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Forest Ecology and Management 212 (2005) 264–277

Forest Ecology and Management

www.elsevier.com/locate/foreco

Fine root biomass, production and its proportion of NPP in a fertile middle-aged Norway spruce forest: Comparison of soil core and ingrowth core methods

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Received 18 August 2004; received in revised form 26 November 2004; accepted 30 March 2005

Abstract

Fine root bio- and necromass, net primary production (NPP) of fine roots and its proportion of the NPP of trees, as well as turnover rate were investigated in a fertile middle-aged Norway spruce (*Picea abies* (L.) Karst) stand by sequential core and ingrowth core methods. The stand's site type is *Oxalis*, the site quality class is I[a] and the soil type is Umbric Luvisol (FAO classification). Twenty soil cores (volumetric samples, core diameter 38 mm) were taken monthly during the period June-1996 to November 1996 and in June-1997. Ingrowth cores were collected, 15 at a time, during the growing seasons from 1997 to 1999, once after first year and three times in the second and third years. Spruce roots from samples collected by both methods were separated into living and dead roots (two diameter classes: <1 and 1 mm $\leq d <$2 mm). The fine root NPP was calculated according to the decision matrix, and root turnover rate was calculated as annual root production divided by mean fine root biomass.

The mean biomass of fine (<2 mm) and finest (<1 mm) roots in ingrowth cores collected in the third year after installation was two times smaller than that in soil cores. The mean fine root biomass was 1420 $\pm$ 170 kg ha^{-1} in soil cores and 700 $\pm$ 105 kg ha^{-1} in the third year ingrowth cores. The finest roots formed ca. 2/3 of fine root biomass. The fine root NPP estimated by the sequential core method was 2510 and 965 kg ha^{-1} year^{-1} by the ingrowth core method (third year after installation). The fine root turnover rate was 1.8 year^{-1} for sequential cores and 1.4 year^{-1} for third-year ingrowth cores. The inverse of the root turnover rate is, in turn, a measure of average root longevity; it was smaller for the finest roots in both cases. In the investigated spruce stand the annual NPP of trees at the age of 40 years is estimated as 21.4 t ha^{-1} year^{-1}, the share of the belowground part forming 31%. Fine roots accounted for 13% of the NPP, which is a relatively small value compared to the results revealed in most studies.

Keywords: Biomass; Fine root; Net primary production; *Picea abies* (L.) Karst.; Turnover rate

1. Introduction

Fine root net primary production constitutes an important, but often unmeasured, part of the carbon

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doi:10.1016/j.foreco.2005.03.064

budget of forest ecosystems. Direct measurements are problematic in many ways, and the assessment methods are extremely labour-intensive. Various methods, both direct and indirect, have been used to measure fine root biomass and production; most often by sequential coring (Persson, 1978; Fairley and Alexander, 1985; Ahlström et al., 1988; Yin et al., 1989; Helmisaari et al., 2002) or ingrowth cores (Persson, 1983; Makkonen and Helmisaari, 1999; Jones et al., 2003), minirhizotron method (Majdi and Nylund, 1996; Majdi and Kangas, 1997; Burton et al., 2000; King et al., 2002), and indirect methods, such as the N budget (Aber et al., 1985; Nadelhoffer et al., 1985) or C budget approach (Raich and Nadelhoffer, 1989). A critical review of the existing root biomass and NPP assessment methods and their advantages and disadvantages was published by Vogt et al. (1998) and some aspects of problems and progress in estimating fine root production were discussed by Nadelhoffer (2000).

However, tremendous controversy exists in the published literature as to which is the best method to determine fine root biomass and NPP. One of the reasons for controversy in estimating fine root production and turnover in forests is that trees have highly variable patterns of allocation of photosynthates to fine roots (varying from 4 to 69% of total plant carbon annually fixed), which can therefore significantly affect the ecosystem-level processes (Vogt et al., 1996). Carbon is translocated from aboveground part to the root system during root growth and maintenance, and is added to the mineral soil and forest floor carbon pools via hyphae at ectomycorrhizas and rhizodeposition as root litter or root exudates. Microbial communities in soil, rhizosphere and in decomposing root litter are supported by assimilates from trees (Lõhmus et al., 1995; Lõhmus and Ivask, 1995; Read, 1997). The estimate of net photosynthates allocated to mycorrhizal fungi can range from 5 to 85% among different systems (Allen, 1991). The carbon cost of fungal or bacterial symbionts in root systems should be included as part of field estimates of belowground production, but is not, because of sampling difficulties (Vogt et al., 1998). Data on how much fungal tissues incorporated in ectomycorrhizas contribute to biomass for field grown tree roots, and information on the carbon cost of the fungal partner incorporated into ECM tissues are still scarce (Rousseau and Reid, 1989; Lindahl et al., 2002; Hobbie and Colpaert, 2003). Further, there was discussed in the literature how big rate of the C allocated to roots is respired (Högberg et al., 2001, 2002). Hence, more empirical data on the belowground part of forest ecosystem are needed.

There is very important to understand how soil environmental factors, such as nutrient availability, water conditions, temperature etc., affect fine root turnover and influence C allocation strategies at the scale of tree or whole forest ecosystem. Improved nutrient availability sometimes leads to decreases in fine root production (in absolute terms or as a proportion of total stand production) and biomass within forest type (Haynes and Gower, 1995), but evidence exists for both increased (Keyes and Grier, 1981; Vogt et al., 1986; Pregitzer et al., 1993) and decreased (Aber et al., 1985; Nadelhoffer et al., 1985; Nadelhoffer, 2000; Pregitzer et al., 1995) fine root life spans in more fertile soils. In optimal site conditions, both the root/shoot ratio and the proportion of fine roots in net production may decrease (Olsthoorn, 1991; Vogt et al., 1987).

This paper reports the results of attempts to analyse the relations of different methods (sequential coring and ingrowth cores) to study fine root biomass and NPP in Norway spruce stand of a high productivity. The sequential coring method has been the most common approach to determining fine root biomass and NPP in the field (Vogt and Persson, 1991), where both the biomass and necromass data reflect the natural status. For ingrowth cores, a stabilisation period is required, and older roots are missing in initially root-free soil volumes. Because the roots are still expanding into the ingrowth cores in the third year (Makkonen and Helmisaari, 1999), comparison of absolute values between the two methods is difficult. Therefore, we suggest, more relative parameters should be used: biomass:necromass ratio, root turnover rate, longevity, biomass and NPP proportions of different root diameter classes and the results received by different methods should be compared. On the basis of the data from the two methods, we tried to find a combined method for determining the NPP of fine roots that would be less time consuming.

We hypothesised that the proportion of fine roots in the total biomass as well as in the annual NPP decreases as site conditions improve. We have studied