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Introduction to carbon in sensitive European ecosystems: from science to land management

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1.1 Rationale for this book

In recognition of the rich body of knowledge already available on carbon sequestration in soils and the effect of land management (Kutsch, Bahn and Heinemeyer, 2009; Roose *et al.*, 2005; Lal and Follett, 2009), it was decided to focus on, especially, sensitive ecosystems and on ecosystems that are still not covered satisfactorily in the available literature.

The book is organized into three parts. Part 1 deals with 'driving factors for greenhouse gas (GHG) emissions'. In Chapter 1, the questions of what are understood as particularly vulnerable sites and situations in which ecosystems are likely to lose greenhouse gases are approached. Also included in this chapter is the 'toolbox of statistics' for emphasizing the opportunities offered, and the limits exerted by, different statistical approaches of data evaluation. The second chapter deals with the effect of land use change on soil carbon pools. The comparison of the soil carbon stock in 'managed' versus 'unmanaged' land has clearly shown that the agricultural

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Soil Carbon in Sensitive European Ecosystems: From Science to Land Management,
First Edition. Robert Jandl, Mirco Rodeghiero and Mats Olsson.

use of soils has led to a strong decline of soil carbon worldwide (Lal, 2004). Marginal agricultural land in Europe is frequently being afforested, with strong implications on carbon fluxes and pools. The state-of-knowledge for land use change is covered and evidence given on how well the understanding of carbon processes is supported by real data. A particular challenge is the temporal extent of the soil carbon change. Consequently, the chapter also explores how knowledge on land use change can be reconciled with the time frame of reporting.

Another chapter deals with disturbances. It is well understood that ecosystem disturbance changes the total carbon pool much quicker and sometimes with more severity than with the gradual evolution of an ecosystem (Körner, 2003). A series of natural and anthropogenic ecosystem disturbances are evaluated with hindsight to soil carbon pools, and it is demonstrated how management may affect the pools. The final chapter in the first part presents an overview on knowledge of soil carbon pools from a European perspective. This information is of crucial importance because it sets the limitations on an international soil carbon accounting scheme. It also addresses the highly important question of the baseline of soil carbon stocks that should be used when interpreting the current stock and stock changes of soil carbon.

Part 2 of the book picks out several types of ecosystems of particular relevance. It is intended to find a niche for this text by focusing on soils that deserve more attention than they have received in the past. In a chapter on mountain and high latitude ecosystems, the topic of above-average warming as predicted by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Fischlin *et al.*, 2007) is covered. Nevertheless, the biological activity of soil microorganisms is constrained by low temperatures and a short growing season. In a warmer climate substantial quantities of carbon dioxide may be lost from soils. A second strong driver is land use change due to the abandonment of alpine pastures and the subsequent reforestation.

A comprehensive treatment is given to ‘Peatlands’. From the knowledge of processes and responses of upland (mineral) soils to global warming, only limited predictions can be deduced for peatlands. Even their delineation on soil maps is uncertain. However, peatlands are a heterogeneous group of soils with different emissions. Drainage and subsequent land use change can have a strong effect on carbon fluxes and GHG emissions. The fate of peatlands as a consequence of climate change calls for a rigorous evaluation.

A separate chapter is devoted to *Mediterranean ecosystems*. Simulation models predict a low carbon sequestration potential for Mediterranean forest soils, mainly because the productivity of sites with a prolonged summer drought is low. More important than adapted forest management may be the effect of land use change (afforestation), because it may reverse the effects of earlier soil degradation. Afforestations in the Mediterranean regions have been shown to lead to considerable increases in soil carbon and nitrogen stocks. It needs to be shown how representative these results are for the entire region and how land use change effects can be communicated to landowners. An obstacle is that land use data and soil data are monitored by different authorities, which means that no harmonized and consistent data set on land use change is yet available.

In Part 3 of the book reporting issues are picked up. Firstly, based on the reports of greenhouse gases, how soils are treated is described, and of special relevance is the heterogeneity of data resources in Europe. The available databases on soil carbon stocks and land use are described. The role of simulation models is potentially very high in the reporting. Reporting soil carbon changes based on simulation results is assigned the highest Tier level in the Good Practice Guidance (IPCC, 2006). The modelling chapter gives an ample overview on different modelling approaches. The chapter is highly descriptive and leads the reader through a number of cases that are commonly encountered in reporting.

1.2 What do we need to know about soils for reporting purposes?

Accounting for changes in soil carbon stock requires an internationally agreed set of rules. The change in soil carbon needs to be reportable and verifiable based on data that are commonly available. Figure 1.1 shows the five compartments that need to be reported for forest ecosystems. For annual crops, the increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year, thus there is no net accumulation of biomass carbon stocks.

The reporting is done differently in the individual countries. The Good Practice Guidance (IPCC, 2006) identifies key categories that have a significant influence on a country's greenhouse gas inventory. When land use (agriculture, forestry, other land use ['AFOLU']) is a key category, countries use methods of higher complexity and with higher data demands (tier levels). Tier 1, the simplest version, applies to countries in which forests and the biomass carbon pool is not a key category and where no country-specific activity data are available. Tier 2 applies where forests and biomass carbon is a key category and where country-specific estimates of activity data (e.g. forest inventories) are available. Tier 3 applies where the forest land and biomass carbon is a key category. It requires detailed national forest inventory data

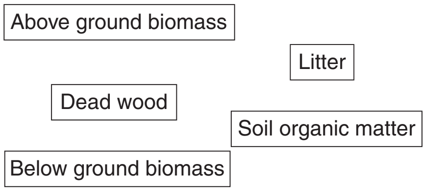

Figure 1.1 Five ecosystem compartments for which changes in soil carbon stocks are reported.

supplemented by dynamic models or allometric equations calibrated to national circumstances that allow for direct calculation of biomass increment.

Assisting in the understanding and reporting in this area is the COST Domain Earth System Science and Environmental Management (ESSEM). COST is a programme fostering the European Cooperation in Science and Technology. Action 639 was a joint activity within ESSEM lasting from 2006 to 2010. The management committee for COST Action 639 is shown in Appendix 1.A.

1.3 Objectives and overview of COST Action 639

The main objectives of COST (European Cooperation in Science and Technology) Action 639 (Greenhouse gas budget of soils under changing climate and land use (BurnOut), 2006–2010) are: (i) *the improved understanding* of the management of greenhouse gas emissions from European soils under different forms of land use and, in particular, disturbance regimes; (ii) the *identification of hot spots* of greenhouse gas emissions from soils; (iii) the *identification of soil and site conditions* that are vulnerable to GHG emissions; and (iv) the development of an advanced *reporting concept* across different forms of land use and land use changes.

The entire COST Action 639 had a strong focus on processes involving soil carbon in recognition that soils represent the largest terrestrial organic carbon pool. The overall role of soils as a sink for carbon dioxide is controversial. This is due to the heterogeneity of ecosystems including various forms of organic pools and the wide range of possible effects of land management on soil carbon pools over time. The representative assessment of soil carbon stocks poses a challenge. Even more difficult is that the detection of soil carbon changes over time, because often a small change has to be evaluated against a large and spatially variable pool. The agreement between simulated and observed temporal changes of soil carbon is sometimes unconvincing. This imposes a further challenge on the current requirement of reporting soil carbon changes within short time-spans. The length of a commitment period is indeed so short that even large soil carbon changes, can only be detected with a considerable amount of samples or with high uncertainty.

1.4 Working Groups of COST Action 639

1.4.1 Working Group – Hot spots for effects of climate change on soil carbon and nitrogen

Research focuses on landforms and situations that are expected to respond strongly to climate change in a manner that is likely to turn these ecosystems into sources of GHGs. Landforms with a particular relevance for different regions in Europe have been selected. In addition, forms of ecosystem disturbances that are believed to be of widespread importance are chosen.

Peatlands are a frequent landform in Nordic countries and Western Europe. As a soil type, they have peculiar properties. From the knowledge of processes and responses of upland (mineral) soils to global warming, only limited predictions can be deduced for peatlands. Even their delineation on soil maps is uncertain. There is concern about peatland degradation in response to climate change or land management and the deleterious effects of such degradation on GHG release, hydrology, water quality and ecosystems. Virgin peatlands (mires) accumulate atmospheric carbon and nitrogen, but emit methane. Nitrogen oxide emissions from natural mires are insignificant. However, peatlands are a heterogeneous group of soils with different emissions. Drainage can have a dramatic effect on GHG emissions. In the Nordic countries, approximately 15 million hectares of peatland are used as managed forest land and have, to a certain extent, been drained. Following drainage, the methane emissions decrease and the net primary production and nitrous oxide (N_2O) and carbon dioxide emissions increases. An integrated assessment of research needs to include an understanding of the links between hydrological processes, biogeochemistry, soil ecology, water flow paths, and the interactions between peatland and climate change. Moreover, peatland is understood as a renewable source of energy. Therefore, peatland is at some places exploited as a source for fuel. The impact of land use change of peatlands and the natural aggradation of peatlands as a consequence of global warming requires a rigorous evaluation. A GHG budget of the entire ecosystem is required in order to establish the net response (i.e. sink of carbon and nitrogen in higher biomass production vs source of GHGs from soils). The loss of peatland also affects the richness of the landscape and needs to be treated in the context of biodiversity issues. Understanding GHG emissions from peatland calls for a close cooperation between forest soil scientists and soil biologists.

In high elevation/latitude ecosystems the biological activity of soil microorganisms is constrained by low temperatures and a short growing season. In a warmer climate substantial quantities of carbon dioxide and nitrogen oxides may be lost from soils. The loss of GHGs from soils can be rapid, because large amounts of carbon and nitrogen occur in chemically labile forms that are rapidly mineralised. Thawing of permafrost may in some areas have a profound impact of emissions of carbon dioxide, nitrous oxide and methane. The extent to which increased plant productivity will compensate for soil GHG emissions is unknown. Budgeting the overall effect of soil warming requires understanding of the mechanisms of stabilization of soil organic matter and the stock of readily decomposable soil carbon. High elevation ecosystems are also undergoing a change because the land use is changing. Societal changes lead to the abandonment of pastures and the subsequent reforestation. The consequences for GHG emissions are not yet quantified.

Simulation models predict a low carbon sequestration potential for Mediterranean soils, mainly because the productivity of sites with a prolonged summer drought is low. More important than adapted forest management may be the effect of land use change (afforestation), because it may reverse the effects of earlier soil degradation.

Afforestations in the Mediterranean region have been shown to lead to considerable increases in soil carbon and nitrogen stocks. It needs to be shown how representative these results are for the entire region and how land use changes can be communicated to landowners.

Natural and human-induced disturbances play an important role in ecosystem dynamics: forests are subject to wind throw and fire with a certain region-specific periodicity. Within a short time, large quantities of soil carbon and nitrogen are converted to GHGs ('slow in / rapid out'). In Central Europe, secondary Norway spruce forests are common. This forest type is highly productive and is the backbone of forestry in several regions. The production risk of spruce monocultures is considerable and storm events regularly destroy vast areas of spruce forests. A second threat is the pressure from insect infestations, which often follow storm damage. As long as merely the economic value of timber production is compared, this forest type is superior to mixed-species forests. The main reason for GHG emissions from agricultural soils is tillage and nitrogen fertilization. Adapted forms of agriculture have a large potential for the reduction of emissions. However, agricultural soils are also responsive to climatic change. A major problem is erosion, especially when soils are bare during a part of the year.

Soils emit GHGs especially during drying/re-wetting cycles. These pulse emissions contribute a lot to the annual nitrogen oxide fluxes into the atmosphere. This knowledge has been soundly established on the basis of laboratory experiments and single case studies. The relevance for a national GHG budget is not clear. Preliminary results show that discontinuous monitoring of nitrogen oxide emissions can underestimate the annual emissions substantially when the short drying/re-wetting cycles are missed.

1.4.2 Working Group – Relation of land use, land use change and land use history on soil carbon and nitrogen

In the first commitment period (2008–2012) of the Kyoto Protocol, different types of land use are treated separately (IPCC Good Practice Guidance; IPCC, 2006). To avoid double accounting of GHG emissions and emission reductions across different forms of land use, a complex patchwork of reporting requirements has been established. It is anticipated that for future periods a transparent system, applicable to types of land use, will be necessary. Soil experts for different types of ecosystems (peatland, agriculture, forestry) need to be prepared for this situation. COST Action 639 served as a discussion platform, where expertise on key soil processes under specific forms of land use was exchanged in order to foster mutual understanding for seamless GHG accounting across different land use forms. Land use and land use history have a strong effect on the soil carbon and nitrogen stocks. For the relevance of land use changes for GHG reports, it needs to be shown how long the transition periods after a land use change are and how long an ecosystem can build up its carbon and nitrogen stocks in the soil until a new equilibrium is reached. Existing data sets were re-evaluated in the context of GHG reporting.

1.4.3 Working Group – Monitoring, statistics, simulation models

European forest soils are *monitored* in a harmonized way (for example, ICP Forest (http://www.icp-forests.org/) and Forest Focus (http://ec.europa.eu/environment/forests/ffocus.htm)), but for other forms of land use the harmonization is less advanced. Peatlands are fundamentally different from mineral soils and require a specific monitoring method. The loss in carbon stocks is difficult to measure and sometimes less relevant in relation to emissions of methane and nitrous oxide. The detection of small changes in soil carbon and nitrogen stocks requires great sampling efforts. Specific sampling schemes will be recommended for the detection of subtle soil carbon and nitrogen stock changes with a large impact on greenhouse gas budgets.

Different simulation models were evaluated with respect to soil carbon and nitrogen dynamics. A particular challenge was the implementation of the dynamic properties of hot spots and of changes in land use. It is crucial for reporting purposes to understand where models are currently failing and to improve the interface with experts in field research and modelling. The assessment of stock changes requires a *baseline* for comparison. The present baseline is, arbitrarily, the pool size in the year 1990. In Chapter 4 an attempt is made to establish a more meaningful baseline based on land use, land use history and site properties.

Pool sizes for soil carbon and nitrogen are calculated from several input values. Each has an error that propagates. On top of the variability at the spot, the small and medium scale spatial variation has to be considered. How the variability of carbon and nitrogen pools can be comprehensively assessed under different situations of data availabilities is elucidated. The size of soil carbon and nitrogen stock changes that are theoretically required in order to be relevant for GHG reporting purposes is addressed. An error budget for undisturbed forests has been established in the project.

A further challenge for modellers is to account for ecosystem disturbances. Signatory countries of the Kyoto Protocol are including the sink strength of terrestrial ecosystems in their GHG budgets. Ecology tells that ecosystems have an inherent stability, a typical life span and have a certain probability of being subject to disturbances. A risk assessment needs to express the probability of ecosystem disturbances based on the knowledge of the past course of events and with hindsight to the effects of future changes (both with respect to land use and to climate). The data requirements for a risk assessment will be collected and compared with the availability of useful statistics in Europe (spatial/temporal resolution of records of wind damages, insect damages etc.).

1.4.4 Working Group – Implementation of results

'End-users' of the suggested methods (experts in greenhouse gas budgets) were involved in order to communicate upcoming reporting needs, recommendations for improvements, feedback on the relevance of the suggestions and testing of suggested methods. Our accounting concept will use existing information on European soils. The IPCC Good Practice Guidance presents a balanced view of available methods and approaches, but does not have the intention of developing new methods. The discussions on post-2012 reporting requirements modify existing Reporting Guidelines. COST Action 639 is aimed at the Tier 3 level methods, in order to use available information in many countries for the optimization of the level for reporting of soil changes. Suggestions for specific forms of land management with the objective of the retention of GHG in soils can be in conflict with aspects of nature conservancy (protection of rare ecosystems, biodiversity issues). These topics need to be resolved early on to avoid unrealistic suggestions for adapted land management.

1.5 Regional coverage

COST Action 639 was met by considerable interest within Europe. The participation is shown in Figure 1.2. COST offers short term scientific missions to foster scientific

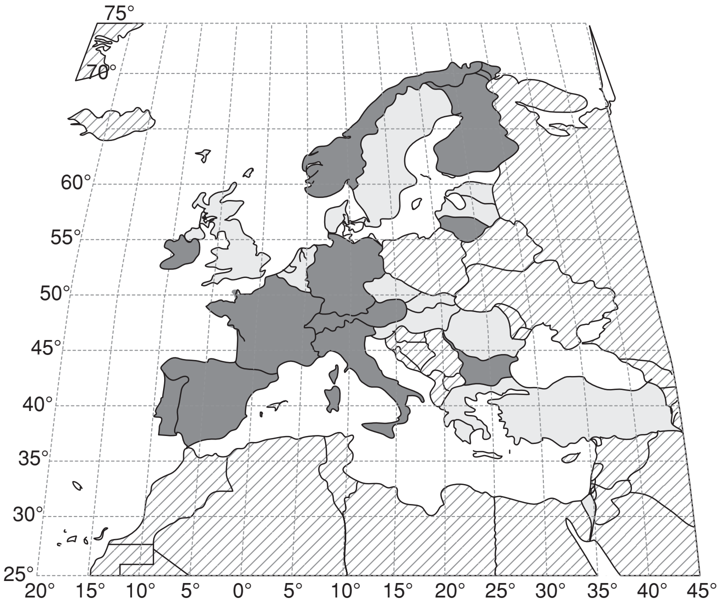

Figure 1.2 Countries participating in COST Action 639. The light shades represents countries participating in meetings and correspondence; dark shades indicate countries that have made use of the scientific exchange programme offered by COST.

exchange, preferably for the benefit of early stage researchers. This instrument of COST has been amply used within COST Action 639. Temporarily, scientists from the Russian Federation and from the United States of America made contributions.

Appendix 1.A Management Committee of COST Action 639

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