on the effect of long-term root exclusion on these processes. The failure of our in situ incubations to show patterns similar to the laboratory incubations may be partially due to the fact that laboratory measurements are made under more optimal conditions of temperature and water content than field measures (Binkley and Hart 1989). Hence, abiotic factors may limit the degree to which laboratory measures of net N transformations agree with field measures (Fisher and Gosz 1986*b*). Differences in the degrees of soil disturbance between the two methods also might contribute to the contrasting patterns (Binkley and Hart 1989), especially considering that in situ incubations create their own small trenched plots. For instance, the excising of roots during soil coring (which would be more significant in the untrenched plots) might have increased net N mineralization rates by increasing substrate availability to microbial heterotrophs (Fisher and Gosz 1986*a*). We know of no other study that has measured rates of net N transformations in situ both inside and outside trenched plots, so we are unable to assess whether or not our results are novel.

The lack of detectable changes in total C and N pools in the upper 15 cm of mineral soil is not surprising given the relative magnitudes of these pools in this old-growth forest and the annual contributions from plant roots. For instance, if we assume that 50% of fine root turnover occurs in this soil layer (Santantonio 1979) and that roots contribute 1.08 $Mg\ C \cdot ha^{-1} \cdot year^{-1}$ to the mineral soil organic matter pool

Table 2. Laboratory indices of C and N availability in mineral soil (0–15 cm) sampled on two different dates from trenched and untrenched plots in an old-growth conifer forest in Oregon.

Sampling date	Treatment	Quartile	Water content (kg/kg)	Microbial biomass C (mg C/kg)	Microbial respiration (mg C/kg)[a]	Microbial biomass N (mg N/kg)	Extractable inorganic N (mg N/kg)[b]	AMN (mg N/kg)[c]	Net N mineralization (mg N/kg)[a]	Net nitrification (mg N/kg)[a]
Oct. 1990	Trenched	75%	0.514	1352	1084	200	1.03	51.5	4.76	2.28
		Median	0.468*[d]	1151	901	173	0.80	38.8	4.38*	2.09*
		25%	0.375	967	856	144	0.67	29.0	3.06	1.94
	Untrenched	75%	0.417	1391	1001	199	0.94	43.6	3.90	1.87
		Median	0.383	995	597	159	0.78	30.6	3.11	1.67
		25%	0.323	751	404	114	0.70	21.7	2.24	1.65
June 1991	Trenched	75%	0.428	998	nd	147	0.90	36.9	4.79	0.56
		Median	0.404*	824		131	0.74	26.6	2.92*	−0.17*
		25%	0.396	673		104	0.65	21.4	2.30	−0.26
	Untrenched	75%	0.461	1510	nd	214	0.76	40.0	2.04	−0.33
		Median	0.440	974		153	0.74	23.8	0.50	−0.35
		25%	0.417	819		117	0.66	14.8	0.14	−0.37

Note: Source of variation in values denoted by the quartiles is within plot for the trenched treatment and among plots for the untrenched treatment; $n = 8$ for all values. The trenched plot was established 13 years earlier prior to sampling. nd, not determined.

[a] Amount produced over a 30-day aerobic laboratory incubation.

[b] All of the extractable inorganic N in the untrenched plots and almost all in the trenched plot was in the NH_4^+ form.

[c] Anaerobically mineralizable N.

[d] Asterisks show median values for trenched plots outside the 25–75% interquartile range of values for the untrenched plots.

(assuming organic matter contains 45% C; organic matter data from Sollins et al. 1980), 13 years of root exclusion should have resulted in about an 8.8 g C/kg reduction in the total C concentration of the 0–15 cm soil layer. Subtracting this amount from the median total C value for the untrenched plot would result in a value that would remain higher than the 25% quartile for total C in the untrenched plot (Table 1). A similar calculation for total N indicates a predicted reduction of about 0.18 g N/kg from 13 years of root exclusion, which also results in a value higher than the 25% quartile for total N in the untrenched plot (Table 1). Even if we had replicated trenched plots and increased our sample size to detect these potential changes statistically, losses in total C and N stocks of these magnitudes may be functionally insignificant, given that we did not observe any negative impacts on C and N transformations after 13 years of root exclusion.

In summary, our study demonstrated that even with the large reduction in organic matter inputs to an old-growth conifer forest by trenching over a 13-year period, few detectable changes in C and N pools and processes occurred. We suggest that these old-growth forests, with their large organic matter reserves, are well buffered against such disturbances. The mechanistic research currently underway in replicated, newly trenched plots on the H.J. Andrews Experimental Forest may help elucidate the functional roles of various organic matter sources and pools within these old-growth conifer forests.

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