

## Belowground turnover rate and carbon sequestration of fine roots in forest soil

Hans Persson

Department of Ecology, Swedish University of Agricultural Sciences, Box 7044, 750 07 Uppsala, Sweden

Investigations of fine-root growth and turnover in forest ecosystem have been hampered by the fact that: i) their important role in the carbon and mineral nutrient cycling has not been clear to many ecosystem research workers ii) there are no simple or standardized methods of fine-root investigation; iii) a hard work is necessary in order to obtain data of turnover rates. One obvious discouragement to investigations of distribution and function of tree root systems is their variable form and extensive distribution in the soil, which complicate root investigations. The root system of a 13-year old Scots pine, with lateral roots that extended 5-6 m from the tree stem, is an illustrative example (Fig. 1).

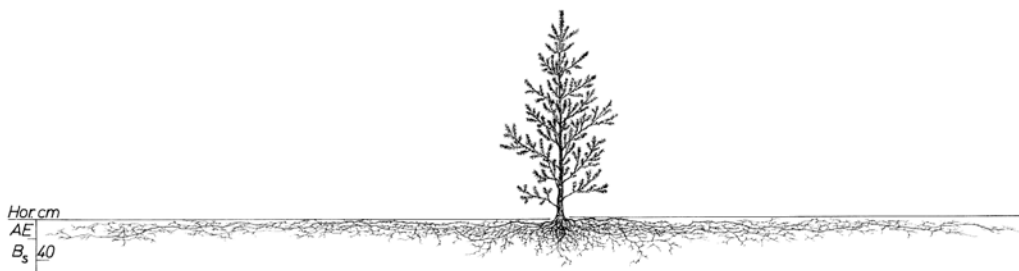


Fig. 1. A 13-year-old Scots pine (*Pinus sylvestris* L.) excavated at Jädraås Central Sweden in connection with the ISRR symposium in August 1988 in Sweden (Kutschera et al. 1997).

The tree root systems are not a conspicuous feature of the terrestrial landscape in temperate and boreal forests, but they comprise for a heavy portion of the biomass of the forest trees (e.g. 15-30 % of the total tree dry weight; cf. Persson 2002). Tree fine roots contribute to some 0.8-5.5 t DW ha<sup>-1</sup> (fine roots < 2 mm in diameter; Scarascia-Mugnozza et al. 2000) and contribute most substantially to the total belowground carbon flow, due to a high turnover rate.

Fine roots are short-lived and must be renewed continuously. As a consequence the amounts of live, dead or live + dead fine roots are fluctuating considerable during the season (cf. Fig. 2). The initiation of new root tips, the penetration and renewal of the absorptive area of the root tissue and the death of inactive ramifications, provides the plant with a root system which is stable in its function at any time. Both sustainability and renewal of the expanding root tips is critical to the overall function of the root systems. Besides the lack of good and not too time-consuming sampling methods of sampling fine roots, fine-root investigations have been hampered by the difficulties of sorting the excavated root fragments into live and dead fractions.

It is essential to use well defined morphological criteria, while sorting the root fragments into species and live and dead root categories (cf. Vogt and Persson 1991). Reliable estimates of fine-root production and turnover (mycorrhizal and non-mycorrhizal) depend on a clear distinction between live (biomass) and dead (necromass) roots. A high live/death ratio, in a forest stand, indicates a healthy root system with a high rate of soil penetration, e.g. an efficient uptake function. The live/death ratio of the fine roots is reflecting the vitality of the fine roots, both temporarily and spatially in the soil profile.

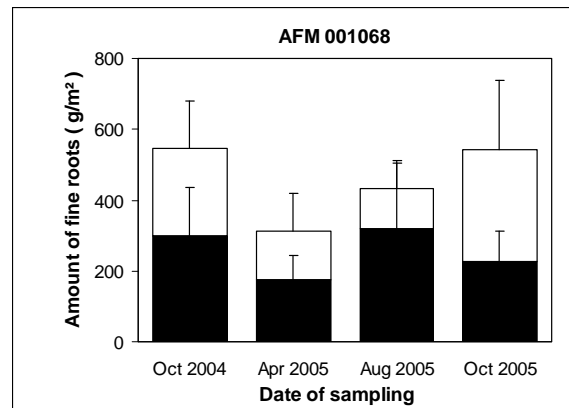


Fig. 1. The amount of live (unfilled bar) and dead (black bar) fine roots (< 1 mm in diameter) on the four sampling occasions during a year (from Persson and Stadenberg 2007). Mean values  $\pm$  SD.

In cases when there is a difficulty to judge if a root fragment is live or dead, it may be useful to cut it lengthwise with a sharp dissection knife and base the vitality judgement on the colour between cortex and periderm. The stele of live roots is white to slightly brown and elastic. Live fine roots are often well branched, the root tips are light and turgid or changed to mycorrhizal ramifications. In dead roots the stele is brownish and easily broken, and the elasticity is reduced. Dead fragmented root pieces with a length < 1 cm are not included as dead and regarded as soil organic matter.

The average amounts of fine roots are strongly affected by the high variability of the samples from one sampling occasion to the next (Fig. 2). It is important to get a good average annual estimate of the amount of fine roots in the live, dead or live + dead compartments from several sampling occasions for the calculation of turnover rates. High levels of starch reserves, up to 30% of the dry weight of roots <5 mm in diameter, are available throughout the growing season (Ericsson and Persson 1980). It is therefore reasonable to conclude that food supply is not limiting root growth.

Tree fine roots stay alive in the soil even if the aboveground photosynthesising parts of the trees are removed. In a mature, 120-year-old, Scots pine stand at Jädraås, the tree fine roots stayed alive for two growth periods after clear-cutting (Fig. 3). The tree stand was clear-felled and the amount of living and dead fine-roots was measured in two strata with and without twice the ordinary amount of felling litter.

The annual changes in live, dead or live + dead fine roots (fluxes) can be calculated from significant increments in the amounts of fine roots obtained from sequential core sampling; from the amount of fine roots in ingrowth cores; or from the root length

increments against transparent minirhizotron tubes (Vogt and Persson 1991). Ingrowth cores consist of cores of root-free soil imbedded in the soil profile and remove sequentially to obtain fine-root biomass and necromass.

The term turnover rate of a certain root category means by definition at what rate that fraction is replaced during a year. There is a large amount of data available on belowground carbon turnover rates in forests; however, these data must be critically evaluated.

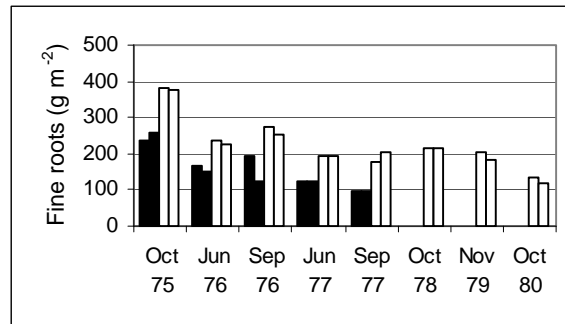


Fig. 2. The amount of live (black bars) and dead (unfilled bars) fine roots (< 2 mm in diameter) before and after clear-felling in a mature 120-year-old Scots pine at Jädraås, Central Sweden. Clear-felling took place in March-April 1976. Root sampling was carried out from October 1975 until October 1980 in two strata (data from Persson 1982).

Only significant increments (production) during one year should be used for live, dead and live + dead amounts of fine roots and compared with averages estimates of the same root compartments (cf. Vogt and Persson 1991; Persson and Stadenberg 2007; Persson and Stadenberg in press). The sum of increments and the averages change in a certain forest site may differ considerable between years; it is therefore advisable to use only data for the same year of investigation for the turnover calculations. The often reported discrepancy in the data of fine roots in literature may, be due to imprecise definition of size classes (diameter), or in unspecified species composition, or most frequently in varying definition of vitality (live and dead) of the sorted root-fragments.

Variations in the amounts of live, dead and live + dead and live/dead ratios in sequential soil cores are caused by changes in biotic and abiotic environmental factors and climate fluctuations (Persson and Stadenberg 2008 and 2009). The live/death ratio reflects the vitality of the fine roots, both temporarily and spatially in the soil profile (Persson and Stadenberg 2009). A high live/dead ratio in the soil profile most frequently occurs in the humus layer and in the uppermost parts of the mineral soil (Persson and Stadenberg 2009). The higher concentration of dead fine roots in the mineral soil is probably due to a high rate of death and a slow rate of decomposition.

Due to the random nature of the average figures, the estimated production will be underestimated (Persson 1978). Nevertheless, these data give an instant measure of the spatial and temporal distribution of fine-root biomass and necromass. Production of new roots represents a great carbon expenditure of in forest trees and appears to be a significant phenomenon in a variety of forest ecosystems. Tree fine roots enrich the soil

with organic matter and nutrients and they may quantitatively play a more important role than needles/leaves (Persson and Stadenberg in press).

Minirhizotrons or observation windows are most valuable for the study of the life history and seasonal changes in root growth. Minirhizotrons in perennial ecosystems are destructively installed; the data obtained are affected by the installation process and the specific environmental conditions along the observation tubes.

Fine-root data (<1 mm or <2 mm in diameter) from various forest ecosystems suggest high production and turnover rates of live, dead or live + dead fine roots of forest trees in relation to the average values of those categories (Persson and Stadenberg in press).

Quantification of the amounts of fine roots is highly desirable due to their important role as carbon sinks and sources of input of soil organic matter to the soil. It is essential to obtain data from sequential coring, if an instant measure of the spatial and temporal distribution of roots in the undisturbed soil profile is a primary goal.

Fine-root data from various forest ecosystems, suggest high turnover rates of live, dead and live + dead amounts of tree fine-roots in the range of 0.2-3.3 yr<sup>-1</sup> in coniferous forests and 0.1-2.2 in deciduous forests (Persson and Stadenberg in press). The root function is extremely costly and is enhanced by a high carbohydrate supply. The methods of estimating fine-root production include sequential soil coring, ingrowth cores, rhizotrons or minirhizotrons, or the use of carbon isotopes.

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