Biogeochemistry (2008) 89:1–5
DOI 10.1007/s10533-008-9181-z

ORIGINAL PAPER

Introduction

Mats Olsson

Received: 7 June 2007 / Accepted: 10 August 2007 / Published online: 15 March 2008

Introduction

The research in this volume was carried out in a Swedish research programme named Lustra. The program's target was to increase the knowledge of greenhouse-gas fluxes and carbon stocks in Swedish forest ecosystems and to relate these to abiotic factors, global change and forest management, and to suggest strategies to mitigate greenhouse-gas emissions. Other goals were to suggest methods for soil carbon monitoring and to develop models for assessing soil organic carbon response to environmental and management changes.

The Lustra programme recognizes that forestry in Sweden has a strong impact on the net emissions of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), and consequently, that strategic adaptation of land-use systems in managed forests can significantly reduce the net emissions in Sweden. The role of forestry is based on its potential to produce biomass for substitution and by affecting sink and source processes in standing biomass and soils, including peatlands. Sweden has a land area of approximately 411,000 km^2 of which 233,000 km^2 (57%) is forest land, defined as land suitable for forest production and with a potential mean stem production >1 m^3 ha^{-1} year^{-1}. Of this about 50,000–60,000 km^2 are peatland and the rest mineral soils. Sweden has a relatively seen high strategic potential to mitigate CO_2 emissions by management of forested land. The annual national yield increment is 114 M m^3 of stemwood (Swedish Statistical Yearbook of Forestry 2006), corresponding to about 41 M ton C in forest biomass, or 4.5 ton C per capita. This indicates the magnitude of the challenge in forestry and urges a better understanding of forest management and greenhouse-gas processes. Sweden has signed the Kyoto protocol and decided 2006 to account for sinks and sources by forest management according to article 3.4 in the Kyoto protocol. Sweden also has a national target to reduce greenhouse gas emissions. In conclusion, a scientific basis is strongly needed for rational decisions concerning forest management and policies as well as carbon monitoring.

Integrated analyses of greenhouse-gas fluxes were carried out in the Lustra programme at three selected field sites in Sweden. Such analyses were considered essential for a comprehensive and holistic understanding of C cycling and emission of greenhouse gases. Results from these studies, and description of the sites, are mainly presented in papers by Berggren Kleja et al. (2008), Lindroth et al. (2008) and Svensson et al. (2008). The three sites are named, from south to north, Asa, Knottåsen and Flakaliden. The forest stands were composed of

M. Olsson (✉)
Department of Forest Soils, Swedish University of Agricultural Sciences, P.O. Box 7001, 750 07 Uppsala, Sweden
e-mail: Mats.Olsson@sml.slu.se

40 year-old Norway spruce trees. They were selected in order to cover some important site factors such as climate, and drainage conditions, whereas soil texture, mineralogy and soil unit were kept as similar as possible (Berggren Kleja et al. 2004). Thus, the sites were all placed on glacial till with Podsol development and the occurrence of an O horizon. In that way they well represented the most common soil conditions in Sweden (Olsson et al. 2008). The research at the selected three sites encompassed significant processes such as biomass production, litter input, decomposition, leaching of dissolved organic carbon (DOC) and net ecosystem exchange (NEE). Data from the sites have also been used as reference for several other papers produced during the Lustra programme. Additional sites on drained peat land under forests were used for investigating impact of peat land characteristics on emission factors for N_2O (Klemedtsson et al. 2005).

The data by Berggren Kleja et al. (2008) show that there was no clear north–south gradient in total litter flux at the three Lustra sites. The tree litter input was higher at Asa, but at the two northern sites a lower tree litter input was largely balanced by a considerable input of litter (27%) from the field layer (shrubs, herbs, grasses) and bottom layer (mosses, lichens) vegetation., mainly as root litter. There are also other, recent studies indicating an important role of field layer vegetation in the C cycling of northern boreal forests (Kolari et al. 2006; Helmisaari et al. 2007). The data from the Lustra field sites indicated that the field- and bottom layer vegetation contribute significantly to litter production (Berggren Kleja et al. 2008). Thus, studies not including this type of litter may misinterpret soil carbon stocks. The high litter production in the ground vegetation in low productive forests with rather open canopies may more or less compensate for the low amount of tree litter, whereas more dense stands have less field- and bottom layer vegetation.

Based on the Swedish National Inventory of Forest Soils it was shown that the SOC (soil organic carbon) stocks in Podsols on forest land declined from south to north ($r^2 = 0.19$, $P < 0.01$). This was consistent with data from the three field sites in Lustra. Similar results have also been obtained by Callesen et al. (2003) based on field measurements for the Nordic countries. This has been and interpreted as an effect of climate (season length, temperature etc.) on productivity. However, the Lustra measurements gave no support for the hypothesis that the higher C stock at the southern site is caused by a higher input of litter. Instead, we propose that a higher N deposition and N availability in the south result in a slower turnover of SOM than in the north (Ågren et al. 2001). This effect seems to overshadow the effect of temperature.

Hyvönen et al. (2008) calculated, based on long-term fertilising experiments, the N use efficiency to 28 kg C in biomass and 12 kg C in soils per kg N added. They concluded that the differences in forest floor organic C pools between north and south can be explained by the effect of N deposition.

In conclusion, several results within Lustra consistently indicated that the SOC distribution pattern may not directly be due to differences in temperature but rather to higher N status in southern Sweden, partly explained by historic atmospheric N deposition levels, and also due to other factors like land use and vegetation.

In average for Podsols on forest land in Sweden the total SOC stock was 8.2 kg C m^{-2}, whereof 35% occurred in the O horizon and 65% in the mineral soil 0–50 cm (Olsson et al. submitted to Silva Fennica). The major flux (74–89%) of C into the mineral soil (0–50 cm) was as root litter, the rest being DOC leached from the O horizon. However, due to the recalcitrant nature of DOC, we estimated that its relative contribution to SOC build-up was considerably higher, ranging between 38 and 64% (Berggren Kleja et al. 2008). Model simulation by Ågren et al. (2008) with the Q model showed that SOC derived from the fine root litter make up around 20–25% and around 30% of the entire soil carbon stock under pine and spruce, respectively. They also showed that SOC derived from stumps and coarse roots amounted around 30% and 20% in pine and spruce stands, respectively.

An important question is how present stocks are currently changing. Available data indicate that accumulation may occur although at a low rate. Berg et al. (2007), based on the Swedish National Inventory of Forest Soils, reported for the O horizon an average growth rate of 14 to 42 g C m^{-2} $year^{-1}$ during 40 years from 1961 to 2001. This corresponds to ca. 0.5–1.4% of the present SOC stock in the O horizon. They also found a higher growth rate for southern than for northern Sweden and stressed that some areas in the north even have a negative growth. Also Akselsson et al. (2007) using a simple N balance method showed a pattern with higher C sequestration rates in southern Sweden than in northern. Ågren et al. (2008) found that the current rate of SOC accumulation is 7.5 g m^{-2} $year^{-1}$, and that the rates were not evenly distributed over the country but showed a trend from almost no changes in the north to up to around 10 g C m^{-2} $year^{-1}$ in the south. They suggest that the current soil carbon stocks are not in equilibrium with the current rate of litter production and that the further south in Sweden, the more the situation deviated from equilibrium because of the larger change in litter production in the south due to increasing forest biomass. It should be stressed that Ågren et al. (2008) did not account for the atmospheric N deposition retarding impact on decomposition (Hyvönen et al. 2008) and may therefore have underestimated the growth rate, particularly in the south. Svensson et al. (2008) used the COUP model for four different regions in Sweden with annual mean temperatures ranging from 0.7 to 7.1°C. They found that the soils in the northern region of Sweden lost 5 g C m^{-2} $year^{-1}$, the soils in the central region lost 2 g m^{-2} $year^{-1}$, and the soils in two southern regions accumulated 9 and 23 g C m^{-2} $year^{-1}$, respectively. The standing forest biomass has from 1926 to 2000 not changed much in northern Sweden but has increased significantly in southern Sweden.

These results suggest a current accumulation of soil carbon in Sweden, and that the growth rate is faster in the south than in the north. An assumed average of 5 g C m^{-2} $year^{-1}$ for 17 M ha forest land on mineral soils (peatland excluded) gives an annual soil sink of 0.9 M ton C $year^{-1}$. However, estimation of net ecosystem exchange by the eddy covariance method on similar soils gave a different picture (Lindroth et al. 2008). The rate of change in soil carbon, estimated as the difference between NEE and the annual tree biomass increment, was negative for all the three Lustra sites, largest for Knottåsen with −186 g C m^{-2} $year^{-1}$, and −93 g C m^{-2} $year^{-1}$ for Flakaliden and −32 g C m^{-2} $year^{-1}$ for Asa. Negative values mean a flux from the soil to the atmosphere, i.e. the soil is a source. These values are surprisingly high in relation to present soil carbon stocks. One factor that may partially explain the high C losses from the soils is that the present stands still are in a phase of decomposition of stumps and coarse roots that were left from the cutting ca. 45 years ago. The report by Ågren et al. (2008) indicates that decomposition of stumps is delayed related to other kinds of material and may 40 years after cutting amount to 20–60 g C m^{-2} $year^{-1}$. However, this explains only a part of the soil net loss at Knottåsen and Flakaliden. It stresses the importance of accounting for all soil organic pools, thus not only fine soil, but also woody debris such as stumps, coarse roots and bark.

Even if most of the investigations are pointing at the mineral soils under forests being small carbon sinks there is a big source of carbon from drained organic soils as shown by von Arnold (2005) as part of the Lustra programme. The total heterotrophic respiration from 1.0 M ha organic soils (i.e. 4% of all Swedish forest land) was estimated to 10.8 M ton CO_2 $year^{-1}$. Taking the uptake rate of C in biomass in consideration the system is more or less in balance for Sweden as a whole (von Arnold et al. 2005). However, if also N_2O and CH_4 emissions are included (0.7 and 0.07 M ton CO_2 equivalents, respectively), the forest on drained peatlands are a small net source (von Arnold et al. 2005). Ernfors et al. (2008) estimated the national emissions of N_2O from drained organic forest soils to 0.41 M ton C equivalents $year^{-1}$. The emissions of CO_2 plus N_2O from drained organic forest soils, amounting to 3.3 M ton C equivalents $year^{-1}$, thus by far exceed the sink in mineral soils making Swedish forest soils to a net source of greenhouse gases.

Jansson et al. (2008) estimated the expected changes in carbon pools due to climate change according to the two IPCC climate scenarios A2 and B2 from Hadley Centre simulations. The net ecosystem exchanges consisted for both scenarios mainly in a big increase in tree biomass production, whereas the change in soil storage was small and negative. They found for southern Sweden, where soil carbon currently is accumulating (Svensson et al. 2008), a slightly decreased SOC future accumulation rate, and for northern Sweden, that currently is loosing soil carbon, a slightly increased SOC loss rate. They stressed that there is a very strong link between decomposition, mineralization, nutrient supply and photosynthesis that together may give the whole ecosystem a more inert behaviour than could be expected from studies of the individual processes. The change in soil carbon was shown as the result of two counterbalancing fluxes where increased litter production was followed by increased soil heterotrophic respiration resulting in only small net changes in soil carbon. No CO_2 fertilising effect was investigated.

Effective ways to manage the soil carbon pools are through N fertilisation (Hyvönen et al. 2008), water regulation at organic soils (Klemedtsson et al. 2008; von Arnold 2005), and choice of tree species. Results from the Lustra programme, based on data from the Swedish National Inventory of Forest Soils, indicate that at similar site conditions the soil organic carbon stock was 60% larger in spruce than in pine stands. However, this is still unpublished material. All together the data collected and the model development may provide good conditions for further conclusions on forest management and the potential to use forest products to mitigate greenhouse gas emissions. In a report by Eriksson et al. (2007) it was shown that the big potential may not lie in the soil as a sink but rather in the use of wood products to substitute fossil fuels or materials that emit greenhouse gases during its production, such as concrete. However, forest management to improve the production of wood will also affect soil processes and the development of greenhouse gas sinks and sources in the soil with importance for accounting. Decisions should therefore be made on a scientifically based knowledge on soil and ecosystem processes.

References

Akselsson C, Westling O, Sverdrup H, Gundersen P (2007) Nutrient and carbon budgets in forest soils as decision support in sustainable forest management. For Ecol Manage 238:167–174

Ågren GI, Bosatta E, Magill AH (2001) Combining theory and experiment to understand effects of inorganic nitrogen on litter decomposition. Oecologia 128:94–98

Ågren G, Hyvönen R, Nilsson T (2008) Are Swedish forest soils sinks or sources for CO_2 – model analyses based on forest inventory data. Biogeochemistry. doi:10.1007/s10533-006-9064-0

Berg B, Gundersen P, Akselsson C, Johansson M-B, Nilsson Å, Vesterdal L (2007) Carbon sequestration rates in Swedish forest soils – a comparison of three approaches. Silva Fenn 41(3):541–558

Berggren Kleja D, Bergkvist B, Johansson MB, Langvall O, Majdi H, Melkerud PA, Nilsson Å, Weslien P, Olsson M (2004) A description of LUSTRA's common field sites. Reports in Forest Ecology and Forest Soils 87. SLU, Uppsala

Berggren Kleja D, Svensson M, Majdi H, Jansson P-E, Langvall O, Bergkvist B, Johansson M-B, Weslien P, Lindroth A (2008) Pools and fluxes of carbon in three Norway spruce ecosystems along a climatic transect in Sweden. Biogeochemistry. doi:10.1007/s10533-007-9136-9

Callesen I, Liski J, Raulund-Rasmussen K, Olsson MT, Tau-Strand L, Vesterdal L, Westman CJ (2003) Soil carbon stores in Nordic well-drained forest soils: relationships with climate and texture class. Glob Change Biol 9: 1–13

Eriksson E, Gillespie A, Gustavsson L, Langvall O, Olsson M, Sathre R, Stendahl J (2007) Integrated carbon analysis of forest management practices and wood substitution. Can J Forest 37:671–681

Ernfors M, von Arnold K, Stendahl J, Olsson M, Klemedtsson L (2008) Nitrous oxide emissions from drained organic forest soils—an up-scaling based on C:N ratios. Biogeochemistry. doi:10.1007/s10533-007-9123-1

Helmisaari H-S, Derome J, Nöjd P, Kukkola M (2007) Fine root biomass in relation to site and stand characteristics in Norway spruce and Scots pine stands. Tree Physiol 27:1493–1504

Hyvönen R, Persson T, Andersson S, Olsson B, Ågren GI, Linder S (2008) Impact of long-term nitrogen addition on carbon stocks in trees and soils in northern Europe. Biogeochemistry. doi:10.1007/s10533-007-9121-3

Jansson P-E, Svensson M, Berggren Kleja D, Gustafsson D (2008) Simulated climate change impacts on fluxes of carbon in Norway spruce ecosystems along a climatic gradient in Sweden. Biogeochemistry. doi:10.1007/s10533-007-9147-6

Klemedtsson L, von Arnold K, Weslien P, Gundersen P (2005) Soil CN ratio as a scalar parameter to predict nitrous oxide emissions. Glob Change Biol 11:1142–1147

Klemedtsson L, Jansson P-E, Gustafsson D, Karlberg L, Weslien P, von Arnold K, Ernfors M, Langvall O, Lindroth A (2008) Bayesian calibration method used to elucidate carbon turnover in forest on drained organic soil. Biogeochemistry. doi:10.1007/s10533-007-9169-0

Kolari P, Pumpanen J, Kulmala L, Ilvesniemi H, Nikinmaa E, Grönholm T, Hari P (2006) Forest floor vegetation plays an important role in photosynthetic production of boreal forests. For Ecol Manage 221:241–248

Lindroth A, Klemedtsson L, Grelle A, Weslien P, Langvall O (2008) Measurement of net ecosystem exchange, productivity and respiration in three spruce forests in Sweden shows unexpectedly large soil carbon losses. Biogeochemistry. doi:10.1007/s10533-007-9137-8

Olsson M (1999) Soil survey in Sweden. In: Bullock P, Jones RJA, Montanarella L (eds) Soil resources of Europe, the european soil bureau, Joint Research Centre, Ispra, Italy, pp 145–151

Olsson M, Erlandsson M, Nilsson T, Nilsson Å, Stendahl J Organic carbon in Swedish Podzols and their relation to site properties. Submitted to Silva Fenn

Svensson M, Jansson P-E, Berggren Kleja D (2008) Modelling soil C sequestration in spruce forest ecosystems along a

Swedish transect based on current conditions. Biogeochemistry. doi:10.1007/s10533-007-9134-y
Swedish Statistical Yearbook of Forestry (2006) Official Statistics of Sweden, Swedish Forest Agency. Jönköping, Sweden, 337 pp
von Arnold K, Hånell B, Stendahl J, Klemedtsson L (2005) Greenhouse gas fluxes from drained organic forestland in Sweden. Scand J Forest Res 20:481–485