Carbon stores in tree fine roots and understorey belowground biomass in forested mineral soils - relationships to site, stand and climate factors

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Introduction

Fine roots of trees and understorey vegetation play an important role in the carbon and nutrient dynamics of forest soils. However, there is insufficient quantitative information available about their contribution to the carbon and nutrient budgets (Gower et al. 1994, Bartelink 1998, Trumbore & Gaudinski 2003). Fine roots are constantly renewed, and their productivity often exceeds aboveground productivity despite the fact that living fine root biomass constitutes only a small fraction of the total stand biomass (e.g. Helmisaari et al. 2002). Globally, 33% of the global annual NPP is estimated to be used for the production of fine roots (Jackson et al. 1997). Although understorey vegetation represents a relatively minor component of the whole biomass of boreal forests, it plays an important role in the annual biomass production and carbon and nutrient cycling, especially at northern latitudes.

Carbon and nutrient inputs into the soil in the form of fine root litter may be several times larger than the corresponding inputs from aboveground litter (Ruess et al. 1996, Scheffer and Aerts 2000). Thus, a high proportion of soil organic matter originates from dead and decomposing fine roots.

Soil properties affect the growth dynamics of fine roots and mycorrhizas both directly and indirectly via the aboveground parts of plants. The rate of growth of fine roots is affected by the availability of carbohydrates and nutrients, and by environmental factors such as soil temperature and moisture content. The relationships between fine root growth dynamics and these factors are not well known. The distribution of fine roots in different soil layers is assumed to be related to climate and site characteristics, such as soil structure and compactness, which also affect soil temperature, moisture content and aeration, as well to the mode of root growth of different plant species.

Quantification of fine roots is needed for estimating their role as carbon stores and sources of the soil litter input. If the relationships between fine roots and more easily measurable variables could be identified, then this would be important for carbon modelling and reporting.

The aims of this study were to 1) to describe the variation of Norway spruce and Scots pine fine root and understorey belowground biomass and their C concentration in different sites in Finland, 2) to assess whether there are relationships between fine root biomass and site, stand and climate factors.

Material and methods

We studied fine root distribution in 25 coniferous stands in Finland - 13 Norway spruce and 12 Scots pine dominated stands. Sixteen of the stands belong to the Finnish intensive network of the Level II EU/Forest Focus and UN-ECE/ICP Forests monitoring programmes.

The stands are located in different parts of Finland and represent relatively different climate, site types and stages of stand development. The thicknesses of the organic layer varied between 5 and 10 cm in the spruce stands and between 2 and 5 cm in the pine stands. The spruce stands are located on till soils with a stoniness varying between 16 and 51 % of the soil volume (0 to 30 cm mineral soil layer). Most of the pine stands are growing on sandy soils, with an average stoniness of between 0.5 and 9 % .

From each stand, 12 soil cores at different sampling times were taken with a cylindrical soil corer, and the samples were divided up into the organic layer, and mineral soil layers down to 30 cm mineral soil. Roots were separated from the soil by washing and sorted into living and dead roots, and further into pine, spruce, birch and other broadleaved, and understorey roots (mainly shrubs and grasses). Roots were divided into diameter classes, and then dried and weighed. Roots smaller than 2 mm were regarded as fine roots, and they included mycorrhizal short root tips. The fine root biomasses in the mineral soil were corrected with the stoniness index.

Tree species, diameter (1.3 m above ground level), tree height and the crown length were measured on all trees on the plot with a breast height diameter of at least 4.5 cm. This allowed accurate determination of individual tree volumes and basal areas, as well as respective stand level characteristics.

Results

Variation in tree and understorey root biomass

The total fine root biomasses of all tree species and understorey roots and rhizomes (< 2 mm diameter) varied between 2070 and 5520 $kgha^{-1}$ in the Norway spruce dominated stands and between 2300 and 4930 $kgha^{-1}$ in the Scots pine dominated stands. Fine and small root (< 5 mm diameter) biomasses varied between 3790 and 11620 $kgha^{-1}$, and the respective C amounts between 1860 and 5690 kg Cha^{-1}.

The spruce stands in northern Finland had nearly twice as large a total fine root biomass than those in southern Finland. This was due to the understorey roots and rhizomes that were clearly more abundant in northern than in southern Finland. The pine stands had a large understorey belowground biomass also in southern Finland. There was a clear relationship between all the fine roots in the stand (understorey belowground biomass and tree fine roots) and latitude as well as with the temperature sum in both the spruce and pine stands.

In northern Finland up to 50 % of the soil carbon in the organic layer was tree and understorey fine and small root (diameter < 5 mm) carbon, while in southern Finland the percentage was considerably smaller. Thus, because only the larger roots are removed prior to milling of the organic layer samples for soil carbon analysis, fine and small roots may explain a considerable part of the temporal and spatial variation in the amount of carbon in the organic layer.

The fine root biomasses in our study were determined on the 2 to 10 cm thick organic layer plus the 30 cm thick mineral soil layer. The proportion of fine root biomass in the deepest layer (20 to 30 cm mineral soil) was small, 7.5 ±4.1 % of the whole soil core in the spruce and pine stands. Thus, the error in fine root biomass resulting from not sampling deeper layers is relatively small.

Fine root biomass and stand characteristics

Commonly used variables describing the stand structure (volume, basal area, number of stems, needle biomass) did not show any notable correlations with the fine root biomass at the stand level. In contrast, considerably better correlations were found when the parameters were calculated for an average tree by dividing the stand values by the stem number. When the

northern and southern sites were analysed separately, the fine root biomasses per tree of both species correlated well with e.g. the basal area per tree.
Most of the understorey belowground biomass consisted of dwarf shrub rhizomes which explains the strong relationship with the dwarf shrub aboveground cover, especially in the spruce stands.

The ratio of needle biomass to fine root biomass varied between 2.1 and 6.4 for spruce, and between 0.8 and 2.2 for pine. The ratio was clearly smaller in the spruce stands in northern (2.1-3.4) than in southern (3.6-6.4) Finland. This seems to imply that less fine roots are needed to maintain a specific amount of foliage when nutrient availability is higher (c.f. Gower et al. 1992, Vanninen & Mäkelä 1999).

Several of the relationships found at the stand and tree level can be used for predicting fine root biomass and the amount of carbon it contains. At the stand level, especially the relationships between needle and fine root biomass ratio and the basal area are useful. However, the number of study sites included in this study was limited which is a frequent problem in studies on the root systems of forest trees and understorey.

Fine root dynamics

We also studied fine root biomass and litter production and decomposition in some of the stands using repeated sampling of soil cores, ingrowth cores and in recent years also minirhizotrones (digital photos taken in transparent tubes for determining fine root longevity and elongation). Fine root litter production was quantitatively comparable to aboveground litter production but the variation was high, e.g. in relation to drought. This means that global change models still have to incorporate the spatial and temporal variability in root turnover rates *(Matamala et al. 2003*). Ecosystem level field studies are continuously needed for understanding and predicting the belowground responses to global change.

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