Roots and carbon allocation - quantity, quality, and controls?

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ABSTRACT

The ability to quantify the amount of carbon plants allocate to fine roots (and their mycorrhizas) and its below-ground C residence time is a major missing link in efforts to quantify and describe forest C cycles (Joslin et al. 2006). Quantification of the role of roots in carbon cycling requires estimating root biomass, turnover rate, and C concentrations. More data is available on fine root biomass (e.g. Finér et al. 2007, Helmisaari et al. 2008), whereas the estimation of root turnover rates and their relationship to environmental factors still remains poorly known. Total C concentrations in roots are relatively well known, but the composition of different C compounds need to be studied more as they have important roles, and affect soil processes through root exudates and litter.

Since the belowground and aboveground parts of plants are closely linked, a whole-tree and ecosystem approach is necessary for estimating and understanding the role of fine roots and their mycorrhizas in carbon cycling. The rate of growth, as well as the longevity of fine roots and mycorrhizal mycelia, are affected by the availability of carbohydrates and nutrients (e.g. Nilsson et al. 2005, Withington et al. 2006), and by environmental factors such as soil temperature and moisture (e.g. Majdi & Öhrvik 2004). The relationships between these factors and fine root dynamics are poorly known for most species and sites.

Recently, there has been an active debate on the accuracy of different methods for investigating fine root longevity (e.g. Strand et al. 2008). Estimates of root turnover and longevity have been obtained through sequential coring and measuring root growth into root-free ingrowth cores, minirhizotrones allowing in situ observations of root growth and mortality, or isotopic methods. Despite the variability in field methods, mean ages of fine roots in ecosystem models have reflected a consensus that the majority of tree fine roots grow and die within a few years, though some studies report turnover times of several years. The age of rhizomes of clonal dwarf shrubs (e.g. *Vaccinium* genera) can be tens of years, but their fine root turnover may be rapid, and the ericoid mycorrhizal fungi significantly contribute to soil C stores (Olsrud & Christensen 2004).

Measurements of mean age of fine root C using radiocarbon isotopic methods (Gaudinski et al. 2001, Matamala et al. 2003) indicated that ^{14}C-values measured in live, dead, and mixed fine roots from temperate forests corresponded to a longer time elapsed since C was fixed from the atmosphere than estimates of root lifetime previously reported using other methods. Part of this discrepancy was caused by root sorting problems, and careful sampling and sorting yielded more comparable root age results with other methods (Tierney & Fahey 2002). Later studies (Luo 2003, Vargas et al. 2009) also showed that the assumption of isotopic methods that root growth only uses recently fixed photosynthetic carbon may not hold in all situations, as stored, non-structural C can be retranslocated, and used for new root growth.

There exists no single method that has proved to be best in all situations for root longevity determinations, as most of the methods have their strengths and error sources. Studies involving several methods for turnover determination on the same sites are valuable. All empirical studies, as well as any literature-based regional or global analyses of fine root turnover, should report not only which methods were used but also how and under which environmental conditions the studies were performed, and exactly which species, and components were analysed.

Nobody is demanding an aboveground researcher to point out a single value for needle/leaf turnover. Modellers have, however, asked this for fine root turnover, but root researchers should point out that there exists no single value, since many factors affect root turnover time, e.g. plant species, climate and weather, soil nutrient status, the root component in question and the mychorrhizal status. Answers to these questions can best be found through continuing empirical and experimental research.

REFERENCES

Finér, L., Helmisaari, H-S., Lõhmus, K., Majdi, H., Brunner, I., Børja, I., Eldhuset, T., Godbold, D., Grebenc, T., Konôpka, B., Kraigher, H., Möttönen, M-R., Ohashi, M., Oleksyn, J., Ostonen, I., Uri, V. & Vanguelova, E. 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 41(3):394-405.

Gaudinski, J.B., Trumbore, S.E., Davidson, E.A., Cook, A.C., Markewitz, D. & Richter, D.D. 2001. The age of fine-root carbon in three forests of the eastern United States measured by radiocarbon. Oecologia 129:420-429.

Helmisaari, H-S, Ostonen, I., Lõhmus, K., Derome, J., Lindroos, A-J., Merilä, P. & Nöjd, P. 2009. Ectomycorrhizal root tips in relation to site and stand characteristics in Norway spruce and Scots pine stands in boreal forests. Tree Physiol. 29:445-456.

Joslin, J.D., Gaudinski, J.B., Torn, M.S., Riley, W.J. & Hanson, P.J. 2006. Fine-root turnover patterns and their relationship to root diameter and soil depth in a ^{14}C-labelled hardwood forest. New Phytol. 172:523-535.

Luo, Y. 2003. Uncertainties in interpretation of isotope signals for estimation of fine root longevity: theoretical considerations. Global Change Biol. 9:1118-1129.

Majdi, H. and J. Öhrvik. 2004. Interactive effects of soil warming and fertilization on root production, mortality and longevity in a Norway spruce stand in northern Sweden. Global Change Biol. 10:182-188.

Matamala, R., Gonzàles-Meler, M.A., Jastrow, J.D., Norby, R. & Schlesinger, W. 2003. Impacts of fine root turnover on forest NPP and soil C sequestration potential. Science 302:1385-1387.

Nilsson, L.O., Giesler, R., Bååth, E. and Wallander, H. 2005. Growth and biomass of mycorrhizal mycelia in coniferous forests along short natural nutrient gradients. New Phytol. 165:613-622.

Olsrud, M. & Christensen, T.R. 2004. Carbon cycling in subarctic tundra; seasonal variation in ecosystem partioning based om in situ ^{14}C pulse-labelling. Soil Biol. Biochem. 36:245-253.

Strand, A.E., Pritchard, S.G., McCormack, M.L., Davis, M.A. & Oren, R. 2008. Irreconcilable differences: fine-root life spans and soil carbon persistence. Science 319:456-458.

Tierney, G.L. & Fahey, T.J. 2002. Fine root turnover in a northern hardwood forest: a direct comparison of the radiocarbon and minirhizotron methods, Can. J. For. Res. 32:1692-1697.

Vargas. R., Trumbore, S.E. & Allen, M. 2009. Evidence of old carbon used to grow new fine roots in a tropical forest. New Phytol. 182:710-718.

Withington, J.M., P.B. Reich, J.Oleksyn, and D.M. Eissenstat. 2006. Comparison of structure and life span in roots and leaves among temperate trees. Ecol. Monogr. 76:381-397.