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Assessing fine-root biomass and production in a Scots pine stand – comparison of soil core and root ingrowth core methods

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Abstract

Soil core and root ingrowth core methods for assessing fine-root (< 2 mm) biomass and production were compared in a 38-year-old Scots pine (*Pinus sylvestris* L) stand in eastern Finland. 140 soil cores and 114 ingrowth cores were taken from two mineral soil layers (0–10 cm and 10–30 cm) during 1985–1988. Seasonal changes in root biomass (including both Scots pine and understorey roots) and necromass were used for calculating fine-root production. The Scots pine fine-root biomass averaged annually 143 g/m^2 and 217 g/m^2 in the upper mineral soil layer, and 118 g/m^2 and 66 g/m^2 in the lower layer of soil cores and ingrowth cores, respectively. The fine-root necromass averaged annually 601 g/m^2 and 311 g/m^2 in the upper mineral soil layer, and 196 g/m^2 and 159 g/m^2 in the lower layer of soil cores and ingrowth cores, respectively. The annual fine-root production in a Scots pine stand in the 30 cm thick mineral soil layer, varied between 370–1630 g/m^2 in soil cores and between 210 – 490 g/m^2 in ingrowth cores during three years. The annual production calculated for Scots pine fine roots, varied between 330–950 g/m^2 in soil cores and between 110 – 610 g/m^2 in ingrowth cores. The horizontal and vertical variation in fine-root biomass was smaller in soil cores than in ingrowth cores. Roots in soil cores were in the natural dynamic state, while the roots in the ingrowth cores were still expanding both horizontally and vertically. The annual production of fine-root biomass in the Scots pine stand was less in root ingrowth cores than in soil cores. During the third year, the fine-root biomass production of Scots pine, when calculated by the ingrowth core method, was similar to that calculated by the soil core method. Both techniques have sources of error. In this research the sampling interval in the soil core method was 6–8 weeks, and thus root growth and death between sampling dates could not be accurately estimated. In the ingrowth core method, fine roots were still growing into the mesh bags. In Finnish conditions, after more than three growing seasons, roots in the ingrowth cores can be compared with those in the surrounding soil. The soil core method can be used for studying both the annual and seasonal biomass variations. For estimation of production, sampling should be done at short intervals. The ingrowth core method is more suitable for estimating the potential of annual fine-root production between different site types.

Introduction

In many forest ecosystems on mineral soils, fine-root dynamics, production, death and decomposition of roots appear to play a very important role in carbon and nutrient cycling. Even though the proportion of the total tree biomass represented by fine roots and mycorrhizas is not large, in average 15–25%, their growth and maintenance use a major part, perhaps as much as 67–70%, of total net primary production (Fogel, 1985).

About 11–57% of the carbon assimilated annually by Scots pine trees is used for the growth of root systems (Persson, 1992). Fine root production may account for 8 to 67% of net primary production (Keyes and Grier, 1981; Grier et al., 1981). The detritus input to the soil from the fine roots may be greater than that from the above-ground compartments (Finer and Laine, 1994). Despite this, there are not many studies in relation to stand biomass and nutrient dynamics.

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Table 1. Some characteristics of the experimental tree stand in 1985

Age, years	37
Number of trees/ha	2660
Mean stem diameter, cm	8.2
Mean height, m	7.5
Basal area, m^2/ha	15.3
Stem volume, m^3/ha	70.3
Volume increment, m^3/ha/year	9

Several methods have been used to estimate fine-root biomass, production and turnover (Santantonio and Grace, 1987; Heindrick and Pregitzer, 1992; Nadelhoffer and Raich, 1992). The sequential soil core method has been widely used (Persson, 1980, 1983; Ahlström et al., 1988; Comeau and Kimmins, 1989; Yin et al., 1989; Kummerow et al., 1990a, 1990b) but is believed to underestimate fine-root production (Kurz and Kimmins, 1987; Hendrick and Pregitzer, 1992). This method is also quite expensive and labour-intensive.

The ingrowth core method has been used alone or in association with the sequential core method to estimate fine-root production (Persson, 1979, 1980; Ahlström et al., 1988; Yin et al., 1989; Messier and Puttonen, 1993). A problem with ingrowth core method is that it greatly modifies the root growth environment. But, on the other hand, it allows the direct calculation of fine-root production and is thus especially suitable for comparison of fine-root production between sites or treatments (Messier and Puttonen, 1993).

Ecophysiological root research has been quite restricted for several reasons: a lack of standardization in methods, and the time and effort needed for root processing. In the future, when more research has been conducted on root methods, techniques will become more refined and standardization will occur among different studies (Vogt and Persson, 1991).

The objective of this study was to assess Scots pine (*Pinus sylvestris* L.) fine-root biomass and production by comparison of soil core and root ingrowth core methods.

Materials and methods

Experimental stand

This study was carried out in a Scots pine (*Pinus svlvestris* L.) stand at Ilomantsi (62 47′ N; 30 58′ E; 144 m a.s.l.), near the Mekrijärvi Research Station of the University of Joensuu.

The experimental stand was a naturally regenerated, pole stage stand (Table 1) on a 500 m^2 plot. The site type was *Vaccinium*-type, according to the classification of Cajander (1949). The field layer was dominated by cowberry (*Vaccinium vitis-idaea* L.) and heather (*Calluna vulgaris* (L.). Hull.). The bottom layer was dominated by red-stemmed feathers (*Pleurozium schreberi* (Brid.) Mitt.) with a few reindeer lichens (*Cladina* sp.).

The mean annual temperature was 1.0°C and the annual rainfall was 699 mm during the study period (1985–1988). The long-term annual averages (1961–1990) were 1.9°C and 649 mm, respectively (The Finnish Meteorological Institute, 1991). About 40% of the annual precipitation consisted of snow and the ground is covered by snow from October until May (Helmisaari and Mälkönen, 1989).

The soil type is a Ferric Podzol according to the FAO classification (FAO-Unesco 1988) and relatively poor in plant-available nutrients. The depths of the soil horizons were: humus layer 2.5 cm, eluvial horizon 5.0 cm, and illuvial horizon 11.0 cm. The surface soil layer is clearly sorted to a depth of 40–60 cm. The proportion of coarse fine sand in this layer is about 50%, while the proportion of clay is only about 2%. Compact till occurs below the sorted layer.

Root sampling

For comparison of soil core and root ingrowth core methods, samples were taken by two methods during four consecutive growing seasons during the period 1985–1988.

In the soil core method, ten samplings, including a total of 140 soil cores, were systematically taken for fine-root biomass determinations during the period 1986–1988. The soil cores were divided into three layers by depth: humus, 0–10 cm and 10–30 cm of the mineral soil.

In the root ingrowth core method, a total of 114 ingrowth core samples were collected during the growing seasons 1986–1988. In August 1985, 120 root-free mesh bags (Ø 5,7 cm) were systematically placed into the soil of the research stand. Mesh bags were filled with homogenous sieved mineral soil and placed at a depth of 30 cm in the mineral soil. An oven-dried humus clod was placed on top of the mesh bag. The mesh size of the bags was 5.5 mm. The first root ingrowth core samples were taken, using a special spade, in July 1986 and the last in October 1988.

In both techniques, the samples were transported from the stand to the laboratory and stored frozen (-18°C) until analysis.

Laboratory analysis

In the laboratory, roots from samples taken by the soil core method were washed free of soil and separated into Scots pine living roots, understorey roots and dead roots. The Scots pine living roots were separated into three classes by diameter: < 2 mm, 2–5 mm and 5–10 mm, and the understorey living roots and the dead roots (necromass) were separated into diameter classes < 2 mm and > 2 mm. The fraction 'dead roots' included both Scots pine and understorey dead roots. The separation of fine roots between the three groups was possible because of differences in root morphology, resilience and colour.

Frozen root ingrowth core samples were divided in the laboratory into three layers: humus, 0–10 cm mineral soil and the rest of the mineral soil. As in the soil core method, roots were separated from soil by washing and sorted by hand into Scots pine living roots, understorey living roots and dead roots.

The sorted roots were then separated into different classes by diameter: living pine roots were subdivided into < 2 mm and 2–5 mm, living understorey roots into < 2 mm and > 2 mm and the dead roots (necromass) into < 2 mm and > 2 mm.

The classified roots were dried at 70°C for 5 days and weighed to determine the oven-dry biomass.

In this study, only fine roots smaller than 2 mm in diameter from the two mineral soil layers (0–10 cm and 10–30 cm) were studied. The soil core data of all three layers (humus layer and the two mineral soil layers) is presented in the article by Makkonen and Helmisaari (1998).

Data processing

The Scots pine fine-root biomass was estimated using the collected samples and the fine-root necromass of Scots pine was extrapolated from the total necromass using the ratio of Scots pine fine-root biomass to total fine-root biomass.

The total below-ground production was calculated by balancing the living and dead root biomass compartments according to the decision matrix presented by Fairley and Alexander (1985).

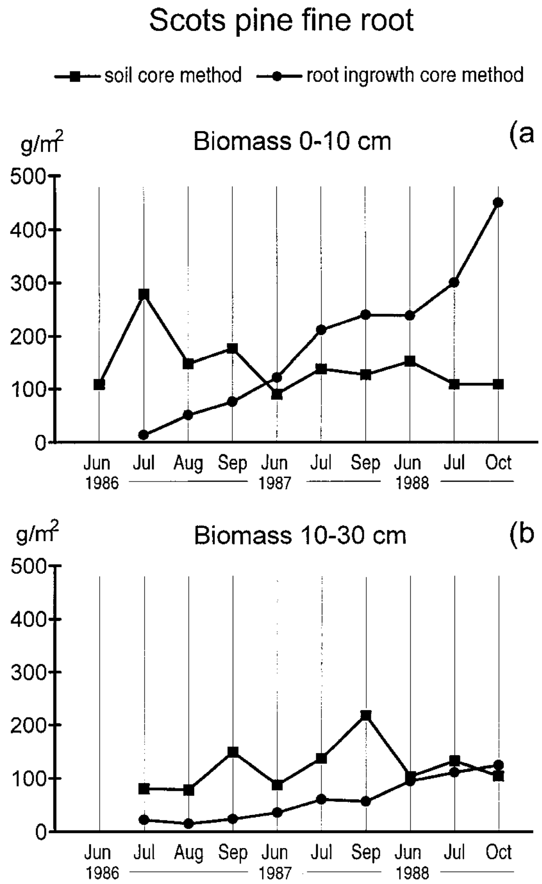

Figure 1. The seasonal variation of Scots pine fine-root biomass (g/m^2) in (a) the upper (0–10) and (b) the lower (10–30 cm) mineral soil layer comparison of soil core and root ingrowth core methods.

Results

Variations of Scots pine fine-root biomass and necromass

In both of the mineral soil layers, the Scots pine fine-root biomass and necromass varied both vertically and horizontally between the different soil horizons. There was no clear seasonal variation in the Scots pine fine-root mass either in the soil cores or in the ingrowth cores (Figure 1). The greatest proportion of fine roots (live and dead), 67% in the soil cores and 71% in the ingrowth cores, was in the upper mineral soil layer. In the soil cores, 40% of all living fine roots and 67% of all dead fine roots were in the upper mineral soil layer. In the ingrowth cores, the respective values were 77% and 66%.

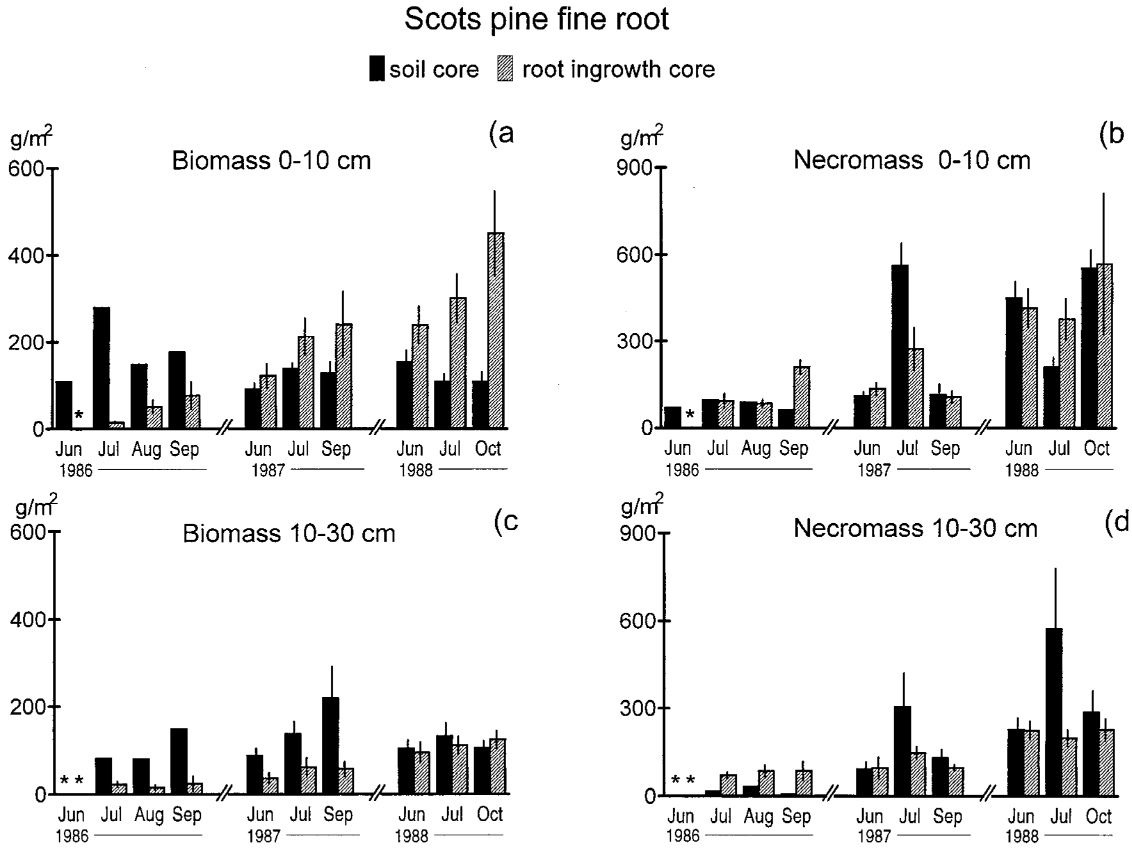

Figure 2. The seasonal variation of Scots pine fine-root (a) biomass (g/m^2) and (b) necromass (g/m^2) in the upper mineral soil layer (0–10 cm), and the seasonal variation of Scots pine fine-root (c) biomass (g/m^2) and (d) necromass (g/m^2) in the lower mineral soil layer (10–30 cm) comparison of soil core and root ingrowth core methods. Standard error of the mean is indicated by bars on the columns (not calculated for 1986 soil core data). Stars indicate missing data.

Table 2. The annual mean biomass and necromass of Scots pine fine roots (g/m^2) sampled by two methods

		Soil core method				Root ingrowth core method			
Year	Soil layer	Living	Se	Dead	Se	Living	Se	Dead	Se
1986	0–10 cm	178	37	78	7	38	9	100	15
1987		119	11	278	47	191	31	168	28
1988		123	13	474	40	327	41	450	84
1986	10–30 cm	104	23	19	7	12	3	47	10
1987		148	28	192	43	49	10	107	14
1988		113	12	420	77	108	12	211	19

The biomass and necromass of roots varied spatially even in a small area. In this study the plot size was 500 m^2, and the biomass of Scots pine fine-roots in different soil core samples varied between 8–813 g/m^2 in the upper mineral soil layer and between 2–649 g/m^2 in the lower one. The total fine-root necromass of Scots pine stand varied between 86–4307 g/m^2 and 9–3071 g/m^2 respectively. In the ingrowth cores, the biomass varied in different samples between 0–1529 g/m^2 in the upper mineral soil layer and between 0–334 g/m^2 in the lower one. The necromass varied between 15–4151 g/m^2 and 5–558 g/m^2 in the upper and lower mineral soil layers, respectively (Table 2).

In the upper mineral soil layer the maxima of Scots pine fine-root biomass estimated using soil cores were in July 1986 (Figure 2a) and in the lower layer in September 1987 (Figure 2c). The fine-root biomass estimated using ingrowth cores continued expanding throughout the duration of the research period, from July 1986 to October 1988, in both layers.

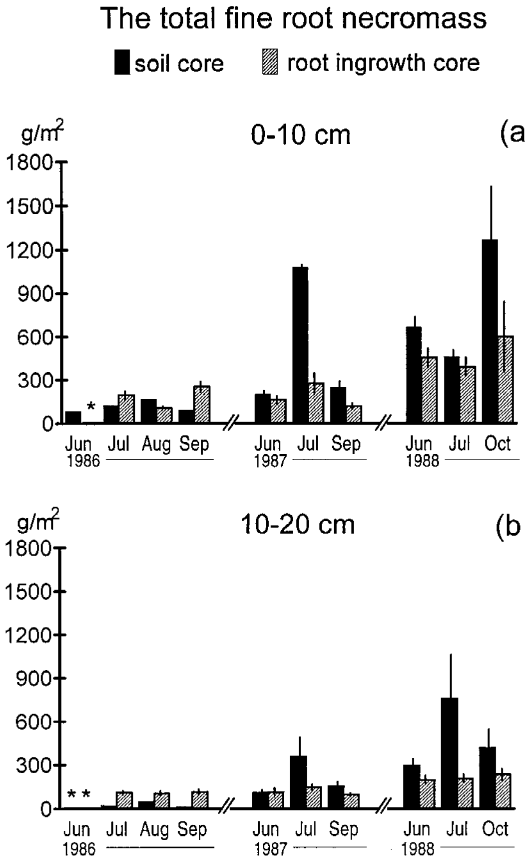

Figure 3. The seasonal variation of total fine-root necromass (g/m^2) (a) in the upper mineral soil layer (0–10 cm) and (b) in the lower mineral soil layer (10–30 cm) comparison of soil core and root ingrowth core methods. Standard error of the mean is indicated by bars on the columns (not calculated for 1986 data). Stars indicate missing data.

There was no clear seasonal variation in the total fine-root necromass (including both Scots pine and understorey necromass) (Figure 3a, b). In July 1987 and October 1988, there were clear maxima in the upper mineral soil layer. In the lower layer, the maximum necromass during the whole research period was in July 1988. In the ingrowth cores, there was no clear seasonal variation in the upper mineral soil layer, but the necromass in both layers increased throughout the research period, from July 1986 to October 1988.

In the soil core samples the maxima of Scots pine necromass were in July 1987, June 1988 and October 1988 in the upper mineral soil layer and in July 1987 and 1988 in the lower layer and there was no clear seasonal variation (Figure 2b, d). In the ingrowth core samples, the mass of dead roots increased from July 1986 to October 1988, but there was no clear seasonal variation.

Table 3. Production of fine roots (g/m^2) determined by soil core and root ingrowth core methods according to Fairley and Alexander (1985). Stars indicate missing data. SCR = soil core roots, ICR = ingrowth core roots

		Production of total belowground		Production of Scotspine	
Mineral soil layer		SCR	ICR	SCR	ICR
0–10 cm	8606/07	281	*	193	*
	8607/08	0	36	0	54
	8608/09	0	164	29	26
	8706/07	973	188	520	302
	8707/09	0	49	0	29
	8806/07	35	59	0	406
	8807/10	0	357	559	149
10–30 cm	8606/07	*	*	*	*
	8607/08	16	0	45	21
	8608/09	69	17	57	10
	8706/07	301	65	276	76
	8707/09	355	0	96	0
	8806/07	416	30	416	16
	8807/10	0	42	0	42

The annual production of fine-root biomass in a Scots pine stand

The annual fine-root production (seasonal growth and death) in a Scots pine stand (including both Scots pine and understorey fine roots), in the 30-cm-thick mineral soil layer, varied approximately from 350 g/m^2 to 1380 g/m^2 in the soil cores and between 224–490 g/m^2 in the ingrowth cores (Table 3).

The fine-root production calculated by the ingrowth core method was 31% of that in the soil cores. The biomass of ingrowth core roots increased throughout the whole research period and there was no levelling off during the three growing seasons.

The annual production (seasonal growth and death) of Scots pine fine roots in the 30 cm thick mineral soil layer varied approximately from 330 g/m^2 to 950 g/m^2 in the soil cores and between 110–620 g/m^2 in the ingrowth cores.

Discussion

In forest ecosystems, the proportion of roots of the tree biomass can be large, varying between 9% and 45%

of the total tree biomass, depending on age and site (Fogel, 1983; Santantonio et al., 1977). According to Helmisaari (1995), in the same stand as in this study, total tree biomass was 5323 g/m^2, of which 78% was above-ground and 22% below-ground biomass. The proportion of fine roots in 1985 was 36% of all roots.

In this study, the three-year average of Scots pine fine-root biomass was 261 g/m^2 in soil cores and 241 g/m^2 in ingrowth cores. According to Persson (1983), in a 15–20 and a 120-year old Scots pine stand, the Scots pine fine-root biomasses were 26 g/m^2 and 123 g/m^2, respectively. Helmisaari and Hallbäcken (1998) reported that the fine-root biomass varied between 210 and 528 g/m^2 in 48–186 year old Norway spruce (*Picea abies* (L.) Karst.) stands. Aber et al. (1985) reported that the fine-root biomass was 289 g/m^2 in a White pine (*Pinus strobus* L.) stand. In this study, fine-root biomass values were greater than Persson (1983) reported, but comparable to those reported by Aber et al. (1985) and Helmisaari and Hallbacken (1998).

The total necromass was 304 g/m^2 in the soil cores and 156 g/m^2 in the ingrowth cores. In soil cores, the calculatory part of dead Scots pine fine roots was 203 g/m^2. This is significantly more than that reported by Persson (1983): 68 g/m^2 in a young Scots pine stand and 64 g/m^2 in the old one. The differences in results between this study and those reported by Persson (1983) may have been caused by differences in research methods: it is very difficult to separate the partly decomposed dead roots from the soil organic matter.

The total annual fine-root production (Scots pine and understorey vegetation) was 814 g/m^2 as determined by the soil core method and 335 g/m^2 as determined by the root ingrowth core method. The Scots pine fine-root production was 721 g/m^2 and 376 g/m^2 respectively (calculated results). This is greater than Aber et al. (1985) reported: 162 g/m^2 for fine-root production of White pine, but less than that reported by Grier et al. (1981): 924 g/m^2 in a 23-year old and 1279 g/m^2 in a 180-year old Pacific silver fir (*Abies amabilis* Forb.) stand.

The root system shows variability both vertically and horizontally. Most fine roots are in the top 20 cm of the soil, in the humus layer and in the upper mineral soil horizons (Messier and Puttonen, 1993). The distribution is dependent on soil aeration and fertility (Fogel, 1983). In this stand, most Scots pine fine roots were in the upper mineral soil layer. The Scots pine fine-root biomass was about 13% smaller in the lower mineral soil layer than in the upper layer estimated by the soil core method, and even 53% smaller estimated by the ingrowth core method. These differences are related to the soil structure: in the soil core method the stratification of soil genetic layers still remains – the eluvial horizon is included in the upper layer and the illuvial horizon in the lower layer, while in the ingrowth core method mesh bags are filled by mixed sand. Grier et al. (1981) have reported similar results: 40% of conifer roots were in the upper mineral soil layer (A-horizon) and 11 % in the lower layer (B-horizon).

Almost all dead roots were in the upper mineral soil layer, with only 34% of the total fine-root necromass being in the lower layer. This is comparable with McClaugherty et al. (1982): 130 g/m^2 in the upper layer (0–15 cm) and 50 g/m^2 in the lower one (15–30 cm). Also the Scots pine fine-root necromass, as measured by the soil core method, was 23% smaller in the lower layer than in the upper one, and 49% smaller when measured by the ingrowth core method.

In the upper mineral soil layer, the annual mean biomass of Scots pine soil core roots was about 24% less than ingrowth core roots (in a three-year period), but in the lower layer the biomass of ingrowth core roots was 53% greater. In both layers the necromass of soil core roots was greater than that of ingrowth core roots, in the upper layer by 13% and in the lower layer by 42%. The reason might be the lack of root competition in the mesh bags: after a three-year period, there is still free space for roots to expand.

The fine-root biomass and necromass varied spatially in the research plots. In the forest, fine roots seek places where the soil properties are optimal for their growth and development. Trees induce heterogeneity in soil properties. The soil, under the influence of a forest, develops properties that vary spatially with relation to the location of trees. This variation in soil properties is frequently reflected in the distribution of the various species of the understorey. The tree has maximum influence under its crown canopy, and the influence decreases outwards from the tree (Liski, 1995).

Estimates of the fine root biomass and production differed substantially depending on the method of calculation employed. There are some methodological problems which influence the results of both methods, and individual differences in root sorting may affect the results. It is quite difficult to separate the fine roots from the mineral soil, even by washing. Small mineral particles adhere strongly to mycorrhizal hyphae and a part can be left after washing. This may influence the results. One difficulty often encountered in root sorting is the inability to distinguish dead fine root material from soil organic matter. Freezing damages root tissues, resulting in some loss of structural integrity. It is impractical and almost impossible to sort all of the small dead root fragments. This necessitates restricting sorting to whole fragments over a certain length of recognisable root material (Persson, 1990).

The time interval between root sampling can be too long, and the intervening variation can thus be lost. In this study, the time interval was 6–8 weeks, and therefore root growth and death occurring between sampling dates could not be accurately estimated. Decomposition of fine roots may also have affected the necromass values (of the ingrowth cores). According to Berg (1984), 1–2 mm diameter Scots pine fine-roots lost about 30% of their mass in two years.

There are some errors originating from the different methods used. The root ingrowth core method gives a lower estimation of production than the soil core method. In this study, the biomass in ingrowth cores increases from July 1986 to October 1988. After three years, the root system was still expanding. In the soil core method, the amount of dead roots influences the estimate of production; if there is a lot of necromass – as in July 1987 in this study – the production estimate will be greater.

Because the roots are still expanding into the ingrowth cores, comparison between these two methods, especially for living roots, is difficult. Living roots have different space for their growth in soil cores than in ingrowth cores. According to some observations, new healthy roots of standing trees of pine can grow through old decomposing roots of the previous pine crop, in old root channels (Nambiar and Sands, 1992). In ingrowth cores there are no channels, and thus new roots may not use this easy way to grow.

Instead of living roots, dead roots are ecologically occupying the same space in both methods. The problem is their dying at different times; thus calculation of the necromass according to the biomass does not give accurate results.

Special problems arise when using the root ingrowth core method. The sieved soil cannot be reconstructed into horizons in the ingrowth core; the typical podsol profile will be disturbed. The bulk density of soil, initially repacked into the cylinders, will be different from that naturally present in the soil of the site. The sieved soil in the ingrowth cores may, furthermore, be drier than the surrounding soil. After a short period, there is no root competition in the soil of the ingrowth cores, so the roots can grow into the ingrowth core faster than into the surrounding soil – particularly because the injured roots around the ingrowth core after their installation may favour the grow of adventitous roots.

The soil core method also has its own problems. The soil core sample is only a momentary representation of fine-root biomass; the growth of fine roots cannot be followed. The spatial variation can be greater than the variation in time.

Both techniques thus have their sources of error. The soil core method is suitable for studying the annual and seasonal fine-root biomass variation. For estimating production, sampling should be done at short intervals. The ingrowth core method is more suitable for comparing the potential of annual fine root production between different site types. However, both methods are useful for studies on the dynamics of Scots pine fine roots.

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