Carbon fluxes in deposition, soil water and litterfall in forested mineral soils - relationships to site, stand and climatic factors

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Carbon fluxes to forest soils comprise litterfall (canopy and root), which is solid organic matter, and deposition, mainly the leaching of dissolved organic carbon (DOC) from the canopy (throughfall). The main fluxes from the soil are soil respiration, which is the CO_2 efflux back to the atmosphere, and as DOC leaching from the soil. In this presentation we present results related to the carbon fluxes in deposition, soil water and litterfall.

Deposition and soil water

The fluxes of dissolved organic carbon (DOC) in bulk deposition (BD), stand throughfall (TF) and soil water (SW) play an important role in the carbon balance of forest ecosystems. Although the annual amount of dissolved carbon in these fluxes is very small compared to the other carbon fluxes and stores in the forest ecosystem, changes in DOC fluxes represent a relatively sensitive indicator of changes in carbon stores. However, relatively little is known about the magnitude and variation in DOC fluxes in deposition and soil water in Finnish conditions. The number of sites where detailed DOC fluxes have been determined is not very large. Determining the DOC fluxes for a forest site requires intensive and continuous sampling and analysis throughout the year. The aim of this study was to determine the carbon fluxes in BD, TF and SW in 13 forest stands located in different parts of Finland. The information about these fluxes can be used when making detailed calculations and models for the carbon budgets of forest ecosystems.

The material for the study was collected in 7 Scots pine and 6 Norway spruce sites during 1996-2004. The sites belong to a network of intensively monitored forest plots (Level II) established as a part of the EU/Forest Focus and UN/ECE/ICP Forests forest condition monitoring programmes. BD was collected in an open area close to the forest plot using 3 precipitation and 2 snow collectors throughout the year. TF samples were also collected throughout the year using 20 precipitation collectors and 6 snow collectors located systematically within the stand. Soil water was collected during the snow-free period using zero-tension lysimeters at depths of 5, 20 and 40 cm below the ground surface. The sampling interval was 2-4 weeks. The annual DOC flux in BD and TF was calculated using the DOC concentrations and the amount of precipitation. The DOC fluxes in SW at different depths in the soil were calculated using the conservative anion (sulphate) budget method. The relationships between the DOC fluxes from the tree canopy (i.e. TF-BD) and several stand parameters were also investigated. The stand parameters were basal area, stem volume, stem number, mean diameter, mean height, latitude, length of the growing season, and the effective temperature sum (ETS).

The mean (1998-2004) annual carbon fluxes (DOC, kg ha^{-1} yr^{-1}) in the Scots pine stands were 11 (variation in plotwise mean values: 7-13) in BD, 41 (20-57) in TF, 121 (40-181) in SW (depth 5 cm), 58 (10-125) in SW(depth 20 cm) and 24 (0-42) in SW(depth 40 cm). The corresponding values for the Norway spruce stands were 11 (10-13) in BD, 59 (33-

85) in TF, 148 (89-208) in SW (5cm), 63 (30-114) in SW (20cm), and 17 (6-39) in SW (40cm). The mean carbon fluxes were somewhat lower in the Scots pine stands than in the Norway spruce stands. For the pine stands, the fluxes were higher on the sites in southern Finland than in northern Finland. There was no corresponding trend for the spruce stands.

The DOC flux leached from the tree canopies (mean 1996-2004) was clearly higher in the stands in southern Finland than in northern Finland. Latitude correlated strongly with the DOC fluxes from the tree canopies in both the spruce and pine stands, primarily due to the higher amount of precipitation and higher temperatures in the south. The DOC flux from the tree canopies correlated positively with the length of the growing season and ETS. The DOC fluxes were also correlated with the mean height of the trees in the spruce and pine stands, and with stem volume in the spruce stands.

The results indicate the importance of climatic factors (southern versus northern Finland), and probably also stand structure, in the carbon fluxes.

Litterfall

Canopy litterfall represents the major above-ground pathway by which carbon (and nutrients) is returned to the forest floor. However, litterfall collection and analysis is laborious and expensive, and not carried out in sufficient stands to allow regional values to be obtained. Such regional data are needed to address international agreements related to carbon budgets and greenhouse gas accounting. In many studies annual litterfall flux has been found to correlate with variables describing the characteristics of the site, stand and climate. This opens the possibility of making models to predict litterfall for stands where it is not measured directly.

With the aim of developing such models, we compiled data from a number of independent projects in which litterfall had been determined. We then used this data set to identify significant and readily available site, stand and climate variables affecting annual needle (LF_{needle}) and total (LF_{total}) above-ground litterfall production, and to develop multiple linear regression (MLR) models that can be used to reliably predict litterfall production. The carbon content of the litterfall can be taken to be ca. 50 % of litterfall oven dry mass.

The data set included 34 Scots pine (*Pinus sylvestris*) dominated stands and 18 Norway spruce (*Picea abies*) dominated stands located throughout Finland. All the stands were growing on upland, mineral soil sites. The age of the Scots pine stands ranged from 35 to well over 200-years-old, and stand stem volume from 46 to 315 m^3 ha^{-1}. For the Norway spruce stands, stand age ranged from 32 to 163-years-old, and stand stem volume ranged from 66 to 603 m^3 ha^{-1}. Litterfall was collected using 6 to 15 funnel-shaped traps located in a sample plot in each of the stands. The catch area of each trap was 0.5 m^2 and placed at about 1.5 m above ground level. Litterfall in the Scots pine stands was collected for 3 to 37 years and in the Norway spruce stands, for 1 to 43 years. We have published the results for the Scots pine stands (Starr et al. 2005), and are currently working with the results for the Norway spruce stands.

For the Scots pine stands, the mean annual LF_{needle} value ranged from 223 kg ha^{-1} to 1567 kg ha^{-1}. The corresponding range for LF_{total} was 322 to 2300 kg ha^{-1}. For the Norway

spruce stands, the mean annual LF_{needle} value ranged from 333 kg ha^{-1} to 2303 kg ha^{-1}, and the corresponding values for LF_{total} were 614 and 4210 kg ha^{-1}. For both Scots pine and Norway spruce stands, there was also considerable inter-annual variation in litterfall production.

To model annual litterfall production, taking into account also the within stand inter-annular variation, we investigated the relationship between litterfall production and site specific stand, site and climate variables using data for the longest period of consecutive years common to each stand (Scots pine and Norway spruce stands separately). For the Scots pine stands, this period covered 3 years, and for 16 of the Norway spruce stands a 4 year period was used (data available for only one year at two of the stands). The period for both Scots pine and Norway spruce stands occurred in the 1990s.

Scots pine stand LF_{needle} and LF_{total} were significantly ($p < 0.01$) and strongly correlated (Spearman) with latitude, stand basal area, effective temperature sum (ETS) of the current year and even higher with that of the previous year, and the previous years' July temperature. LF_{needle} had a weak negative, although significant ($p < 0.05$) correlation with stand age, but age was not significant for LF_{total}. MLR models using latitude and stand basal area (also dominant height in the case of LF_{needle}) as predictive variables accounted for 82% of the variance in both LF_{needle} and LF_{total}. Latitude effectively describes the climate at each stand but ignores the considerable within-stand variation in annual litterfall production. Using the annual values for the climate variables instead of latitude, 70% or more of the variation in both LF_{needle} and LF_{total} in MLR models could be explained.

Norway spruce stand LF_{needle} and LF_{total} were significantly and strongly correlated with latitude and stand factors as was the case with the Scots pine. Of the stand variables, the highest correlation with LF_{needle} was obtained with mean height. Of the climate variables, the ETS of the current year and that of the 3 preceding years all gave the strongest correlation with litterfall production. MLR models using stand mean height, canopy needle biomass per unit area and precipitation of the current and that two years previously explained 70% of the variation in LF_{needle}. MLR models using mean height, stand basal area, and precipitation two years previously accounted for 73% of the variation in LF_{total}.

We have thus been able to derive MLR models that accurately predict litterfall production for both Scots pine and Norway spruce stands with a considerable degree of precision for any specific site and stand using site, stand and climate variables that are readily available or attainable (such as national forest inventory data). These models will enable regional estimates of litterfall and associated carbon inputs to the forest floor to be estimated, and which take into account annual differences in climatic conditions and the characteristics of the developing stand.

Reference

Starr, M., Saarsalmi, A., Hokkanen, T., Merilä, P. and Helmisaari, H-S. 2005. Models of litterfall production for Scots pine (Pinus sylvestris L.) in Finland using stand, site and climatic factors. Forest Ecology and Management 205: 215-225.