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A global analysis of fine root biomass and biomass production in forest stands

Leena Finér[1], Mizue Ohashi[2], Kyotaro Noguchi[3] & Yasuhiro Hirano[4]

[1]Finnish Forest Research Institute, Joensuu Research Unit, P.O. Box 68, 80101 Joensuu, Finland. [2]School of Human Science and Environment, University of Hyogo, 1-1-12 Shinzaike-honcho, Himeji City, Hyogo, 670-0092, Japan. [3]Forestry and Forest Products Research Institute (FFPRI), Shikoku Research Center, 2-915 Asakuranishimachi, Kochi, 780-8077, Japan. [4] Kansai Research Center, FFPRI, Nagai-Kyutaro 68, Momoyama, Fushimi, Kyoto 612-0855 Japan.
Contact: Leena Finér, phone: +358 50 391 3067, fax: +358 1021 3113, e-mail: leena.finer@metla.fi

ABSTRACT

Fine roots are the most significant components contributing to carbon cycling in forest ecosystems. Here, we refined estimates of total fine root biomass (≤ 2 mm) (FRB) and biomass production (FRP) in different forest biomes using the database of forest stands compiled from literature, and elucidated what is the effect of variation in root diameter class and sampling depth on the estimates. The mean total FRB (g m^{-2}) did not differ significantly between the biomes; for the boreal forests it was 419±253 (N=81), and those for the temperate and tropical forests 487±335 (N=176) and 465±365 (N=68), respectively. When the FRB estimates were reevaluated for the whole rooting depth the differences became significant (p=0.031), and the extrapolated FRB estimate for the boreal forests (526±321 g m^{-2}) was smaller that those for the temperate (807±632 g m^{-2}) and tropical (776±522 g m^{-2}) forests, respectively. The mean FRP (g m^{-2} a^{-1}) was significantly (p=0.013) smaller for the boreal (307±286, N=33) and temperate (397±308, N=64) forests than that for the tropical (595±470, N=33) forests. Also the fine root turnover rate (FRP/FRB) was significantly smaller in the boreal (0.8) and temperate (1.3) forests than in the tropical forests (1.5). We found significant positive correlations between the ≤ 1 and ≤ 2 mm and between the ≤ 2 and ≤ 5 mm FRB and FRP. These relationships were used to standardize the estimates, and the ≤ 1 mm FRB was 0.7 times smaller and the ≤ 5 mm FRB 1.6 times higher than the ≤ 2 mm FRB. The corresponding figures for the FRP were 0.5 and 1.3. Our results indicate there are differences in FRB and FRP between the different biomes and the FRB and FRP estimates are much dependent on the sampling depth and fine root diameter class.

KEYWORDS: below-ground biomass, biome, turnover, rooting depth, root diameter

1. INTRODUCTION

The forests of the world contain 80% of all above-ground carbon (C) and 40% of all below-ground terrestrial C (Dixon *et al.* 1994). In forest ecosystems the below-ground C pool often exceeds the above-ground pool. Fine roots are the most significant component contributing to the forest ecosystem below-ground C fluxes, since up to 75% of the annual net primary production can be allocated into fine roots (e.g. Vogt *et al.* 1996; Gill & Jackson 2000). Thus the fine roots play a key role in forest ecosystem C and nutrient cycling and accumulation. However, we know much less about the role of fine roots on soil C pools than those of the above-ground parts of the vegetation partly due to the methodological difficulties and controversies in determining FRB and FRP, the labor-intensive nature of such studies, and the variety of internal and external factors affecting root biomass and biomass production (e.g. Vogt *et al.* 1996; Majdi *et al.* 2005). FRB and FRP estimates are important to include in the forest ecosystem C pool estimates and they are needed for calculating fine root turnover rates.

Fine root biomass and FRP has been estimated to vary between biomes (Vogt *et al.* 1986, 1996; Jackson *et al.* 1996, 1997; Leuschner & Hertel 2003; Finér *et al.* 2007; Noguchi *et al.* 2007). However the differences between biomes have not always been consistent (Vogt *et al.* 1996; Finér *et al.* 2007). Numerous factors such as the representativeness and the size of the data, e.g. in relation to species composition, stand characteristics and environmental conditions, the differences in the included fine root diameter fractions and the variation in sampling depths may cause the differences between studies (Leuschner & Hertel 2003). The addition of new data into the databases will make the estimates more accurate than those in the previous studies (Finér *et al.* 2007; Noguchi *et al* 2007), while the factors making the difference between the earlier studies can be reconsidered.

The aim of this study was to show new estimates for FRB and FRP in different forested biomes and elucidate what is the effect of the variation in root diameter class and sampling depth on these estimates. That was done by analysing comprehensive global FRB and FRP databases compiled from literature.

2. MATERIAL AND METHODS

The whole database included live FRB data (including all roots) from total of 512 stands and FRP data from total of 107 stands from boreal, temperate and tropical forests. The FRB data was collected with the soil coring, pith or monolith methods and the FRP was derived with the sequential coring, ingrowth bag, minirhizotron and nitrogen budget methods. The data comprised the following diameter classes: ≤ 1 mm, ≤ 2 mm and ≤ 5 mm. We formulated regression equations for the relationships between ≤ 2 mm and ≤ 1 mm and between ≤ 2 mm and ≤ 5 mm FRB and FRP fractions and used them to standardize the results. We recorded the sampling depth and since it was in most cases lower than the maximum rooting depth presented for the forest biomes by Schenk and Jackson (2002), we extrapolated the ≤ 2 mm FRB for the whole rooting depth with the equation presented by Gale and Grigal (1987):

$$Y = 1 - \beta^{d} \qquad (1),$$

where Y is the cumulative root fraction (varying between 0 and 1) from the soil surface to the depth d (cm) and β -parameter values fitted by Jackson *et al.* (1997) with a global database. We used the analysis of variance and covariance for identifying the differences between the biomes. The sampling depth was used as a covariate for the analyses with the original sampling depth.

3. RESULTS AND DISCUSSION

3.1. The relationships between different diameter classes

We studied relationships between the different FRB and FRP diameter classes. The total FRB estimates would have been 0.7 times smaller if we had standardized the results to the ≤ 1 mm diameter class and 1.6 times higher in the case of ≤ 5 mm diameter class (Table 1). The corresponding figures for the FRP were 0.5 and 1.3, respectively (Table 1). In many of the earlier review studies the different fine root factions have been treated together and that can have increased variation and given biased estimates for FRB (Leuschner & Hertel 2003).

Table 1. FRB and FRP for the different biomes calculated by standardizing all available data into the ≤ 1 mm, ≤ 2 mm or ≤ 5 mm diameter classes. Data shown are the mean±standard deviation and (the number of stands).

	FRB (g m^{-2})			FRP (g m^{-2} a^{-1})		
	≤ 1 mm	≤ 2 mm	≤ 5 mm	≤ 1 mm	≤ 2 mm	≤ 5 mm
Boreal	211±124 (81)	298±175 (81)	488±286 (81)	167±155 (33)	307±285 (33)	414±385 (33)
Temperate	298±195 (175)	421±275 (175)	690±451 (175)	216±167 (64)	397±308 (64)	535±415 (64)
Tropical	329±251 (73)	465±356 (73)	761±582 (73)	323±255 (33)	595±470 (33)	801±633 (33)

3.2. The sampling depth

According to Schenk and Jackson (2002) and our database the rooting depth is lower in the boreal forests than in the forests of the other biomes (Table 2). The studies included in our database covered in most cases 50% of the FRB, but seldom the whole rooting depth (Table 2). When the FRB estimates were reevaluated for the whole rooting depth with the equation (1), the extrapolated FRB estimates for the boreal, temperate and topical forests were 526 g m^{-2}, 807 g m^{-2}and 776 g m^{-2}, respectively (Table 2). They were 1.3 –1.7 times higher than the ones based on the original sampling depths.

Table 2. The 95% and 50% sampling depths for the FRB according to Schenk and Jackson (2002) and the mean sampling depth calculated based on our database for the different biomes. Also the mean FRB calculated based on the original sampling depth and that extrapolated for the whole rooting depth with the equation (1) are presented.

	Sampling depth for the 95% FRB, (cm)	Sampling depth for the 50% FRB, (cm)	Sampling depth in our database, (cm)	FRB, original sampling depth, (g m^{-2})	FRB, extrapolated for the whole rooting depth, (g m^{-2})
Boreal	58	12	32	419	526
Temperate	104-121	21-23	50	487	807
Tropical	91-94	14-19	50	465	776

3.3. The fine root biomass in different biomes

The mean tree FRB calculated with the original sampling depth did not differ between the biomes, but the extrapolated FRB estimates for the whole rooting depth (p=0.003) as well as the FRP and turnover were higher in the tropical and temperate forests than in the boreal forests (p=0.003 and p=0.023, respectively). Our FRB, FRP and turnover rate estimates based on the original sampling depth were in general higher for the boreal forests and fell within the same range than those reported in the earlier studies for the temperate and tropical forests (Vogt *et al.* 1986, 1996; Jackson *et al.* 1996, 1997; Gill & Jackson 2000; Leuschner & Hertel 2003; Finér et al. 2007; Noguchi et al. 2007). But our estimates extrapolated for the whole rooting depth were in general higher than the earlier ones including roots also from deeper layers (Jackson *et al.* 1996

1997; Leuschner & Hertel 2003). The data in the earlier studies partly originated from the same studies as here, but our database was more comprehensive than before.

These refined FRB and FRP values especially in the case of calculation of root turnover rates, can be used to parameterize global C models and will give significant insights on the estimation of forest ecosystem C cycle. The clear relationships between ≤ 1 mm and ≤ 2 mm diameter classes and between ≤ 2 mm and ≤ 5 mm enable us to standardize FRB and FRP data to ≤ 2 mm diameter class. The results suggest that the in most studies the sampling depth does not cover the whole rooting depth, which gives, if not taken into account biased underestimates of FRB for the different biomes.

4. REFERENCES

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Texler, M.C. & Wisniewski, J. 1994. Carbon pools and fluxes of global forest ecosystems. Science 263:185-190.

Finér, L., Helmisaari, H.S., Lõhmus, K. *et al.* 2007. Variation in fine root biomass of three European tree species: Beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* L. Karst.) and Scots pine (*Pinus sylvestris* L.). Plant Biosystems 141:394-405.

Gale, M.R. & Grigal, D.F. 1987. Vertical root distributions of northern tree species in relation to successional status. Canadian Journal of Forest Research 17: 829-834.

Gill, R.A. & Jackson, R. B. 2000. Global patterns of root turnover for terrestrial ecosystems. New Phytologist 147:13-31.

Jackson, R.B., Canadell, J., Ehleringer, J.R., Mooney, H.A., Sala, O.E. & Schulze, E.D. 1996. A global analysis of root distributions for terrestrial biomes. Oecologia 108: 389-411.

Jackson, R.B., Mooney, H.A. & Schulze, E.E. 1997. A global budget for fine root biomass, surface area, and nutrient contents. Proceedings of the National Academy of Sciences 94:7362-7366.

Leuschner, C. & Hertel, D. 2003. Fine root biomass of temperate forests in relation to soil acidity and fertility, climate, age and species. Progress in Botany 64: 405-438. Springer-Verlag Berlin Heidelberg.

Majdi, H., Pregitzer, K., Morén, A.S., Nylund, J.E. & Ågren, G.I. 2005. Measuring fine root turnover in forest ecosystems. Plant and Soil 276: 1-8.

Noguchi, K., Konôpka, B., Satomura, T., Kaneko, S. & Takahashi, M. 2007. Biomass and production of fine roots in Japanese forests. Journal of Forest Research 12: 83-95.

Schenk, H.J. & Jackson, R.B. 2002. The global biogeography of roots. Ecological Monographs 72: 311-328.

Vogt, K.A., Grier, C.C. & Vogt, D.J. 1986. Production, turnover, and nutrient dynamics of above- and belowground detritus of world forests. Advances in Ecological Research 15:303-378.

Vogt, K.A., Vogt, D.J., Palmiotto, P.A., Boon, B., O´Hara, J. & Asbjornsen, H. 1996. Review of root dynamics in forest ecosystems grouped by climate, climatic forest type and species. Plant and Soil 187: 159-219.