Carbon sequestration rates in Nordic forest soils - some results from three approaches.

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Carbon sequestration rates to the forest floor (O-horizon) are usually estimated by field sampling e.g. in forest inventories. However, such measurements are costly, time consuming and the results often uncertain. An alternative is to use the concept of calculable stable remains from decomposing litter and by direct measurements. Using Sweden as a case study we made an upscaling of carbon sequestration rates in the humus layer to the forested land covering $27*10^6$ ha with mainly Scots pine and Norway spruce. Two different theoretical approaches based on (i) limit values for litter decomposition and (ii) N balance in soil give similar average carbon sequestration rates (180 and ca 100 kg C /ha/yr). The third approach is to directly measure the development of humus depth. Such measurements over 40 years, combined with C analyses give an average rate of 180 kg C ha/yr that is not different from that calculated using limit values.

For the upscaling (limit value approach), annual actual evapotranspiration (AET) was estimated for 17 000 grids of 5*5km. For the forested area we obtained an annual sequestration of $4.8*10^6$ tons of C in SOM, with an average of 180 kg C ha/yr. The gradient in C sequestration rates follows AET and ranges from 410 kg C ha/yr in southwest to 40 kg C ha/yr in the north. Differences in litter fall and limit values among tree species give different sequestration rates. Norway spruce forests accumulate annually on average 200 kg C per hectare in SOM, Scots pine and the two dominant birch species have an average rate of 150 kg C ha/yr. For beech and oak, limited to south Sweden, the C-sequestration rates were around 400 kg ha/yr.

Using the N-balance method we used the same upscaling approach but used the assumption that the C/N ratio in the accumulating SOM has the same C/N ratio as the SOM layer, the approximate C sequestration rate could be estimated by multiplying the N accumulation by the C/N ratio in the SOM layer.

Sequestration rates based on field sampling (Swed Natl Forest Survey > 600 000 single measurements) were analysed within the same area as the limit value approach (above). Carbon sequestration rates ranged from ca 0 to a maximum of ca 700 kg C ha/yr with an average of 180 kg C ha/yr. Scots pine-dominated forests had a significantly higher sequestration rate (average 263 kg C ha/yr) than those dominated by Norway spruce (178 kg C ha/yr).

Although climate influences the sequestration rates, it appears to be just one of several factors. A Danish tree species trial on soils of different nutrient status showed that a soil factor may be needed for correct prediction using the limit value concept. For instance the sequestered amount of C was negatively related to concentrations of P and Ca in the soil. There was also a clear difference between tree species as regards the influence of the soil factor on C sequestration with species as Norway spruce and common beech being very sensitive, pedunculate oak less so and lodgepole pine being quite unaffected. We are currently analyzing the ability of the limit values concept to predict C sequestration in forest floors of different soil types.

Key words; Stable humus, recalcitrant, carbon sequestration, litter decomposition, limit value, N-balance, direct measurements, upscaling .

On methods of regional and local soil organic matter pools evaluation and modelling for soil monitoring in the forests of European Russia

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A quantitative evaluation of soil organic matter (SOM) pools and their dynamics in forest soils under the impact of changing climate and forest management is crucial for the assessment of the role of forests and silviculture in carbon balance at national level. This is an important task in a frame of Kioto Protocol. Russia has very rich forest soil data. This data allows for a compilation of soil databases of different spatial resolution. Obviously, the soil data of any spatial level should be combined with forest inventory for carbon balance assessment. We propose the methods of implementation of regional soil databases and compilation of spatially distributed SOM data of local/stand level joined with forest inventory maps, local and regional forest statistics.

At the regional level, the method is based on scientific materials (collected in the given region) on correlation of soil units and SOM pools with forest vegetation and site types. This data is linking with the regional forest statistics at a matrix “forest type – dominating tree species – age class - area” with SOM pools calculation for every unit and the whole region. At the local level, the same approach to use the experimental data is applied. However, the values of SOM pools are compiling for every forest inventory compartment for the area under investigation. The compiled SOM pools at regional and local levels can be further aggregated for soil C evaluation at national level. The obtained SOM data is an indispensable base for running SOM and forest ecosystem simulators to understand the trends of soil C changes under various silvicultural regimes and environmental changes. Two case studies on the application of regional and local SOM pools compilation combined with simulation models ROMUL and EFIMOD are discussed in the presentation. This approach allows for an effective assessment of SOM pools and dynamics for the forests of European Russia.

Effect of the model choice for simulating soil carbon stocks and stock changes: comparison of four soil models.

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Models are essential tools to analyze the effects of climate change and forest management on carbon stocks in forest soils. In this study, we evaluated how four different soil models affected the assessment of carbon stocks and stock changes in forest soils The models were 4C, ROMUL (the soil sub-module of EFIMOD), RothC and Yasso. All models were run for four forest sites in Finland and two sites in Germany. The sites differed in their climatic and soil conditions and stand composition (dominated by Scots pine or Norway spruce). The models were initialized with measured soil data (4C, EFIMOD), equilibrium runs with stand litter data (Yasso) or a combination of both (RothC). The simulation was run over a 20-year time period. All models were driven by litter input data generated with 4C and EFIMOD. Soil carbon stocks were compared for the carbon in the organic layer (4C, ROMUL), the mineral soil (4C, ROMUL, RothC), and the total soil carbon (4C, ROMUL, Yasso). Preliminary results showed that the simulated soil carbon stocks and stock changes varied considerably between the models. The initial carbon stocks of the models differed in a range of ± 45% from the average. The inter-annual total stock changes simulated by the four models ranged from -60% to +110% from the average. The 4C model simulated the highest stock increase followed by ROMUL, RothC (for the mineral soil) and Yasso. The differences can be partly explained by the different initialization procedures (measured values versus equilibrium assumption) and by the internal model assumptions (e.g. fine root allocation). This model comparison showed that the choice of the model considerably influences the estimation of carbon stocks. However, in order to assess the models results in terms of reality, they should be compared to measured soil carbon stock changes.

Modelling soil carbon sequestration of forest soils for different nitrogen fertilization and deposition levels

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The long-term effects of N fertilization and N deposition on the carbon and nitrogen balances of forest stands in Sweden were studied (Gärdenäs et al. 2003; Gärdenäs & Eckersten 2006). Fluxes of carbon and nitrogen were dynamically coupled with the SOILN model (Eckersten et al. 1998) and calculated as a function of water and heat fluxes, which in their turn were simulated with the CoupModel (Jansson & Karlberg, 2001). Three main forested vegetation zones in Sweden (pine in northern and central Sweden, and spruce in southern Sweden) were represented with their own climate, soil type, stem production and N deposition level. The simulations were done for a whole forest rotation period (75-100 years). The tested N deposition levels were 50 %, 100 % and 150 % of the level in 1996 for each region. A single N fertilization dose was set to 150 kg/ha. The maximum total fertilization for each region followed the fertilization recommendations by the National Board of Forestry Sweden with 0, 300 and 600 kg N per ha and rotation period for southern, central and northern Sweden, respectively.

The uptake of organic N by the plant (presumably by symbiosis with mycorrhiza) was shown to be essential to simulate biomass production and plant N content of the same magnitude as that found in the literature. We found that soil C sequestration increased most with N deposition level in central Sweden. Increasing deposition level enhanced plant growth and N demand to such a degree that uptake of organic N was also stimulated. The uptake of organic N caused less soil respiration than uptake of mineral N and had a positive feedback on C sequestration (see also Aber et al. 1998; Beier et al., 2001). The effect of N fertilization on soil C sequestration depended on the N deposition level. We conclude that C sequestration is, in a complex way, sensitive to N addition rate, plant growth and climatic conditions. These relationships need to be considered in assessments of climate and management (change) impacts on soil C sequestration.

Aber, J. McDowell, W., Nadelhoffer, K., Magill, A., Berntson, G., Kamakea, M., McNulty, S., Currie, W., Rustad, L. Fernandez, I. 1998. Nitrogen saturation in temperate forest ecosystems. Hypotheses revisited. BioScience 48: 921-934.

Beier, C., Eckersten, H., Gundersen, P., 2001. Nitrogen cycling in a Norway spruce plantation in Denmark - A SOILN model application including organic N uptake. *The ScientificWorld* v. 1 (no.S2) p. 394-406

Eckersten, H., Jansson, P-E., & Johnsson, H. 1998. SOILN model, user´s manual. Version 9.2. Swed. Univ. Agric. Sci., Dep. Soil Sci., Communications 98:6, 113 pp.

Gärdenäs, A, Eckersten, H. & Lillemägi, M. 2003. Modeling long-term effects of N fertilization and N deposition on the N balance of forest stands in Sweden. 30 pp. Emergo 2003:3

Gärdenäs, A. & Eckersten, H. 2006. 100 Years of nitrogen leaching under various levels of N fertilization and N deposition from forest stands in Sweden – a modeling study. (*in prep.*)

Jansson, P-E. & Karlberg, L. 2001. COUP model - Coupled heat and mass transfer model for soil-plant-atmosphere system. Dept. of Civil and Environmental Engineering, Royal Institute of Technology.

Detecting C stock changes in soils of afforested areas in Hungary

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Large scale afforestations are thought to have considerable potentials that can contribute to international efforts to sequester carbon, and thus mitigate climate change. Hungary is among the countries with large areas to afforest, and declared to increase her forest cover from 19 to 25 % in the next decades. The amount of C that can be fixed in the biomass can easily be predicted, however, little is known about what may happen in soils.

In this study the C-stock changes in the forest floor and mineral soil (0-60 cm) after afforestation of croplands and grasslands were measured at 6 different sites using chronosequences, and an asymptotic function was fitted on data over age. It was found that increases of C in the soil of afforested croplands amounted to 43 Mg ha^{-1} over 150 years. In average 7 Mg C ha^{-1} was fixed in the forest floor, the rest in the mineral soil. This is confirmed by a more detailed sampling of ten sites of stands of ages up to 20 years, which showed no carbon loss even in the first years, and an increase of C in litter and in the soil. In contrast, afforestation of grassland does not increase the C stocks in a long term, rather, a net C emission of 10 Mg ha^{-1} could be measured in the first three decades, which is than offset over the following 100 years.

The C-budget of a large-scale (750,000 ha) afforestation scenario, which was put forward as a policy option, was calculated assuming a proportion of 1/3 grassland and 2/3 arable land. Our results suggest that C-stock change in the soil of the afforested areas is too insignificant to exert a major influence on the C-budget of Hungary, as it would take approx. 300 years to fix the annual gross emission of the greenhouse gases of the country. Furthermore, the soil itself becomes a net C emitter in the first decades, even if only to a small magnitude. These results suggest that, with soils, protecting current C stocks seems much more important than to use soils as potential means of mitigation.

Uncertainties in the model of soil organic matter pools dynamics ROMUL

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The description of soil processes of mineralization and humification in forest ecosystems deals with follow main sources of uncertainties: litter fall variables, climate variables, splitting of the soil organic matter into different fractions, which are decomposing with different rates; evaluation of the coefficients of the decomposition rates in dependence on splitting conditions; robustness of these coefficients concerning the accuracy of evaluation; initialization of the model in relation to the suggested splitting.

The ROMUL model (Chertov et al., 2001) has been developed using the classic pedological concept of the 'humus types'. Each litter fraction is represented as: undecomposed litter, partly humified organic material in the organic layer (forest floor and peat) or the same in the mineral topsoil (fraction of 'labile humus'). Stable humus bonded with the mineral matrix of the top soil is a summator of the humified fractions. Humification is modeled as a consequence of a successive processes regulated by three communities of saprophages. We have evaluated the decomposition coefficients as a function of the biochemical properties of litter, soil temperature and moisture using a set of laboratory experiments in controlled conditions. Verification have been done on a set of field experiments.

A Monte-Carlo procedure in relation to litter fall and climate variations resulted in small sensitivity of leading variables. Litter fall was taken from the ecosystem model EFIMOD (Chertov et al., 2003; Komarov et al., 2003).

We found that sensitivity of small Monte-Carlo changes of coefficients' values increase with stage of decomposition. The rate of mineralization of stable humus is most sensitive to changes. It looks realistic and could be taken as a calibration parameter.

A procedure of initialization of soil data uses a concept of primary forest succession and forest types. It was found that in this case simulated results fit well with measured experimental data. The dynamics of leading variables converges to any equifinal state due to linear structure of the model. Splitting of the soil organic matter into labile and stable humus also results in converging of leading variables due to the same reason.

Validation of modelled soil organic carbon pools by DRIFT-PLS

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Pool-based models for the turnover of soil organic carbon (SOC) are often successfully applied to describe soil organic matter dynamics under different management. Model validation is typically obtained by comparing measured with modelled bulk SOC contents. Because pools are mathematically defined and regarded as conceptual, a direct comparison of pools with measurable soil properties is challenging. A linkage between modelled pools and measurable soil attributes would be valuable in particular for the experimental validation of short to medium-term C pools that respond relatively fast to management. Moreover, assigning chemical or physical attributes to soil C-pools could contribute to an improved process understanding.

We have used the process-oriented model CANDY to simulate SOC in long-term field experiments at Bad Lauchstädt, Germany. The soil carbon module of CANDY consists of several C pools (i.e., 'inert', 'stabilised', 'active', 'plant residues') that differ in their turnover time. The selected field treatments included different types and levels of fertilisers at different days of the year and represent steady-states at high and low SOC contents and transitional states from high to low or vice versa. Measured and modelled C contents agreed reasonably well (R2 = 0.85 – 0.94). Pool size values were taken as y-variables to perform partial least squares (PLS) regression on diffuse reflectance infrared FT (DRIFT) spectra of bulk soils. Prediction for cross-validated samples were of reasonable quality (R2 = 0.82 - 0.90; relative standard error of prediction 6 - 7%) for bulk SOC and 'inert' C, the latter contributing approximately 75% of the total SOC. Prediction of the 'active' and 'stabilised' SOC pools required separate calibration of high and low fertiliser treatments. For the so partitioned samples, these pools could be predicted with similar accuracy as above. The latent variables of the PLS regression were markedly different, indicating that the corresponding chemical constituents of a single pool are not the same for all of the treatments. Prediction of 'plant residues' failed, most likely because they accounted for less than one percent of the SOC and thus contributed only little to IR reflectance.

The prediction of modelled pools by DRIFT-PLS offers a tool for model validation. The results demonstrate that the pools are not purely conceptual, but have some chemical analogy. Apart from errors in measuring and modelling, we suggest that some of the unexplained variance is attributable to SOC-stabilisation processes that are not directly related to the chemical composition of the soil and are thus not detectable by spectroscopic methods, for example.

Modelling soil carbon balance at large scales

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It is often necessary to rely on models when estimating the carbon balance of soils at large geographical scales. Measurements may not be available for even the current balance because they are laborious to take. To estimate the balance in the future, models are the only option.

To be useful, the model-estimates must be reliable. Their reliability depends on, first, how realistically and comprehensively the models describe the processes and factors controlling the carbon balance and, second, how accurately the effects of the chosen processes and factors are quantified in the models. The first requirement calls for complex models whereas the second limits their usefulness as data available may be inadequate to determine the values of their numerous parameters. This is the dilemma between the complexity of models and possibilities to determine their parameter values in obtaining reliable estimates for the carbon balance of soils at large scales. A useful model contains the most important process and affecting factors which rates and effects are still possible quantify based on the data available.

What is an appropriate compromise between the complexity of a model and the possibility to determine its parameter values? A way to answer this queston is to validate the output of the model, both the whole model and its parts, against various measurements. How well this can be done depends on the availability of different measurements.

These two issues that affect the reliability of the model-calculated estimates for the carbon balance of soils at large scales, namely the complexity of models vs. the determination of their parameter values and possibilties to validate the results of the model, are discussed in this presentation with the help of examples.

Soil carbon modelling applied for nation-wide forest carbon inventory

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Forest carbon sinks were included in the Kyoto Protocol, since they contribute notably to the global GHG budget. The use of C sinks for compensation of emission reductions have created a timely need for more reliable forest C monitoring systems. Reporting of the C sinks should cover all pools including soil C. Methods to assess the changes in soil C stock are still under discussion, even in the countries with extensive soil surveys. Heterogeneity of forest soil together with small expected changes, may lead to costly and time consuming sampling scenarios in large-scale inventories. Therefore, many countries have to find means other than direct soil measurements to fulfill the reporting requirements under the Climate Convention.

Our objective was to develop a method to assess the changes in the C stock of forest vegetation and soil that can be applied in various regions across the temperate and boreal zones. The method integrates information provided by forest inventories, models of biomass allometry and biomass turnover, and dynamic soil C model Yasso (Liski et al. 2005, Lehtonen 2005). The soil model estimates the C content of litter and soil down to 1 meter, which was the depth used in its parameterization. Yasso is based on a conception that chemical compounds existing in litter determine the rate that the litter decomposes. This process has been parameterized and tested only for mineral soils with no peat cover (Liski et al 2005), and other models are therefore needed for the GHG fluxes of peatlands.

This method was applied for Finland where the C budget of the forests over an 80-year period was calculated (Metsätilastollinen 2004, Lehtonen 2005, Liski et al 2006). Forest vegetation and soil had a tendency of increasing C stock over this study period from 1922 to 2004. However, the C sink was highly variable between years depending on climate and the level of harvesting. The estimated changes in soil C were often opposite to those in biomass, which underlines the need of full accounting of C pools of forests.

In addition to component-wise tests of validity of the applied models on allometry of trees, biomass turnover and soil dynamics, this modeling approach as a whole was tested with empirical data from Southern Finland (Peltoniemi et al 2004). Furthermore, the overall uncertainty of the modelled C sinks in vegetation and soil were simulated with Monte Carlo approach (Peltoniemi et al. submitted ms). For the soil C stock change assessment the major source of uncertainty was soil model initialization, but this uncertainty decreases with time elapsed since model initialization. Thereafter, most important factors causing uncertainty were related to decomposition temperature, harvest residues, net forest area change, and soil model parameterization. In many countries soil C monitoring will rely on other methods than direct measurements of repeated soil surveys. Here we demonstrated that the preliminary estimates of soil C sink/source can be provided by modeling. Furthermore, the modeling approach can guide in stratification of the soil sampling when nation-wide soil surveys are conducted.

Lehtonen, A. 2005. Carbon stocks and flows in forest ecosystems based on forest inventory data. Dissertationes Forestales 11. 51 p. www.metla.fi/dissertationes/df11.htm

Liski, J., Palosuo, T., Peltoniemi, M. & Sievänen, R. 2005. Carbon and decomposition model Yasso for forest soils. Ecological Modelling 189: 168-182.

Liski, J., Lehtonen, A., Palosuo, T., Peltoniemi, M., Eggers, T., Muukkonen, P. & Mäkipää, R. 2006. Carbon sink of the Finnish forests 1922-2002 estimated by combining forest inventory data with modelling of biomass, litter and soil. Submitted manuscript.

Metsätilastollinen vuosikirja 2004. Metsäntutkimuslaitos, Vammalan kirjapaino, 415 p.

Peltoniemi, M., Mäkipää, R., Liski, J. & Tamminen, P. 2004. Changes in soil carbon with stand age – an evaluation of a modeling method with empirical data. Global Change Biology 10: 2078-2091.

Comparing and predicting soil carbon quantities under different land use systems on the Red Ferrosol soils of Southeast Queensland

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Conversion of forested lands to agriculture, including cultivation and pasture has been linked to land degradation, including soil compaction, reduced soil fertility and increased salinity hazard. The Queensland Government is currently providing incentives for landholders to plant ex-pasture and cropping areas with hardwood plantations. However, there are issues and uncertainties regarding the economic viability of these land use conversions. Carbon credits resulting from additional carbon (C) sequestration achieved in the plantations are now recognised under the Kyoto Protocol, but the nature of the carbon trading scheme that will apply is still unclear, as Australia has not ratified the Protocol. This study compared the total soil C under native scrub (subtropical dry vine forest), grazed pasture, cultivation and spotted gum (*Corymbia citriodora*) forest on the Red Ferrosol soils of the Kingaroy region in southeast Queensland (SEQ). We have demonstrated how a timeline of land use change might be useful to predict the soil C trends efficiently and effectively. Cumulative soil C (including surface litter and particulate organic matter) to 1.2 t m^{-2} dry soil ranged from 72 t ha^{-1} at the cultivated site to 281 t ha^{-1} under the mature spotted gum forest. The predicted annual rate of soil C loss under cultivation was 2.1%, which was similar to the *ROTHC* predicted value. The annual rates of soil C gain under pasture and spotted gum plantation were predicted to be 1.1 and 1.4%, respectively. Therefore there is considerable potential for spotted gum plantations to sequester soil C when planted on ex-agricultural land in SEQ.

Key words: Red Ferrosol, land use change, dry land farming, inland Queensland, carbon sequestration, carbon credits

Forest soil dynamics at different silvicultural regimes: simulation modelling

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The forest simulation model of the stand/soil system uniting population and balance modelling approaches, EFIMOD, has been used for a long-term forest simulation of different silvicultural regimes. The ROMUL model (Chertov et al., 2001) is a sub model of soil organic matter dynamics based on a concept of the ‘humus types’. It allows for simulation of the carbon and nitrogen pools dynamics in soil taking into account mineralization and humification of soil organic matter. Structure of the model system allows for a use of standard forest inventory data. Output variables are the inventory stand data, pools of carbon and nitrogen in the stand and soil, the dynamics of CO2 emission and some other characteristics. The case study was conducted on a 300-hectare forest area with 108 stands in the experimental forest “Russky Les” 100 km south of Moscow, Russia.

Four strategies of silvicultural regimes were simulated for a 200 year time span: natural development, selective forest harvest, authorised Russian forestry practices according to the forest laws, and unauthorised forest practices that have increased over the last decade in the country.

The naturally developed forest has maximal increase of carbon in soil (22 ton/ha in 200 years) on the simulated forest section. At selective cuttings scenario pool of soil increased on 7.4 ton/ha, at authorized practice scenario it slightly increased on 1.3 ton.ha. Unauthorised practice scenario demonstrates gradual decrease of carbon in soil on 8.2 ton/ha in 200 years). Undecomposed forest floor maintains in the scenario of natural development only. The stable humus stock changes slightly in all scenarios. Scenario of natural development leads to the notable increase of coarse woody debris (30-40 ton/ha), in other scenarios it is two-three times lower.

The results obtained allow for the conclusion on the advantage and shortcomings of different regimes of forest management for their correspondence to the concept of sustainable forest management. Selective forest technology has clear advance over all other regimes. Actually, the simulation of ecosystem development and tree growth at forest territory (enterprise, landscape) level gives also opportunity for a combination of different regimes.

Monitoring Soil C Stocks Using a Simulation Model-Based Approach

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Modelling offers opportunities for monitoring soil C stocks across large regions, but it also presents unique challenges it order to produce a viable approach with reasonable accuracy. There are several steps for developing a robust model-based monitoring system, including 1) select/develop an appropriate model, 2) verify the adequacy of the model by comparing to measurement data, 3) identify sources of model input data such as soil surveys, land use and management activity records, and climatic data, 4) assess uncertainties, 5) implement the model, and 6) evaluate results with an independent set of measurements.

This approach has been used to develop a model-based monitoring system for US agricultural lands. The system has several components, including 1) a simulation model (i.e., Century Model) for estimating changes in soil organic C storage, 2) spatio-temporal model input data on management activity and environmental conditions, 3) a Monte Carlo Analysis for addressing uncertainties in model input data, 4) an empirically-based estimator for incorporating additional uncertainties associated with the structure of the simulation model, and 5) a data management system to organize and process model inputs, simulations and results. Underlying this assessment are national soil survey data, which provide key soil characteristics needed as model input; climatic data based on a model-based interpolation of national weather service records; and National Resources Inventory data that are used to schedule land use and management activity based on historical patterns recorded at about 400,000 point locations.

This system has been used to estimate a net sequestration in US agricultural lands during the 1990s, ranging from 21 to 25 Tg C yr^{-1}. With a well-developed monitoring system, trends in soil C stock changes can be used for policy assessment, including an evaluation of GHG mitigation, as well as for reporting purposes as required for domestic programs and international treaties (e.g., UNFCCC).

National Soil Surveys in Soil Carbon Monitoring

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Soil organic carbon may play a profound role for the greenhouse-gas balance since it is a big pool, that gobally, is 40% bigger than carbon bound in living terrestrial vegetation. The Marrakesh Accords specify that this C pool should be counted. Carbon monitoring is also justified by IPCC´s report on Good Practice Guidance. It states that it is good practice to use methods that provide the highest levels of certainty, i.e. highest tier level, and to use available resources as efficiently as possible. Soil organic carbon monitoring should therefore preferable be included in an integrated ecosystem assessment of all forest carbon pools, with explicit linkages between the soil, biomass and dead organic matter pools. Soil organic carbon is referred to as carbon in mineral soils and organic to a specified depth chosen by the country. Live fine roots can be included with soil organic matter where they cannot be distinguished from it empirically. The soil organic carbon pool does not include the O horizon (L, F and H horizons) that is classified as litter, which is not consistent with practise in soil science.

Monitoring of soil organic carbon stocks in mineral soils and their changes involves field sampling with or without stratified random sampling, extraction of soil samples for carbon analyses, laboratory analyses and evaluation of data. Changes in organic soils C stocks can not easily be measured by monitoring C stocks but have to be evaluated through measurements or estimations of emissions. Uncertainties may be due to sampling errors, systematic errors, analytical errors and errors in used models or functions. Particular errors may be due to wrong estimates of bulk densities and of the occurrence of coarse material.

Sweden, based on experiences from the National Soil Inventory, concluded that adequate depth of the soil carbon pool is 50 cm in mineral soils. Due to glacial soils with high content of coarse material core sampling is not possible. Instead soil samples are taken at set depths and by pedotransfer functions the real carbon stock is assessed. Different sample depths are used for different soils. A model for bulk density is applied, based on depth and carbon content. The content of coarse material is determined by the rod penetration technique. In total ca 23000 permanent sample plots are studied during 5-10 year cycles. Results from previous sampling, 1993 – 2002, show that the spatial variation within the country is high, eg for podsols resulting in a standard deviation of around 80 % of the mean carbon concentration in B horizons, or 70 % for the carbon stock to 50 cm . Based on knowledge of uncertainties it is possibly to estimate precision and number of samples needed to verify a certain C change. Because the inventory is carried out also for other purposes than carbon monitoring it can not be stratified in order to optimise detection of carbon stocks. ´The most important site factor for the soil carbon stock was soil moisture. Comparison of plots with podsols for two sampling periods, 1983-1988 and 1992- 2003 does not show any significant change in carbon stocks.

Model stratified sampling for soil carbon stock changes

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Monitoring of carbon stocks in soil and organic matter has become an important issue due to reporting requirements set by Climate Convention and Kyoto Protocol. Repeated measurements provide a direct way to assess possible changes in soil carbon stocks.

Forest soils are often highly heterogeneous and most of this heterogeneity is already present within small distances. This presents a practical problem for measuring soil carbon content, since a large number of samples are required to get a reliable estimate of mean stock. Detection of changes in soil carbon stocks is even more difficult, since the expected changes are usually extremely small in comparison to stocks of carbon. In addition to these challenges, field work needs to be efficient and practical, which sets further restrictions on soil sampling.

In this work, we used predicted changes of soil carbon stocks as a basis for stratification of soil sampling. We simulated soil carbon contents for permanent sample plots of national forest inventory. The sites that accumulated or lost most carbon during the measurement interval had a higher probability to be sampled. Also the assumed homogeneity of soil carbon changes within a plot affected the probability of the plot to be sampled. The specific question of the study was: How much the model based stratification of soil sampling could decrease the sampling effort to detect a significant change in soil carbon.

Methodologies for estimating forest soil carbon stocks using annual forest inventory data

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The USDA Forest Service Forest Inventory and Analysis (FIA) program performs an annual forest inventory that includes measurements of down woody material and soil quality. These measurements are taken on a systematic nation-wide grid of approximately 125,000 plots where each one may represent up to 38,850 ha of forest. Between ten to twenty percent of these plots are measured every year. I combined tree, down woody material, and soil measurements collected over three years (2001 - 2003) to evaluate current methodologies for estimating the contribution of soil carbon to total carbon storage in forests of the United States. Tree measurements include species, height, and diameter at breast height. Carbon content of live tree biomass is estimated with carbon conversion constants. Down woody material carbon stocks (coarse and fine woody debris) are estimated using line intercept transects and carbon conversion constants. The soil quality indicator includes volumetric sampling of the forest floor and the collection of mineral soil cores representing depth increments of 0 – 10 cm and 10 – 20 cm. Carbon content of the soil samples is determined by dry combustion. Carbon storage by pool is roughly ranked as follows: standing tree biomass > 0 – 10 cm mineral soil > 10 – 20 cm mineral soil > coarse woody debris > the forest floor ≈ fine woody debris. The tree measurements actually occur on a denser sampling network than either the down woody material or soil measurements. Additional research is underway to determine effective geospatial modeling techniques for estimating the soil carbon at all tree measurement locations.

Combining soil and forest models with spatial data sets to assess climate impacts on European forest soils

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Forests are a major land use in Europe, and European forest soils contain about the same amount as carbon as is found in tree biomass. Changes in the size of the forest soil carbon pool could have significant impacts on the European carbon budget. We present the first assessment of future changes in European forest SOC stocks using a dedicated process-based soil organic carbon (SOC) model and state-of-the-art databases of driving variables. Soil carbon change was calculated for Europe using the Rothamsted Carbon model using climate data from four climate models, forced by four IPCC emissions scenarios (SRES). Changes in litter input to the soil due to forest management, projected changes in NPP, forest age-class structure, and changes in forest area were taken into account. Results are presented for mineral soil only. Under some climate scenarios carbon in forest soils will increase slightly (0.1 to 4.6 Pg) in Europe over the 21st Century, whilst for one scenario, forest SOC stocks are predicted to decrease by 0.3 Pg. Different trends are seen in different regions. Climate change will tend to speed decomposition, whereas increases in litter input due to increasing NPP and changing age-class structure will slow the loss of SOC. Increases in forest area could further enhance the total soil carbon stock of European forests. Whilst climate change will be a key driver of change in forest soil carbon, changes in age-class structure and land-use change are estimated to have greater effects.

Soil Carbon Model Parameterization and the Equilibrium Assumption

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The soil carbon model YASSO well captures important features of soil carbon changes. Because of its simplicity it is suited for integration with inventories and various forest growth models. The Parameterization of the YASSO model was based on the assumption of soil carbon stocks to be at or near equilibrium. However, many forest soils in central Europe are recovering from degradation of former intensive usage (e.g. former agricultural use, cattle drift, or litter raking).

We present an approach of parameterization of the YASSO model that is based on a weaker assumption. The pool with the slowest turnover rate is exempted from the equilibrium assumption. The approach requires the knowledge of the current rate of change in soil carbon stocks. We assumed that this rate could be estimated by a repeated soil carbon inventory.

However, this method will not detect small changes.

Already small rates of current change of soil carbon stocks result in a huge changes in total equilibrium stocks. These stocks represent the potential carbon storage after thousands of years with same inputs and environmental conditions. This way of parameterization does not change the short term carbon dynamics. However, there are long term consequences on carbon dynamics and the potential ability of forest soils to act as a significant carbon sink.

Monitoring of organic carbon stocks in forest soils in Southwest Bulgaria

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The carbon stocks in forest soils take important place both in environmental protection and in forest production. With the signing of the UNCCC Bulgaria demonstrates its willingness to contribute the activities minimizing the global climate change and to fulfill the obligations. The Bulgarian forests are 34 % from the territory of the country and the status of these types of ecosystems in the period of global climate change together with the management practices of forest resources are of a great importance for arise the forest- absorbance capacity. The study reports estimates of the organic carbon stocks of forest soils from southwest Bulgaria based on available data of organic carbon, bulk density and coarse fragments measurements along the profiles depths of different soil types. Tree soil groups are presented in the forest area of southwest region of Bulgaria (Leptosols, Luvisols and Cambisols). Average organic carbon density is from 0,8 kg.m^{-2} to 7.3 kg.m^{-2} for the upper 0-20 cm of soil, from 0,6 kg.m^{-2} to 5.6 kg.m^{-2} for the layer 0-10 cm. The estimated organic carbon density in organic layer (litter) ranges from 6,25 to 9.9 kg.m^{-2}. For estimations is used the current methodology applied in our country and the main point that have to be harmonized are presented. The maps with the present status and the changes in soil organic carbon stocks of the studied region for last decade are elaborated. The ArcGIS 9.0 & Spatial Analyst is used for spatial data analysis and mapping at regional scale.