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Nitrogen-fertilization impacts on carbon sequestration and flux in managed coastal Douglas-fir stands of the Pacific Northwest

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Abstract

We examined whether N-fertilization and soil origin of Douglas-fir [*Psuedotsuga menziesii* (Mirb.) Franco] stands in western Washington state could affect C sequestration in both the tree biomass and in soils, as well as the flux of dissolved organic carbon (DOC) through the soil profile. This study utilized four forest sites that were initially established between 1972 and 1980 as part of Regional Forest Nutrition Research Project (RFNRP). Two of the soils were derived from coarse-textured glacial outwash and two from finer-textured volcanic-source material, primarily tephra, both common soil types for forestry in the region. Between 1972 and 1996 fertilized sites received either three or four additions of 224 kg N ha^{-1} as urea (672–896 kg N ha^{-1} total). Due to enhanced tree growth, the N-fertilized sites (161 Mg C ha^{-1}) had an average of 20% more C in the tree biomass compared to unfertilized sites (135 Mg C ha^{-1}). Overall, N-fertilized soils (260 Mg C ha^{-1}) had 48% more soil C compared to unfertilized soils (175 Mg C ha^{-1}). The finer-textured volcanic-origin soils (348 Mg C ha^{-1}) had 299% more C than glacial outwash soils (87.2 Mg C ha^{-1}), independent of N-fertilization. Soil-solution DOC collected by lysimeters also appeared to be higher in N-fertilized, upper soil horizons compared to unfertilized controls but it was unclear what fraction of the difference was lost from decomposition or contributed to deep-profile soil C by leaching and adsorption. When soil, understory vegetation and live-tree C compartments are pooled and compared by treatment, N-fertilized plots had an average of 110 Mg C ha^{-1} more than unfertilized controls. These results indicate these sites generally responded to N-fertilization with increased C sequestration, but differences in stand and soil response to N-fertilization might be partially explained by soil origin and texture.

Keywords: Carbon sequestration; Lysimeters; Dissolved organic and inorganic carbon; *Pseudotsuga menziesii*; Urea fertilization; Soil texture; Volcanic and glacial soils

1. Introduction

Due to the potential for increased forest products yield as well as higher financial returns, N-fertilization

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impacts on Pacific Northwest forests continue to be a subject of interest in the region, including additional C sequestration from applied N (Johnson, 1992; Canary, 1994; Harrison et al., 2003). Carbon uptake through increased growth of trees is well documented, but the effects of N-fertilization on soils are much less understood (Johnson, 1992; Birdsey et al., 1993; Huntington, 1995; Lal, 2004), particularly at time intervals greater than a few years (Carter et al., 2002). Variations in input of litterfall over time, changes in fine and coarse-root growth, death, decay and production and decomposition of exudates are particularly poorly understood (Prescott et al., 1999; Neff and Asner, 2001; Kalbitz et al., 2000; Qualls, 2000). Most studies of N-fertilization impacts on C sequestration in soil have also sampled relatively shallow soil profiles (Canary, 1994; Harrison et al., 2003), sometimes ignoring what happens in the deeper, more massive subsoil horizons common in the region. Carbon in subsoil horizons can change substantially over time periods of decades under certain conditions (Cole et al., 1991), though this is commonly discounted as a major impact of N-fertilization. Earlier work on N-fertilization effects on soil C indicated that C sequestration in aboveground tree biomass increased with fertilization in sandy skeletal to rocky soils (Canary et al., 2001; Nohrstedt et al., 1989), but results on finer-textured soils were more variable. Urea fertilizer increased the short-term movement of SOC by a factor of 2–3 in an eastern deciduous forest (Kelly, 1981) with most of this flux occurring during the 3 months following urea application. There is no data available on long-term impacts of N-fertilization, though there is evidence that it can affect mineralization and movement of organic N (Prietzel et al., 2004).

This study considered previous N-fertilization effects on stand and soil C in two important soil-origin types for intensive forestry in Pacific Northwest Douglas-fir: (1) two soils derived from coarse-textured glacial outwash, and (2) two soils derived primarily from volcanic-origin. Ecosystem C pools to 1.0 m depth were quantified, and soil-solution C flux at four soil depths were estimated to determine if movement of soluble C into the soil profile might partially explain any changes in C in the soil profile over time due to fertilization.

2. Materials and methods

2.1. Site description

Starting in 1969, the Regional Forest Nutritional Research Project (RFNRP) established several hundred studies in the Pacific Northwest to evaluate the response of coastal Douglas-fir to N-fertilization (Stegemoeller and Chappell, 1990a; Stegemoeller et al., 1990b; Briggs, 1999). Research installations normally included N-fertilization, and always included an unfertilized control. Plot measurement areas were typically 0.0404 ha. Stand response was measured over time by periodic measurement of tree diameters and heights. The studies were not initiated with the idea of measuring C sequestration, but the relatively long life of the RFNRP compared to typical research projects makes these sites ideal for determining the long-term impact of N-fertilization on forests and soil. For this study, four installations were selected (Table 1) that had been previously fertilized beginning at least 20 years previously. Data on the stand and site are presented in Table 1. Total N application rates ranged between 672 and 896 kg N ha^{-1}, with either three or four individual applications of 224 kg N ha^{-1} as urea.

The soils represent a regional grouping of parent material types from a very coarse skeletal glacial outwash to deep, silt loam derived from volcanic-origin (Soil Survey Staff, 2004). Soil profile descriptions are given in Table 2. Site 1, a Barneston series soil, was coarse outwash with 88% of the soil >2 mm. Site 2, a Poulsbo series soil, was deep sandy outwash, with only 23% of the soil in the silt or clay fraction, and finer only in comparison to the soil at Site 1. Site 3, a Winston series soil, was coarse loamy ash above glacial or fluvial (mudflow) material with 57% silt and 8% clay, and Site 4, a Typic Hapludand, was a deep (>1 m) ashy loam, tephra mix, with 64% of the total soil matrix in the silt fraction (Table 2).

2.2. Aboveground tree carbon

As part of RFNRP protocols, stem diameters at 1.3 m and heights of all live trees (DBH) on each plot were measured between the time of the initiation of fertilization and over a 20-year period. Aboveground tree biomass (including branches, bark and foliage)